Understanding and Mitigating the Impact of Internet Demand in Everyday Life

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This dissertation is submitted for the degree of

Doctor of Philosophy

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I would like to dedicate this thesis to my mum, an absolute anchor in my life who started this journey in the first place by encouraging me to use a computer as a toddler.

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this thesis are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This thesis is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the contribution statements at the beginning of this thesis. This thesis does not exceed the maximum permitted word length: it contains fewer than 80,000 words including appendices and footnotes, but excluding the bibliography.

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Abstract

Digital devices and online services are increasingly embedded within our everyday lives. The growth in usage of these technologies has implications for environmental sustainability due to the energy demand from the underlying Internet infrastructure (e.g. communication networks, data centres). Energy efficiencies in the infrastructure are important, but they are made inconsequential by the sheer growth in the demand for data. We need to transition users' Internet-connected practices and adapt Human-Computer Interaction (HCI) design in less demanding and more sustainable directions. Yet it's not clear what the most data demanding devices and online activities are in users' lives, and how this demand can be intervened with most effectively through HCI design.

In this thesis, the issue of Internet demand is explored—uncovering how it is embedded into digital devices, online services and users' everyday practices. Specifically, I conduct a series of experiments to understand Internet demand on mobile devices and in the home, involving: a large-scale quantitative analysis of 398 mobile devices; and a mixed-methods study involving month-long home router logging and interviews with 20 participants (nine households). Through these studies, I provide an in-depth understanding of how digital activities in users' lives augment Internet demand (particularly through the practice of *watching*), and outline the roles for the HCI community and broader stakeholders (policy makers, businesses) in curtailing this demand. I then juxtapose these formative studies with design workshops involving 13 participants; these discover how we can reduce Internet demand in ways that users may accept or even *want*. From this, I provide specific design recommendations for the HCI community aiming to alleviate the issue of Internet growth for concerns of sustainability, as well as holistically mitigate the negative impacts that digital devices and online services can create in users' lives.

List of Publications

Contributing publications

Widdicks, K., Bates, O., Hazas, M., Friday, A. and Beresford, A.R., 2017, May. Demand around the clock: Time use and data demand of mobile devices in everyday life. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (pp. 5361-5372). ACM.

Morley, J., **Widdicks, K.** and Hazas, M., 2018. Digitalisation, energy and data demand: The impact of Internet traffic on overall and peak electricity consumption. Energy Research & Social Science, 38, pp.128-137.

Widdicks, K., Hazas, M., Bates, O. and Friday, A., 2019, April. Streaming, Multi-Screens and YouTube: The New (Unsustainable) Ways of Watching in the Home. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (p. 466). ACM.

Widdicks, K.V. and Pargman, D., 2019. Breaking the Cornucopian Paradigm: Towards Moderate Internet Use in Everyday Life. In Proceedings of the 2019 Workshop on Computing within Limits (LIMITS'19), pages 2:1–2:8. ACM.

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Additional publications

Widdicks, K.V., Ringenson, T., Pargman, D., Kuppusamy, V. and Lago, P., 2018. Undesigning the Internet: An exploratory study of reducing everyday Internet connectivity. ICT4S 2018.

Tendedez, H., **Widdicks, K.** and Hazas, M.D., 2019. Planning for the things you can't plan for: lessons learnt from deployments in the home. Interactions, 26(1), pp.52-57.

Contribution Statements

Chapter 2

Parts of this chapter are published (or under submission) in the related work sections of a Conference on Human Factors in Computing Systems (CHI)'17 paper [392], a CHI'19 paper [393], a Computing within LIMITS'19 workshop paper [394], and a Transactions on Computer-Human Interaction (TOCHI) journal paper [395, under review]. Section 2.2 in particular is formed from the TOCHI paper [395, under review]. As first author for all of these publications, the analysis of related work is my own.

Chapter 3

Parts of this chapter are published or under submission: section 3.1 at CHI'17 [392] and Energy Research and Social Science (ERSS)'18 [249]; section 3.2 at CHI'19 [393]; and section 3.3 at TOCHI [395, under review]. I was the first author of three of these papers and wrote the relevant method section in the paper for which I am a second author (i.e. [249]); therefore the write-up of the methods is my own. I conducted the quantitative analysis of the Android dataset myself, however this is a secondary dataset (collected by the University of Cambridge within the 'Device Analyzer' project) and my analysis scripts had to be executed by Alastair Beresford in Cambridge due to restrictions of moving the data out of their servers. I also solely conducted all of the household deployments in the home Internet demand study, except H7 where Mike Hazas helped due to the amount of participants involved; Mike also conducted two interviews for H9 as I knew the participant too well, and therefore I did not want this familiarity to affect the results. The design workshop was primarily designed by myself, with input from Christian Remy, Oliver Bates, Adrian Friday, Mike Hazas and Helena Tendedez; Christian, Oliver, as well as Kathy New, helped conduct the workshops due to the exercises requiring involvement from experts in HCI.

Chapter 4

Parts of this chapter are published in the CHI'17 [392], ERSS'18 [249], CHI'19 [393], and LIMITS'19 [394] papers or under-submission at TOCHI [395]. Specifically, section 4.1 shows visualisations and analysis published in the CHI'17 [392] and ERSS'18 papers [249]; parts of section 4.2 are published in the CHI'19 [393] paper; most of section 4.3 is under submission in the TOCHI paper [395]; and parts of the discussion and implications are published in the CHI'17 [392] and LIMITS'19 [394] papers, or under submission in the TOCHI paper [395]. I am the first author for four of these papers [392, 393, 394, 395] and therefore the primary contributor to the analysis, ideas, discussion and implications, with the exception of Adrian Friday (co-author of the CHI'17 paper [392]) who conducted the permutation test analysis on the Android dataset. I am the second author of the ERSS'18 paper [249]; here, my primary role was to carry out the quantitative analysis of the Device Analyzer dataset, which I explore in this chapter. The majority of the findings I provide on this quantitative data are my own, but I cite the Morley et al. paper [249] twice to indicate which contributions lie with the first author.

Chapter 5

The majority of this chapter, focusing on watching, is published in the CHI'19 paper [393]. This paper was developed alongside the co-authors Mike Hazas, Oliver Bates and Adrian Friday. However, I was the first author of this paper and the primary contributor to the data collection, analysis and ideas. Parts of the discussion and implications are also published in the LIMITS'19 paper [394]. I am also the first author for this paper (co-authored with Daniel Pargman); the ideas and write-up are primarily my own.

Chapter 6

This chapter is currently under review as a journal paper for TOCHI [395], for which I am the first author. It also builds upon discussion I have first authored at LIMITS'19 [394]. All of the analysis, findings, and implications are my own—yet they were verified by the co-authors to ensure validity of the results. I also link to some of my arguments in my sole authored article, currently in submission of a First Monday special issue on 'Responsibility in Digital Design' [391, under review].

Chapter 7

Some of the future work presented in this chapter is currently under review in the First Monday article for a special issue on ‘Responsibility in Digital Design’ [391]. I am the sole author and therefore the arguments made are my own.

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Finally, thank you to Greta Thunberg for initiating necessary climate change strikes and providing some hope for our future.

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List of Abbreviations

2G Second Generation cellular network.

3G Third Generation cellular network.

4G Fourth Generation cellular network.

5G Fifth Generation cellular network.

ACM Association for Computing Machinery.

CAGR Compound Annual Growth Rate.

CD Compact Disc.

CDN Content Delivery Network.

CHI Conference on Human Factors in Computing Systems.

DHCP Dynamic Host Configuration Protocol.

DNS Domain Name System.

DTB Digital Terrestrial Broadcast.

DVD Digital Versatile Disc.

EB Exabytes.

EMEA Europe, the Middle East and Africa.

ERSS Energy Research and Social Science.

EU European Union.

FOMO Fear of Missing Out.

GB Gigabytes.

GDP Gross Domestic Product.

GiB Gibibytes.

GPS Global Positioning System.

HCI Human-Computer Interaction.

HD High-Definition.

ICT Information Communication Technology.

ID Identifier.

IETF Internet Engineering Task Force.

IoT The Internet of Things.

IP Internet Protocol.

ISO International Organization for Standardization.

ISP Internet Service Provider.

IT Information Technology.

KB Kilobytes.

KiB Kibibytes.

kWh Kilowatt-hours.

LCA Life-Cycle Analysis.

LED Light-Emitting Diode.

LTE Long-Term Evolution communication.

MB Megabytes.

MiB Mebibytes.

OECD Organisation for Economic Co-operation and Development.

OS Operating System.

PC Personal Computer.

PDF Portable Document Format.

PVR Personal Video Recorder.

QoE Quality of Experience.

SD Standard-Definition.

SHCI Sustainable Human-Computer Interaction.

SMS Short Message Service.

SNMP Simple Network Management Protocol.

TCP Transmission Control Protocol.

TOCHI Transactions on Computer-Human Interaction.

TV Television.

UDP User Datagram Protocol.

UHD Ultra High-Definition.

UK United Kingdom.

US United States.

USB Universal Serial Bus.

UTC Coordinated Universal Time.

UX User Experience.

VCR Video Cassette Recorder.

VHS Video Home System.

VoD Video on Demand.

VR Virtual Reality.

Wh Watt-hours.

ZB Zettabytes.

Today, we use about 100 million barrels of oil every single day. There are no politics to change that; there are no rules to keep that oil in the ground.
So, we can no longer save the world by playing by the rules, because the rules have to be changed.
Everything needs to change, and it has to start today.
So, everyone out there, it is now time for civil disobedience.
It is time to rebel.

—THE 1975 AND GRETA THUNBERG

Chapter 1

Introduction

If you're reading this thesis now, chances are you accessed it from some sort of digital device; possibly a smartphone, a tablet, a desktop computer, or a laptop. In fact, you've probably been using such devices regularly today, yesterday, and in the past weeks, months, and years. Smart- watches, televisions, e-readers, TV boxes and dongles, games consoles, VR headsets, speakers, energy meters, thermostats, lights, security cameras; the variety of digital devices continues to grow. Yet despite the similarities and differences between them (e.g. size, placement, function), *all* of these devices now typically have one thing in common: Internet connectivity. Without these Internet-connected digital devices and their services, many of the things we do in today's (western) society would be difficult or even impossible. Just take a minute to think about the things you may use these technologies for: streaming, banking, working, communicating, social networking, shopping, searching, learning, reading, navigating, exercising, storing files or photos? Technologies and their services cross both personal and professional aspects of our lives—finding ways of complementing, changing and coordinating our daily activities and fulfilling the accomplishment of practices [316]. They have, and do, shape us; individually, economically, and even politically (e.g. Facebook's role in the United States (US) election [62]). We *rely* on digital devices, their connectivity, and the data they bring; and we have become to expect more from technology and its services than we do of other people [377].

To put the prevalence of Internet-connected digital technology into perspective: 3.9 billion people used the Internet in 2018, a number which has grown from 1.5 billion 10 years prior [358]. In the Organisation for Economic Co-operation and Development (OECD) region, subscriptions to broadband have increased for both mobile (from 88.6

per 100 inhabitants in 2010, to 109.7 in 2018) and fixed networks (23.4 in 2010 to 30.9 in 2018) [171]. In the United Kingdom (UK), connected device uptake has increased dramatically in the last decade [271, Fig. 1.18] and trends show that consumers are spending more and more time online [271]. Increased 4G coverage and adoption are driving data usage [268], meaning Internet use will also likely rise with the availability of even faster network speeds (such as 5G [139] and 'full-fibre' [33]) that allow for more data-intensive services (e.g. 4K video) and devices (e.g. The Internet of Things (IoT)). In fact, the number of IoT connections is expected to grow from 13 million in 2016 to over 150 million by 2024 in the UK alone [269], further embedding connectivity in our lives. This is all leading to an increasing amount of data traffic which is expected to reach 4.8 zettabytes (ZB) per year by 2022, a Compound Annual Growth Rate (CAGR) of 26% from 2017 to 2022 [78].

Yet this *"demand for network connectivity and online services"* [211, p. 2729], known as 'data demand', is problematic due to its associated environmental impact. In terms of global electricity demand, the consumption from digital devices and infrastructures is growing at a rate of 7% per year; that's more than double the global total growth rate of 3% per year [156]. Fast forward to 2030, and it is expected that more than 21% of global electricity use will be due to Information Communication Technology (ICT) [8]; this could be as low as 8%, or as high as 51%, in the best and worse cases respectively [8]. In more recent research, it has been estimated that ICT could exceed 14% of global greenhouse gas emissions by 2040—that's half of the transport sector's current impact [40]. We are in a state of climate emergency and ecological crisis [378], and technology is often seen as a 'rescue' platform in the Anthropocene[1] (e.g. *"computational sustainability"* [135]). But the environmental impacts of Internet-connected technology *itself* is largely unknown, hidden and quietly growing. We need to act now to avoid this continuous drive for Internet connectivity, and mitigate the significant (and potentially irreversible) environmental impacts that the technology sector is introducing through innovation and growth.

An important aspect of reducing the environmental impacts of data demand involves creating energy efficiencies in the Internet infrastructure. Yet, these savings are quickly made irrelevant due to the extreme growth of Internet connectivity [293, 298, 300] and 'rebound effects' [304].[2] Network operators plan their capacity based

[1]The current geological epoch formed from unsustainable human activity (see [93]).

[2]A direct 'rebound effect' is described by Hilty [161]: *"If a unit of output can be produced using less units of input than before – which means to improve the efficiency of the production process – increased*

on peak hours of Internet demand [320], and the 'busy hour' of Internet use is actually rising most rapidly: increasing by a factor of 4.8 between 2017 and 2022, compared to average Internet traffic increasing by a factor of 3.7 [78]. Given this growth, efficiency gains in the infrastructure do not change the overarching energy problem for ICT. It is therefore unlikely that we will be able to rely on efficiencies alone; instead, more significant changes are required to avoid the worrying level of energy and greenhouse gas emissions expected in the future. Researchers have suggested that new and current data centres could be fully run on renewable energy to omit their environmental impact—but the communications networks are more difficult to tackle in this way due to their diverse and decentralised nature,[3] and due to the lack of data surrounding how these networks may harvest renewable energy [40]. Rather than allowing for continuous, unchecked growth, we must ensure the environmental sustainability of Internet use through devices and services by *curtailing* the demand for these technologies.

The environmental consequences from ICT are juxtaposed with concerns surrounding digital technology's impacts on users. Whether it's our mental wellbeing [342], ability to work productively [12], relationships with others [177] or online privacy [37]: there are an increasing number of headlines in the media with negative connotations towards our reliance on Internet connectivity. Whilst 59% of UK users agree that the Internet brings more benefits than drawbacks, 8/10 adults now have concerns about online activities and the majority of adults would support additional regulation of the Internet (70% of adults for social media, 64% for video sharing sites, and 61% for messaging services) [276]. Given the need to reduce data demand for climate concerns, can we do this in a way which *benefits* society and combats these negative impacts on users? The overarching context of this thesis is to better understand the impact of data demand and how we may reduce reliance upon it in everyday life for a more sustainable, and desirable, future for society.

1.1 Data demand: HCI's role and my research

Human-Computer Interaction (HCI) plays a significant role in the demand growth for Internet-connected devices and online services. The development of novel devices and services leads to their uptake from users, increasing the network traffic associated with

demand for the output can result, countering the potential savings on the input factor" [161, p. 1].

[3]Communication networks are diverse and decentralised as they *"range from cellular base towers and stations, to switches and routers, to wired, wireless and smartgrid networks"* [40, p. 460].

these technologies and pushing the need for Internet infrastructure growth; this, in turn, allows for more data demanding designs of technology, which then enables further device and service innovation, and hence demand grows again [298]. Data (and its growing environmental impact) is therefore *designed into* the many online services we access and the digital devices we use. Even small changes to interaction design can have significant impacts on Internet traffic: for example, Facebook's decision to auto-play[4] the short-form videos on their news feed contributed to a 60% increase of data demand for a US mobile network, and over 200% for a US fixed network [323]. As the Internet is generally free and globally managed, there is no current regulation monitoring and mitigating these network and consequent environmental impacts. Moreover, the energy impacts are unattributed to the service providers that enable them.

However, HCI *does*, and *can*, have an impact on issues of sustainability through the field of Sustainable HCI (SHCI). For over two decades (beginning in 2007 by Blevis [45]), researchers have been investigating the role of users, ICT and HCI design in reducing the environmental impacts of technology. This has included research that looks to: reduce energy and resource consumption [80, 207, 292]; investigate how ICT can support green living [148, 153]; and even use ICT to support users in shifting their electricity use to reduce the associated climate impacts [166, 346].

Data demand research is relatively new in SHCI, beginning approximately six years ago. Bates et al. provided a qualitative assessment of data demand in the home in 2014, but they call for the need for a quantitative understanding of this growing problem [25]. In 2015, Lord et al. extended this work through a mixed-methods study of iOS mobile device users—gathering quantitatively logged network use and qualitative interviews with participants [211]. However, this only reveals data demand for 13 Apple smartphones and tablets in total [211]—understanding the data demand at scale or from other popular devices (e.g. smart TVs, laptops) is yet to be investigated. In 2016, Preist et al. define a set of principles for the HCI community to develop more sustainable online services [298]—yet, while these are well-intentioned, they are relatively difficult for the HCI community to act upon [394]. For example, a principle states *"Does the service encourage a healthy relationship with digital technology, and avoid promoting inappropriate dependency on the digital infrastructure?"* [298, p. 1332]; what relationships could be classified as 'healthy', and what dependency is 'inappropriate', remain to be explored. We need to better understand data demand in everyday life and

[4]Auto-play is the playing of videos automatically without users interacting with a 'play' button.

uncover specific opportunities for the HCI community to transition its trajectories of growth in more sustainable directions [340].

Given the gaps in prior work surrounding data demand and SHCI, there are a number of questions left unanswered. How is the demand for mobile devices composed at a larger scale (in comparison to Lord et al. [211]), and what are the times, places or online activities that are the most data demanding? How is data demand in the home *quantitatively* formed (adding to Bates et al.'s qualitative assessments [25]), and how does the home network support the variety of non-mobile devices used in everyday life (e.g. smart TVs, game consoles)? What are users' perceptions of their use of ICT, and what specific design recommendations can be made for the HCI community (building on Preist et al.'s suggestions [298]) to mitigate the impact of data demand? Can HCI design reduce data demand in ways that benefit society as well as the environment?

Larger scale studies of Internet use provide the HCI community with an initial understanding of data demand [78], showing the most significant categories of global traffic: video streaming (57.69% downstream traffic, 22.43% upstream), web browsing (17.01% down, 20.98% up), gaming (7.78% down, 2.68% up) and social networking (5.10% down, 3.73% up) [322]. However, these studies do not go into depth about how this traffic is formed in everyday life, nor do they uncover how the associated impacts can be mitigated through HCI design. This thesis therefore pursues the following aims:

1. Explore home and mobile device network traffic to understand how devices and online services are used both spatially and temporally in everyday life, and discover how this Internet connectivity supports people in meaningful ways.

2. Discover opportunities for the SHCI community and broader stakeholders (e.g. policy makers), to reduce Internet demand whilst positively affecting society.

Given the focus on Internet use reductions that aim to positively affect society, this thesis also speaks to the wider HCI community aiming to reduce use of digital devices and online services for societal concerns (e.g. for mental wellbeing); this becomes most significant in chapter 6, as highlighted in the thesis outline (described next).

1.2 Thesis outline

I outline the environmental impacts of technology and how the demand for Internet connectivity lies within other concerns of sustainability in computing in chapter 2. I then provide an overview of the effects that digital devices and online services are introducing on users' wellbeing, work productivity, relationships and online privacy. Following this, I characterise previous studies investigating user activity, and outline the approaches to investigating technology use. I conclude this chapter with a broader overview of Sustainable HCI research and the critiques of this theme.

Following the evaluation of prior work, I provide details of the methodological approaches taken in this thesis (chapter 3). In this chapter, I explain the three datasets and studies that I have analysed or conducted: 1) a quantitative analysis of 398 mobile devices from an Android dataset; 2) a mixed-methods study of home Internet demand, involving both fine-grained quantitative network data and semi-structured qualitative interviews for 20 participants across nine households; and 3) a qualitative design workshop, designing device and service interventions with 13 Internet users.

In chapter 4, I present an overview of data demand in everyday life. This utilises quantitative data from the Android dataset and the home Internet demand study to understand how data is consumed through time, across devices and by category of application. I also add to this discussion with the qualitative interview data from the home Internet study: revealing the household participants' experiences of digital device and online service use, and highlighting opportunities for data demand reduction that users may accept or appreciate. From this analysis, I outline a number of challenges and implications for working in this space; two of these implications form the basis of chapters 5 and 6.

Chapter 5 delves into the practice of watching. I explore the household study data to reveal the new norms in which video streaming is becoming more data-intensive. From this analysis, I identify opportunities for reducing the data demand from watching, and highlight the challenges that HCI researchers and practitioners will face when pursuing reductions in the consumption of online video. I conclude this chapter with implications for the HCI community to overcome the obstacles of working in this space, and to collaborate with wider stakeholders for a more responsible stance on data demand.

Chapter 6 explores the notion of designing for sufficient digital experiences to reduce data demand—specifically through creating more moderate and meaningful uses of Internet-connected devices and online services. This reveals findings from the design workshop: further exploring users' digital experiences, and designing interventions to device and service use with Internet users. The design workshop exposed a number of interesting intervention themes; I utilise these to provide specific design recommendations for the HCI community. These recommendations aim to moderate the environmental and negative societal impacts from digital devices and online services, through advocating more meaningful uses of such technologies. I then provide a summary of challenges that these designs may introduce, and conclude with the significance of taking a holistic approach to designing for related concerns (both societal and environmental) in HCI.

Finally, chapter 7 concludes with the overall findings and implications of my PhD research. I summarise the unifying themes across chapters 4, 5 and 6, and discuss what these outcomes mean for the HCI community. I then outline a number of outstanding questions or explorations required for future work; these are directed to HCI researchers and practitioners aiming to transition everyday device and service use in ways which are better for society and the environment.

1.3 Contribution statement

This PhD thesis provides a number of contributions to the HCI community. Firstly, I provide a detailed overview of data demand through time, by devices and in everyday life (chapter 4)—providing the most comprehensive understanding of UK mobile and home data demand to date [25, 211]. I identify the most demanding categories of services that we need to target as a community, including: watching (the most data demanding activity), as well as other categories such as gaming and social networking. I then suggest opportunities to mitigate the impacts of data demand through HCI design, particularly in ways that users may accept or actually appreciate; these include shifting traffic from updates, and designing for 'sufficient' levels of Internet use for users by creating more moderate and meaningful digital experiences. This chapter provides implications which motivate the rest of the thesis contributions.

My second contribution lies in my in-depth analysis of watching in everyday life (chapter 5). As video streaming is the largest category of online traffic (as found in chapter 4), I explore how the practice of watching is becoming more data-intensive and uncover the 'new norms' of watching which need to be targeted for data reduction. I then provide implications for the HCI community to work solely, and collaboratively with broader stakeholders (e.g. policy makers), to mitigate the impacts of this significantly data demanding (and continuously growing) activity.

My next contribution, provided in chapter 6, explores the notion of designing for more moderate and meaningful digital device and online service use. This follows the findings of chapter 4, highlighting that there are ways in which users actually *want* to reduce their use of the Internet. I therefore further uncover opportunities for reducing Internet connectivity in everyday life, and design these Internet interventions with users. This leads to specific design recommendations that intend to benefit both the environment and society, through *holistically* designing for overlapping concerns in HCI—an approach that has not yet been taken for reducing the impact of data demand.

Throughout this thesis (chapters 4 to 6), I also discuss the challenges of researching data demand and designing for reduced Internet connectivity. This is because my findings and implications often: conflict with businesses, have broader impacts outside of HCI, or even require political intervention. These are not meant to undermine the impact that the HCI community can have on data demand reductions, but instead emphasise the interwoven nature between service design, sustainability and societal forces. The discussions highlight the complexity of this research area and offer suggestions for HCI researchers and practitioners to overcome these challenges; this forms my final contribution.

Sympathy for the fauna,
Fragile life in the sauna,
In the sea getting warmer,
Endlessly ’round the corner.
And though I try, I do the same, as though I must.
And in the air of today is tomorrow’s dust.

—TAME IMPALA

Chapter 2

Related Work

Internet-connected devices are increasingly embedded into our everyday lives. This abundance of connected technology provides useful, meaningful and perhaps even *vital* facilities, interactions and activities, as we become increasingly reliant on the Internet. From 1970 to 2016, the average number of consumer electronics (e.g. TVs, set-top boxes) per UK household has increased from 2 to 13, with the average number of home computing devices (e.g. desktops, laptops) also increasing from 0 to 3 [138]. Furthermore, the number of global Internet users has grown year-on-year from 1.5 billion in 2008 to 3.9 billion in 2018 [358]. This growth trend corresponds with time spent online: UK 'connected consumers' claimed to spend an average of 24 hours per week online in 2017, a figure which has grown from 12.1 hours 10 years prior [271, Fig. 1.6]. Globally in 2019, IT users are now spending an average of 6 hours and 42 minutes online per day [184] for data-intensive activities such as video streaming, web browsing, gaming and social networking [322]. Increasing numbers of devices, users, time spent online and data demanding services are all leading to exaggerated growth in global data traffic: from 1.5 ZB per year in 2017, to an estimated 4.8 ZB in 2022 [78].

Yet, this growth in digital technology and Internet access has impacts on our environment. The total electricity consumption for consumer electronics and home computing in the UK has increased from 271 thousand tonnes of oil equivalent in 1970 to 2,323 in 2016 [138]. Going forward, ICT is expected to contribute to 21% of global electricity use by 2030 [8], and may even exceed half the current relative contribution of greenhouse gas emissions for the transportation sector by 2040 [40]. Adding to these environmental effects, is the negative impact that digital technology and 'constant connectivity' is having on users. These concerns relate to technology overuse or addictions [7, 36, 168, 389], mental health [38, 228, 314, 342], our relationships and family life [61, 177], and even our online privacy and security [32, 37, 62, 258, 287].

Rethinking the HCI design of devices and services has the potential to alleviate, or even ‘undo’, these impacts on users and our environment. Yet, the HCI community needs to build on prior work in this space [25, 211, 298, 299] to better understand how Internet connectivity is embedded into everyday life, and uncover the opportunities for HCI researchers and practitioners to intervene. In this chapter, I delve into more detail surrounding the environmental impacts of ICT and, specifically, Internet connectivity, as well as the different impacts digital technology has on users and the prior work in this domain. I then provide an overview of studies of everyday life with technology, and a summary of broader Sustainable HCI research. Within these sections, I discuss the drive for my PhD research and how this builds on prior work; I then summarise these arguments, identifying the research gap which motivates this thesis.

2.1 Environmental impacts of digital technology

All digital devices have an environmental footprint through their life-cycle: from their manufacture, during their use phase, to their disposal. Blevis highlighted these issues to the HCI community in 2007, driving the need for interactive technology design processes to consider sustainability [45]. He created a rubric for understanding designs in terms of their use, reuse and disposal. From this, he shows how elements of this rubric can affect sustainability e.g. Apple creating multiple versions of the iPod (i.e. the classic, the Mini, the Nano) would have driven users to buy the newest technology and dispose of the old whilst it was still usable [45].

As recapped from [249]: when technologies are in use (i.e. their ‘use phase’), they consume electricity through directly powering the hardware, yet also *indirectly* consume electricity via the Internet infrastructure. All network traffic sent and received between technologies require transmission, processing and storage from the Internet infrastructure (e.g. data centres, communication networks), which requires electricity consumption. Direct electricity consumption through personal computers (e.g. laptops) were noted to form 1.6% of global electricity demand in 2012; this is around half the indirect electricity consumption (3.1%), with networks forming 1.7% and data centres contributing 1.4% [156]. These proportions of electricity use are expected to continue, with networks and data centres negating technological efficiencies (i.e. supporting the same use with fewer resources) in the direct electricity consumption of end-user devices [8]. This shows the prominence of cloud infrastructure in the environmental impact of digital technology. Such impacts are particularly notable with smaller end-user devices: Internet service access forms more than 90% of the energy impact for tablets and smartphones when considering the entire life-cycle environmental footprint of the devices (production included) [165].

With the growth in the amount of devices that users own, as well as their associated Internet connectivity, Internet traffic is rising rapidly. In 1992, global Internet networks carried an estimated 100 gigabytes (GB) of data per day; this increased to 2,000 GB per second by 2007, 46,600 GB per second by 2017, and is estimated to triple by 2022 to 150,700 GB per second [78, Tab. 1]. Mobile data traffic is growing at an alarming rate, with a year-on-year growth rate of 79% recorded in 2018; this was the highest recorded growth rate since 2013 [110]. Currently, the bulk of global Internet traffic is still accessed through fixed networks, demanding 67 exabytes (EB) per month; this was 57 EB more than mobile [78, Tab. 15]. In 2017, Cisco estimated that fixed network traffic will reach 225 EB by 2022—a 27% CAGR 2017–2022 [78, Tab. 15]. With the rise of 5G networks and IoT, mobile Internet traffic is also expected to soar [110].

The energy consumption of the Internet infrastructure is not elastic, i.e. users' service and data consumption does not directly correlate with an increase in energy used. Rather, the extreme increases in data traffic outlined here push for growth in the infrastructure to cope with rises in demand [298]; this makes the indirect energy consumption associated with the Internet even more significant. However, previous researchers have attempted to put network traffic into energy terms: in 2015, transferring 100 megabytes (MB) may have equated to 20 watt-hours (Wh) via Wi-Fi and 35 Wh via 3G/LTE—these values were found to be *"an order of magnitude greater than the typical daily charging"* of mobile devices [211, p. 2731]. Researchers revealing such energy consumption values associated with ICT utilise Life-Cycle Analysis (LCA), and focus on creating or reporting efficiencies in the Internet infrastructure. In the rest of this section, I discuss this LCA research, as well as an alternative approach to mitigating the issue of Internet growth through HCI design.

2.1.1 Life-Cycle Analysis of ICT

To understand the exact energy consumption associated with ICT and the Internet infrastructure, researchers have been utilising LCA techniques for a number of years [8, 10, 40, 156, 220, 221, 222, 328, 332]. LCA involves calculating the energy consumption of *all* stages of 'life' for the Internet infrastructure and its connected devices, i.e. the impacts from sourcing the materials, the use phase, and its depreciation/end of life. There are two approaches to LCA [86]: 1) top-down, i.e. estimated by the total energy demand of the Internet or for a region, as well as the total traffic for that region; and 2) bottom-up, i.e. estimated by modelling specific technologies in the Internet infrastructure (e.g. end-user devices, routers, access networks, core networks, data centres) and their individual energy demands, to lead to an overall estimate of energy consumption.

With these different approaches alongside the varying scopes of equipment (e.g. the variety of end-user devices) in which LCA researchers apply within their work, estimates of the Internet's energy consumption and its growth trajectory vary greatly. Some researchers argue that the energy problem of communication technology is expected to worsen, rising to 21% of global electricity use by 2030 (with the best case only forming 8% of global electricity, but the worst case rising to 51%) [8]. Others argue that the energy footprint from the ICT and Entertainment and Media sectors is now diminishing despite Internet traffic increases [222].

As a consensus is unable to be reached in this field, meta-reviews of this work have been carried out to better understand the differences between LCA estimates. Aslan et al. researched 14 estimation studies conducted between 2000–2015 and highlighted their different results [10]. Through analysing the each studies' methods, successes and failures, Aslan et al. created a checklist for researchers measuring the Internet's electricity intensity [10]. Similarly, Belkhir and Elmeligi [40] have assessed their own estimates of ICT's global carbon footprint alongside those of Andrae and Edler's [8] and Malmodin's [219]. The fact that the environmental impacts of ICT have been under debate for quite some time highlights the complexity of assessing this topic.

To examine ICT energy impacts more deeply, researchers have looked into specific application areas. For online news content, Schien et al. analysed the impact of location on accessing 'Guardian News and Media Limited' [330] as well as the use phase energy consumption associated with 10 minutes of news browsing [332]. By measuring both textual and video content across different user devices (desktop, laptop, tablet, and smartphone), they found that data center energy consumption can vary for read articles (between 4–48% of total energy consumption) and watched content (2–11%) depending on the users' device and access network used [332]. For games distribution, Mayers et al. investigated whether the carbon impact is lower when buying a physical disc or downloading a game via the Internet—finding that the former can actually have lower greenhouse emissions for an average sized 8.8 GB game [236].

It's important to note that LCA has also shown the significant benefits that the Internet can have to curtail other, more energy-intensive activities. Coroama et al. [85] investigated the energy impacts of running a conference at two locations (Japan and Switzerland) and connecting them via the Internet; this was in aid of avoiding high environmental costs from researchers physically travelling. For the entire conference, they estimate an energy use of 43 kilowatt-hours (kWh) for data transmissions and 108 kWh for the terminal equipment at both sites (e.g. plasma screens); if researchers were to have travelled between the two venues, a single round-trip for one participant would've totalled to 9880 kWh [85]. With such comparisons, the Internet is clearly the best option. Yet, this does not negate the issue of rising traffic from general service access and devices—i.e. technology use that is not 'replacing' activities with larger forms of energy consumption, but use that is 'just' becoming more intensive.

In this thesis, I take the view that the energy consumption of the Internet will increase and lead to more environmental impacts. This is because users' demand for Internet connectivity and service consumption outgrows efficiency gains in the Internet infrastructure [298, 300]: efficiencies *"easily evaporate"* through rebound effects [304, p. 788], e.g. Jevons paradox[1] whereby efficiency increases end up creating more consumption. This is described through the 'Cornucopian paradigm': demand for data leads to growth in the Internet infrastructure, allowing for new data-intensive services which lead to an increase in demand, and so on [298]. In addition, emerging technologies such as IoT, cryptocurrencies and connected-cars will only increase this energy intensity—in fact, Bitcoin alone could contribute 7.67 gigawatts of electricity in the future, making it comparable to countries such as Austria (8.2 gigawatts) [96]. Even if efficiencies in the Internet infrastructure do and continue to follow 'Moore's Law'[2] [222], our networking architecture, computing and practices will most likely need to adapt due to depleting resources and futures of scarcity [174, 301, 302, 303]—ensuring Internet access for *"the largest number of people and for the longest duration of time"* [284, p. 29]. As a result, energy efficiency improvements in the Internet infrastructures alone will not solve the rising issue of data demand [300]; we must tackle the demand for digital devices and online services too.

[1] Jevons found that *"technological efficiency gains—specifically the more "economical" use of coal in engines doing mechanical work—actually increased the overall consumption of coal, iron, and other resources, rather than "saving" them"* [4]. Therefore Jevons paradox is the idea that technical efficiencies aiming to decrease environmental impact actually lead to increased environmental impact.

[2] 'Moore's Law' assumes that the number of transistors on circuits doubles each year.

2.1.2 Data demand in HCI

To understand the demand of online services and discover how this can be adapted for more sustainable uses of the Internet, researchers in HCI have been investigating data demand and how this supports people in their everyday lives. In a study of 13 participants' mobile device use [211], both quantitative and qualitative data was gathered through logging participants' devices (via an iOS device logger) and interviewing each participant; this aimed to uncover an understanding of their device use and data demand. Lord et al. found that users are filling pockets of *"dead time"* (cf. [316], e.g. time waiting for a bus, or time in which they are bored) with their mobile devices, leading to the demand for data during these time periods. The researchers provided a number of opportunities for the design of devices and services to reduce data demand (e.g. turning the network off whilst device screens are off to avoid unnecessary background data demand) and for *"undesigning"* [289] data demand from everyday life (e.g. emphasising periods of 'dead time' as slow time to encourage time away from technology for mental reflection, possibly through the use of a mobile device application) [211]. This thesis builds upon this work by investigating data demand in everyday life more deeply i.e. across other devices (e.g. TVs, laptops etc.), applications (e.g. YouTube, Facebook) and activities (e.g. watching, communication) involving Internet use.

To uncover a more holistic view of the energy impacts from media and IT, Bates et al. investigated the direct energy impact (i.e. power consumption) of technologies via quantitative sensor logging, and their indirect energy impact (i.e. data demand) via qualitative interviews with 33 students [25]. The researchers found that participants use their devices in 'constellations', defined as *"when two or more connected or associated devices are consuming electricity at the same time, often working in concert to support the same practice"* [25, p. 1175]; a typical example of a constellation involves the use of a TV and a games console for the practice of gaming. Bates et al. also found certain technology users to be 'connoisseurs': these types of users use more high quality devices and buy new technology often. Despite these findings, Bates et al. are unable to quantify the indirect impact of the devices and users they explore; the researchers suggest analysing home network data is a next step for understanding these indirect impacts [25], e.g. through logging software on programmable routers [23].

Following this work, Bates et al. [26] explored the unsustainable growth of devices in everyday life through a 10-participant photo elicitation study—identifying six categories of growth, including the growth in constellations (cf. [25]) or groups of devices.

The researchers provide directions for ICT and sustainability to limit this growth, emphasising the need for changes which will create the most impactful growth reductions [26]. These included that designers should consider background data usage as 'wasteful', and design for non-reliance of technology to help users disconnect [26]; these suggestions require further investigation to reveal their impacts on data demand.

Motivated by the unsustainable growth in digital infrastructure demand, Preist et al. created a 'Rubric of Infrastructural Effects' which provides a set of questions for HCI researchers and practitioners to consider when designing their services more sustainably [298]. For example, *"Does the design encourage 'digital waste', or the avoidance of it?"* [298, p. 1330]; digital waste involves downloading cloud-based service material that is underutilised or unused. They note how a simple design change to the downloading of PDFs from browsers could avoid the redownloading of content, e.g. by checking the file does not already exist on the user's file system [298]. Using the example of digitally wasted video-content when users only listen to the audio of YouTube videos, Preist et al. revealed in 2019 that turning the video off in this case could have a comparable emission reduction to running a data centre on renewable energy [299].

Blevis et al. [47] added to discussion in [298] by merging the concepts of Sustainable Digital Infrastructure Design[3] and Sustainable Interaction Design[4] through three conceptual design scenarios [47]. One of these scenarios discusses how reduced image resolution (and therefore decreased data demand associated with the image online) could be reached by better informing users that the best resolution does not always mean the best picture, or by reconstructing lower resolution as stylish [47].

Despite these considerations, our understanding of data demand is relatively incomplete. In particular, it's unclear which data demanding Internet activities or devices in everyday life require most focus in SHCI research, or even have the most potential for data demand limits in terms of time or data volume [155]. It is also unknown which cloud services are more negotiable [298] when it comes to data demand reductions, and whether there is the possibility that these reductions could be incorporated into service or device design to benefit society as well as the environment. This latter hypothesis is made based on the increasing body of HCI research attempting to overcome the negative impacts that digital technology has on users; discussed next.

[3]Sustainable Digital Infrastructure Design refers to the design of Internet-connected devices and services that consider sustainability e.g. by avoiding Internet infrastructure expansion or obsolescence, and encouraging efficient use of the infrastructure through sharing [298].

[4]Sustainable Interaction Design refers to the design of devices that consider sustainability—particularly ensuring sustainable invention and disposal, as well as promoting renewal and reuse [45].

2.2 Digital technology's impacts on users

Beyond environmental sustainability, digital technology adds other impacts on our society. In a recent survey, UK Internet users have been seen to be more dependant e.g. feeling 'cut off' (29% of adults) and 'lost' without it (34%), and smartphone use in the presence of others can be seen as socially unacceptable (e.g. at meal times) [271]. Without Internet connectivity, UK users can feel liberated (10% of adults), more productive (10%) and less distracted (16%) [271]. Whilst another survey found a significant portion of technology and health experts in America believe digital life will *help* users' wellbeing (47%) or keep it the same as it is now (21%), the remaining 32% suggest that digital technologies will do more harm [6]; such harmful themes include digital addiction, deficits (e.g. reduced ability to focus), distrust (e.g. online social divisions), duress (e.g. stress), and dangers (e.g. to democracy, privacy) [6].

To avoid some of technology's negative effects, mechanisms now exist to help users manage their digitally-mediated lives, e.g.: 'digital detoxes' for reducing or taking short-term breaks from digital media consumption [365], or the Forest app[5] to *"be present"* with friends. Even tech-giant Facebook pledged to create *"time well spent"* for their users through encouraging *"meaningful interactions between people"* on the site [407]. Such design considerations have been discussed in HCI research, e.g. designing interactions for 'slowness' and 'reflection' [149, 262], and investigating instances where it is better to 'undesign' technology [289].

Given the extent to which digital devices and Internet connectivity are embedded in western society, they can effect many strands of users' lives. The HCI community has therefore been investigating, and attempting to solve, the negative effects of technology on users': digital wellbeing, relationships, work productivity, and online privacy. The following sections discuss work in HCI which aim to address these negative effects.

2.2.1 Digital wellbeing

Wellbeing has received significant consideration in the HCI community. Through investigatory studies and analysis of how users use technologies, research has found that users' attention span can be hindered by alerts and notifications [203]; and notions of addiction are linked to social mobile app experiences [98]. Users have been found

[5]Forest, an application for promoting time offline: `https://www.forestapp.cc/`, accessed October 2019.

to engage in technology 'non-use' [325] e.g. by taking breaks from their social media [333] and limiting their Facebook use [29]—perhaps due to the ways of life lost to *"datafication and automation enabled and reinforced by mass-mediated forms of networked connectivity"* [158, p. 2007]. To better understand digital wellbeing, researchers have explored: perceived overuse of the Internet for different demographics [145]; digital technology's role in the wellbeing of children [256] and older adults [159]; the costs and benefits to 'unplugging' from digital communication [369]; and the potential to monitor wellbeing in the long-term via social media [317].

To maintain users' wellbeing, the HCI community have developed technologies that promote mindfulness [405]; enable self-tracking [14]; reduce time spent on applications [278]; view 'wellbeing-as-interaction' rather than a goal [313]; and even recreate publicly available tools for digital wellbeing to evaluate their effectiveness [248]. Focusing primarily on self-tracking, Roffarello and De Russis found that users tend to like wellbeing tools, but critically highlight that the tools are not restrictive enough to change behaviours that users perceive as 'addictive' [248]. By analysing users' feedback on the tools available, the researchers present some ideas for future design of digital wellbeing apps (e.g. to consider *"social-supporting techniques"*) [248, p. 12].

Designing for the 'right' engagement and the correct metrics to model it, is difficult when it comes to users' digital wellbeing. Lyngs et al. highlight the complexities in designing for users' *"true preferences"* for engagement given users' desires or needs change over time and in different contexts [216, p. 1]; they suggest that future work should focus on alternatives to current engagement metrics, and give users the choice of how a system will infer their preferences [216]. Researchers have begun to identify an agenda for the future of digital wellbeing design [68], and have outlined the research methods and frameworks for incorporating psychological wellbeing in technology [64] e.g. the 'Motivation, Engagement and Thriving in User Experience' model [288].

2.2.2 Relationships

It has been noted that, through the growing presence of digital technology in our daily lives, we have begun to expect more from technology than we do of other people [377]. Observations such as these have prompted the HCI community to explore the different aspects of device use impacting relationships. In 2016, Odour et al. uncovered that smartphones can create moments of *"desirable disengagement"* allowing for family members to have some alone time—however, non-urgent device use in the presence of others was observed to make family members or couples feel *"socially disconnected"* or frustrated by this use [263, pp. 5-6]. Similarly, Moser et al. found that perceived importance of activity and the amount of time spent on the activity highlights whether using a smartphone at the dinner table is appropriate [254]. For couples, a partner's technology reliance has been found to lower relationship satisfaction [206].

Researchers have also investigated the impacts of device use and control between parent-child relationships, from both the perspective of the parent and the child [133, 164, 186, 238]. Conflicts in these relationships can arise through the use of digital technology, e.g. as parents' use of technology can make them seem *"emotionally unavailable"* to their children [186, p. 591]. Whilst technologies exist to help limit children's access to devices for extended periods of time, they are not always utilised as they do not take into account the complexities and dynamics of everyday life [238].

Other interventions to develop 'better' social experiences have been designed and studied. Park et al. created a 'Social Context Aware Notification' (SCAN) system to detect social context, and potentially defer device notifications, in order to reduce disruptions in social situations [285]; and Ko et al. designed an app named 'Lock n' Lol' for groups of users to simultaneously lock their smartphones and *"'laugh out loud' together"* [195, p. 998]. In contrast to this, HCI has highlighted the *benefits* that technology can bring for relationships. Researchers have embraced the use of *"celebratory technologies"* to enhance family interactions at mealtimes [121], and have highlighted that technology is particularly important in facilitating closeness or aiding relationships which span a long distance [70, 76, 399].

2.2.3 Work productivity

Online services and technologies have become embedded in our working lives. Researchers have looked into how this is both improving and complicating workers' lives and society. Whilst constant connectivity can enable benefits for employees from flexible working strategies (e.g. working from home), their time and availability is being used as an economic service [237] and email can cause stress for employees [202, 226, 227] as it *"speeds up the pace of work"* [227, p. 562]. Anxieties surrounding devices and service use can also negatively affect productivity [387]. To help employees switch off from work when they are at home, Cecchinato et al. highlight the *"micro-boundaries"* that users employ for their email e.g. checking work and personal email on separate clients [67, p. 3996]. Furthermore, to encourage breaks at work that benefit productivity, Epstein et al. suggest break recommendation systems should consider what type of break may be most appropriate given the employee's task (e.g. some tasks may only require shorter breaks) [109].

To help improve users' focus on their working tasks, productivity tools have been developed and are available e.g. StayFocusd[6] and Cold Turkey[7] for blocking access to 'distracting' sites during periods of work. Given these tools' uptake, HCI researchers have investigated their functionality and effects [190, 225]. Mark et al. explored their use within the workplace, finding that workers that most benefited from these tools were those who felt least in-control of their online distractions—and that non-work distractions can actually sometimes benefit employees [225]. They recommend designs for future versions of productivity tools including the introduction of time limits (e.g. 30 seconds) on non-work breaks [225], allowing *"micro breaks"* which provide enough time for users to refresh and restore concentration [349, p. 3054]. Another design recommendation included providing notifications on when or what breaks to take e.g. going for a walk [225]—a design that has been evaluated for breaking sedentary workplace behaviour [215]. Recognising that productivity tools concentrate on time spent on work, Kim et al. investigated how workers define productivity—finding that productivity is a *"multifaceted concept"* whereby even personal activities or work not involving computing devices can be seen as productive [189, p. 9]. They envision productivity tools will need to combine manual and automated logging techniques to *"capture comprehensive and personally meaningful tasks"* [189, p. 10].

2.2.4 Online privacy

Digital devices and online services can also have negative implications for users' privacy—leading to an abundance of HCI work aiming to understand and mitigate this issue. Research has involved understanding different users' perceptions of, and behaviours towards, their online privacy [108, 131, 200, 305, 363], as well as the strategies they employ to protect it [217, 324]. Such work has included exploring service agreements and data management with users [52, 366]; uncovering the data sharing practices of online services to users [115, 122]; and studying voice-driven technology to understand [130, 242] or mitigate [336] associated privacy concerns. Tools have also been

[6]StayFocusd, a tool for encouraging work focus and productivity: `http://www.stayfocusd.com/`, accessed October 2019.

[7]Cold Turkey, an application for blocking websites: `https://getcoldturkey.com/`, accessed October 2019.

created and studied to increase users' awareness of their online privacy and security, and reduce the associated risks e.g.: *"X-Ray Refine"* exposes the data that apps collect about users and suggests alternative apps so that users can make an informed decision to their privacy trade-offs [381]; and *"Nirapod"* helps users manage their data privacy through 'shared' and 'secret' accounts on shared devices [3].

Wijesekera et al. created a privacy management system for apps' resource requests (e.g. for device location, access to contacts) [396]. Whilst their tool led to fewer privacy violations, 14% of their participants actually wanted to know *why* the requests were being made for resources—with this information they may actually be *"better positioned to make decisions that meet their privacy and functionality expectations"* [396, p. 10]. Yet, improving users' understanding of their data privacy and security through device and service design is difficult, e.g. making security mechanisms (such as encryption) visible in HCI designs can vary both usability and user experience (UX) [102]. To create positive UX, Distler et al. state that the transparency of security designs should be *"provided in a meaningful and purposeful way that is aligned with users' goals"* [102, p. 10]. It is currently unclear how the HCI community can fully mitigate against the negative impacts of device and service use on users' privacy.

2.2.5 Summary: mapping data demand to broader HCI concerns

As I have outlined, the HCI community are looking to ways in which we might alleviate or remove the negative impacts that digital devices and Internet connectivity have on our lives. Given these impacts and research agendas, can we reduce data demand in a way which benefits society by also addressing these impacts? I expect that this would ensure the data demand reductions needed within digital device and online service use, whilst creating digital interactions that users enjoy and benefit the environment. To explore this notion through better understanding data demand, digital device and online service use, users' everyday lives with ICT need to be studied. In the next section, I outline prior work that has investigated technology use in everyday life through quantitative and qualitative research studies.

2.3 Studying ICT use in everyday life

Researchers have been investigating how users interact with devices and services in everyday life, and particularly how different locations or spaces impact this. In this section, I detail the significant amount of work exploring current, and future, use of digital devices in the home. I then expand on this related work to include research surrounding users' use of devices 'on-the-go' (specifically, mobile devices).

2.3.1 Digital devices and Internet connectivity in the home

As the home is a significant place for device usage, it is an interesting location for investigating device use in everyday life. With the rise of portable devices (e.g. laptops), computing can be integrated into areas of the home that were *"previously unacceptable"* [356, p. 2642]. The communality of these domestic settings has led to investigations into device and account sharing between home dwellers: labelling devices 'public' and 'private' in the home and how they are used by families [59]; understanding sharing practices of couples and their preferences for maintaining privacy [172]; and creating a taxonomy of sharing characteristics that households follow, whereby themes of trust and convenience alter sharing patterns [234]. The emergence of IoT in the home (e.g. Amazon's 'Alexa' home assistant) has also raised questions around: how these should be developed and deployed [92]; the challenges to their adoption and acceptance by users [65]; and how they are currently used (e.g.: the use of voice interfaces [296], integrating smart home technology actions into the family calendar [245]).

By logging Internet use in the home, Kawsar and Brush [183] unraveled the different devices used (e.g. laptops, game consoles) for the top six Internet activities: web communication, online social networking, online gaming, home working, online shopping, and video watching. Juxtaposing these quantitative logs with qualitative data from participants, they found that the Internet activity dictates which device users choose to facilitate the activity, e.g. work activities would lead to the selection of laptops or personal computers (PCs) [183]. Similarly, Chetty et al. log application usage on home computers, yet they focus on power management strategies [73].

Studies have looked to visualise the home network through user interfaces [72, 187, 252, 253]. These interfaces enable users to manage Internet Service Provider (ISP) caps [187], network performance and bandwidth consumption (e.g. by setting limits on each device's bandwidth [72]), as well as prioritise and police network activities in the home (e.g. parents blocking their children's access to certain websites [253]). The management tool *"uCap"* for home Internet data has also been created [74]—helping users cap their bandwidth consumption and discover whether they could move to lower network tariffs with their ISP. Researchers working in this space have highlighted the difficulties of mapping network data to users' use of digital devices [58, 74, 91], e.g. users refer to 'Skype' rather than 'Voice over Internet Protocol (IP)' [58, 91].

Whilst these studies in the home unveil details of digital device and online service interactions, they do not investigate the data demand associated with this technology use. Some studies do *implicitly* provide directions for more sustainable uses of the Internet, e.g. a bandwidth management tool led to one heavy Internet user moving their data demand off-peak [72]; and *"uCap"* sets limits on Internet demand for monetary reasons rather than sustainability [74]. However, a more in-depth understanding of data demand, and *how* it can be reduced in everyday life, is required.

2.3.2 Digital devices on-the-go: characterising mobile device use

The use of *mobile* devices and their applications has been extensively studied. This has most commonly occurred through installing loggers on such devices [50, 117, 178, 380]. Through deploying an Android logging service, Böhmer et al. were able to quantify fine-grained usage patterns for 4,100 users—providing details such as the average app use duration (72 seconds) and total amount of use per day (59 minutes) [50]. Using a similar logging method, Jones et al. studied 165 users' habitual device and app patterns of use; this uncovered that communication and social media apps are revisited the quickest [178]. The use of iPhones and the associated Internet connectivity has also been logged: at a large-scale (10,000 jailbroken devices) [251] to compare to larger Android studies [50]; and at a small scale (24 iPhones) to explore the differences between users who frequently access the browser as well as their apps, and users who concentrate their use via apps [375].

Other analyses in this form have found scenarios where mobile device usage increases, e.g.: 70% of users have a 'peak hour' of phone use where they double their mean usage [117]; habits lead to increased device and app use [279]; and teens use their devices for an average of three hours in a day [41], an estimate that is two hours more than the average use time found by Böhmer et al. [50]. Research has also revealed the differences of mobile device use: showing how usage is affected by different device settings [354] or contexts which require various cognitive attention by users [280]; and arguing that researchers, mobile manufacturers, mobile carriers and app developers should all embrace such differences [404].

Whilst some of these mobile device usage investigations quantify brief statistics of data demand (cf. [117]), their focus has not been sustainability. Mathur et al. investigate data traffic, yet aim to provide users with more control of their data usage for monetary concerns over data costs [233]—a similar goal to home network studies [74]. Athukorala et al. aim to increase users' awareness of their energy usage [13], however they focus on *direct* energy consumption from battery drain rather than data demand. Only Lord et al. study mobile device use from a perspective of data demand (as discussed in section 2.1.2)—however, they do not link data demand to everyday practices and their temporality [211]. In this thesis, I extend the analysis of mobile device characterisation (and the associated data impact) linked to the everyday practices of users.

2.4 Prior work in SHCI

From the food we eat, to the cars we drive, the new products we buy, and even just turning the heating up a notch: humanity is taking more from the planet than is sustainable. We are in a state of climate emergency (cf. [378]), and we need to adapt our constant drive for *more* consumption to avoid societal and environmental collapse. We do not have a 'Planet B' [43]. With these concerns in mind, there is a plethora of work in SHCI that goes beyond data demand research, to attempt to overcome the environmental issues our planet is facing from a HCI perspective. Addressing sustainability in HCI has been seen to be studied in two ways: 1) sustainability *in* design i.e. ensuring products are designed in a sustainable way; and 2) sustainability *through* design i.e. designs which support sustainable lifestyles and decisions [223]. Through these approaches, the SHCI community has conducted both formative and interventionist studies for improving sustainability. Given my research aims to understand data demand and discover opportunities for intervening with its growth and volume in everyday life, I provide a brief overview of the most directly relevant formative and interventionist work in SHCI. I also summarise the critiques of, and suggested futures for, SHCI research.

2.4.1 Formative studies in SHCI

Much like the studies investigating Internet-connected device use in everyday life (sections 2.1.2 and 2.3), broader SHCI research has focused on understanding people and their practices or consumption. These studies are in aid of creating more sustainable technologies, or transitioning everyday practices in more sustainable directions [340]. Such work has covered many topics in sustainability, including: uncovering attitudes towards sustainability from Millennials, the first generation to have grown up with technology [150]; comparing usual supermarket shoppers with *"food pioneers"* to unearth ways in which HCI can develop sustainable food choices [81, p. 28:1]; understanding how HCI can discourage e-waste [169] and device obsolescence [306]; investigating personas of smart home users to highlight how their desires undermine sustainability [176]; and discovering opportunities for more sustainable deliveries in the 'last-mile' between local depots and consumers [24].

Research has also focused on specific spatial areas to uncover how we can reduce energy and resource consumption. For example, researchers have used 'the home' as an investigatory space [75, 87], as well as exploring energy consumption practices in 'workplace settings' where individuals are not always financially motivated to reduce their energy consumption [124]. From such studies, strategies and opportunities for energy conservation efforts have been derived (e.g. *"trimming"* [292, p. 1987] energy use by using a lower power setting for a product)—discussing how the designs of technologies and products could be adapted to change social norms (e.g. having a 'high-energy cycle' on a washing machine, rather than 'normal' and 'eco' settings) [292].

The SHCI community has also aimed to understand how people live sustainably or take green approaches in their everyday life—taking the view that researchers can then find ways in which ICT could support such green practices, or discover how the population majority could begin to take on these sustainable qualities. This has included qualitative research into those who live simply and establish what is 'enough', e.g. by using the car less, buying locally and limiting product consumption [148]. Similarly, researchers have studied US households that have taken significant changes to be respectful for the environment [398], or explored the role and difficulties of green product designers [125]. From such formative studies, SHCI research has begun to design and establish *interventions* for developing sustainability in, or through, computing.

2.4.2 Interventionist studies in SHCI

Many of the inverventionist approaches in SHCI have followed *persuasive* research techniques (45% of SHCI research in 2010) [100] and 'eco-feedback' [128]. This agenda aims to prompt users to act in more sustainable ways through the use of technology, data collection and information visualisation (e.g. [17, 129, 337, 376]). For example, Laschke et al. deployed a shower calendar in two family homes to visually display water usage and persuade family members to use less [207]. Despite the significant body of interventionist research in SHCI [100, 128], it has come under much criticism due to its focus on individuals and the difficulty of ensuring more sustainable living in the long-term [60, 291, 362]. In fact, once provided with such 'eco-feedback' information via smart energy monitors, household practices can actually become harder to adapt in sustainable ways [151].

Interventionist approaches in SHCI have also included: replacing the car for a year with light electric vehicles to investigate technology's role in sustainable transport practices [153]; observing the use of sustainability games to raise awareness and understanding of environmental issues [246]; and creating a 'Housing Cooperative Energy App' for mapping energy actions to energy data [152]. As heating and cooling is a significant portion of energy use (particularly in the UK, with space heating forming 17% of domestic electricity consumption in 2018 [140]), SHCI researchers have looked to create thermostats [147, 173, 196, 335, 400, 401] and systems [79, 80, 88, 235] for managing, negotiating or creating more sustainable thermal comfort. Furthermore, the concept of *shifting* demand (rather than reducing it) has been applied to electricity use e.g. at times of renewable energy generation [346] or away from times of high demand [166]. Researchers have explored the challenges of these interventions [53, 127], and focused on washing machine use since laundry practices can shift in time [51, 89].

2.4.3 SHCI: futures and critiques

Moving beyond people and behaviour change, SHCI researchers have discussed the need to think and act more broadly. The SHCI community has been critised for focusing too long on defining Sustainable HCI and creating small, incremental changes using technology for sustainability; this is perhaps not enough to address the significant issues of climate change we face [191]. Knowles et al. argue that we should instead focus on encouraging activism and radical societal transformation through HCI [191]; helping technology users overcome any psychological barriers that prevent them from taking environmental action and demanding more from world leaders [192].

Furthermore, there has been a push for ensuring HCI researchers involve or collaborate with policy makers and wider stakeholders in order to make environmental and societal change [60, 100, 103, 368]. However, this broader stakeholder involvement does not come without its challenges, specifically as sustainability can become a lower priority for different companies and practitioners [308]. Blevis proposes that designers of technology can influence global policy just by designing for respect in sustainability, and that even small designs (e.g. Apple writing *"Designed by Apple in California. Assembled in China."* on their products) affect global tensions and harmony—meaning we should make sure what we design is respectful and *"matters"* [46].

With what seems like a more pessimistic attitude than other SHCI research, Tomlinson et al. [371, 372] introduced the idea of 'collapse informatics' i.e. *"the study, design, and development of sociotechnical systems in the abundant present for a use in a future of scarcity"* [372, p. 655]. They discuss how preparing for adaption, rather than mitigation, can help our survival in a collapsed society due to environmental change, and that technology can facilitate this: e.g. 'the Climate Change Habitability Index' allows people to monitor different places in regards to resources (such as water, food, and ecosystems) and consider whether they can stay living where they are (and if not, where they can move to) [371]. However, as collapse informatics prepares us for a future of scarcity, how can we prepare for these futures if we do not understand the events that take us there? [112]; given this, 'counterfactual history' has been proposed as a method to position significant environmental change in the past (e.g. *"What if there had only been half the oil?"* [283]) to imagine what would've happened, what we could've done, and what we should do now [112].

Calls for more optimistic approaches to issues of sustainability have been proposed through *"regenerative computing"*—ensuring researchers in this field become *"ambassadors of hope"* [224, p. 1]. Mann et al. argue that a more positive framing is needed to avoid defeatism and galvanise the community [224], e.g.: assuming our path towards a more sustainable society will filled with feelings of pain and guilt [194]; predictions of, and preparing for, *"bleak futures"* [281]; and viewing technological futures such as the sustainable smart city as potentially impossible [311]. To make sustainability research (and particularly the Association for Computing Machinery (ACM) 'Computing within Limits' community) more 'positive', Mann et al. link to Gui and Nardi's argument of transitioning our focus on *"less"* for sustainable computing (e.g. less energy), towards the *"mores"* it can bring (e.g. empowerment, sustainable morals) [146]. In this thesis, I utilise these positive viewpoints—aiming to reduce the issue of data demand through HCI designs which can benefit both society and the environment.

2.5 Scoping the PhD research

Internet-connected digital devices and online services are increasingly embedded into our everyday lives—but this has consequences for the environment. It is unclear exactly what the total energy impacts of ICT are, but they are expected to form 21% of our global electricity demand by 2030 [8]. This is, in part, due to the extreme growth of Internet connectivity and the associated energy consumption from the Internet infrastructure (e.g. data centres, communication networks), as this indirect electricity usage from ICT forms approximately double that of its direct electricity consumption (e.g. device charging) [156]. Furthermore, the rate in which this growth is accelerating quickly eliminates energy efficiencies created in the Internet infrastructure [298].

To ensure efficiencies maintain the energy savings they create, we need to stop the continuous growth in the demand for data through more sustainable device and service HCI design. Prior work in HCI has begun to investigate data demand and how it may be curtailed [25, 211, 298], but these do not uncover how data demand is formed at a large-scale, across different devices (e.g. smart TVs) and for various online activities (e.g. watching video streams). Large-scale statistics of Internet use exist that give some insight into the different demanding Internet activities (cf. [78, 322]), but they do not uncover nuance in how this Internet use is formed in users' everyday lives, nor do they suggest opportunities to reduce data traffic. Studies have investigated users' Internet and application use (cf. [50, 183, 251]), targeted devices' direct energy consumption (cf. [13, 73]), and even created applications which limit traffic [74], but they do not focus on data demand or mitigate the impacts that this brings for the environment.

We need an in-depth understanding of how Internet and device use (and the associated data demand) is incorporated both temporally and spatially in everyday life, and expose the mechanisms for which data-intensive practices can be transitioned in more sustainable directions [340, 341]. We also require more specific design recommendations for the HCI community that aim to create effective data demand reductions in device and service use—and particularly those which take a more positive approach to SHCI [146, 224] by *benefiting* society at the same time (e.g. by overcoming the negative effects that digital technology can add to users' lives, discussed in section 2.2). This thesis aims to address these gaps in prior work by uncovering how data demand supports people in their everyday lives in meaningful ways, and discover opportunities for SHCI design that reduce the demand for data whilst positively affecting society.

2.6 Summary

In this chapter, I have provided an overview of the environmental impacts of ICT (section 2.1), and in particular, the indirect effects of ICT that are investigated through LCA and SHCI research. Alongside these environmental effects, I've outlined the different impacts that technology is having on users (section 2.2), e.g. on their wellbeing, relationships with others, work productivity and online privacy. I've also described prior work studying the use of ICT in the home and on-the-go via mobile devices (section 2.3), and discussed a broader body of work in SHCI which aims to mitigate issues of climate change through, or in, technology design (section 2.4). Based on this prior work, I have identified a research gap in the literature (section 2.5) which motivates this thesis. In the next chapter, I describe the methodological approach taken to addressing this research gap—detailing the studies and data analysis carried out.

We’re on a rollercoaster stuck on its loop-de-loop,
’Cause what we did, one day, on a whim,
Has slowly become all we do.

—TAME IMPALA

Chapter 3

Methodology

As brought out in chapter 2, we need to curtail the demand for Internet connectivity—ensuring efficiencies in the Internet infrastructure are utilised and mitigating the environmental impacts of ICT. Given the need for demand-side reductions in Internet connectivity, a human-centred approach to studying this issue is required. This will allow for an in-depth understanding of the temporalities and activities involving data demand in everyday life, and through this, opportunities for curtailing this demand via more sustainable device and service HCI design can be uncovered. While other analyses would be useful to understand data demand (e.g. studies of data centres), they would not provide the level of detail needed to fully explore and mitigate the roots of data demand in everyday life that HCI research can deliver.

There are theories in sociology that underpin work in HCI, enabling an understanding of how people use technology and how this contributes to HCI design. Social practice theory is one way of understanding how technology use is constructed in users' everyday lives and how these change over time. Social practices have been defined as a composition of linked elements which change over time. A simple but popular model consists of three elements defined by Shove et al.: 1) the materials involved, i.e. objects and technologies that people use; 2) the competence to carry out the practice; and 3) the meaning we give it in society [338]. For example, in the case of driving a car in the US between the 1900s–1910s: the materials comprise of the carriage design and how the engine presents required skills to drive the vehicle; the competences include the driver's mechanical expertise and their ability to use tools, steer or brake; and the meaning elements could include how driving signifies innovation or wealth to the driver, or links to ideas of adventure, fresh air and nature [338].

Changes in these three elements in turn change how the overall practice itself plays out in everyday life—showing how practices are dynamic. Links between the three elements are made and broken which amend a given practice, e.g. for driving: the introduction of mirrors in cars meant drivers had to begin checking these for traffic, and drivers needing to read a map became obsolete with satellite navigation [338]. Practices are also shaped by elements overlapping from other practices, e.g. cars have been associated with masculinity, an element of meaning which appears in driving and repairing practices—consequently a change to this element impacts both practices [338]. Practice theory has therefore been applied and developed to understand how everyday life *changes*, with a particular focus on how resource-intensive practices develop and become new norms [339]. Rhythms of everyday practices in media-dense homes have also been exposed [255]—giving insight into how users temporally manage and coordinate technology practices in domestic settings.

ICT is shaping our everyday lives and practices, e.g. broadcast TV leads to viewers coordinating their time to watch together; yet ICT is also, in turn, shaped by *"rhythms and routines of the people with whom our lives are intertwined"* [210, p. 1450]. Such developments raise sustainability concerns: Røpke et al. [316] link everyday life with energy demands. They discuss how ICT allows for the *"partial decoupling of many practices from previous time and space constraints"* [316, p. 356]; this is because ICT can now practically be used anywhere (e.g. throughout the home rather than at a specific desktop PC location, or removing the need for people to be physically co-located for social interaction) and at any time (e.g. periods of *"dead time"* as mentioned in section 2.1.2). This increased connectivity means users' everyday lives have the potential to become *"more densely packed"* [316, p. 356], and changes in our everyday practices are leading to increased energy intensities in our digitally-mediated lives [316].

To study data demand and how everyday life is moving in more data-intensive (and therefore energy-intensive) directions, I take a social practice-based approach; this follows prior work and arguments in HCI [26, 199, 312, 316]. I conceptualise, where possible, practices that are shaped by Internet connectivity (e.g. 'watching', chapter 5) and the rhythms forming why, when and where they occur [255]; and further the understandings of connections between social practices and interactions with digital technology [316]. I investigate the material, competence and meaning elements of these practices. The materials consist of the Internet-connected digital devices (e.g. smartphones, TVs) and their associated online affordances. The competences are comprised of people's ability to select and use digital devices in an appropriate way, e.g. knowing how to use a smartphone and make a WhatsApp call, or knowing how to turn on the TV and select a channel to watch a show. The meanings underpin why people use their competences, and choose the materials, to conduct the practice, e.g. making a WhatsApp call to be in contact with a loved one, or watching a show because it brings joy and nostalgia. By studying these linked elements and taking a practice-based approach, the findings in this thesis move beyond the individuals studied and their *"specific, isolated behaviors"*, to instead *"consider energy in the context of broader sociocultural practices"* [60, p. 954]—enabling an understanding of how the demand for digital devices, online services, data demand and everyday life are co-evolving.

To investigate the data demand associated with everyday practices, I explore how Internet connectivity is demanded through time (see methods in sections 3.1 and 3.2), by device (section 3.2) and for users' activities (sections 3.2 and 3.3). This takes a practice-as-performance view of practices (i.e. investigates the way in which particular people carry out a practice) rather than the practice-as-entity approach (i.e. the composition of a practice across society, which can be transformed over time through individuals' practice-as-performances) [315, 327]. To do this, I utilise quantitative logging techniques, similar to those used or suggested by prior work (cf. [23, 183, 211]). These logs are juxtaposed with qualitative data (from semi-structured interviews and workshops) to further explore how data demand is embedded in everyday life and how it may be mitigated through more sustainable HCI design—uncovering what is needed to transition everyday practices and their current trajectories [340, 341], as well as the associated Internet intensities, in more sustainable directions. I also take a focus on data demand, rather than the underlying energy consumption, as the Internet infrastructure and the associated energy impacts only increase if data demand increases (as section 2.1 highlighted). Therefore, by investigating the most data demanding activities in everyday life and targeting those, we can curtail data demand and prevent further increases in the infrastructure and its energy impacts.

In this chapter, I detail the methods used in three different studies carried out for this thesis. These involve formative studies to understand the data demand of mobile and in-home devices, as well as a design workshop to develop ideas for reducing data demand in everyday life. Specifically, I first discuss a quantitative approach used to understand the activities and themes of mobile data consumption to target for data demand reduction, with a population of 398 Android devices (section 3.1). I then describe the procedure for a mixed-methods study I conducted to gain insight into home Internet demand (section 3.2); this involved merging both quantitative and qualitative data to study in-depth the use of digital devices and online services with 20 participants in nine households. Finally, I describe the method taken for a design workshop I ran with 13 participants (section 3.3)—aiming to uncover opportunities for Internet interventions that reduce data demand whilst improving users' experiences of device and service use (e.g. by addressing the impacts ICT is having on users, discussed in section 2.2), and exploring how *users themselves* envision Internet interventions being incorporated into digital device and online service design.

3.1 The Android dataset

To develop a larger scale understanding of data demand, uncover how this is formed temporally and how it links to everyday practice, and reveal the data demanding activities to target for reduction through HCI design: I carried out a secondary analysis of quantitative Android smartphone and tablet data from the 'Device Analyzer' dataset. The Device Analyzer is a data logging application for the Android platform (developed at the University of Cambridge)[1] which records mobile device usage statistics such as screen locked/unlocked and power on/off states, device battery levels and voltage, and the data usage associated with each app.[2] From the deployment of Device Analyzer on users' smartphones and tablets, the University of Cambridge have made usage data (on an opt-in basis for users) available to researchers; this has led to a dataset containing over 16,000 devices worldwide [385].

Through collaborating with Alastair Beresford (a member of the Device Analyzer team at the University of Cambridge), I was able to carry out analysis on a subset of this dataset where devices: 1) contributed at least 14 days of usage logs with the latest data collected on or after 1st January 2014; 2) had a network-based location in the UK or Ireland for at least half of the contribution days; and 3) used apps or demanded data during their logging period. These restrictions were made in order to look at data demand in the Atlantic Archipelago,[3] and avoid devices which were rarely used or only had the Device Analyzer installed for a short period of time. This resulted in a partition of 398 devices from the original Device Analyzer dataset. The steps taken to analyse the data demand of these 398 Android devices are described below.

[1]Device Analyzer webpage: **https://deviceanalyzer.cl.cam.ac.uk**, accessed October 2019.

[2]A detailed list of what the Device Analyzer logs: **https://deviceanalyzer.cl.cam.ac.uk/collected.htm**, accessed October 2019.

[3]Great Britain, Ireland and other British islands.

3.1.1 Quantitative analysis of the Android dataset

To highlight how patterns of time and routines impact data demand, as well as uncover the most demanding activities and relate devices' data demand across users' practices, the Android dataset was analysed by: 1) day of week, and 2) application category. To uncover this detail, multiple quantitative analysis steps were taken. Firstly, the set of Device Analyzer logs for each device needed to be parsed; section 3.1.1.1 outlines the types of logs collected by the Device Analyzer and the specific logs utilised for understanding data demand through time and by each application. Secondly, a mapping approach was required to map the apps into services and categories of services; this was carried out to reveal the collective data demand, across the 398 devices, for different user activities in everyday life. The mapping strategy is detailed in section 3.1.1.2.

3.1.1.1 Parsing the Device Analyzer logs

The Device Analyzer outputs a variety of different timestamped logs (UTC timestamps at millisecond granularity e.g. '`2015-12-25T12:05:13.400+0000`') about the device for which is is installed on; these are stored in a .csv file and use a 'nested' logging technique. For example, for information about the device screen, the log data would start with '`screen`'. A log which then indicated the screen's power was on consisted of '`screen|power;on`'; '`screen|power;off`' would indicate the screen was off. For information on the screen's brightness, the Device Analyzer had two nested '`screen|brightness`' logs: 1) '`level`', outputting the brightness level value of the screen (e.g. a brightness level of 100 would produce: '`screen|brightness|level;100`'); and 2) '`mode`', outputting whether the brightness was automatically being set by the device ('`screen|brightness|mode;automatic`') or manually set by the user ('`screen|brightness|mode;manual`').

To understand the data demand of the Android dataset, I focused on two sub-groups of logs outputted by the Device Analyzer: 1) '`app|installed`'; and 2) '`net|app`'. The '`app|installed`' logs provided a comma-separated list of apps installed on the device and additional information about each of those apps (e.g. the app's list of permissions, the app ID). For the purposes of my analysis, I was only interested in the app name and the app ID—therefore to simplify the log as an example (removing detail by using '[...]'): '`app|installed;com.facebook.orca [...] |14| [...],com.facebook.katana [...] |15| [...]`' indicates that the mobile device has two apps installed: 1) 'com.facebook.orca' (Android's name for Facebook Messenger) with the app ID '14', and 2) 'com.facebook.katana' (Android's name for Facebook) with the app ID '15'.

The '`net|app`' logs outputted the network statistics for a particular app ID, e.g. the log '`net|app|14|rx_bytes;3000`' indicates that 3000 bytes have been received ('rx') by the app with the ID '14'; the log '`net|app|14|tx_bytes;700`' shows that 700 bytes have been sent ('tx') by the app with the ID '14'. App IDs were then compared to the '`app|installed`' logs to find out their names. Given these sample logs, app information regarding the app ID '14' would be linked to 'com.facebook.orca'—meaning Facebook Messenger had sent 3000 bytes and received 700. Logged bytes were running numerical totals which could overflow and reset to zero; therefore the analysis scripts I created to parse this data had to manage differences between the bytes values of the '`net|app`' logs to understand the actual amount of data demanded by each app. Each log timestamp for these network statistics was used to determine the data demanded through time (e.g. hourly, across days of the week) for the devices.

3.1.1.2 Mapping Android app names to services and categories

To understand the data demand associated with different activities in everyday life, device applications were mapped into services and then into categories; this enabled a transition to be made between the Device Analyzer's logs (i.e. the data demand of Android-named applications, such as 'com.facebook.katana'), to application names as humans understand them (i.e. 'Facebook'), and then to application categories to view how data demand is formed in everyday life through online activities (such as 'Social Networking'). For the categorisation, no automatic mapping tools were available; a manual mapping technique was therefore used for grouping apps, adopting a mix of semantic reasoning of the apps and online research (e.g. on developer forums).

Device Analyzer users typically *do not* give permission for app names on their devices to be shared with researchers outside of the University of Cambridge. To prevent the identification of participants from their app use profiles, data demand was not analysed for any apps installed on less than 50 devices to maintain an anonymity set. As a result, a list of 404 apps that were installed on at least 50 of the handsets in the dataset was generated for analysis. This privacy precaution creates the disadvantage that data demand for unpopular apps are not recorded. Despite this, 72% of the total data demand of the devices were able to be categorised.

A total of 23 categories were found in this dataset: Watching; Background Processes and Services; Searching and Wikis; News, Weather and Magazines; Tools; Office; Reading; Shopping; Listening; Browsers; Communication; Short Message Service (SMS) and Phone; Storage, Backups and Transfers; Photography; Software and Application Updates; Security; Settings; Navigation and Travel; Health and Fitness; Social Media; Analysers (i.e. apps that analyse information about the device and its use); Gaming; and Speciality (e.g. apps for specific activities that do not fit into the other categories). The categories, the number of apps in each category, and examples of the apps in the categories are summarised in table 3.1. To further maintain participant anonymity, categories which had less than 10 devices demand data during the study period have been removed from the analysis; this affected ‘Gaming’ and ‘Security’, taking the actual number of categories analysed to 21.

It is important to note that these categories are not practices themselves, as the categories (e.g. ‘Browsers’) may cross multiple practices. Whilst some of the categories are activities (e.g. ‘Social Networking’), not all of the categories are directly associated with activities; e.g. ‘Background Processes and Services’ links to software running in the background by the device, meaning data demand from this category may be formed as a consequence of many activities or solely device-initiated. In addition, data demand from the categories which are activities may not occur at the same time as the users’ performances of the activities, e.g. delivered notifications for ‘Communication’ apps would add data demand to the category but the user wouldn’t necessarily have to interact with the notification at the time of its delivery.

Aggregate data demand values for the 398 devices are presented in this thesis (chapter 4) to visualise data demand through time and by application category. For the visualisations, devices are omitted who were not ‘active’ in a given group i.e. did not exhibit data demand (e.g. a device who did not demand data on a Monday would be omitted from the plotted values for Monday, or a device which did not demand any data for the category of ‘Social Networking’ would not be included in the plotted values for the category). Data demand is presented in this way to compare average usage for these groups, and identify where we might shift practices’ reliance from more demanding times or activities. However, to expose the prevalence of these groups, the number of contributing devices is provided in brackets on relevant figure legends (figures 4.1 and 4.3); for these figures, data is averaged across days for each device and then averaged across devices. In this thesis, data demand values are provided in kibibytes (KiB), mebibytes (MiB) and gibibytes (GiB) i.e. follow traditional Computer Science representations of bytes (base-2), rather than modern metric scales (base-10).

Category	No. of Apps	Example Apps
Analysers	3	uk.ac.cam.deviceanalyzer, com.farproc.wifi.analyzer
Background Processes and Services	167	com.android.defcontainer, com.android.vending
Browsers	7	com.android.chrome, org.mozilla.firefox
Communication	17	com.facebook.orca, com.whatsapp
Gaming	2	com.google.android.play.games, com.sec.android.app.gamehub
Health and Fitness	6	com.google.android.apps.fitness, com.sec.android.app.shealth
Listening	10	com.spotify.music, com.samsung.music
Navigation and Travel	12	com.google.android.apps.maps, com.tripadvisor.tripadvisor
News, Weather and Magazines	13	bbc.mobile.news.uk, uk.gov.metoffice.android
Office	24	com.microsoft.office.word, com.google.android.calendar
Photography	11	com.sec.android.gallery3d, com.google.android.GoogleCamera
Reading	2	com.google.android.apps.books, com.amazon.kindle
Searching and Wikis	6	org.wikipedia, com.google.android.voicesearch
Security	6	com.samsung.android.securitylogagent, com.android.providers.security
Settings	5	com.android.settings, com.sec.usbsettings
Shopping	5	com.ebay.mobile, com.paypal.android.p2pmobile
SMS and Phone	11	com.android.dialer, com.android.smspush
Social Networking	5	com.facebook.katana, com.twitter.android
Software and Application Updates	6	com.sec.android.preloadinstaller, com.android.providers.downloads
Speciality	3	com.rightmove.android, com.justeat.app.uk
Storage, Backups and Transfers	39	com.dropbox.android, com.sec.android.sCloudSync
Tools	31	com.google.android.deskclock, com.android.inputmethod.latin
Watching	13	com.netflix.mediaclient, com.google.android.youtube

Table 3.1: The Android dataset app categories (in alphabetical order).

3.1.2 Benefits and limitations

Due to the anonymity restrictions associated with the dataset, I do not know the demographic information (e.g. age, gender, race, profession) of the device users. However, all users must confirm that they are 18 years or older when participating in the research—meaning it can be assumed that the dataset only comprises of adults. Furthermore, the data demand from the Android dataset analysis cannot be differentiated between whether apps demanded data via mobile (e.g. 4G) or Wi-Fi over fixed access networks; this is a limitation of the dataset and would be a useful avenue for future work. Yet prior work has made this differentiation [211], and this study builds on such work by investigating data demand through time and for users' everyday activities instead. Data analysis for the dataset is also restricted to average hourly means and total data demand per category due to the complexity and time required to run scripts at the University of Cambridge; this issue is alleviated through the different views of data demand able to be produced from the household study (as described next in section 3.2).

3.1.3 Summary: from mobile devices, to households

Whilst the Android dataset provides an interesting overview of mobile device data demand and the contributing categories of service use, it is limited in what it can inform about data demand as a whole. Specifically: 1) the dataset is formed from only Android mobile devices, meaning the data demand from other devices (e.g. smart TVs, laptops etc.) or operating systems (OSs) (e.g. iOS, Windows) are not covered; 2) only average hourly means and total data demand *per category* were gathered, meaning more fine-grained detail (e.g. data demand of services) is missing from the analysis; and 3) the dataset is quantitative only, and therefore does not provide nuanced detail about how data demand is formed within users' everyday lives. As highlighted in section 2.5, such detail is needed to build upon current understandings of data demand (cf. [25, 211, 298]) to uncover how the HCI community can best create data demand reductions. As a result, I conducted a study of Internet demand in the home, which gathers both quantitative and qualitative data about data demand across a variety of devices.

3.2 The home Internet demand study

To explore the use of a variety of Internet-connected devices and their relation to data demand, I carried out a mixed-methods study to gather both quantitative (Internet usage logs) and qualitative data (semi-structured interviews) from participants' homes. This builds on prior work from this domain in HCI [25, 211], as well as the Android dataset (section 3.1), by investigating data demand in-depth beyond 'just' mobile devices (e.g. to include devices such as smart TVs, PCs, games consoles) and using both quantitative and qualitative data capture to understand the data demand of users' activities. This cross-device data capture is enabled by quantitatively logging data demand in households at the home router-level—eliminating the overhead of multiple logging applications for various device operating systems, such as using the Device Analyzer which specifically only works for Android devices (section 3.1).

20 participants (nine households) took part in the study between June 2017–January 2018, and were recruited through email flyer advertisement and snowballing methods by convenience sampling. To incentivise participation, all households were entered into a draw to win a £50 Amazon voucher. No specific criteria was required for recruitment, other than the need for the households to own (and use) home broadband; households were recruited throughout the eight-month study period until findings began to converge. To protect the anonymity of the participants, pseudonyms are used throughout the thesis. All participants were fully informed of the nature of the study through a participant information sheet and had to sign for consent (with guardians required to sign for under 18s). Forms used for participant recruitment and consent are provided in the appendices (information sheet: appendix A, consent form: appendix B, and consent form for guardians: appendix C). The participants, their demographic data, and their household relationships are summarised by the family trees in figure 3.1. The study procedure is described in detail below.

3.2.1 Study procedure

The mixed-method study, gathering both quantitative and qualitative data, involved the following: 1) an interview with each participant; 2) an Internet logging period; and 3) a follow-up interview with each participant. The study structure is outlined in figure 3.2, and each stage is described in detail below. Both interviews were scheduled at a time and place suitable for the household (all interviews except Ella and Xavier's

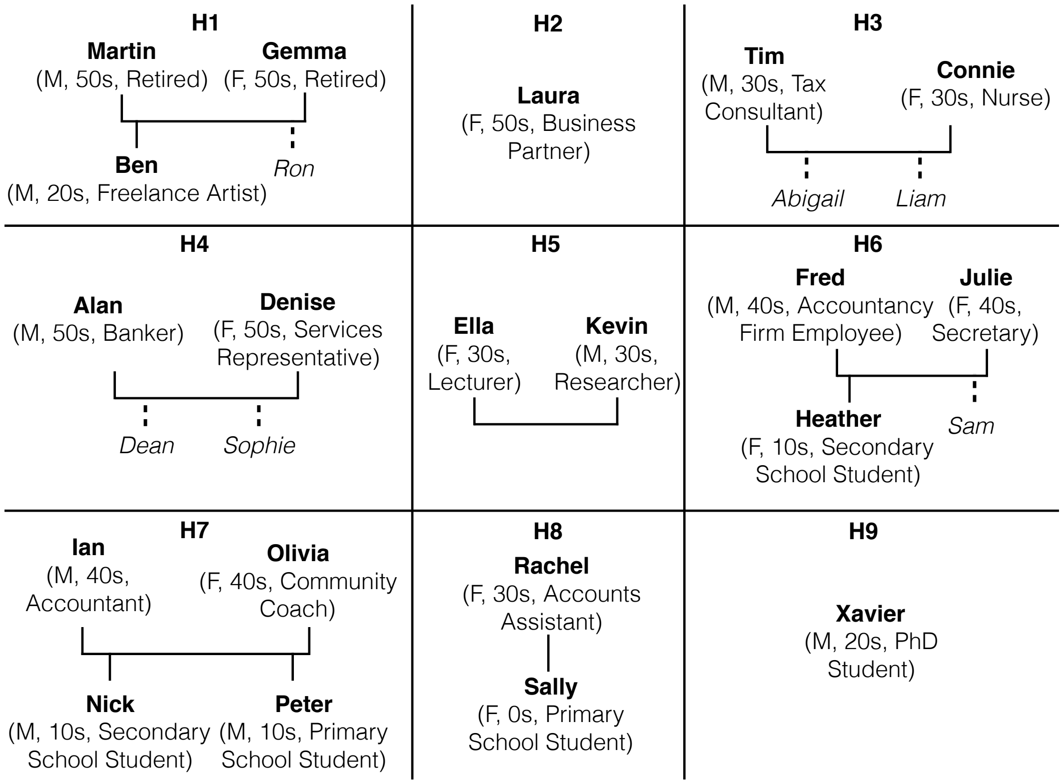


Figure 3.1: The household study participants and their relationships. Family members in italics were not participants, but are included as they help highlight the relationship dynamics of the household: Ron, Dean, Sophie and Sam no longer live at the family home; and the data demanded by Abigail (aged 5) and Liam (aged 3) is logged on their parents' devices and discussed in this thesis, but they were too young to be interviewed.

post-study interviews were carried out in the participants' homes), audio recorded, fully transcribed and open coded for themes. Each participant attended both of their interviews except Kevin (H5), who only undertook the first interview due to being busy starting a new job. Participants could also opt-in for video interviews (4/20 participants opted-in) whereby interesting and impactful clips may then be shown to academics and other relevant stakeholders.

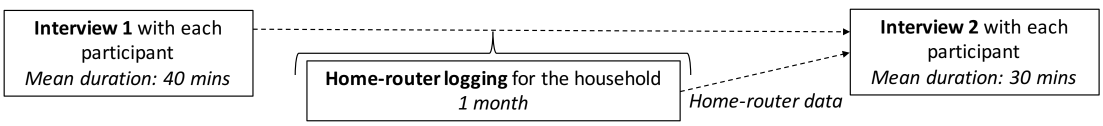


Figure 3.2: The structure of the household study.

3.2.1.1 The first interview

The aim of the first semi-structured interview was to gather an understanding of how the Internet is interwoven in each participant's life. Interviews lasted from 16 to 88 minutes (mean 40 minutes). All participants in each household were interviewed alone; this includes participants under 18 years old, although guardians were invited to join.

Each digital device they (or their household) owned was discussed in detail, including the typical times, days, activities and locations these are used. Questions focused on delving into scenarios of use (e.g. how they deal with flat batteries, how they update the software or applications on their devices) and their opinions of digital technology (e.g. whether they would change anything about their devices, how they may react if their Internet use was constrained). In addition to this, participants were asked to describe their hobbies and their usual routines on a weekday and weekend; these questions were aimed to find out more about the participants' daily lives and how their devices support this. Throughout the interview, I made efforts not to positively or negatively value or judge the participants' Internet demand or service use. The first interview schedule is provided in appendix D.

From these interviews, I created an inventory of the participants' Internet-connected devices. In total, the participants owned 75 devices including: 22 smartphones, 11 tablets, 11 laptops, seven TV set-top boxes, five TV dongles (e.g. Google Chromecast), four PCs, three smart TVs, three e-readers, three Wi-Fi speakers, two games consoles, one Wi-Fi printer, one iPod Touch, one Amazon Echo and one smart meter.

3.2.1.2 The Internet logging period

Directly after the first interviews with a household of participants, the Internet logging period began. This part of the study consisted of deploying an OpenWrt[4] router and mini PC to log and store Internet flows[5] in each home for one month (mean logging period duration 35 days, max. 58, min. 26). 'Logging routers' (i.e. running OpenWrt) were connected to each household's home router, and all device connections were transferred from the household's router to the logging router. The deployment was set up in this way to ensure the equipment installation was uniform across households (see section 3.2.3.2 for further information). Participants were asked to use their devices

[4]OpenWrt: `https://openwrt.org/`, accessed October 2019.

[5]Internet flows are a series of IP packets sharing the same IP information e.g. the same source and destination network addresses. NetFlow Internet flows (version 5) were used. The data fields for a NetFlow flow is shown in table 3.2 (origin 'NetFlow' fields only).

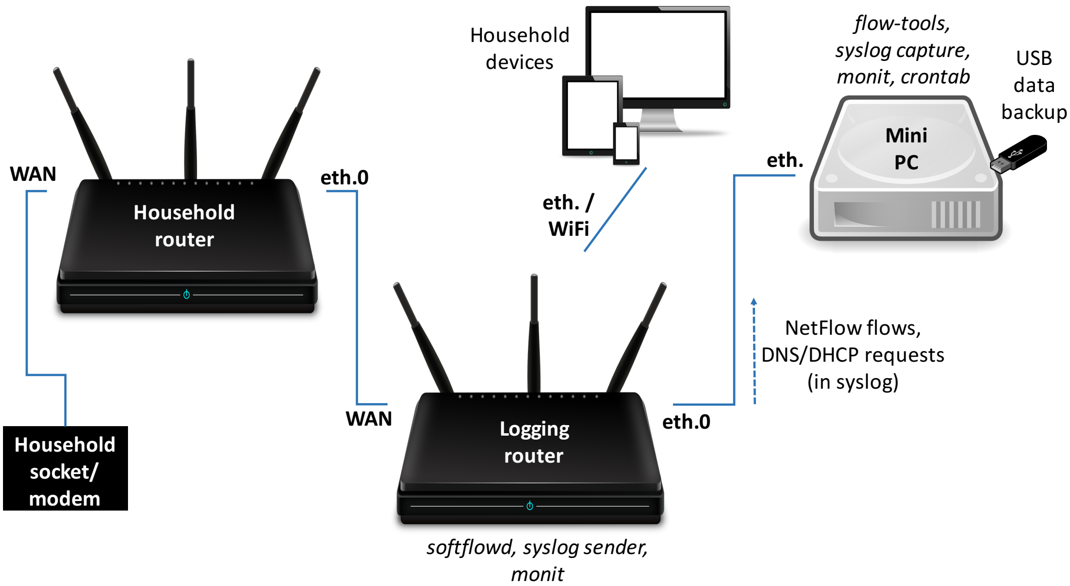


Figure 3.3: The Internet logging deployment setup for the household study. Software tools used on the logging router and mini PC are shown in italics. Images were taken from Pixabay [294] with CC0 licences [83].

and the Internet as they *normally* would whilst the equipment was installed; the month-long[6] logging ensured a comprehensive understanding of their Internet demand and helped mitigate the Hawthorne effect (i.e. the participants' behaviour changing as a result of their awareness of being observed). An overview of the deployment setup, i.e. the hardware, software tools and data used, is shown in figure 3.3; this took around one hour per household to install, varying based on the number of devices in the home.

NetFlow Internet flows[7] were gathered using *softflowd*[8] on the logging router, and captured on the mini PC using *flow-tools*.[9] These flows included source and destination IP addresses, date-timestamps, and throughput (in bytes). Figure 3.4 shows a sample of the raw NetFlow data and table 3.2 details each flow field (origin 'NetFlow' fields only). This data was required to understand the volume of traffic being sent or received between different IP addresses on the home network and the Internet.

Domain Name System (DNS) and Dynamic Host Configuration Protocol (DHCP)

[6]The logging router was deployed for longer than one month if the participants expected to leave their home for an extended time period, e.g. H7 had an additional week to accommodate for their holiday.

[7]NetFlow, version 5: **https://www.cisco.com/c/en/us/products/ios-nx-os-software/ios-netflow/**, accessed October 2019.

[8]softflowd: **http://manpages.ubuntu.com/manpages/xenial/man8/softflowd.8.html**, accessed October 2019.

[9]flow-tools: **https://linux.die.net/man/1/flow-tools**, accessed October 2019.

```
1498727221,272466000,65816660,192.168.1.1,1,66,65476434,65476436,0,0,192.168.1.109,192.168.1.1,0.0.0.0,0,0,53790,53,17,0,0,0,0,0,0
1498727221,272466000,65816660,192.168.1.1,9,7874,62131993,62198050,0,0,72.247.176.33,192.168.1.109,0.0.0.0,0,0,80,51124,6,0,27,0,0,0,0
1498727221,272466000,65816660,192.168.1.1,9,664,62131993,62198050,0,0,192.168.1.109,72.247.176.33,0.0.0.0,0,0,51124,80,6,0,26,0,0,0,0
1498727221,272466000,65816660,192.168.1.1,6,854,62201306,62201781,0,0,148.88.18.50,192.168.1.109,0.0.0.0,0,0,443,51129,6,0,26,0,0,0,0
1498727221,272466000,65816660,192.168.1.1,11,2153,62201306,62201781,0,0,192.168.1.109,148.88.18.50,0.0.0.0,0,0,51129,443,6,0,24,0,0,0,0
1498727281,302538000,65876690,192.168.1.1,1,207,65554285,65554285,0,0,192.168.1.1,192.168.1.109,0.0.0.0,0,0,53,52504,17,0,0,0,0,0,0
```

Figure 3.4: A sample of the NetFlow data. Information about each field is displayed in table 3.2 (origin 'NetFlow' fields only).

```
Jun 29 13:34:02 openwrt.lan dnsmasq[1270]: query[AAAA] smtp.gmail.com from 192.168.1.236
Jun 29 13:34:02 openwrt.lan dnsmasq[1270]: cached smtp.gmail.com is <CNAME>
Jun 29 13:34:02 openwrt.lan dnsmasq[1270]: forwarded smtp.gmail.com to 148.88.65.52
Jun 29 13:34:02 openwrt.lan dnsmasq[1270]: reply smtp.gmail.com is <CNAME>
Jun 29 13:34:02 openwrt.lan dnsmasq[1270]: reply gmail-smtp-msa.l.google.com is 2a00:1450:400c:c06::6d
Jun 29 13:34:02 openwrt.lan dnsmasq[1270]: reply smtp.gmail.com is <CNAME>
Jun 29 13:34:02 openwrt.lan dnsmasq[1270]: reply gmail-smtp-msa.l.google.com is 64.233.184.108
Jun 29 13:34:02 openwrt.lan dnsmasq[1270]: reply gmail-smtp-msa.l.google.com is 64.233.184.109
Jun 29 13:35:53 openwrt.lan dnsmasq-dhcp[1270]: DHCPREQUEST(br-lan) 192.168.1.236 00:22:68:67:7d:6a
Jun 29 13:35:53 openwrt.lan dnsmasq-dhcp[1270]: DHCPACK(br-lan) 192.168.1.236 00:22:68:67:7d:6a cutecat-Veriton-N260G
```

Figure 3.5: A sample of the DNS/DHCP data. This shows a set of DNS query and reply logs, as well as as a DHCP request and acknowledgement.

requests were also captured on the logging router via the system log (syslog), and captured on the mini PC. This was required to map the NetFlow IP addresses to the correct: domain names at a given time (DNS data), and therefore discover the services accessed; or the names of the participants' devices at a given time (DHCP data). IP address lookups alone did not provide the resolution of data required (see section 3.2.2.2 for details). Figure 3.5 shows a sample of the raw DNS and DHCP log data. This data was later transformed, via a Python script, into two log files that were easier to analyse programmatically: 1) a mapping of DHCP requests and DHCP acknowledgements (fields: date-timestamp, device name, IP address, device MAC address); and 2) a mapping of DNS queries and replies, including handling of multiple replies, caching and forwarding (fields: date-timestamp, IP address, domain name).

Other software tools were also deployed on the logging router and mini PC to ensure the data capture tools (i.e. softflowd, flow-tools, syslog transfer) ran smoothly and overcame faults with the software or hardware in real-time. These consisted of *crontab*[10] on the mini PC to run nightly backups of the data to the USB, and *monit*[11] on both the logging router and mini PC to handle run-time issues e.g. if softflowd stopped running, the tool would be restarted. Emails from monit and crontab were also sent to notify myself of any issues occurring on the equipment; I could then contact the participant to rectify any issues that could not be handled by software alone (e.g. a power cut at a household meant the mini PC needed to be restarted).

[10] crontab: **https://linuxconfig.org/linux-crontab-reference-guide**, accessed October 2019.

[11] monit: **https://mmonit.com/monit/**, accessed October 2019.

```
2017-06-29T12:12:01,1498738381,422472000,10975472,192.168.1.1,1,90,7315857,7318787,0,0,157.240.1.18,192.168.1.109,api.facebook.com,iPhone,0.0.0.0,0,0,443,51510,6,0,24,0,0,0,0
2017-06-29T12:12:01,1498738381,422472000,10975472,192.168.1.1,2,104,7315857,7318787,0,0,192.168.1.109,157.240.1.18,iPhone,api.facebook.com,0.0.0.0,0,0,51510,443,6,0,16,0,0,0,0
2017-06-29T12:12:01,1498738381,422472000,10975472,192.168.1.1,3,156,7315945,7347041,0,0,192.168.1.109,157.240.1.23,iPhone,scontent-lht6-1.xx.fbcdn.net,0.0.0.0,0,0,51514,443,6,0,16,0,0,0,0
2017-06-29T12:12:01,1498738381,422472000,10975472,192.168.1.1,3,4350,7315945,7347041,0,0,157.240.1.23,192.168.1.109,scontent-lht6-1.xx.fbcdn.net,iPhone,0.0.0.0,0,0,443,51514,6,0,16,0,0,0,0
2017-06-29T12:12:04,1498738381,422472000,10975472,192.168.1.1,1,52,7319309,7319309,0,0,192.168.1.109,148.88.18.50,iPhone,exchange.lancs.ac.uk,0.0.0.0,0,0,51518,443,6,0,16,0,0,0,0
2017-06-29T12:12:05,1498738441,182459000,11035232,192.168.1.1,45,2434,7320120,7411976,0,0,192.168.1.109,157.240.1.19,iPhone,video-lht6-1.xx.fbcdn.net,0.0.0.0,0,0,51521,443,6,0,24,0,0,0,0
2017-06-29T12:12:05,1498738441,182459000,11035232,192.168.1.1,87,123687,7320120,7411976,0,0,157.240.1.19,192.168.1.109,video-lht6-1.xx.fbcdn.net,iPhone,0.0.0.0,0,0,443,51521,6,0,24,0,0,0,0
2017-06-29T12:12:06,1498734901,342441000,7495392,192.168.1.1,1,40,7321196,7321196,0,0,192.168.1.109,40.101.19.146,iPhone,outlook.live.com.g.office365.com,0.0.0.0,0,0,51516,443,6,0,4,0,0,0,0
2017-06-29T12:13:40,1498738441,182459000,11035232,192.168.1.1,1,99,7414664,7414664,0,0,157.240.1.18,192.168.1.109,star.c10r.facebook.com,iPhone,0.0.0.0,0,0,443,51524,6,0,24,0,0,0,0
```

Figure 3.6: A sample of the mapped NetFlow and DNS/DHCP data. Information about each field is displayed in table 3.2.

Once the Internet logging period was over, the equipment and data were collected at a time suitable for the participants. In order to carry out data analysis on the households' data, the raw NetFlow and parsed DNS/DHCP data needed to be merged. This involved carrying out a lookup for each NetFlow flow to match each source and destination IP addresses to the correct domain or device (see section 3.2.2.1 for detail of this mapping strategy and its limitations). Figure 3.6 shows a sample of the merged data and table 3.2 describes each field.

Data analysis scripts were then run on the participants Internet log data (e.g. data shown in figure 3.6). These scripts created a number of graphs of the participants' (and their shared household's) devices' Internet demand. Graphs consisted of: average hourly data demand (KiB) throughout the day for each device (plotted as a line graph); hourly data demand (KiB) on particularly irregular days (e.g. high peaks, low troughs) for each device (plotted as a line graph); and average data demand (KiB) throughout the week for each device (plotted as bar a chart). Lists of the top demanding domain names for each device were also created. The visualisations[12] created were discussed with the participants in their final follow-up interviews, described next.

3.2.1.3 The second interview

A few days after collecting the equipment and data from the household, a second semi-structured interview was conducted with each participant. Interviews lasted from 12 to 70 minutes (mean duration 30 minutes). As with the first interview, participants were interviewed alone. The interview involved showing each participant the visualisations of their Internet use (described in section 3.2.1.2) as discussion probes to help *"understand people's experiences in the context of their lives"* [319, p. 11]. Discussing the quantitative data with the participants allowed for more detail to be uncovered about their Internet demand composition, revealing routines and notable irregularities in their Internet use. The second interview schedule is provided in appendix E.

[12]Sample visualisations are not provided in order to avoid compromising participant anonymity.

Field	Description	Origin
date-timestamp	The date and time of the flow (calculated using NetFlow fields: unix_secs, sysuptime & first)	Calculated from NetFlow
unix_secs	*Current count of seconds since 0000 UTC 1970*	NetFlow
unix_nsecs	*Residual nanoseconds since 0000 UTC 1970*	NetFlow
sysuptime	*Current time in milliseconds since the export device booted*	NetFlow
exaddr	The IP address of the NetFlow exporter	NetFlow
dpkts	*Packets in the flow*	NetFlow
doctets	*Total number of Layer 3 bytes in the packets of the flow*	NetFlow
first	*SysUptime at start of flow*	NetFlow
last	*SysUptime at the time the last packet of the flow was received*	NetFlow
engine_type	*Type of flow-switching engine*	NetFlow
engine_id	*Slot number of the flow-switching engine*	NetFlow
srcaddr	*Source IP address*	NetFlow
dstaddr	*Destination IP address*	NetFlow
srcdomain	Source domain/device name	DNS/DHCP
dstdomain	Destination domain/device name	DNS/DHCP
nexthop	*IP address of next hop router*	NetFlow
input	*SNMP index of input interface*	NetFlow
output	*SNMP index of output interface*	NetFlow
srcport	*TCP/UDP source port number or equivalent*	NetFlow
dstport	*TCP/UDP destination port number or equivalent*	NetFlow
prot	*IP protocol type (for example, TCP = 6; UDP = 17)*	NetFlow
tos	*IP type of service (ToS)*	NetFlow
tcp_flags	*Cumulative OR of TCP flags*	NetFlow
src_mask	*Source address prefix mask bits*	NetFlow
dst_mask	*Destination address prefix mask bits*	NetFlow
src_as	*Autonomous system number of the source, either origin or peer*	NetFlow
dst_as	*Autonomous system number of the destination, either origin or peer*	NetFlow

Table 3.2: The Internet flow data fields from the household study. ‘Origin’ refers to the dataset that the field originates from (i.e. NetFlow or DNS/DHCP logs). Fields are ordered in the order they appear in figure 3.6. NetFlow version 5 descriptions in italics are taken from Cisco [77].

3.2.2 Quantitative data analysis: strategies taken

To understand data demand in the lives of the participants, quantitative Internet use logs needed to be mapped into users' online activities; this followed a similar approach to the Android dataset mapping (section 3.1), whereby domain names recorded from the Internet logging period were mapped into services and then into categories. However, this is difficult to achieve perfectly in practice given the ambiguity of domain names in detailing the online services they serve. In this section, I detail these complexities and the strategies taken for the analysis of domains, services and categories. Specifically, I describe the processes conducted for: 1) mapping NetFlow to the DNS/DHCP data; and 2) mapping domains to services and categories. Before providing these details, it is worth noting that: for the entire nine households, 8,070,538 NetFlow flows (795.15 GiB) were gathered. Flows were removed if they had incorrect dates (i.e. dates outside of the study range) or were logged on the days of deploying or removing the equipment (i.e. to ensure only full log days were analysed). This totalled to 98,315 NetFlow flows (14.98 GiB) across all households, leaving a total of 7,972,223 flows remaining (780.17 GiB) to be analysed (98.78% of the number of flows and 98.12% of the data demand initially captured); this partition of data is what this section provides mapping analysis and statistics on.

3.2.2.1 Mapping NetFlow to DNS/DHCP

NetFlow IP addresses were mapped to the DNS/DHCP log where possible, as briefly mentioned in section 3.2.1.2. However, there were some discrepancies between the two log types, meaning some NetFlow IP addresses could not always be clearly mapped to a domain name in the DNS log. To alleviate this issue, I derived the following strategy (in the order it appears):

1. If a device had accessed an IP address in a NetFlow flow and the same request was missing from the DNS/DHCP log, DNS queries from *other* devices on the household network were used to map the IP address to a domain. Here I assume the domain has not changed between the two devices accessing the IP address. This gives a more reliable reading of what domain the IP address was at that time period (rather than fully relying on reverse DNS lookups in step 3). 1.60% of analysed flows (3.63% of data demand) were mapped in this way for either the source IP, destination IP, or both.

2. IP addresses were then checked to see if they were special IPs e.g. multicast address.

3. If an IP address could still not be mapped to a domain, reverse DNS lookups were carried out. This mapping was re-run in March 2018 after all of the studies due to an error in the merging script; as domains are reassigned IP addresses, this could potentially mean the domains from the reverse DNS lookups are not actually the domains accessed by the participants. However, only 0.68% of analysed flows (3.24% of data demand) were mapped in this way for either the source IP, destination IP, or both.

4. If the reverse DNS lookup failed, then the IP addresses were set to 'unknown'. 0.47% of analysed flows (2.34% of data demand) are classed as unknown for either the source IP, destination IP, or both.

Following this mapping, a total of 777.10 GiB across all households was found to be 'external' traffic i.e. data demand between users' devices or special IPs (e.g. multicast addresses) and network domains outside of the home. The remaining 3 GiB (from the 780.17 GiB initially analysed) was noted as internal traffic (i.e. data transferred between devices *within* the home). Unless specified otherwise, the analysis and statistics of the participants' data demand in this thesis refers to external data demand; this therefore provides an understanding of the participants' traffic travelling on the Internet infrastructure outside the home (e.g. on communication networks, to and from data centres).

3.2.2.2 Mapping domains to services and categories

To understand the data demanded in the participants' lives, domain names needed to be mapped into their associated service and service category; this allowed for a easier links to be made between the quantitative data and how the *participants* discuss their Internet-connected everyday practices in the interviews. Despite efforts to create, or find, a tool which would programmatically map domains to services, a manual mapping approach had to be taken. This is because currently available tools do not provide enough granularity e.g. 'WHOIS'[13] lookup on 'googlevideo.com' would return 'Google' as the registrar, rather than the actual service: 'YouTube'. Future work

[13] WHOIS lookup to find registration details of a domain: **`https://whois.icann.org/en`**, accessed October 2019.

would benefit from developing a more detailed domain-service mapping database, or taking a machine learning approach to revealing this data from network flows.

From the nine households, 20,000+ different domains were logged. Despite this vast number of domains, 90% of the data demand was actually only linked to 359 IP addresses; these were manually mapped into services and then into categories. I take the view that it is not particularly revealing to explore the 'long tail' 10% of least data demanding domains, which would also require manually mapping the remaining 10s of thousands of domain names.

A mix of semantic reasoning of the domains and online research (e.g. on developer forums) was used for the categorisation process. To provide examples of the mapping strategy: 'pc-nowtv-ak.vod.sky.com' mapped to the service 'Now TV' and was categorised into the 'Watching' activity; i.instagram.com' i.e. 'Instagram' falls into 'Social Networking'. Special case domains such as 'video.xx.fbcdn.net' (a Content Delivery Network (CDN) for Facebook), where the service is Facebook but the content is video, the category chosen is 'Watching'; domains associated with a watching device (e.g. 'yv1-api.youview.tv') are also categorised as this activity. The same mapping approach was taken for services hosted by a non-service specific CDN e.g. 'audiblecdn-vh.akamaihd.net' was categorised as 'Audible' (despite being hosted by the CDN 'Akamai') in the 'Listening' category. However, if the service could not be deciphered from the CDN, the CDN was named the service and the most appropriate category was chosen (e.g. 'vod-dash-uk-live.akamaized.net' i.e. 'Akamai' was put into the 'Watching' category due to the presence of 'VoD' (Video on Demand)). Of the 359 IP addresses, nine had unknown domain names: eight of these were associated with watching devices (categorised as 'Watching'); the remaining two were left in an 'Unknown' category. As a result, 357 domains were able to be fully categorised.

If a domain outside the 90^{th} percentile of data demand had the same high-level domain name as a suffix, it was also included with the high-level domain as the same activity in order to fully represent the demand for each service. For example, as the domain 'video.xx.fbcdn.net' appeared in the top 90%, all 'fbcdn.net' domains outside the 90^{th} percentile were mapped into services and categories. However, this was only carried out if the domain (or a subdomain of that domain) carried semantic information. For example, the domain 'r1—sn-aigl6n76.c.drive.google.com' is the service 'Google Drive' and therefore the category 'Storage, Backups and Transfers'; domains outside of the 90^{th} percentile were then added if they contained 'drive.google.com'. Using 'google.com' would not be specific enough, and therefore would've provided many different Google services that did not necessarily link to Google Drive.

In total, 25 categories of domains were produced: Advertising; Amazon Web Services, CloudFront and Media; Analysers; Background Processes and Services; Banking; Cedexis[14] Digital Services; Cheetah Mobile Services (Tools or Games); Communication; Gaming; Listening; News Weather and Magazines; Office, Work and Tools; Other Apple Products and Services; Other Google Products and Services; Other Microsoft Products and Services; Photography; Searching and Wikis; Security; Shopping; Social Networking; Storage, Backups and Transfers; Unknown; Updates and Installs; Verizon Digital Media Services; and Watching. A summary of these categories is provided in table 3.3, detailing: the category names, the number of services and domains the category contains, and examples of the services within the category.

In the analysis phase, mappings which seemed incorrect were manually amended. For example, H2's laptop was seen to access an 'xboxlive.com' domain in two NetFlow flows (out of 322,494 analysed for the household); given the participant's Internet use patterns discussed in the interviews, this was a highly unlikely mapping and therefore the two flows were edited to 'Unknown' category. Similar cases were found for 12 devices across other households (H1, H3, H6, H7, H9), affecting 358 flows in total (5.05 MiB): 3.25 MiB was reclassified as 'Unknown IPs for Watching Devices' in the 'Watching' category; the other 1.79 MiB were reclassified as 'Unknown IPs' in the 'Unknown' category. A table outlining all these manual mapping amendments, including potential reasons for their original incorrect mapping, is provided in appendix F. As a result of this mapping strategy, I was able to categorise 93.87% of the data demand (729.50 GiB of 777.10 GiB); removing the 'Unknown' category (7.30 GiB of demand), approximately 92.94% of data demand is fully categorised.

It is important to note that some categories could not be specified as user-focused online activities, and so are classed as company-specific. For example, the Google domain 'www.googleapis.com' did not provide enough semantic interpretation for categorisation: it could be for 'Google Search' and therefore the 'Searching and Wikis' category, or 'Google Photos' and therefore the 'Photography' category, and so on. To avoid categorising the domain incorrectly, it was categorised as 'Other Google Products and Services' and the domains outside the 90^{th} percentile with the high level domain suffix 'googleapis.com' were not added. Out of the 25 categories, seven are

[14]Cedexis: a traffic management and optimisation company. Taken over by Citrix 'Intelligent Traffic Management': `https://www.citrix.com/products/citrix-intelligent-traffic-management/`, accessed October 2019.

classed as company-specific and consist of: Amazon Web Services, CloudFront and Media; Cedexis Digital Services; Cheetah Mobile Services (Tools or Games); Other Apple Products and Services; Other Google Products and Services; Other Microsoft Products and Services; and Verizon Digital Media Services.

3.2.3 Benefits and limitations

3.2.3.1 Recruitment

Recruiting for this study was difficult: people were reluctant to participate due to the intrusive network logging and time required for this month-long study. However, I was able to recruit enough households for the study findings to converge, and the sample size of twenty participants aligns with typical sample sizes in HCI research [63]. The study also allowed for a nuanced understanding of Internet use in the home, rather than larger scale but uncontextualised studies of network use (cf. [78, 322]).

3.2.3.2 Missed devices

Not all of the participants' devices were quantitatively logged. During the deployment setups, I missed some devices when changing the households' devices' Internet settings to connect to the logging router. This was a result of *connecting* the logging router to each household's router (see figure 3.3), rather than *replacing* each household's router with the logging router. If the household's router had been replaced by the logging router, then any missed devices would not have been able to access the Internet during the study without the participants connecting the devices to the logging router. It is therefore likely that participants would have connected the missed devices to the logging router, in order to access online services on their devices.

However, the deployment setup was purposely designed this way due to the varying nature of home networking equipment. Some households may have a modem router, whilst others may have a separate modem to their router—meaning different households would've required varying equipment to be installed. In addition, different ISPs vary in the steps required for installing new modems/routers, and often need participants' original ISP login details which may have been difficult to source. Connecting the logging router to the household's router simplified the deployment and eliminated these issues. Furthermore, keeping the participants' routers meant the households' had: a 'backup' access to the Internet if any issues occurred with the logging router; or

Category	No. Services (Domains)	Example Services
Advertising	3 (180)	DoubleClick Ads, Vungle
Amazon Web Services, CloudFront and Media	4 (10)	CloudFront, Web Services
Analysers	2 (11)	ScorecardResearch, Amazon Device Metrics
Background Processes and Services	6 (35)	3GPP Network, Android
Banking	1 (2)	*Santander, NatWest*
Cedexis Digital Services	1 (1)	Cedexis
Cheetah Mobile Services (Tools and Games)	1 (11)	N/A
Communication	7 (138)	Apple Mail, WhatsApp
Gaming	2 (181)	PlayStation, Xbox Live
Listening	3 (302)	Spotify, Audible
News, Weather and Magazines	1 (2)	Sky News, *BBC News*
Office, Work and Tools	3 (28)	Microsoft Office, *Google Docs*
Other Apple Products and Services	1 (5)	N/A
Other Google Products and Services	8 (22)	Google APIs, Google Storage Upload
Other Microsoft Products and Services	1 (1)	N/A
Photography	1 (1)	Google Photos, *iCloud*
Searching and Wikis	3 (33)	Pinterest, Rightmove
Security	1 (37)	McAfee, *AVG*
Shopping	1 (14)	eBay, *ASOS*
Social Networking	5 (424)	Facebook, Instagram
Storage, Backups and Transfers	2 (19)	Dropbox, Google Drive
Unknown	1 (19)	Unknown IPs
Updates and Installs	6 (30)	Apple Updates, Windows Update
Verizon Digital Media Services	2 (3)	N/A
Watching	31 (1549)	BBC iPlayer, YouTube

Table 3.3: The household study domain and service categories (in alphabetical order). The services in the company-specific categories for Google and Amazon are not technically services but sub-groups of the category; the services in other company-specific categories (i.e. Apple, Cedexis, Cheetah Mobile, Microsoft, Verizon) could not be semantically interpretted. The 'Unknown' category represents 19 IP addresses (service 'Unknown IPs') that could not be mapped to services or domains; and a watching service is 'Unknown IPs for Watching Devices'. Services in italics are not present in the quantitative log data, but are provided as examples to: 1) avoid revealing services that could potentially compromise the anonymity of the participants (e.g. in 'Office, Work and Tools'); and 2) some categories only have one service in the top 90% (e.g. 'Shopping'), so additional examples of the types of services that would appear in the category are given (using examples from participant interviews where possible).

'non-logged' access to the Internet for devices they didn't want to be studied.

66 devices were logged in total; nine devices were not logged (shown in italics in table 4.1 in chapter 4). H1 requested for their two Sonos speakers and smart meter not to be logged due to the inconvenience of switching their Wi-Fi networks as they rarely used them. H5's Google Chromecast and Now TV box, Kevin's laptop (H5), and Sally's iPad (H8), were missed during deployment setups. Fred (H6, work laptop) and Olivia (H7, work Android phone) were concerned about their workplaces permitting their work devices to be logged, and therefore these devices were not connected to the logging router. However, the participants reflected on their use of these devices in the qualitative interviews.

3.2.3.3 Potential data demand misrepresentation

The data demand values for the logged devices could potentially be misrepresented due to: 1) participants' freedom to choose not to conduct certain activities during the study, such as watching pornography or illegally downloading data; 2) potential discrepancies in the mapping of domains to services (e.g. reverse DNS lookups occurring at a later date to the NetFlow logs, as described in section 3.2.2.1); 3) not all domains for a service appearing in the top 90% of data demand; and 4) some domain services being difficult to decipher into categories due to the ambiguity of domain names (as described in section 3.2.2.2). In the latter, the data demand outlined in this thesis could particularly under-represent the largest corporations (Google, Apple, Amazon) due to the variety of services they provide; this is because some of their domains can only be categorised within company-specific groups (e.g. 'Other Google Products and Services' as described in section 3.2.2.2), rather than user-focused activities (e.g. 'Watching'). However, domains from these categories (seven in total, listed in section 3.2.2.2) only form 4.20% of the total data demand for the households. Furthermore, the purpose of this study was to uncover how data demand is formed in the participants' lives; it was not to provide a large-scale quantitative overview of data demand in the UK (like Sandvine [322], or the Android dataset in section 3.1).

It is important to note that watching data demand (discussed in detail in chapter 5) may not always be directly linked to immediate use by the end-user: due to background processes (e.g. for a watching device), or a user not looking at the screen whilst it is demanding data (e.g. if a smart TV has been left on, but a user has left the room). Determining this would require undesirably intrusive study methods such as video recording the participants for the full study period. Furthermore, the data discussed from this study is associated with the home network and therefore is Wi-Fi only. Mobile data is not detailed for the nine households, however this is partially covered with the Android dataset analysis (see section 3.1).

3.2.4 Summary: from households, to workshops

The mixed-methods study of the households enabled a detailed understanding of data demand in the home and users' experiences of digital device use. To evaluate and further explore the findings of this study and the Android dataset analysis, I conducted a design workshop with participants to understand how the HCI community might design for less reliance on digital devices and Internet connectivity—reducing data demand in everyday life in ways that users might support or appreciate. I discuss the method for this design workshop next.

3.3 The design workshop

To understand how data demand and Internet reliance can be reduced in everyday life through more sustainable HCI design, I developed and ran two design workshops with a total of 13 participants (six at the first workshop, seven at the second). The design workshops followed 'Research through Design' methods, *"probing on what the world could and should be"* [406, p. 168] e.g. to explore possibilities for *"artifacts that both sensitize the community and broaden the space for design action"* [406, p. 168]. To enable a focus on users and gain new insights from them, co-creation and participatory design approaches are taken at this ideation stage of the design process [318]. These experiences and designs are then analysed to suggest how the HCI community can reduce data demand in ways which users might want, without moderating their meaningful Internet activities (see section 4.5.4 and chapter 6).

Three HCI expert facilitators were also involved to design solutions with the participants and keep discussion on-track with the schedule: the first workshop was facilitated with a colleague from Aarhus University (Christian Remy), the second was facilitated with the same colleague and an additional two colleagues from Lancaster University (Oliver Bates and Kathy New). Both workshops were conducted in March 2019 on Lancaster University campus, lasted three hours each, and followed the same schedule. However, they were organised at different times of day to accommodate various work and lifestyles: on a Friday morning, and the following Monday evening. Participants were recruited through email flyer advertisement, physical flyers placed on the University campus and in the local town, and via snowballing methods; the call for participation is provided in appendix G. The only recruitment criteria was that the participants used the Internet regularly, and participants were provided with an information sheet (appendix H), consent form (appendix I), and an outline of the workshop schedule (appendix J) prior to the start of the workshop. As a thank you for their time, each participant received a £10 Amazon voucher. The workshop participants (anonymised through the use of pseudonyms), their age, gender, occupation, and workshop setup (see section 3.3.1.3) are summarised in figure 3.7.

3.3.1 Workshop schedule

The workshop schedule (figure 3.8, appendix J) consisted of the following: 1) introduction and ice-breaker (15 mins); 2) an individual post-it note exercise (15 mins); 3) table discussions on Internet use (15 mins); 4) designing moderate Internet use (45 mins); 5) prototyping the designs (45 mins); and 6) an evaluation session (30 mins). Both workshops were audio recorded. A formal coffee break was scheduled halfway through the workshop. With permission from the participants, photos were taken throughout the workshops; two photos depicting the post-it note exercise and the prototyping session are displayed in figure 3.9 for context. The design workshop structure is outlined in figure 3.8, and each component of the schedule is detailed below.

3.3.1.1 Introduction and ice-breaker

Participants were welcomed to the workshop and asked to randomly sit down at one of the two tables. One (in workshop one) or two (in workshop two) of the workshop organisers were also located on each table. As the term 'Internet use' was referred to regularly throughout the workshop, the participants were informed upfront what was meant by this: a user (e.g. themselves) accessing online services on a digital device, such as an iPhone or smart TV. I also highlighted that Internet use can be seen as bad or good, and that the organisers were not there to judge that. After this initial introduction, all participants were involved in an ice-breaker: providing their name, occupation and what they use the Internet most regularly for. This was designed to make the participants feel more comfortable with each another whilst also enabling an initial understanding of each participant's Internet use to be gathered.

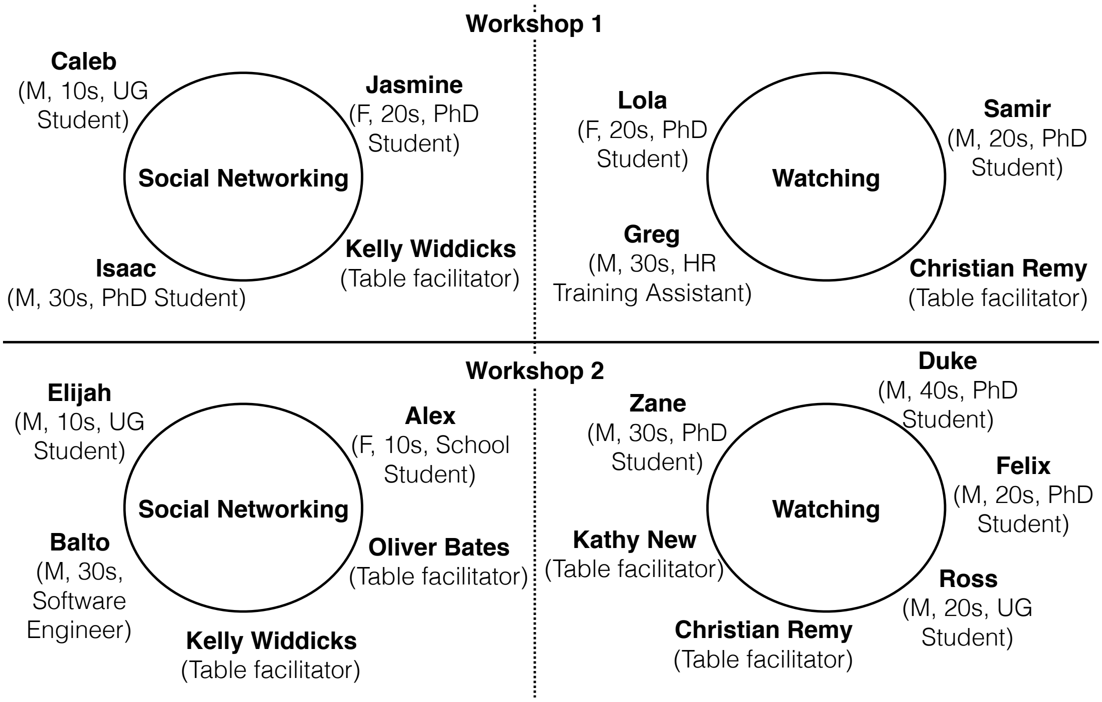


Figure 3.7: The participants and organisers at each table at the design workshops.

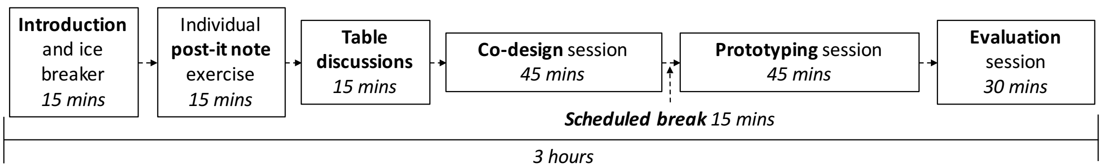
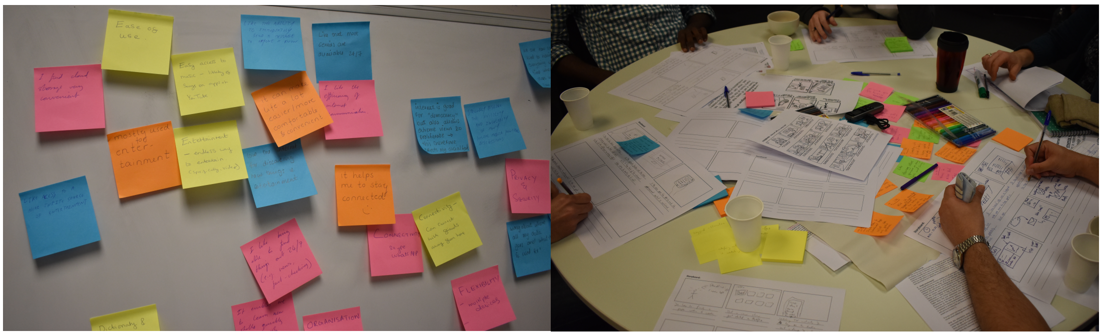


Figure 3.8: The schedule of the design workshop.

3.3.1.2 Individual post-it note exercise

To gather an understanding of the participants' opinions on their Internet use, each participant was asked to write up to 10 thoughts on post-it notes to the following question: *'What are your feelings towards your Internet use in everyday life? Particularly things that you like and don't like'*. The words 'up to 10' were specifically chosen to avoid participants feeling forced to write more than they needed to, and they were allowed the freedom to provide any split of negative or positive post-it notes. Participants were also informed that they were not restricted to what they wrote down (e.g. an online service they like/dislike, or a positive/negative activity the Internet allows them to conduct), as long as they explicitly highlighted whether the post-it had a negative or positive association. Each participant carried out this activity individually in



(a) Sample of the post-it notes in workshop 1. (b) A table storyboarding in workshop 2.

Figure 3.9: Photos of the workshop sessions: post-it note exercise and storyboarding.

order to avoid the opinions of others interfering with their own. Post-it notes were then added to a board, where the organisers arranged them into themes and summarised the commonalities to the group.

3.3.1.3 Table discussions

This session was conducted to find out more about the participants' Internet use in their everyday life. Due to the vast number of possible Internet services to be considered, and to avoid overwhelming participants, I chose to focus table discussions on two of the most data demanding categories: 1) watching; and 2) social networking [322], identified as categories to target during in the studies conducted for this thesis (see chapters 4 and 5). A table at the workshop was given watching as their discussion point, the other given social networking. Discussions were open and semi-structured through prompts from the organisers, with topics surrounding: the participants' use (or non-use) of the category, routines of use, and the services and devices involved. Discussions were also prompted using the common themes from the post-it note exercise. This session better positioned the participants' thoughts for the next exercise.

3.3.1.4 Designing moderate Internet use

In the design exercise, each table was given a brief based on their table's category of Internet use: *'Pretend you're a designer of Internet applications or technologies. There a set of users that are [streaming video/accessing social media] for many hours of the day and wish to moderate their use. How can you, in groups, redesign Internet applications or technologies to create more moderate and meaningful use for these* *users?'* The term 'moderate' was purposely chosen rather than 'reduce' in order to avoid the negative connotations associated with the word 'reduce'. The design session was also framed around this fictional case study, rather than designing for the participants themselves; this is because the participants' may have become defensive over their Internet use, and we wanted participants to maintain a positive framing to their designs—creating moderate Internet use which users may accept or even want. Participants were asked to critique their ideas as they discussed them, thinking about the associated challenges, advantages and disadvantages, and the relation of their ideas to the previous sessions (i.e. the post-it note exercise and table discussions). They were asked to keep notes and informed that these designs would be prototyped in the next session. Whilst the participants designed and critiqued the interventions *with* the organisers at each table, the organisers let the participants lead the discussions.

3.3.1.5 Prototyping designs

From the design exercise, the participants were asked to prototype the group's ideas through storyboarding—helping visualise how the intervention might work in practice. Resources were provided to each table consisting of pencils, colouring pens, and storyboard templates (each with six boxes for drawing six aspects of the design prototype). Two off-topic storyboard samples (a short storyboard and a long storyboard) were provided to the participants to help those not familiar with the concept; this also helped highlight that the participants did not have to use all six boxes on the storyboard template, or alternatively were able to prototype across multiple templates. Participants were welcome to create storyboards as a table, in smaller groups, or individually based on the number of ideas they had designed; if multiple ideas were being storyboarded, participants prototyping individually or in smaller groups were asked to draw and annotate different ideas to others on their table.

3.3.1.6 Evaluation session

To close the workshop, each table presented their designs to the entire group. All participants gathered around the watching table for the first half of the evaluation session, and then the social networking table for the second half. This allowed for additional comments and critiques to be made from the wider group. It also helped identify the common designs and challenges across both the watching and social networking categories—as well as other services that the participants discussed (e.g. news sites, music streaming services).

3.3.2 Data analysis

Both workshops were fully transcribed and analysed by myself in-depth. This involved carrying out thematic analysis on workshop transcripts, with high-level themes including: accounts of the participants' Internet use, their experiences of Internet connectivity and device use, the moderate Internet designs they discussed, and the challenges of these designs. These were then discussed with Christian Remy (who also analysed the data) and re-organised until a consensus was made. The post-it notes were typed-up into themes of positive, negative or 'neutral' (i.e. post-it notes with no positive or negative association) experiences towards digital technology use. Digital copies of the prototypes were made and examples of these are used in chapter 6 to show how users perceived their designs. The detailed workshops led to: 11 hours of audio recording (omitting workshop breaks), 107 post-it notes (61 positively associated, five neutral, 41 negative), and 23 storyboards (nine from workshop one, 14 from workshop two).

3.3.3 Benefits and limitations

3.3.3.1 Participant demographic

Despite efforts to recruit non-university locals, I note that the participant pool is mostly composed by university students and younger age groups (10s–30s); this could have been due to the workshops being held on Lancaster University campus. However, this is a good contrast to the household study (section 3.2) where this demographic was less represented. The sample is also swayed towards participants that identify with a male gender and so the designs created (presented in chapter 6) may best represent males; the design recommendations should be studied in the future with a diverse set of participants to ensure all gender preferences are considered. Furthermore, I acknowledge the sample size is small. Yet, this is in-line with other qualitative HCI work [63], and the small workshops allowed for in-depth discussion with each participant.

3.3.3.2 Internet service categories

As I have outlined in this section, the table discussions and design session focused on the categories of watching and social networking. It is important to note that there are other services and application categories to target for data demand reduction too: e.g. ‘Listening’ and ‘Background Processes and Services’ (as I outline in chapter 4), or ‘Software and Application Updates and Installs’ and ‘Gaming’ (as I outline in chapter 5). Gaming was only prominent in the household study, so social networking and watching were chosen above this activity as the demand for these categories was prominent in *both* the household (section 3.2) and mobile device analysis (section 3.1); gaming would be an interesting topic to consider in future work. The other prominent categories (e.g. listening), however, are more ‘passive’ data demanding activities (i.e. mostly occur in the background) rather than Internet use which (arguably) requires full concentration or interaction from users (e.g. to watch a film, or view social media). Furthermore, the design recommendations I suggest from this workshop could actually be applied across different Internet services beyond watching and social media (e.g. news sites, gaming) as I discuss in chapter 6.

3.4 Summary

In this chapter, I have illustrated how social practice theory can be used as an approach to understand how data demand in everyday life is composed, how it changes, and how it may be adapted in more sustainable directions [340, 341]. I have then described the HCI methods taken for quantitatively and qualitatively uncovering and mitigating data demand through three studies. The first study involved analysing a dataset of 398 Android devices to reveal the data demanding activities through time associated with smartphone and tablet use (section 3.1). The second study consisted of logging nine households’ Internet demand and conducting interviews with 20 participants to understand their data demanding activities, temporal patterns and device use (section 3.2). The third and final study involved two design workshops with 13 participants, aiming to uncover how Internet interventions may be adopted in everyday life for reducing data demand in ways that users may appreciate or want (section 3.3). In the next chapter, I reveal the findings from the analysis of the Android dataset and the household study to provide an overview of data demand in everyday life—exposing the most data demanding activities that require HCI intervention.

And we can find out the information,
access all the applications,
that are hardening positions based on miscommunication.

—THE 1975

Chapter 4

Data Demand in Everyday Life

As outlined in section 2, the issue of data demand in everyday life is relatively under-researched in HCI. Previous work has qualitatively analysed data demand [25], outlined opportunities for service designers to adapt traffic-consuming designs [298], and produced a small-scale quantitative and qualitative analysis of mobile data demand [211]—the latter producing the most detailed analysis of user practices involving Wi-Fi and 3G Internet connectivity. However, these papers do not quantitatively explore data demand at a large-scale, nor do they explore the traffic of other devices (e.g. smart TVs, laptops) in the home—this is paramount given the majority of traffic consumption occurs via fixed-access networks [78]. To fully understand data demand in everyday life, we need to explore: the trends (including peaks and troughs) of Internet traffic through time, alongside the demanding categories and devices worth targeting. Qualitative research is also required to uncover opportunities for HCI to reduce data demand in ways that work best for users.

In this chapter, I provide a detailed overview of how data demand is embedded within everyday life. This consists of a quantitative analysis of 398 mobile devices from the Android dataset (section 4.1, method in section 3.1)—uncovering patterns of data demand throughout the day and by categories of application. To further this large-scale analysis, I provide a primarily quantitative overview (utilising some of the qualitative interview data with participants) of data demand in the home for 20 participants across nine households (section 4.2, method in section 3.2). Traffic consumption of *other* devices (i.e. beyond mobile devices, such as smart TVs and laptops) is analysed here, and a more detailed understanding of online services accessed via the home network is revealed. Building on the quantitative data, I provide a summary of the household participants' digital experiences and how these link to data demand (section 4.3). From these findings, I provide a discussion detailing the difficulties for the HCI community in combating data demand growth (section 4.4). I am then able to provide implications that cover: the categories of Internet activity to target; how to redesign software and application updates to reduce and shift the associated data demand; the need for the HCI community to seek collaborations with businesses and ISPs; and the opportunities for HCI researchers and practitioners to design for more moderate, meaningful and sufficient online experiences for users (section 4.5).

4.1 Mobile data demand: patterns and categories

Utilising the Android dataset,[1] this section unveils the peaks, troughs and categories of data demand from mobile devices. Figure 4.1 depicts the hourly data demand of the Android mobile devices (tablets and smartphones) by day of week. When viewing data demand this way, it is obvious to see how demand coincides with users' device use through their temporal patterns of everyday life: data demand is lowest during usual sleeping hours (typically midnight to 6am) and then increases throughout the usual waking hours of the day (6am–midnight).

On weekdays (figure 4.1a), data demand begins to rise around 6am, with peaks in the morning (8am), early evening (5pm–6pm), and in the late evening (10–11am). These follow the traditional waking, commuting and sleeping times for a significant portion of UK society. All weekdays show a sharp decline of data demand after 11pm, with only Friday showing slightly higher demand at midnight and 2am. In fact, Friday and Monday follow slightly different average hourly data demand to that of the other weekdays. Friday shows higher demand in the morning (8am–10am) and early evening (6pm); Monday has the lowest demand in the afternoon and early evening (11am–8pm), as well as 10pm. This could be due to these days being adjacent to the weekend, acting as 'transition periods' between work (weekdays) and free time (weekends).

Weekend data demand differs to weekdays'. For Saturdays and Sundays, morning peaks are later (at 9am, rather than 7am or 8am on weekdays)—possibly due to users' waking times not being defined by their working hours. Throughout the day, data demand is more steady at the weekend, whereas the weekdays show more irregular patterns of peaks and troughs. The time of evening peaks at the weekend are also

[1] 398 devices devices in the UK and Ireland, 2014–2016—method in section 3.1.

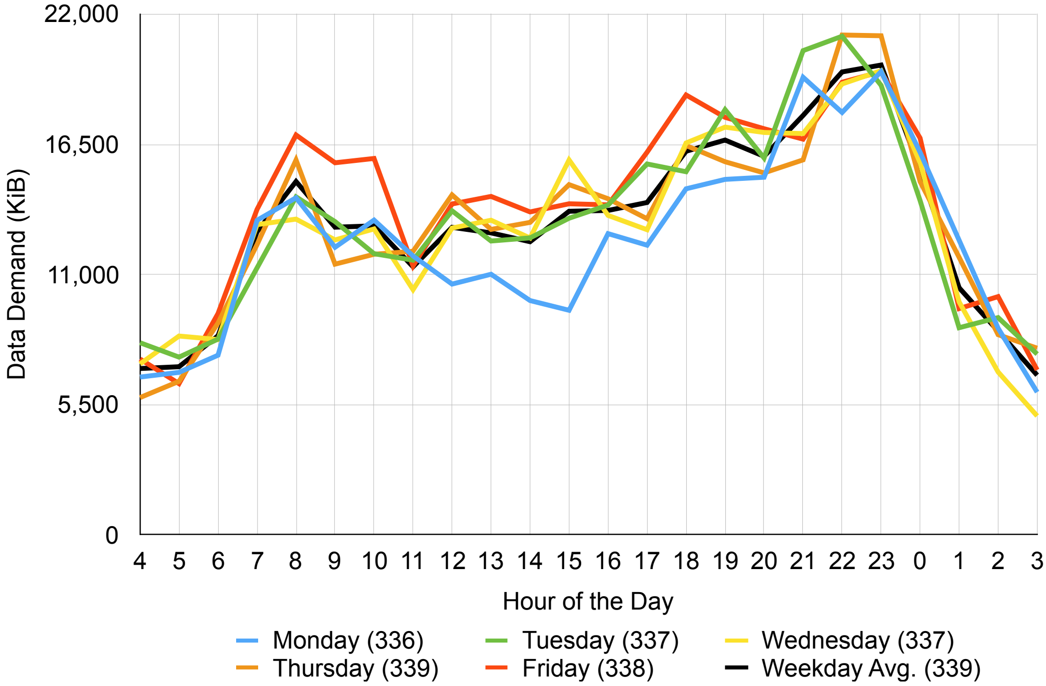
different to weekdays: data demand peaks are not as high as those shown on weekday evenings (particularly Tuesdays and Thursdays). Given the lack of constraints to work at the weekend (with the standard working week forming the hours 9am–5pm Monday–Friday in the UK), users are more free to use their devices; this could be an explanation for the higher average data demand throughout the day at the weekend.

Sundays and Saturdays also slightly differ: Sunday indicates more data demand throughout the day with a peak in the evening (8pm), whereas Saturday incurs a trough at this time, with peaks occurring later (10pm and past midnight). In this sense, Saturday is more similar to Friday with the earlier evening trough (7pm–9pm) and late peak (10pm). This could be due to the normalities in social events: as Friday and Saturday evenings are not usually followed by work the following day, people may attend social events (indicating the troughs) and perhaps revisit their devices after these events have finished (explaining the post-midnight peaks).

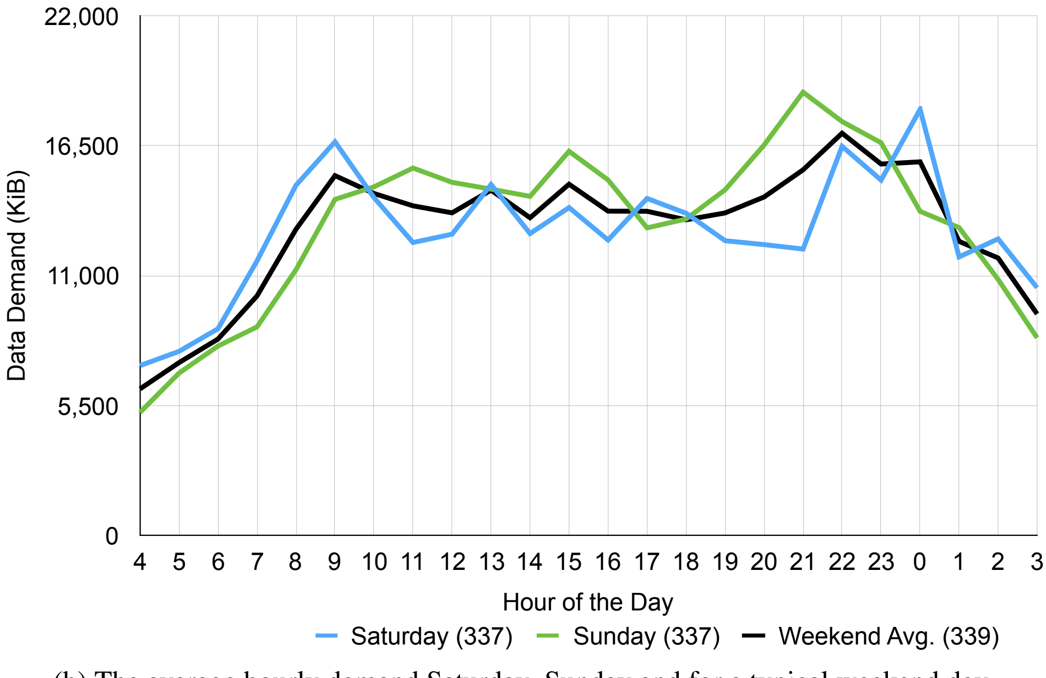
Given the timings of data demand, it can be speculated that Internet traffic is mostly formed by user and societal norms: sleeping patterns (midnight–6am), working hours (9am–5pm), and social occasions (Friday and Saturday evenings). Luckily, the largest peaks of data demand from Android devices occur later in the evening (9pm–11pm) than that of national UK peak electricity demand (5pm–7pm) [249]; however, there are smaller peaks for mobile devices on weekdays during this time. As network operators plan capacity using peak traffic [320], it has a significant impact on the growth of the Internet infrastructure. Catering for such peaks in Internet demand, through infrastructure expansion, would then add to the challenge of ensuring enough electricity for the nation during peak electricity hours. But what online service access is contributing to these peaks in data demand?

4.1.1 Data demanding categories of online services

By viewing data demand from a perspective of application categories, we can begin to uncover what activities in everyday life require intervention. Figure 4.2 depicts the total data demand (in MiB) for each of the application categories that were accessed by the devices in the Android dataset. Streaming video for ‘Watching’ is the most demanding activity on mobile devices (20.76% of total data demand), followed by streaming music for ‘Listening’ (11.3%). ‘Browsers’ (8.49%) and ‘Social Networking’ (8.15%) are other large contributors, with ‘Communication’ (3.25%), ‘News, Weather and Magazines’ (1.49%), ‘Analysers’ (1.18%) and ‘Navigation and Travel’ (0.82%)



(a) The average hourly demand Monday–Friday and for a typical weekday.



(b) The average hourly demand Saturday–Sunday and for a typical weekend day.

Figure 4.1: The Android devices' hourly data demand by day of week. Values in brackets represent the number of tablets or smartphones that contributed to that day.

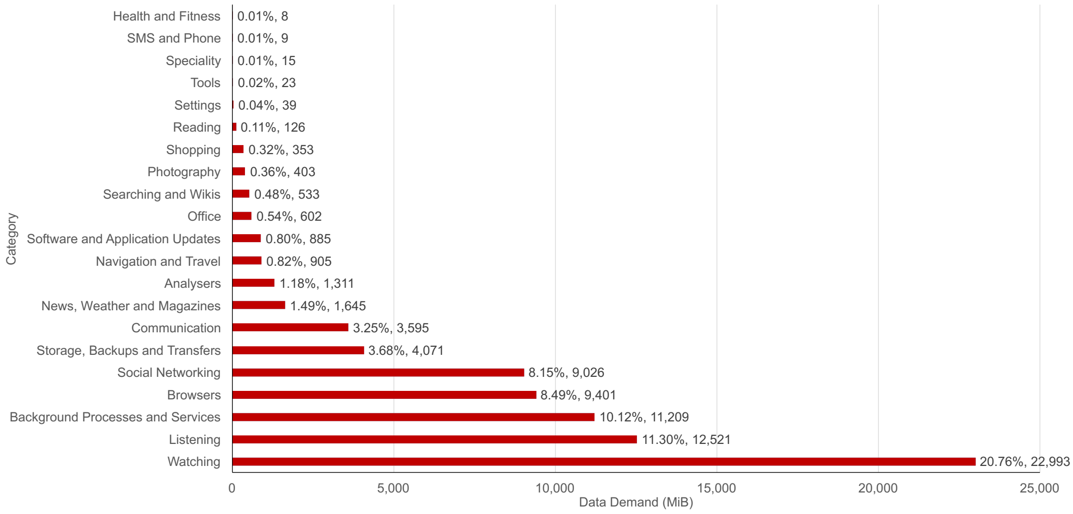


Figure 4.2: The total data demand for each Android app category. Each category's data demand (in MiB, rounded to nearest whole number) and percentage of total data demand is displayed next to each bar. Note that 28% of data demand was uncategorised for anonymity reasons (see section 3.1) and so is not displayed.

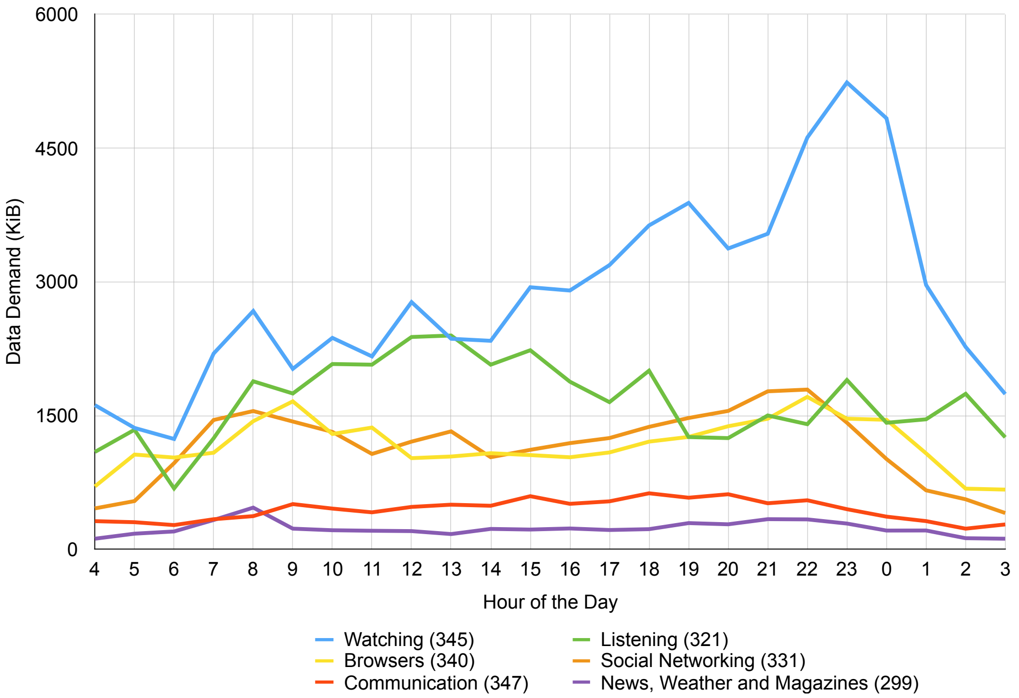
appearing in the top 10 demanding categories. More device-initiated demand (rather than user-initiated) formed a total of 14.6% of data demand for the mobile devices; this was contributed to by 'Background Processes and Services' (10.12%), 'Storage, Backups and Transfers' (3.68%) and also 'Software and Application Updates' (0.8%). Other less demanding categories[2] formed the final 1.9% of data demand that was possible to categorise.[3] These minor categories included: Office (0.54%); Searching and Wikis (0.48%); Photography (0.36%); Shopping (0.32%); Reading (0.11%); Settings (0.04%); Tools (0.02%); Speciality apps (0.01%); SMS and Phone (0.01%) and Health and Fitness (0.01%). In this section, I delve into detail about the most demanding categories and how they are composed temporally (as shown in figure 4.3).

4.1.1.1 Streaming music and video

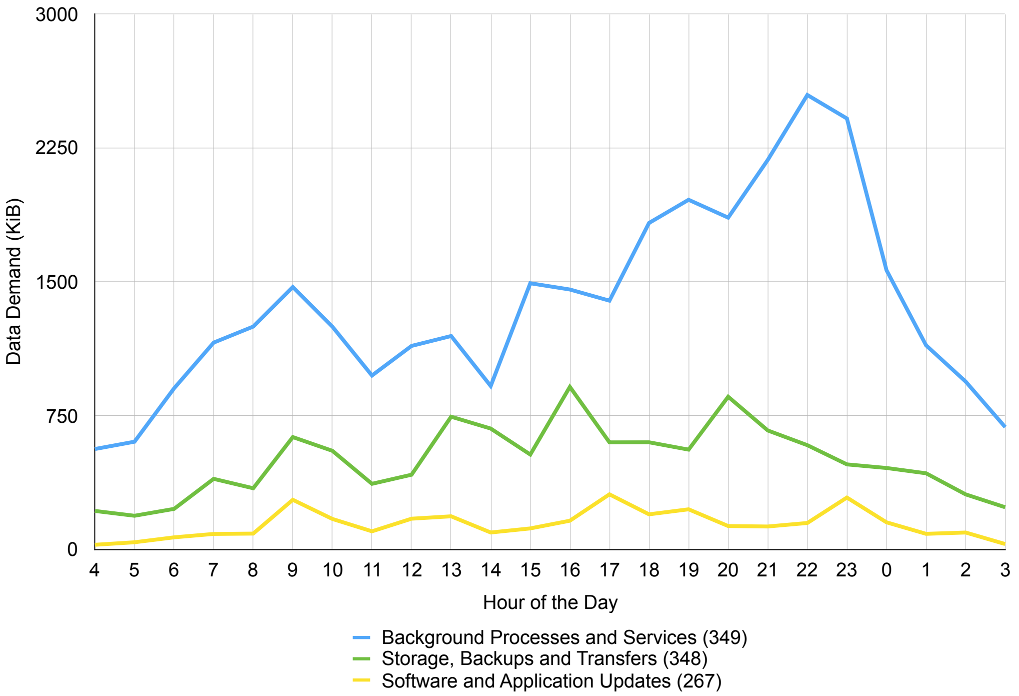
Streaming music and video were prominent categories of Android data demand, contributing to 32% of traffic for the devices. This is not surprising due to the data-intensive nature of these online activities. For example, in 2013, a two-hour film from iTunes typically consumed 1.5 GB, and a single song download took 4 MB [266];

[2]The categories 'Gaming' and 'Security' each had less than 10 devices demand data in the study, and so have been removed from the analysis to maintain participant anonymity (as described in section 3.1).

[3]28% of data demand was not categorised due to reasons of participant anonymity (see section 3.1).



(a) The hourly data demand for notable demanding categories.



(b) The hourly data demand for 'hidden demand' categories.

Figure 4.3: The Android devices' hourly data demand, averaged across days, by app category. Values in brackets represent the number of tablets or smartphones that contributed to that category.

this is much more data demanding than other online activities, such as downloading a single page text document (10 KB) [266].

'Watching' was the largest category of mobile data use, consuming a total of 22,993 MiB across 345 devices. In fact, at all hours of the day, watching was the most demanding activity on mobile devices with a mean data use of 2.8 MiB/hour; this was 1.15 MiB/hour more than the next most demanding activity, 'listening' at 1.6 MiB/hour ($p < 0.01$).[4] Peaks for streaming video occurred: in the morning (8am) as users get ready for the day; at lunchtime (12pm) as they take a break from work or other activities; as users potentially begin to arrive home or commute from work (3–7pm); and just before people would go to sleep in the late evening (10-11pm).

Interestingly, there is a trough in data demand for watching on mobile devices between 7pm and 10pm—this does not match the usual 'prime time' TV watching hours in the UK at 8–10pm [374]. Users could be using *other* devices such as televisions or laptops for watching content at this time. The largest watching peak actually occurs later at 11pm, meaning the traditional prime time watching hours are being 'extended' through on-demand content via mobile devices. This may be down to the portability of mobile devices: they can be moved around the house and therefore into the bedroom to be used before users go to sleep [249].

'Listening' followed as the second largest category of mobile data use, forming a total of 12,521 MiB across 321 devices. This demands a much more steady pattern of data throughout the morning and afternoon (8am–6pm), continuing through the evening and creating later peaks at 11pm and 2am. This demand may be due to the fact listening to music or podcasts is a more passive activity and can therefore coincide with other activities. Listening data demand can therefore 'fade' easily into the background whilst users work, commute, relax, or even try to sleep (a potential reason for the late evening and early morning peaks at 11pm and 2am). It can also be layered on top of the demand from other online activities that users engage in and require foreground attention, such as social networking and communication.

[4]Pair-wise two-sample and k-sample permutation tests were used to compare the data demand associated with activities, rather than more well known statistical techniques for analysis of variance since data demand is non-normal. The permutation tests find for the alternative hypothesis, that the true mean data demand between the activities observed, differ from each another, and that this difference is statistically significant with probability $p < 0.01$.

4.1.1.2 Social networking, communication and news

'Social Networking' sites (e.g. Facebook, Twitter) form the fifth most data demanding category for mobile devices, demanding a total of 9,025 MiB across 331 devices during the study (figure 4.2). This category has smoother peaks in data demand (e.g. 7am–9am in figure 4.3a), with smaller troughs at 11am and 2pm and a more significant trough at 1am. Interestingly, social media access is most demanding in the period of 8am–10pm—a time in which the data demand for watching and listening falls. Users are increasingly known to participate in *"media multi-tasking"* [265, p. 4] e.g. accessing mobile phones whilst watching TV. Given the added material element of mobile devices in watching practices [338], social media may be used whilst users participate in prime time watching on other devices.

Social networking had a mean data demand of 1.1 MiB/hour; this is approximately 0.7 MiB/hour ($p < 0.01$) more data-intensive than 'Communication' (3,595 MiB across 347 devices) despite the similarity between the two categories (i.e. the ability to connect with others). Yet communication apps still demand data steadily throughout the day. Although the peaks and troughs are small, there are some inclines in demand in the morning (9am), the afternoon (3pm), evening (6pm, 8pm) and late evening (10pm), as well as more obvious troughs at 6am, 9pm and 2am. Whilst data demand seemed to peak for many of the user-initiated categories ('Watching', 'Listening', 'Social Networking', and 'News, Weather and Magazines') at 8am in the morning (figure 4.3a), the communication morning peak is at the slightly later time of 9am alongside browsers; this could be due to users beginning to access their email and contacts at the start of the working day. The highest peaks are later in the day, around the time that many schools finish for the day (3pm) or for contacting family or friends after the end of the working day (6pm, 8pm) and before bed (10pm).

For 'News, Weather and Magazines', data demand is relatively low throughout the day and only contributed 1,645 MiB (from 299 devices) to the total demand. Yet there is an obvious peak in the morning (8am) as users check the news at the start of the day, or perhaps check the weather to plan the most appropriate clothing. There are also slight increases in the evening (7pm–11pm). However, it is possible that some of the data demand for news will be under-represented in this category and actually form part of the social networking demand. This is because Internet users can, and do, access news rapidly via social media, e.g. 43% of US adults were found to access news via Facebook [230]; this is despite the associated issues with fake news [343].

4.1.1.3 Browsers: a demanding, yet largely unknown, contributor

Browsers (e.g. Google Chrome, Safari) can be used for accessing any website, and therefore with the current granularity of the Device Analyzer log data (i.e. data demand at application level), it becomes difficult to attribute the demand of browsers to specific user activities. In fact, users could be accessing apps from any of the other categories (e.g. 'News, Weather and Magazines', 'Shopping', 'Searching and Wikis' etc.)—meaning more fine-grained log data is required to really delve into how browsers add utility into users' everyday lives. Despite this, the 'Browsers' category demanded a total of 9,400 MiB across 340 devices, making it the fourth most demanding category of apps for mobile devices (figure 4.2). The demand for this category throughout the day follows a similar, yet delayed, pattern to that of social media; with browser-related data demand also rising during the troughs of music and video streaming (9pm–10pm). Browser access shows small increments at 5am and 11am: both times that mostly other categories incur low demand or decrease.

4.1.1.4 'Hidden' demand: updates, backups and background processes

So far, the categories discussed in this section have focused on data demand which is more user-initiated. This is because they often directly link to users' online activities. For example, for a user to post content on Facebook, their mobile device will immediately upload that content to the social site's server. However, there are three categories that are more 'hidden' as they are device-initiated or exist at the system level: 'Background Processes and Services' (contributing to 1,209 MiB of total data demand across 349 devices), 'Storage, Backups and Transfers' (4,070 MiB across 348 devices), and 'Software and Application Updates' (884 MiB across 267 devices). Whilst some of demand from these three categories may be linked to user actions (e.g. downloading a file to storage, selecting to immediately download a device software update), some data traffic will not necessarily link directly in time with user actions (e.g. Apple's 'update overnight' option).[5] Other examples of traffic in these categories may consist of push-notifications from devices and different apps, or apps demanding data in the background (e.g. for targeted adverts).

As shown in figure 4.3b, the demand for these categories also coincide with typical waking hours (as like the more user-focused categories shown in figure 4.3a).

[5] Apple's 'update overnight' option: `https://support.apple.com/en-us/HT204204`, accessed October 2019.

Peaks occur in the morning (9am) and lunchtime (1pm), as well as significantly higher peaks in the later periods of the day for 'Background Processes and Services' (11am). The demand throughout the day for updates and backups (with a mean demand of 1.4 MiB/hour) is especially surprising given that much of this data can be automated during troughs of user-initiated demand.

4.1.1.5 Other categories

Other categories[6] not yet discussed in this section consist of: Analysers[7] (350 devices demanding data in the category); Navigation and Travel (338); Office (293); Searching and Wikis (344); Photography (258); Shopping (207); Reading (261); Settings (21); Tools (313); Speciality (94); SMS and Phone (203); and Health and Fitness (80). Taken together, these demanded a total of 4326 MiB from the mobile devices in the study; this is extremely minimal in comparison to other categories such as 'Watching' which demand much more data (18667 MiB) just for one type of online activity (rather than 12). Yet these categories show just how much the Internet, online services and mobile devices form a consistent part of daily life: data now seeps into previously 'offline' activities such as health and fitness activities.

4.1.2 Summary: from mobile devices, to households

To summarise: mobile data demand mostly follows periods of typical waking hours, with peaks in the evening; weekdays and weekends data demand differ, with Mondays in particular being less demanding than other weekdays; streaming music or video, and accessing social networks or browsers, are the most data demanding user-activities; and there is additional 'hidden' demand occurring in the background on mobile devices (e.g. for application updates). These insights have enabled an initial quantitative understanding of how data demand is composed in everyday life by smartphones and tablets, across a large dataset of mobile device use. However, this analysis only uncovers *mobile* device use, and reasons for the timeliness of data demand have been speculative. Many questions remain. How does this demand compare to that of home networks, and how does the home network facilitate Internet access within users' lives? What is contributing to the data demand of the 'Browsers' category? Are 'Watching', 'Social

[6] See section 3.1 for examples of apps in each category.

[7] Due to the the Device Analyzer app's regular uploads of user data to the University of Cambridge's servers, it contributed to the 'Analysers' category (a group which demanded 1,311 MiB in total).

Networking' and 'Listening' prominent categories of home network demand, and what services are being accessed? And how is the demand for online services composed for *other devices*, beyond smartphones and tablets, such as smart TVs, PCs, TV dongles and laptops? The next section aims to answer these questions by providing a quantitative overview of the data demand from the household study; this also draws on some of the qualitative interview data with participants to understand how data demand is embedded in their everyday lives.

4.2 Household data demand: patterns and categories

Data demand was heavily ingrained within the lives of the 20 participants, with the network logging capturing a total of 777.1 GiB of data demand for the households (method in section 3.2). This was facilitated by a variety of devices across participants (as outlined in table 4.1), including: smartphones, tablets, e-readers, laptops, PCs, smart TVs, set-top boxes, TV dongles (e.g. Amazon Fire TV Stick), games consoles, Wi-Fi speakers and a smart assistant (e.g. Amazon Echo). Due to the popularity of smartphones, this device type was the most data demanding: leading to a total of 279.82 GiB across the 21 smartphones in the households (table 4.4). Tablets were the second most popular device (12 tablets across the households totalling to 136.50 GiB of data), meaning mobile devices contributed to over half (53.57%) of the all the households' data demand at 416.33 GiB (table 4.4). However, unlike the Android dataset analysis (section 4.1), this household study allowed for the data demand from *other* types of devices to be uncovered: table 4.4 outlines the most common and demanding device types across the households. Particularly prominent device types included games consoles (in H7 and H9), TV dongles (H3, H6, H8) and laptops (Hs 2–9).

The demand for data also varied across households; interestingly, this was less linked to the number of people in each home, and more coupled to the types of services the participants accessed. Highly data demanding households (such as Xavier in H9 demanding a total of 185.61 GiB, and H6 at 163.94 GiB) were mostly involved in data-intensive service use, such as those for watching and gaming (table 4.2). This was similar to other households that demanded lower, yet still significant, amounts of data (H1, H3, H5, H7, H8)—between 63.68 GiB–94.03 GiB over the study (table 4.2). In contrast, H2 and H4 did not rely significantly on Internet services for entertainment. Laura's (H2) devices in particular had extremely low levels of data demand in comparison to the other households; her Internet access was predominantly facilitated by her Amazon Fire tablet (table 4.1), and focused particularly on her work (table 4.2). Unsurprisingly, data demand for each household was mainly made up of received (downstream) data (721.42 GiB); data uploaded by the households formed only 55.68 GiB (7.17%) of total traffic, with uploads associated with Google being particularly significant for households H1, H3 and H8 (table 4.2).

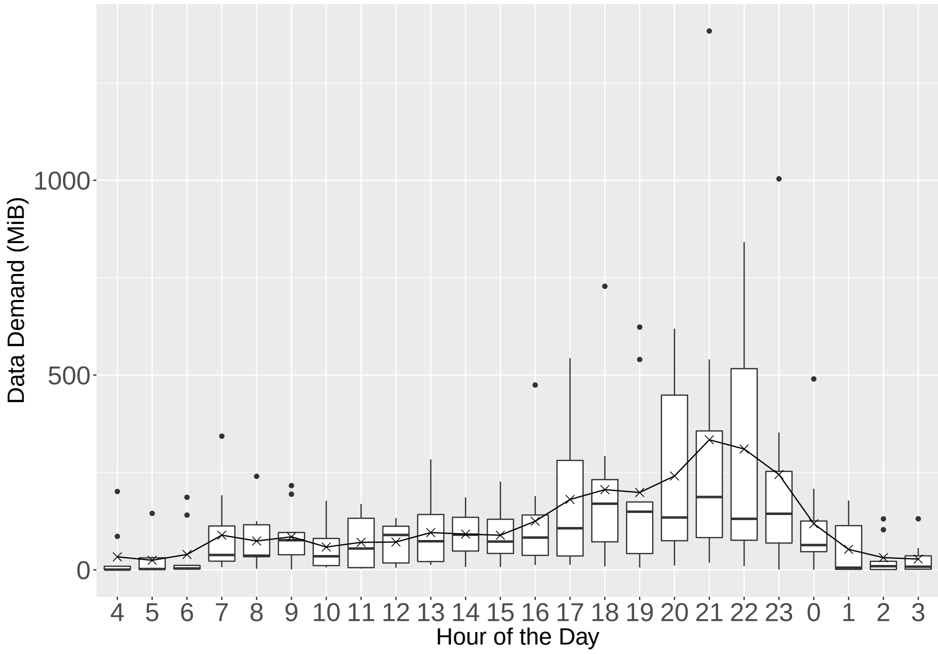
Figure 4.4 shows the average data demand for the households through time. When looking at this data hourly (figure 4.4a), data demand occurs throughout the day and follows user waking hours—with rises in the mean in the morning, lunch and evening (similar to the Android dataset findings in section 4.1). Most data demand occurs in the evening (particularly 8pm–10pm), with an earlier peak visible (5pm–6pm); troughs occur at 10am, 7pm, and during the early morning (2am–6am). Viewing this data by day of week, median data demand is similar each day (figure 4.4b). The smallest interquartile ranges are present on Sunday and Monday, with the lower data demand on Mondays corresponding to the Android dataset (section 4.1). It's important to note that highly data demanding households in the dataset can significantly skew the mean: e.g. H9's data-intensive practices (including video streaming and online gaming) creates outliers for both Wednesday (figure 4.4b) and daily at 9pm (figure 4.4a). In the next section, I detail the categories of services which are contributing the most to data demand.

4.2.1 Data demanding categories of online services

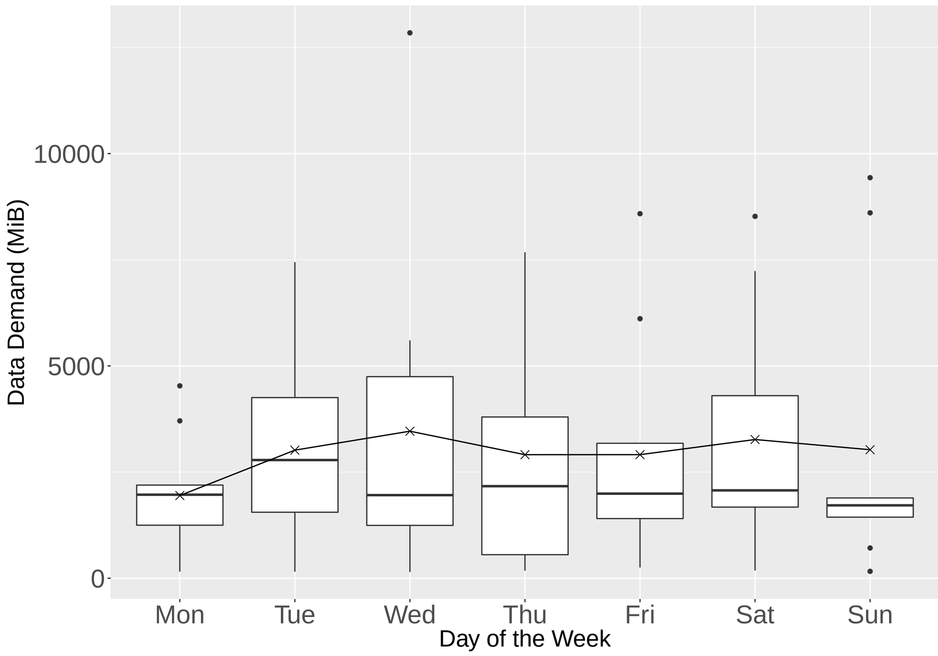
Table 4.3 provides an overview of the different categories of services accessed by the households. The majority of data was demanded by 'Watching' services (558.58 GiB); this is just under 72% of the data demand for all the households. Other significant categories across the households included 'Updates and Installs' (40.41 GiB), 'Gaming' (24.09 GiB across H7 and H9), 'Other Google Products and Services' (22.39 GiB), 'Communication' (13.76 GiB), 'Social Networking' (13.40 GiB) and 'Background Processes and Services' (10.57 GiB). In fact, 88.6% of the data demand was made up by these top eight categories alone. The prominence of 'Watching', 'Social Networking' and 'Background Processes and Services' for the households is similar to that of the Android dataset discussed in section 4.1. 'Listening' (0.94% of household data) was a more important contributor to demand in the Android dataset (11% of mobile device data demand), however the households still demanded 7.27 GiB of data

H#	Participant Pseudonym	Personal Devices (Avg. Daily MiB, No. of Days)	Shared Devices (Avg. Daily MiB, No. of Days)
H1	Ben	Android Phone (911, 50), PC (476, 7), Amazon Echo (21, 48), Kindle (11, 47)	Freeview Box (60, 57), *Sonos Speakers, Smart Meter*
	Gemma	iPhone (63, 57), iPad (177, 56)	
	Martin	iPhone (300, 57), iPad (195, 57)	
H2	Laura	Android Phone (31, 31), Amazon Fire Tablet (101, 33), Work Laptop (87, 16), Personal Laptop (29, 2)	
H3	Tim	Android Phone (1305, 34), Amazon Fire Tablet (35, 3), Laptop (521, 7)	Smart TV (387, 34), YouView Box 1 (15, 36), YouView Box 2 (44, 36), Android Box (40, 1), Google Chromecast (2899, 4), Windows Phone (19, 17)
	Connie	Android Phone (273, 33)	
H4	Alan	Android Phone (3, 25), Windows Laptop (146, 9)	iPad (342, 29)
	Denise	iPhone (77, 29)	
H5	Ella	Android Phone (99, 27), Laptop (2716, 27)	*Google Chromecast, Now TV Box*
	Kevin	iMac (216, 7), Android Phone (36, 1), *Laptop*	
H6	Fred	Android Phone (2435, 28), *Work Laptop*	Amazon Fire TV Stick (453, 20), Laptop (25, 16), Desktop PC (508, 9), Smart TV (47, 28)
	Julie	Android Phone (266, 28)	
	Heather	Android Phone (1696, 27), Android Tablet 1 (977, 20), Android Tablet 2 (655, 18)	
H7	Ian	Work iPhone (157, 12), Personal iPhone (110, 10), iPad (66, 11), Laptop (171, 4)	Sky Box 1 (704, 20), Sky Box 2 (1101, 32), Hudl Tablet (100, 16), Xbox 360 (170, 10), Printer (0.3, 7)
	Olivia	Personal Android Phone (36, 24), iPad (65, 9), Laptop (285, 8), *Work Android Phone*	
	Nick	Android Phone (318, 21)	
	Peter	Android Phone (0.2, 10)	
H8	Rachel	iPhone (568, 27), Amazon Fire TV Stick (2634, 27), Laptop (373, 13)	
	Sally	iPod Touch (145, 26), Amazon Fire TV Stick (46, 27), *iPad*	
H9	Xavier	iPhone (586, 23), iPad (2699, 25), Kindle (1, 23), MacBook Pro Laptop (99, 22), Sonos (14, 25), TV (9, 19), PlayStation (5072, 21)	

Table 4.1: The household participants and their device use. The number of log days varies per device due to devices not demanding data on every study day or logging issues for Ben's PC and H7's printer. Devices in italics were not logged in the study; reasons for these are provided in section 3.2.3.2. For each device, data demand values show total demand to the Internet and small data transfers between devices in the house (i.e. internal and external demand—see section 3.2.2.1).



(a) The average hourly data demand for all households.



(b) The average day-of-week data demand for all households.

Figure 4.4: The households' data demand throughout the day and across the week. The overlaid line and crosses represent the mean; the dots represent the outliers. Some samples lie outside the inter-quartile range as data demand is non-normally distributed.

H#	No. of Days	Sent Data (GiB)	Received Data (GiB)	Top Sent Data Service (GiB, No. of Days)	Top Received Data Service (GiB, No. of Days)
H1	57	12.37	80.73	Google Photos (4.26, 34)	YouTube (41.87, 53)
H2	33	0.83	4.76	*Workplace service* (0.10, 16)	*Workplace service* (0.68, 16)
H3	36	16.98	65.29	Google APIs (11.50, 34)	Warner Bros UltraViolet (11.22, 6)
H4	32	2.33	10.85	Amazon Web Services (1.00, 29)	Apple iOS Apps (2.25, 21)
H5	34	3.11	72.59	Now TV (0.62, 13)	Now TV (44.95, 13)
H6	28	6.83	157.11	YouTube (4.29, 28)	YouTube (129.21, 28)
H7	33	1.37	62.31	Sky (0.83, 32)	Sky (45.17, 32)
H8	27	2.94	91.09	Google Storage Upload (0.68, 25)	TV Player (40.59, 17)
H9	25	8.91	176.70	FaceTime (3.55, 8)	YouTube (77.81, 24)

Table 4.2: The households' sent and received data demand and top demanding services. All data demand values are to two decimal places. Note H2's top services have been omitted to preserve anonymity.

associated with streaming music, radio and books (e.g. via Spotify and Audible).

In the rest of this section, I provide an overview of the most notable categories and the other, less demanding categories outlined in table 4.3; this enables a more detailed understanding of data demand in the participants' lives.

4.2.1.1 Watching

From streaming TV programmes, films or video clips, the category of 'Watching' formed a significant amount of data consumption in the household study: 558.57 GiB in total. This is a dominant share of 72% of the total data demand across all households, with each household engaging in the activity in some form via 8/12 different device types (table 4.4) including smartphones, tablets, game consoles, TV dongles, laptops, TV boxes, TVs and PCs. Video content was watched across: paid streaming services such as NetFlix, Sky and Now TV; free services such as YouTube and TV Player; as well as more socially-orientated services such as Facebook and Twitch. Of these online services, YouTube was the most demanding—forming 275.12 GiB of demand (nearly half the watching data demand at 49.25%). Watching data demand is consistently demanding throughout the day (as shown in figure 4.5a), but particularly

Category	Total GiB	No. of Hs	Top Services (GiB, No. of Hs)
Watching	558.58	9	YouTube (275.12, 9), Now TV (49.46, 2), Netflix (48.65, 3)
Updates and Installs	40.41	9	Apple iOS Apps (22.71, 5), Apple Updates (6.33, 6), Microsoft (4.04, 4)
Gaming	24.09	2	PlayStation (23.04, 1), Xbox Live (1.05, 1)
Other Google Products and Services	22.39	9	Google APIs (12.75, 9), Google User Content (2.68, 9), Google Storage Upload (2.26, 5)
Communication	13.76	9	FaceTime (7.10, 1), Outlook (4.00, 6), Snapchat (1.14, 5)
Social Networking	13.40	9	Facebook (6.52, 9), Imgur (3.29, 8), Instagram (2.21, 9)
Background Processes and Services	10.57	9	City Telecom (6.26, 3), Sky Broadband (2.01, 5), Android (0.96, 7)
Unknown	7.30	8	N/A
Listening	7.27	9	Spotify (4.79, 8), Audible (1.95, 2), TIML Radio Podcast (0.52, 1)
Amazon Web Services, CloudFront and Media	6.88	9	CloudFront (2.41, 4), Digital Media (1.97, 4), Web Services (1.63, 9)
Storage, Backups and Transfers	4.47	7	Google Drive (4.07, 5), Dropbox (0.40, 3)
Photography	4.46	1	Google Photos (4.46, 1)
Searching and Wikis	2.92	9	Pinterest (1.44, 9), Google (1.19, 9), Rightmove (0.28, 5)
Office, Work and Tools	1.92	6	Microsoft Office (0.79, 3), *H2's workplace service* (0.78, 1), *Work service* (0.36, 3)
Verizon Digital Media	1.87	5	ECDNS (1.59, 4), Edgecast CDN (0.28, 2)
News, Weather and Magazines	1.79	2	Sky News (1.79, 2)
Other Apple...	1.62	6	N/A
Advertising	1.47	9	DoubleClick Ads (0.80, 9), Google Ads (0.40, 9), Vungle (0.27, 3)
Banking	1.27	1	*Banking service* (1.27, 1)
Cedexis Digital...	1.24	3	Cedexis (1.24, 3)
Analysers	0.57	9	Amazon Device Metrics (0.29, 7), ScorecardResearch Tracking (0.28, 9)
Other Microsoft...	0.47	4	N/A
Security	0.27	3	McAfee (0.27, 3)
Shopping	0.27	8	eBay (0.27, 8)
Cheetah Mobile...	0.24	2	N/A

Table 4.3: The household app categories' data demand. Note that services in italics are described in general terms to preserve participant anonymity.

Device Type (No. of Devices)	Total	Watching	Updates & Installs	Other Google	Commun-ication	Social Networking	Other
Smartphone (21)	279.82	186.17	18.29	19.30	10.54	6.74	38.80
Tablet (12)	136.50	83.63	13.94	2.67	2.69	5.19	28.39
Games Console (2)	105.66	78.99	0.57	0.00	0.00	0.00	26.11
TV Dongle (4)	90.80	81.85	0.00	0.13	0.00	0.00	8.82
Laptop (9)	84.40	65.85	2.72	0.25	0.53	1.16	13.89
TV Box (6)	51.35	51.00	0.00	0.00	0.00	0.00	0.35
TV (3)	14.04	6.71	0.00	0.00	0.00	0.00	7.33
PC (4)	12.74	4.38	4.90	0.05	0.00	0.32	3.09

Table 4.4: The households' total and prominent app category data demand (in GiB) across device types. Note that 'Gaming' is omitted from the table as it demanded 24.09 GiB only on games consoles (H7, H9); and less demanding and/or less popular devices are omitted from the table, including a smart speaker (total demand: 0.96 GiB), e-readers (0.51 GiB), Wi-Fi speaker (0.31 GiB) and Wi-Fi printer (0.41 MiB). Also note that 'Other Google' is short for the category 'Other Google Products and Services', and that the 'Other' column represents the total data demand (in GiB) for the rest of the categories for each of the device types. The total number of devices for each device type is provided, yet they may not all contribute to the data demand values of each category.

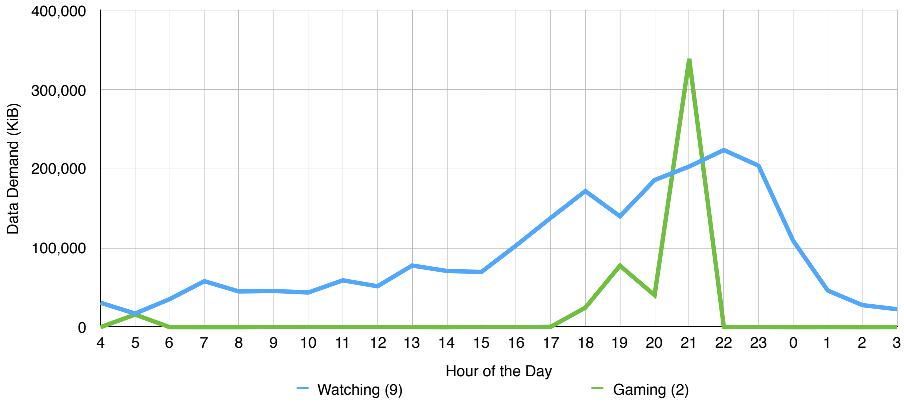
in the evening (6pm, 8pm–11pm); this evening video streaming ‘fills’ the data trough for watching present between 8pm–9pm for the mobile dataset (figure 4.3a).

Unsurprisingly, the large amount of data consumed for this activity makes watching the most data demanding activity for the households. This follows the analysis in larger scale studies such as those by Sandvine, whereby video was found to have the largest application category share of global traffic in 2018 (forming 57.69% of downstream global traffic and 22.43% of upstream) and that YouTube was the most demanding service in the EMEA (Europe, the Middle East and Africa) region [322]. Watching was also the most demanding activity for the Android dataset of mobile devices discussed in section 4.1. However, watching in the home takes a much larger proportion of data demand (i.e. 72%) than video streaming on mobile devices (21% of Android data demand, see section 4.1.1.1).

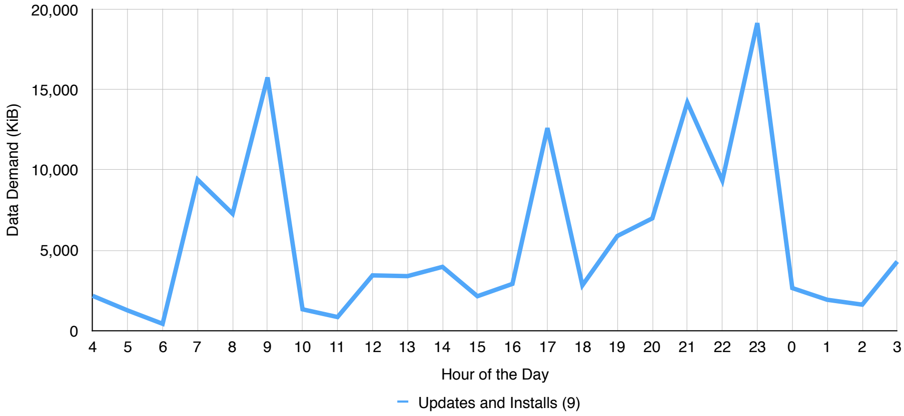
4.2.1.2 Updates and installs

The second most data demanding category was ‘Updates and Installs’ at 40.41 GiB (5.2%) of data demand, formed by updates and installs for: Apple iOS apps (22.7 GiB or approximately 56.2% of the updates and installs data demand); other Apple updates (6.3 GiB, 15.7%); Microsoft (4 GiB, 10.0%); Google Play (3.3 GiB, 8.3%); Sony mobile software (2.9 GiB, 7.2%) and Windows updates (1.1 GiB, 2.7%). This demand predominately occurred on mobile devices (smartphones and tablets) during the study—due to the large demand from Apple iOS apps—but was also present on games consoles, laptops and PCs (table 4.4). Figure 4.5b shows this demand for updates and installs throughout the day: peaks of data demand occur earlier in the day at 7am and 9am, and later in the evening at 5pm, 9am and 11pm. The lowest trough occurs at 6am and some updates and installs are occurring during off-peak traffic hours (e.g. 3am).

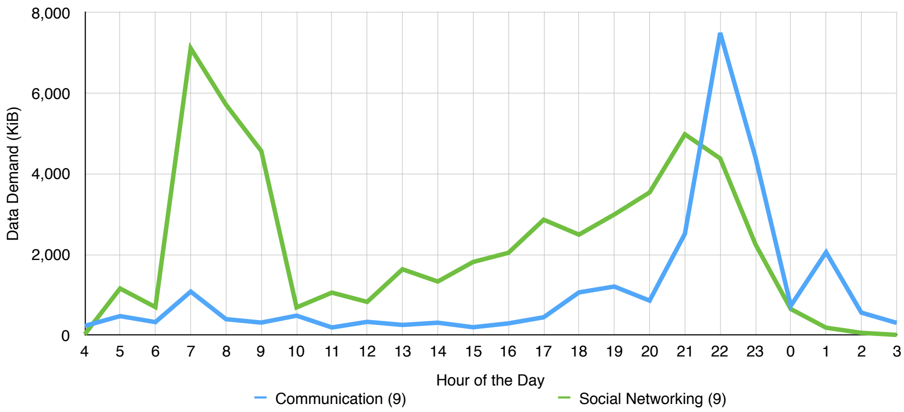
Compared to the Android dataset (section 4.1.1.4), household updates and installs are much more data demanding—reaching an average peak of 19,130.1 KiB at 11pm (by comparison, software and application updates reached a peak of 309 KiB at 5pm in figure 4.3b). Yet both studies are similar in that the majority of this category’s data demand occurs during hours that users are awake: a particularly surprising find, since updates and installs are potentially easier to defer to periods of lower traffic.



(a) The average hourly data demand for gaming and watching.



(b) The average hourly data demand for updates and installs.



(c) The average hourly data demand for social networking and communication. Note that H9's FaceTime data demand (daily average of 290.73 MiB) was omitted from the average hourly communication data as it heavily skewed the data and made the trends of the other households unreadable.

Figure 4.5: The households' data demand throughout the day for notable categories. Numbers in brackets for each category in the legend represent the number of households contributing to the plotted averages.

4.2.1.3 Gaming

The data demand from ‘Gaming’ (24.09 GiB) led this category to become the third most demanding in the household study—formed from Peter and Nick’s (H7) shared Xbox (1.05 GiB from Xbox live domains) and Xavier’s (H9) PlayStation (23.04 GiB from PlayStation domains). Obviously, these two values differ significantly, with H9 actually contributing the majority of the data demand for this activity. The qualitative interview data revealed why this was the case: Xavier (20s age range), who lives alone, plays online games regularly on his PlayStation in the evening. Peter and Nick (both in the 10s age range), however, are more constrained to *when* and *how* they play due to parental restrictions from Ian and Olivia (H7): the two boys are actually only allowed to play offline games (such as Skate 3, Forza 6, Terraria, Minecraft Story Mode) during ‘screen time’ hours (3pm–6pm on weekends). These time and offline-only access restrictions explain the low data demand for the Xbox—perhaps meaning the daily 170 MiB demanded for this device during the study (table 4.1) is for more device-orientated demand (e.g. advertising, tracking, game or console updates and hence belonging in a different category such as ‘Advertising’, or ‘Updates and Installs’), rather than being usage orientated. Yet the difference between these two devices in H7 and H9 show the significance of online games in adding demand to gaming activities.

For the Android dataset (section 4.1), gaming did not contribute significantly to mobile data demand despite having two gaming-related applications being installed on 50 or more of the handsets (see section 3.1). In the household study, gaming traffic also did not appear on mobile devices. Yet four of the younger participants (Heather, H6; Nick and Peter, H7; Sally, H8) did mention playing games: Heather (H6) plays games on one of her tablets; Nick (H7) plays games on his smartphone; Nick and Peter (H7) swap between the Hudl tablet (playing games such as Clash of Clans) and the Xbox during their screen time; and Sally listed off many games she likes to play on her iPod Touch: *“Solitaire, Piano Tile Piano Tile 2, Wordle, Colour Switch”[. . .]“Subway Surf, Fruit Fruit Ninja”[. . .]“Flow Free, Banana Bunch, What the Fox, Panda Pop...”*. The data demand for these games must not have been significant enough to fall within the top 90% of demand categorised (following the method described in section 3.2). That said, the data contributed by the company-specific category ‘Cheetah Mobile Services (Tools and Games)’ was only demanded by Heather’s tablet, Nick’s smartphone and H7’s Hudl—meaning the demand for this category could potentially be just for games (rather than other tools that Cheetah Mobile[8] provide, such as 'Clean Master' for optimising Android devices).

4.2.1.4 Communication and social networking

All of the households' devices demanded some form of 'Social Networking' or 'Communication' data, leading to a total of 27.16 GiB for this social aspect of Internet use (table 4.3). The communication apps used enabled real-time video or phone calls (i.e. FaceTime, total demand: 7.1 GiB, accessed by H9), emailing (Outlook, 4 GiB; Exchange Mail, 0.49 GiB; Apple Mail, 0.49 GiB) and text or image sharing (SnapChat, 1.14 GiB; WhatsApp, 0.44 GiB; Facebook Messenger, 0.11 GiB). Social media apps consisted of popular services Facebook (6.52 GiB) and Twitter (0.62 GiB), alongside photo-sharing (Imgur, 3.29 GiB; Instagram, 2.21 GiB) and social blogging services (Tumblr, 0.75 GiB). Such service access mostly occurred on smartphones and tablets (table 4.4), with smartphones more popular for communication (10.54 GiB) than tablets (2.69 GiB) and social networking nearly split equally between these two device types (6.74 GiB for smartphones, 5.19 GiB for tablets). Other data for these two categories was accessed via laptops (0.53 GiB for communication, 1.16 GiB social networking) or PCs (0.32 GiB social networking).

The data demand for communication (13.76 GiB in total for all households during the study) was actually slightly higher than that of social networking (13.40 GiB) for the household study; this is significantly different to that of the Android dataset (section 4.1), where communication demanded much less data on average. This could be due to households having less restricted Internet access via the Wi-Fi network (mostly unlimited, rather than mobile plans which may be capped), allowing for more data-intensive application usage. This could include: 1) images to be sent or uploaded socially (e.g. for SnapChat, Facebook, or via email), or 2) high-definition video calls (e.g. via FaceTime). The variance in demand could also be due to the deeply fine-grained data available from the household study, as video content on social networks (such as Facebook) was able to be more correctly classified into the 'Watching' category—a process not possible for the Android dataset.

The data demand for social networking within the household study was generally higher on average in most hours of the day (figure 4.5c) than the mobile devices (figure 4.3a), and the household study has more prominent troughs during the early morn-

[8] Cheetah Mobile Services: `https://www.cmcm.com/product`, accessed October 2019.

ing (2am–4am)—however, both studies follow similar trends of demand with peaks in the morning (7am–8am) and the evening (8pm–10pm). Communication for the Android study was mostly continuous with no large peaks (figure 4.3a), yet the household study communication demand throughout the day (figure 4.5c) shows large peaks in the evening (10pm); this is even with H9's data-intensive FaceTime activity (daily average of 290.73 MiB) omitted from the plot. Communication being more 'peaky' in this way could (again) be due to Wi-Fi networks generally having less restrictive traffic caps, therefore enabling more data-intensive uses of apps.

4.2.1.5 Other categories

Out of the notable categories discussed so far, 'Other Google Products and Services' (22.39 GiB) and 'Background Processes and Services' (10.57 GiB) are two other significantly data demanding categories. However, the demand from these categories is difficult to understand or comment on, given the variety of activities in the participants' lives that these could be supporting. This is similar to other categories such as 'Unknown' (7.3 GiB) and the company-specific categories (totalling to 12.3 GiB, omitting 'Other Google Products and Services'). Other activities included: Listening; Storage, Backups and Transfers; Photography; Searching and Wikis; Office, Work and Tools; News, Weather and Magazines; Banking; Analysers; Security; and Shopping. Whilst these service categories played a part in the participants' Internet use, they only totalled to 3.24% (25.2 GiB) of the households' total data demand. 'Advertising' only consumed 1.47 GiB of traffic but *all* households contributed to this category.

4.2.2 Summary: from network data, to participant experiences

To summarise: Internet access via the home network occurs continuously throughout the day, with spikes in the evening (particularly between 5pm–10pm); and households can greatly vary in their traffic consumption due to the types of services they access, rather than simply the number of devices or people in the home. Data demand in the home supports a variety of user practices, with streaming video forming the largest contribution to traffic (72%); and updates and installs, gaming and communication are more demanding in the home than the Android dataset. Despite the variety of devices connected to the home network (e.g. TV dongles, laptops), mobile devices (smartphones and tablets) still form a significant proportion of traffic (53.57%). Given this quantitative insight, how do users perceive their online activities? What context can the participants provide to show how this data demand has become part of their practices? And what opportunities lie for adapting their online service access in less data-intensive directions, that they might actually appreciate?

4.3 Household study: digital experiences

In this section, I explore the qualitative interview data from the household study; this aims to uncover the participants' digital experiences (i.e. their accounts and perceptions of interaction with devices and services) and how this links to data demand. I identify six prominent themes of digital experiences that impact the demand for data: 1) how marketing of services and experimentation with devices creates pathways to data demand; 2) the contextual impacts from relationships and space that affect service consumption; 3) how participants perceive meaningful uses of services online, which are not necessarily the most data demanding; 4) participants' need to overcome 'black holes' and 'rabbit holes' online; 5) the confusion experienced by participants about what their devices are actually doing, particularly as a result of this study; and 6) how the data demand of updates is heavily linked to trust in online service providers. I explore these each in detail below.

4.3.1 Pathways to data demand

As shown through the quantitative data in section 4.2, data demand is embedded in the participants' everyday lives through online activities. New services and devices (i.e. digitally-connected materials) available have enabled users to *add* Internet connectivity to practices which previously would've been held offline (e.g. gaming, watching). However, the participants themselves pointed out additional ways in which data demand can further become part of their lives—specifically through: 1) offers, free services and trials advertised by online service providers; and 2) experimentation and settling in with innovative devices, to form new or adapted practices. These are discussed below.

4.3.1.1 Offers, free services and trials

When discussing subscription services with the participants, it became apparent that savvy deals can encourage further data demand in everyday life. For example, H1's free 3-month trial to Apple Music, played through their Sonos speaker, led Martin to develop a new practice of online listening. Free cloud backup services also played a part in transforming H1's data demand in more intensive directions. As Martin maxed out on his free 5 GiB storage plan from Apple iCloud, he introduced Google Photos both to his and Gemma's devices—explaining the 4.26 GiB of uploaded data to Google Photos in H1 (table 4.2). This use of multiple backup services extended into H4, where Denise had both a paid subscription to iCloud and free DropBox account. Denise commented that she takes full advantage of DropBox's deal allowing more free storage for users if they recruit other users (in her case, three or four people) to join the service: *"if you introduce friends,* (laughs) *you get some extra space, so I've never actually had to, I've not got to the stage where I've had to pay for it yet"*.

This type of deal not only allows Denise's data demand 'allowance' to increase, but can potentially spiral the demand for cloud services by recruiting those who might not have used cloud storage otherwise. Yet it's not just *free* deals for service adoption that formulate data demand in everyday life: Ben dips in and out of his paid subscription to the library-style Audible scheme that allows him to download books, trade them in and then repeat this cycle of downloading and trading. He discussed how this enables him to acquire more book downloads for less 'credits':

> *"...you get one credit, and then you could listen to the whole book and then you could trade it in and get a credit back and it wouldn't be at cost to you at all [. . .] so I was just doing that, so I got like, I probably spent, I probably bought three credits, and I'd got about 20 books from using the trade in thing [. . .] I've got probably 10 books that I haven't listened to yet because I've done that so didn't seem any point continuing subscription until I've, until I've listened to all of those books"* (Ben, H1).

Ben has been joining and cancelling his subscription to Audible for the past year. As he was currently in his 'cancelled' phase during the study, the demand for this service in H1 contributed only 35.03 MiB per day (1.95 GiB across 57 logging days); this is likely to be higher in the periods when he will subscribe to Audible for exchanging his 20 books. This was also the case for Martin, where he described that both he and Gemma *"dip in and out of subscription services as and when* they *need it"*; for example, he mentioned that they would restart their Now TV subscription for a new series of 'Game of Thrones'.[9]

[9]Game of Thrones: **https://www.hbo.com/game-of-thrones**, accessed October

As well as these service deals, the participants mentioned how they search for the best deals on broadband and mobile data plans: offering *more* data for less money (Martin, Kevin, Fred, Julie, Ian, Xavier). Such deals included half-price plans for short periods of time (Ian, Xavier) or 'free for 12 months' offers (Martin). Kevin even discussed the potential impacts of him moving from a contract of 6 GiB mobile data (costing £50 per month), to 18 GiB (£20 per month):

> *"...now I've got this 18 gigabyte contract, I might be more inclined to, erm, use my phone to sync with something like DropBox, whereas I would never think about doing that before because that wouldn't help the band-, the data erm. And like I would never have really thought about watching videos on my phone maybe five years ago, just because the speed wasn't, 2G it wasn't, quick enough, erm but as soon as it, as soon as I got 3G connection for my phone, I realized I could watch YouTube videos just by clicking play and it would play, and then it became, it became a feasible thing to do."* (Kevin, H5).

Here, Kevin shows how previous changes to the Internet infrastructure have led him to demand more data—and given his cheaper, yet larger, mobile data plan, he expects his usage to further increase. Similarly, Julie's switch from pay-as-you-go to a cheaper mobile data contract allowed her to get *"more unlimited data"* (Julie, H6). Martin also managed to negotiate a *"pretty good deal"* (Martin, H1) of 4 GiB mobile data for £9 per month, despite admitting he didn't really 'need' this plan: *"I probably use less than 500 megabyte of data, because nearly all of my Internet is Wi-Fi"*.

4.3.1.2 Experimentation and settling in

With smart home devices being a relatively new concept, there is still a large amount of experimentation required by users in order to figure out how such Internet of Things devices are useful or meaningful in everyday life. In H5, both Ella and Kevin have contemplated getting an Amazon Echo; here Kevin discusses potential uses and experimentation:

> *"I'd probably use it for things like, setting reminders and turning on the radio, erm, yeah I reckon I'd use it but the thing is I couldn't predict what*

2019.

> *I'd use it for, I'd have to sort of play with it and figure out what you could do with it first, and then, but I get the feeling that it is something that I would use..."* (Kevin, H5).

Like Kevin, Ella is also confused about what she would use the Amazon Echo for. Despite this, she is keen to trial the technology and believes it will have a profound effect on their lives, similar to the way their introduction to the Google Chromecast changed their watching practices:

> *"I'm really quite interested in it, but erm I don't, I don't know whether I'd use it for, for kind of general entertainment purposes, erm, it's, but then I said* [to Kevin] *'what do you want a Chromecast for? You can just stick it in, you can just plug the laptop in, it's a waste of money' so it's probably the type of technology that if I had it I'd use it all the time [. . .] the Chromecast absolutely revolutionised* (laughs) *the way we watch TV so, and was the starting point for us kind of moving off live television and things like that"* (Ella, H5).

Here Ella shows how new technology 'revolutionises' Internet use within everyday practice: the Google Chromecast was the beginning of their move from watching broadcast TV to on-demand content only. Whilst only imagining the Amazon Echo in their lives now, the introduction of this technology could further intensify their data reliant practices. However, these scenarios discussed by Kevin and Ella are not just speculative, as Ben (H1) describes 'settling in' with his Amazon Echo smart assistant:

> *"I think there's a period when you get something new like that you're more interested in experimenting with it, erm, I've sort of settled into habits of its usage just getting like a minute summary of the news for the day and that's it [. . .] it's early days I might test* [the smart assistant] *to see what, how, what it's capable of, so if I'm sat at my PC I might say 'what's, what's the temperature in east Pakistan' or something* (laughs) *something stupid, like* (laughs) *but that's all I would use it for"* (Ben, H1).

This initial playful use with this smart home device was also carried out by Kevin when his colleague brought an Amazon Echo into his work, *"getting it to tell jokes and you know, asking it rude things"*. Yet it seems that once this initial 'play around' with the device has finished, new meanings and habitual routines are developed like Ben's news summaries. Ben often 'asked Alexa' for news updates first thing in the morning and last thing at night; despite the low use, this new practice developed around his sleeping routine, and alongside the background communication by the device itself, had introduced a total of 21 MiB to H1's daily data demand (see table 4.1). With the number of smart home devices now available (e.g. Amazon's home automation range),[10] their presence in homes is likely to become more common and therefore the data demand from both playful and settled activities with these devices is likely to rise.

4.3.2 Contextual impacts: relationships and space

The ways in which participants used their devices and services varied based on their environments and the people around them: Alan receiving a tablet as a gift led to Denise also using the tablet; Fred (H6) uses Facebook and YouTube to stay awake before he gets up for work, as Julie's morning routine wakes him up early; Ben (H1) avoids using his smartphone whilst in the company of others as he finds it rude to do so; Kevin (H5) works in a different room to Ella in order to not disturb her with his music; Connie (H3) uses her smartphone whilst pretending to be asleep during her children's bedtime routine; Ben's decision to sell his tablet led to Martin (H1) gaining the iPad, a device he did not previously use; Ella (H5) watches more streamed television content when her husband Kevin is away; Rachel (H8) bought a larger data plan (5 GiB instead of 2 GiB) as her boyfriend doesn't have Wi-Fi at his house; and Xavier (H9) *"leeches"* off his girlfriend's parents' Amazon Prime subscription. These are just a few of the scenarios that show how users' relationships and their device and service use are interlinked.

A particularly common way in which relationships affected online service use was for parental monitoring of children's access to devices. As mentioned in section 4.2.1.3, Nick and Peter (H7) are only allowed to use the Hudl tablet and offline Xbox games during screen time; this was defined by Ian and Olivia as weekends between 3pm–6pm, as long as the boys' homework is complete. This constraint on time and online games shows its effect on the data demanded from these devices (Hudl: daily avg. 100 MiB, Xbox: 170 MiB—as shown in table 4.1) when comparing to similar devices in other households (e.g. Heather, H6's tablet 1: daily avg. 977 MiB, and

[10] Amazon's home automation range: `https://www.amazon.co.uk/home-automation`, accessed October 2019.

tablet 2: 655 MiB; Xavier, H9's game console: 5072 MiB). Peter (the younger brother of the two) didn't seemed phased by this control, discussing *"it's alright how I use them already"*; Nick on the other hand, whilst understanding his parents' screen time enforcement, would *"just prefer more time"* on his Xbox and Hudl. In H8, Sally's device constraints are in the form of getting permissions from her mother (Rachel) for app installations; these requests are sent between her iPod Touch and Rachel's iPhone.

Whilst Julie and Fred in H6 didn't mention controlling Heather's device use, they did discuss how they watch the amount she uses her devices. Julie had even downloaded Instagram in order to *"keep an eye on"* Heather's use of the app. These accounts show that monitoring use and parental controls not only affect the child's use of devices and applications, but also the parents' use too as they adopt new services or processes. This was the case in H7, who as a household, practice device and Internet use constraints at home for reasons of wellbeing and online safety; this is perhaps a reason to why their household data demand is lower than other households (table 4.2), despite having the largest number of household members. They simply do not bring devices upstairs; they have not bought TVs for their bedrooms (located upstairs), and smartphones and tablets live in the downstairs kitchen (on charge or in a drawer) overnight:

> *"I think* [keeping devices downstairs is] *something to stick with, because it only disturbs sleep doesn't it? And they say it's not good for you so, and I think with the kids as well I think if they're downstairs then it's easier to monitor, not necessarily easy but easier, if they're not locked away in their room and they're looking at something that maybe they shouldn't be on, not only that but cyber bullying"* (Olivia, H7).

The mother of H7's family, Olivia, describes here that this routine is better for all the family—suggesting the meanings behind practices like sleeping and the associated activities (i.e. leaving devices downstairs) may actually curtail H7's data demand growth as the family avoid device use upstairs. Whilst Internet-free zones *at home* were not as common for other participants, many of them did discuss utilising holidays as ideal spaces for breaks from the Internet. Connie (H3) discussed how her lack of access to Wi-Fi and mobile data meant her family were *"enjoying the moment as opposed to looking at what everybody else is doing all the time"*; Alan (H4) didn't *"feel the need to feel as connected, news wise, and sport wise"* when getting away from his everyday routine; and Laura (H2) just doesn't *"want to be bothered with"* online services on holiday.

Holidays provide an interesting disruption to the usual pattern of everyday life, and it was obvious to these participants that they would take time away from the Internet for relaxation, 'getting away' and 'enjoying the moment'; all feelings linked to wellbeing. However, using space as a way of defining limits for device and Internet use can create frictions in relationships when the expectations of household members do not align, as Gemma (H1) describes:

> *"I get shouted at, cause* [Martin and Ben] *always have their phones next to them and I'll be on the settee at night and Martin will say 'where's your phone?' and I'll go 'I think it's in the fruit bowl' or 'it might be in the wardrobe'"* (Gemma, H1).

Gemma often keeps a distance between herself and her smartphone, as she doesn't like it within reach. But as she describes here, keeping her smartphone elsewhere conflicts with others' assumptions that Internet-connected devices should always be readily available.

4.3.3 Searching for meaning and keeping in contact

The most meaningful uses of devices and the Internet to users were revealed when asking the participants what they use their devices for; how they would feel if a mobile device of theirs ran out of battery; and how they would feel if the Internet was constrained on any of their devices. Seven of the participants considered communication meaningful (Ben, Gemma, Julie, Ian, Olivia, Rachel, Fred). This was particularly the case for parents: Gemma (H1) wouldn't like her Internet use to be constrained as then she wouldn't be able to contact her son who lives abroad; Ian (H7) mostly relies on text messaging to keep in contact with his children (Nick and Peter); Rachel (H8) keeps her phone charged in case her daughter, Sally, needs to get in touch; and Julie (H6) needs to be contactable for her daughter, Heather: *"if she couldn't get home from school or there was a problem or what, or school needed to ring me [...] Internet-wise, no,* [no smartphone battery] *wouldn't bother me, it's more keeping in touch"*.

This need to keep in touch and maintain meaningful use on their smartphones can create anxieties around charging processes. Olivia (H7) gets *"jittery"* (i.e. nervous or worried) if her smartphone battery hits 60%: *"I'm not gunna panic if I can't get on YouTube or one of those things you know, but I need to know that I can get hold of the* *kids"*. To maintain his meaningful communication, Fred (H6) has introduced a *"remedy"* to his smartphone running out of battery by purchasing an in-car charger. The availability to charge allows him to ensure constant contact with his family, particularly when he is struggling to get home from work due to traffic issues.

As highlighted in section 4.2.1, 'Communication' data demand contributed 1.77% to the total data demand across all households—making it the fifth most data demanding category. For the Android dataset, communication contributed 3.25% of demand (section 4.1.1). In both of these instances, there are other categories of demand which are significantly more data-intensive (particularly watching at 72% of demand in the household study, or 21% of demand in the Android study). Yet, given these participant accounts, the most data-intensive services do not necessarily map up to the most meaningful: keeping in contact via communication applications was almost seen as a requirement in everyday life for these participants.

As well as communication, the participants discussed what is meaningful and what is not *within* the applications they access day-to-day. For example, Olivia discussed how she prefers Twitter over Facebook: *"Facebook's more 'what are you having for tea?' type thing whereas Twitter's actually more informative, more about what's going on in the community"*. Kevin (H5) and Xavier (H9) pointed to similar concerns that the perhaps more meaningful 'social' part of Facebook was losing out to more commercial content. Kevin described Facebook content as *"tedious"* and noted that *"you have to trawl through so much, so much chaff before you get to the wheat"*. Xavier expressed that he began to stop using Facebook when it changed from *"a social network to being an advert"*.

Whilst email is associated with communication, the use of this service also had meaningful and meaningless content embedded within it that users have to separate. Ella (H5) will go through her emails regularly to *"delete all of the kind of GroupOns and all that type of rubbish"*, and Martin (H3) checks his email to pick out the important messages from the usual *"junk that comes through, erm adverts and what have you"*. This contrasts with a study from Bentley et al. [42], finding participants' most common reason for using email was for receiving adverts and coupons—showing the challenging subjective nature of meaning within device and service use. Nevertheless, it is likely that some of the data demand embedded within different categories (e.g. communication, social networking) is not always fully appreciated; and the participants show how they have to 'search' for meaningful content.

4.3.4 Overcoming ‘black holes’ and ‘rabbit holes’ online

Nearly half (eight) of the participants discussed (or used negative connotations to describe) how they felt they could become ‘trapped’ in their device and application use. These accounts were linked to watching, news and communication services, but mostly associated with social networking; this ‘Social Networking’ category contributed to 13.40 GiB of data across the households (table 4.3). For example, Xavier characterised his *“tedious, boring”* Reddit use as *“a real drain of* [his] *time”*. Kevin also described Reddit as a *“time vampire”* due to spending hours at a time browsing, and has already *“quit Facebook”* for personal use by deleting all of his friends (using it only for work). Ella similarly described Facebook as *“an absolute black hole of your time”* and *“pure procrastination”* when it comes to busy work periods; she even avoided opening BuzzFeed in order to prevent ‘binges’ on the site as it *“sucks up all* [her] *time”*. Ben discussed how his use of Facebook and YouTube could take him *“down a rabbit hole”*, and expressed a possible change in design that he would find *“useful”*:

> *“impulse actions probably, you know, a few seconds going onto a website could take you down a rabbit hole for half an hour, or a longer period [. . .] if there was more friction between, you know, the impulse action to go onto something and then it taking so long for that thing to load up, it, it’d probably give you time to think, you know, ‘do I have the time to do this in the first place?’”* (Ben, H1).

Tim (H3) also struggled with the impulse actions Ben describes in his reflexes for *“checking crap”* on specific apps, including: BBC News, BBC Sport and Facebook. To deal with this, Tim has begun to consciously *“make an effort to put* [his phone] *down*”. This is similar to Gemma (H1), who purposely has not signed up to Facebook as she thinks it *“would steal a lot of* [her] *time”* and has to actively manage her use of Pinterest: *“it can lead you astray [. . .] you’ve gotta be quite strict with yourself so that you stick to what you’re actually looking for, not get side tracked”*.

When asking the participants about how they might respond to data demand reductions, blocking access to the Internet at particular times of day was considered possible—helping them reduce wasted time online. Connie (H3) suggested specific times to use the Internet (e.g. between 9pm–10pm) to avoid wasting time *“checking things all the time”* throughout the day. Fred (H6) alluded that such time slots would help him manage his schedules and make him *“feel less guilty”*.

Xavier reflected on whether his time on Reddit actually would be better spent elsewhere, as he might just end up *"twiddling* [his] *thumbs"*. However, an area where 'black holes', 'rabbit holes' and 'time vampires' become particularly challenging for the participants is in concentrating on work tasks. For this, Ella has attempted to use productivity tools in the past, and contemplated reinstalling the application StayFocusd due to the fact it helps her manage the use of sites like Facebook. To maintain focus on his work, Ben (H1) has learned how to add websites to a system file on his personal computer in order to block access to 'attention seeking' applications (YouTube and Facebook). As a freelance artist, Ben described how he wishes Photoshop has a similar facility to that of a word processor he'd seen where a PC becomes a *"one function device"* for 30 minutes. Like Ella, he has also attempted to use productivity tools in the past to avoid YouTube and Facebook during his working day. He discussed that StayFocusd is easy to override, and was considering buying the service Cold Turkey as *"it's impossible to unblock something"*. Kevin (H5) also found StayFocusd too easy to override when trying to block his social media use:

> *"social media used to be a sort of fairly frivolous thing that you would dip into for 20 minutes a day, and that would be as much as you'd get out of it, whereas now I think, there's so much information that it becomes almost addictive [. . .] so I think, the productivity tools came to mind as a way of sort of curbing my, you know, habitual use of these things"*...[but] *"you can always, always find a way to override* [productivity tools] *erm, and even though I wouldn't welcome the idea of a technology that can overrule the wishes of a human being, I kinda wish, I kinda wish there was sometimes"* (Kevin, H5).

Yet being productive at work sometimes means managing access to services used *for* work, as they can become just as distracting as the other services the participants have described (e.g. Facebook, Reddit, Pinterest). Ella (H5) sets aside time in the morning or afternoon (and even *"admin days"*) for email, then 'works offline' in other periods of the day to avoid email distractions; the latter involves closing the mail client she uses: *"I don't actually turn the Internet off but I'll close everything down, so that I'm kind of working offline as it were"*. This is similar to Xavier, where he discussed how he turns off Slack (a workplace messaging service): *"it's the most distracting work thing, cause you just get these, bombarded with notifications and because you're online, people expect an immediate response"*. Xavier turning this service off like this of course runs counter to Slack's intended purpose. Such tools for work, alongside the ability to be 'always available' online, can be seen as a negative impact on productivity.

Despite knowing their distractions, reflecting on their patterns of use *and* introducing methods for disconnecting, it is difficult for the participants to take time away from their digital devices and online services—particularly since the Internet hardware itself cannot be turned off without problems occurring:

> *"every night I used to switch* [the router] *off at the plug like I do with the telly, or the everything else, and then they* (BT) *came out, fixed it, put a load of new wires in, and then it happened again, and the second time they came out a month later they said 'oh no you never unplug it, just leave it all plugged in'"* (Fred, H6).

4.3.5 What is my device doing?

The empirical study uncovered some confusion around what data demand is and how it occurs. A lack of understanding revolved around Internet traffic not being correlated to participants' direct usage of online services. When presented with a graph of their average data demand by day of the week, both Martin and Gemma (H1) were surprised at Thursday being their most demanding day as that is when they are occupied looking after their niece's daughter, Paige. Through further discussion around Martin's use of cloud services, he realised that this Thursday demand is not surprising after all. With both himself and Gemma using iCloud and Google Photos for automatic media backup, and WhatsApp for sharing content with family members, looking after Paige at the same time as documenting her early years became quite data demanding:

> *"we're always taking photos of Paige and then I'll usually ping a few photos off to her mum and what have you, erm, through WhatsApp so that's using, that's using data isn't it? [. . .] When you talk about data use you think about going on websites but it's, in this case, it's about photos and being down-, saved isn't it? And perhaps being sent to errr, to Paige's mum, and my sister..."* (Martin, H1).

The confusion surrounding when data was used and whether this linked to patterns of device use (specific days and times, or durations) was surprising for other participants too (Ben, Julie, Heather, Nick, Peter). For example, Nick (H7) couldn't understand why his data traffic would be higher on Friday due to his parents' screen time regulations: *"I don't know why the Xbox* [data traffic] *is higher on Friday than it is Saturday and Sunday cause we're not allowed Xbox on Friday"*. Heather (H6) was even surprised at the data demand on her tablets: *"I go on my tablets a lot more than I thought I did [...] I didn't know I went on them that much"*.

The participants couldn't always see that their devices may demand more data when they're not necessarily using them (e.g. downloading content or large system updates)—despite explanations from the researchers. Furthermore, many participants (Fred, Ian, Olivia, Rachel, Sally) could not recognise many of the domain names nor appreciate why they could've been accessed. Ian (H7) expressed how this worried him: *"particularly like iCloud, I don't have any account on iCloud [...] whether there's stuff running in the background all linking, you just don't know"*. Rachel (H8) also illustrated her confusion: *"Would they be like, you know the adverts that pop up if you click on them by accident, they could be like that couldn't they?"*.

Textual detail in domain names partially reveals their source and allowed participants to speculate their use (e.g. Olivia noticed the use of 'ads' in a domain were for advertisements)—yet, it's typically difficult to explain data flows, due to the complexity of services and the lack of transparency about what services' data flows are for. Tech-savvy Xavier, in contrast, *is* aware that his devices and services are often sharing data in the background; reflecting that *"these phones do loads of shit all the time"*:

> *"There's always privacy concerns whenever you install an app but Facebook are notoriously known for erm mining every bit of data they possibly can, so I no longer have the Facebook app on my phone, the only 1 I have is Messenger, which you could argue that the same thing could still exist, but I try and lock it down as much as I can [...] they do mine your messages, so when you type like 'oh I'd like to, you know, go play table tennis', you'll get adverts on table tennis..."* (Xavier, H9).

Similarly to Xavier, Kevin's (H5) understanding of technology means that he puts more thought into how different devices and services share data: *"I'll notice that somebody that I've just added their phone number on my phone is now coming up when I'm logged into Google and I think, 'oh, so something must've synced'"*. Kevin noted that this was something he didn't have control over, much like Xavier with his worries about data mining. These discussions highlighted the extent to which data demand is currently hidden, meaning that users typically cannot be aware of the degree of data traffic linked to their daily activities (by no fault of their own) unless they have some further understanding of technology. This is despite some of the participants actively wanting to take precautions to protect their data privacy (i.e. Xavier).

4.3.6 Updates: a matter of trust

As highlighted in this chapter, software updates and installs are significant contributors to data demand throughout the day—with the 'Updates and Installs' category forming 5.2% (40.41 GiB) of the households' total traffic (section 4.2.1). The interviews with the participants revealed that there's an element of trust encompassed within updating software and applications. For example: Martin (H1) updates apps and the operating systems for his iPad and iPhone when they alert him to, as he imagines that *"if* [the service provider] *are updating it, they've improved, they've improved it"*—trusting that the update will be useful. Martin's demand for updates and installs on these two Apple devices totalled to 8.27 GiB during the study (iPhone: 4.11 GiB, iPad: 4.16 GiB) and were actually the second and third most data demanding devices across the households for that category (just falling behind H8's smartphone at 4.21 GiB). His confidence in such updates is similar to that of Fred's (H6), as he reflected on the forced Windows 10 *"Shutdown and update"* feature of his laptop and desktop PC: *"it's connected to Windows so it's probably a good idea"*. Updates and installs for his laptop device only generated 191.57 KiB, but his PC contributed 1.71 GiB.

Whilst Martin and Fred show instances of trust, Ben (H1), Alan (H4) and Kevin (H5) face fears when it comes to updating their devices' operating systems or their applications. Like Fred's forced Windows updates, Ben discusses how he would prefer if these OS updates were not compulsory on his PC due to an issue he had with an optional update on his old Apple Mac:

> "[the update] *messed it up, like, I had graphical issues and it would just shut down, it's still in my garage, and I can't use it anymore, so I think I'll have to sell it for scrap, because it's, possibly because of an update."* [...] *"if I had the option not to update on a PC I wouldn't update it because I'd rather not run the risk"* (Ben, H1).

Ben's PC only demanded a total of 302.90 MiB during the study for updates and installs, despite him noting the forced nature of OS upgrades on his PC. Yet his worry of the implications of updates perhaps explains the low data demand for this category across his other devices: totalling to 25.12 MiB for his phone, with neither his kindle or Amazon Echo being updated during the study period. Worries of updates that cause device problems are not unknown to Kevin either, who hasn't upgraded his Macbook Pro laptop in fear that something will go wrong or that his applications would be rendered useless. Despite the lack of updates, Kevin noted how his laptop still works as he wants it to:

> *"I tend to sort of read, read upon what sort of issues are being caused, and either wait until they've been resolved by the software distributors or just don't upgrade. I mean I've been using, I don't think I've upgraded my current laptop for a few years and it still works just as, as I want it to so, 'if it ain't broke, don't fix it'"* (Kevin, H5).

Rather than worries about broken devices and software, Alan's concerns surround new interface designs. He prefers not to install updates as he gets *"used to seeing applications and icons the, the way we do"* and doesn't like the changes they bring. He particularly dislikes how his messages display on his and Denise's shared iPad due to an update he installed in the past. His update procedure now encompasses the following: *"when there are reminders on the iPad we tend to defer it because we don't always understand the implications of it, so if it gives you the reminder we probably say 'remind us later' meaning 'please don't bother again'"* (Alan, H4).

This contrasts to Denise's updating approach for the iPad, where she accepts updates when the OS informs her that there is an update available. Denise's willingness towards updates led to their shared iPad demanding 1.83 GiB for this category. Yet the fact that Denise (like Gemma, H1) only updates when the OS tells her to suggests there is little attention given to these maintenance processes by some users. In fact, three of the participants did not know for sure whether their updates were automatic or not (Laura, H1; Ella, H5; Julie, H6) and Fred (H6) sarcastically mentioned that he's *"got a super bright LED flash light now apparently"* due to an update on his torch app. Whilst updates are sometimes required for important feature changes such as security patches, the participants' accounts here indicate that the total demand associated with updates is not always necessary nor even wanted.

4.3.7 Summary

In this section, I have explored the qualitative data on the participants' digital experiences, and probed how this links to the quantitative network data from the households. Specifically, I have demonstrated: how marketing strategies, and other contextual impacts from space and relationships, impact users' data demand; how users can find their device and service use frustrating; and the differences in meaning users place on their online activities (with communication being paramount). The qualitative interviews also uncovered that data demand is not always understood, nor even sometimes wanted (e.g. with mandatory updates). Next, I discuss the challenges of this work and outline implications for HCI community to transition users' everyday activities in less data demanding directions.

4.4 Discussion

In this chapter, the quantitative and qualitative data gathered has allowed me to provide a detailed overview of how data demand is formed in everyday life. From this, the HCI community can develop device and service interactions which transition data demand in less intensive directions. However, the methodological constraints faced whilst carrying out this research mean the Android and household datasets still do not provide a complete picture of data demand, neither within the UK, nor even for the participants involved. Furthermore, given the marketing approaches to service and device use that the participants discussed in section 4.3.1, there are broader obstacles that the HCI community will face when designing more sustainable Internet activities. These two challenges are discussed below.

4.4.1 Gathering a complete, detailed view of data demand

Both the Android and household datasets have enabled different views of everyday data demand to be revealed: the Android dataset enabled a large-scale overview of demand from smartphones and tablets, and the household study provided both fine-grained, quantitative network flows to be analysed alongside qualitative interviews with participants. This has led to a more detailed understanding of data demand in time, and by device and service, than prior work in SHCI (e.g. [211]). Yet these datasets have limitations. For the Android dataset (section 4.1), there are still unanswered questions for what specific service access contributes to the broad categories: ‘Browsers’ (8.49% of total data demand), and ‘Background Processes and Services’ (10.12% of data demand). For ‘Browsers’, the unexplained data demand is due to the Android only logging *applications installed on the device* (e.g. the Chrome browser) rather than *service access*; for ‘Background Processes and Services’, the lack of understanding for this category is due to the limited information available online (e.g. in developer forums) or the lack of semantic reasoning for linking Android application names to services.[11]

The Internet flows gathered from the home routers in the household study were associated with specific domain names, and thus removed the ‘Browsers’ abstraction issue faced in the Android dataset—yet the issue of ‘Background Processes and Services’ is still present. Gathering domain name data from home routers also led to further issues surrounding company-specific data demand. For example, ‘Other Google Products and Services’ was the fourth most data demanding category in the household study, but it could not be broken down into specific online user activities due to the lack of semantic reasoning for those Google domain names (see section 3.2.2.1). The qualitative interview data for this study provided more nuance to the quantitative data and addressed some uncertainties, however the participants themselves do not always know what their devices are doing (as found in section 4.3.5).

For both datasets, mapping the device and network data (e.g. application or domain names) to data that both researchers and participants understand (e.g. service names and categories), was a challenging and highly manual process (as outlined in sections 3.1 and 3.2). The application names on Android needed to be researched so that they could be contextualised and understandable, e.g. ‘com.facebook.katana’ is Facebook, ‘com.facebook.orca’ is Facebook Messenger. Similarly, research was required for the domain names in the household study (e.g. YouTube is at least associated with the high-level domain names ‘youtube.com’ and ‘googlevideo.com’); this becomes increasingly difficult when content is provided by CDNs e.g. Akamai which host a variety of services’ data. Given the datasets’ complexity, researching a technical solution for mapping this data would represent months of work, in its own right. Yet, the HCI community needs to develop better mapping strategies, or gather different datasets for the same group of users at the same time, if we want to understand traffic consumption completely. A cohesive understanding using different datasets may

[11]For example, it is difficult to understand what the app ‘com.android.vending’ (provided as an example for a ‘Background Processes and Services’ app in table 3.1) does, and the device or service use it supports.

include gathering: router logs such as NetFlow, DNS and DHCP data; device logs expanding on the Android dataset, for additional device or browser logging; and online service usage logs if the HCI community are able to obtain these from companies.

4.4.2 Marketing impacts and responsible business models

As the participants highlighted during the interviews, there are a number of ways in which marketing strategies are directly leading to increased device use and data demand (section 4.3.1.1): Denise (H4) was rewarded with extra DropBox storage space when getting friends or family to join the service; flexible subscriptions can lead to new data demanding practices (as with Ben and Martin in H1); and lower-priced broadband or mobile services enable more data demand than was previously affordable (Kevin). Such marketing strategies, aiming to enable usage on more services and for longer, are common amongst providers. These are particularly routine for data-intensive music and video streaming services through free trials (e.g. Apple Music,[12] YouTube Music 1-month free trial,[13] Spotify's 60-day free trial,[14] Now TV's 7-day free trial,[15] Netflix's 30-day free trial,[16] Amazon's Prime Video 30-day free trial).[17]).

Furthermore, innovation in technology and the development of novel Internet-connected devices (e.g. smart assistants or IoT) leads to users acquiring or wanting such devices, despite its use case not being entirely clear (section 4.3.1.2). Kevin, Ella and Ben all discussed this 'experimentation' process with new devices to see how they may become useful, and embedded, in their everyday lives. Ben himself even described novelty uses of his Amazon Echo, which led him to develop a routine of asking 'Alexa' for news updates in the morning and evening—an activity which he could, arguably, have carried out with the mobile device he already owned.

I should note here: I am not trying to blame users for such activities, nor do I believe we should stop innovation in digital devices or services. However, smart assistants and IoT (at least) indirectly lead to further background data demand and will

[12] Apple Music 30-day free trial: **https://www.apple.com/uk/apple-music/**, accessed October 2019.

[13] YouTube Music: **https://www.youtube.com/musicpremium**, accessed October 2019.

[14] Spotify: **https://www.spotify.com/uk/legal/new-60-days-free-trial-terms-and-conditions/**, accessed October 2019.

[15] Now TV: **https://www.nowtv.com/**, accessed October 2019.

[16] Netflix: **https://www.netflix.com/gb/**, accessed October 2019.

[17] Amazon Prime Video: **https://www.amazon.co.uk/gp/video/offers/ref=dvm_uk_sl_ambr%7Cc_324956339455_m_GI9EKwya-dc_s_**, accessed October 2019.

no doubt add to the issue of device obsolescence (cf. [306]) as newer models surface in the future (e.g. similar to the iPod Classic, iPod Mini and iPod Nano series of devices that Blevis described as unsustainable [45]). Given the impact businesses can have on data demand, they need to establish more responsible service and device development models; without the 'more is better' approach to technology and data, the HCI community may have a greater chance of reducing the issue of data demand growth.

4.5 Implications for HCI

Based on both the findings and challenges discussed in this chapter, there are a number of clear implications for the HCI community: 1) to target the most data-intensive user activities; 2) to shift and reduce the data demand from updates; 3) to seek collaborations with businesses and ISPs; and 4) to design for sufficiency through moderate and meaningful online experiences.

4.5.1 Targeting the most data-intensive user activities

'Watching' was found to be the largest category of data demand for both datasets, forming 21% of Android data demand (section 4.1) and 72% of the households' data demand (section 4.2). This corresponds with broader estimates of Internet traffic, as video streaming was found to be the dominant application category of global traffic in 2018 by Sandvine (58% of downstream, 22% of upstream) [322] and by Cisco (recording Internet video as 72% of consumer traffic in 2017) [78]. Other significant categories that can be tightly linked to users' online activities, consisted of: 'Gaming' (third most demanding category for the households), 'Social Networking' (8% of Android data demand, sixth demanding category for households), 'Communication' (fifth demanding category for the households), and 'Listening' to audio streams (11% of Android data demand, ninth demanding category for households). This also corresponds with large-scale aggregate estimates, whereby all of these groups appeared in Sandvine's top 10 application categories contributing to global traffic in 2018 [322].

Some of these categories are set to increase: Internet video has an expected CAGR of 34% for 2017–2022 [78, Tab. 15] and is expected to grow on mobile devices to form 74% of mobile data traffic in 2024 (from 60% in 2018) [111]; mobile data traffic from social networking is forecast to rise by 22% between 2018 and 2024 [111]; and gaming data demand will inevitably grow with the introduction of cloud gaming services (e.g.

Google Stadia, with a suggested 'best' connection speed of 35 Mbps for 4K resolution) and the consistent growth of the e-sports industry. To have the greatest impact on reducing data demand growth, HCI researchers and practitioners should concentrate on user practices which involve these more data-intensive online activities.

While it helps that popular services such as BBC iPlayer and Spotify implement the *"nudge"* approach (i.e. defaulting to lower quality streams) described by Preist et al. [298, p. 1330], it is also the *sheer number of devices demanding such services* (e.g. 345 or 87% for watching in the Android dataset, and all nine households in the household study) and the prominence of data demanding services through the day (figures 4.3 and 4.5). HCI researchers and practitioners should therefore aim to create more impactful designs which reduce data demand. For example, removing the digitally wasted video streams of YouTube videos used for audio-only activities, can be just as advantageous as running a data centre on renewable energy [299]. If the service therefore is data-intensive and is popular amongst consumers (i.e. has a large customer base), then small interaction design changes can have a great effect. Furthermore, a design like this can even reduce data demand without interfering with the users' core activity (in this case, listening to music).

HCI researchers and practitioners should aim to create designs which *support* users' activities, yet still *reduce* the data demand associated with it. For example, social networking data demand could be reduced by designing social media apps that force users to 'work' for their rich media, e.g. through reducing media previews, removing video auto-play or increasing the number of access levels to such content; this may dissuade users from simply viewing media just because it's easily accessible (rather than being particularly important, as the participants themselves pointed out; section 4.3.4), yet still provides them the freedom to access the content if they wish. Further exploration into the most demanding categories is required (building on the overview I have provided in this chapter), uncovering: how activities are becoming more data-intensive, including the data demand impacts of the changing material, competence, and meaning elements of Internet-connected social practices [338]; and what opportunities lie for better supporting users and the sustainability of digital infrastructure. Through such investigation, interventions should be scoped and tested with users; these may focus on specific times, devices, or services that contribute most to the categories' data demand.

4.5.2 Shifting and reducing data demand from updates

As uncovered in this chapter, the demand for software and application updates and installs occurs throughout the day; this was the case for the Android dataset but most significant in the home, with the 'Updates and Installs' category being the second largest contributor to the households' traffic at 40.41 GiB (5.2% of total demand). Such traffic is particularly concerning as it is initiated by devices or services, and so is *"growing unwatched and unabated"* [155, p. 4] with potentially less limits to growth than other user-focused categories (e.g. users' *time spent* watching). This demand also partially occurred during the peak electricity demand hours of 4pm–8pm, with a large peak at 5pm (figures 4.3b and 4.5b). The energy consumed at peak times on the electricity grid tends to have higher carbon intensity. As Sandvine point out [320], network operators use peak demand to plan their capacity. Building infrastructural capacity, itself, causes energy consumption and carbon emissions, and also leads to further demand in the future through the 'Cornucopian paradigm' [298].

Previous work discusses how services should be designed to *"reduce or avoid usage of infrastructure at peak times"*, focusing on the use of technology to shift users' demand off peak [298, p. 1329]. With low levels of data demand during the early morning (3am–5am) in both datasets, as well as lulls on Mondays compared to other days of the week, peak demand for updates (which do not require synchronous use) could easily be shifted to these time periods for demand balancing [211]. Whilst operating systems such as Apple[18] do offer 'update overnight' options to users, the time visualisations within this chapter raise the question to whether these designs are accomplishing this shift. HCI researchers and practitioners should instead try more persuasive designs which drive overnight updates, e.g.: 1) options given to users may default to updating OS and apps overnight, 2) update notifications may only appear as users are going to bed, or 3) 'update now' options may only become available during real-time lulls in traffic. This builds on calls for interface designs to remove 'update all' options in app stores, or only offering to update apps which users most frequently use [211].

More mature shifting designs would be required for a significant update affecting many customers (such as major OS updates for Apple, Android, or Windows), in order to avoid creating a large, shifted peak during the night (e.g. Apple's iOS 8 caused a 10% rise in traffic for Virgin Media [54, 211]). Updates would therefore need to be period-

[18] Apple's 'update overnight' option: `https://support.apple.com/en-us/HT204204`, accessed October 2019.

ically ‘staggered’ (cf. [211]) *across* customers during off-peak demand hours. Shifting other online activities may also be possible (e.g. backups, pre-downloading watching content). Yet, updates and installs arguably lie in the control of the service provider (i.e. are deployed by developers and initiated by the service or app store) [94] and require less input or planning by the user (e.g. for pre-downloading video, users would need to remember to do this in advance of when they want to watch the content)—meaning updates and installs are an easier category to target at scale.

Alongside shifting updates to low periods of demand, HCI researchers and practitioners should also look to ways in which the data demand from updates can be reduced as a whole. As uncovered with the qualitative data, the participants’ willingness to update their devices and services was often coupled with the trust they put into service providers (section 4.3.6). Worries of major interface changes (Alan, H4) or previous negative experiences with updates (Ben, H1; Kevin, H5) meant these users tried to avoid upgrading their services; this supports findings from previous privacy research [231, 232, 384]. This could potentially be detrimental to their online privacy and security without important security updates. Given this, HCI researchers and practitioners should experiment with multiple, concurrent update streams: offering basic and core security updates, *alongside* larger functionality updates [384]. Such separation of app updates would add to the complexity of managing OS and app versions—requiring training, incentives and appropriate resources for software developers [231]. However, offering updates in this way would reduce the data demand of large updates that users may not necessarily want (e.g. Ben’s forced Windows updates), yet still allow secure online service use for customers and additional functionality for users that want it (e.g. Martin, H1; Fred, H6). Such a design is *“conscientious of resources”* [383, p. 3224], and potentially a more secure way forward than only updating most frequently used apps [211] or avoiding updates entirely, which was the strategy some participants took.

4.5.3 Seeking collaborations with businesses and ISPs

Following the discussion in section 4.4, there are still uncertainties regarding the full, complete picture of data demand due to the abstractions made in computing systems and companies; and marketing strategies often focus on more demand at a lower retail price, or drive innovation which conflicts with the sustainability of the technology industry. It is clear that we need businesses to develop more responsible service and device development models. With these challenges, I see an opportunity for HCI researchers to seek projects that enable collaborations with businesses and Internet Service Providers (ISPs).

For understanding traffic consumption, business partnerships with top services (e.g. YouTube, Facebook) or ISPs (e.g. BT, Now TV) would make it easier for gathering and analysing large-scale datasets of service use. Designers could gain a detailed understanding of the service providers' backend servers, domain naming constructs, and data transmissions—making it easier to categorise and calculate the traffic volumes of different application areas (e.g. the company-specific categories, or 'Background Processes and Services') or domain names which users themselves don't recognise (section 4.3.5). This is similar to how researchers have teamed up with the BBC [329] and Guardian News and Media Ltd [331] to measure the environmental impact of these online services. However, this comes with its own challenge of getting businesses to openly reckon with the environmental impact of their services, especially if this is then to be used for creating interventions which may aim to reduce users' access of that service. This is a tricky tension, and so the HCI community may have to make do with the 'best effort' router-logging approach presented in this thesis.

Furthermore, the offers we see today for services and data consumption need to be adapted: businesses could instead offer shorter (e.g. one day free trials) or reduced cost trials, rather than the typical one month free trials shown for music and video services. Companies also need to be more responsible when positioning the use cases and usefulness of innovative technology. For example, smart assistants could be better advertised towards focusing on the affordances they bring to the elderly or the disabled (e.g. by improving task efficiency and independence [297]), rather than just providing additional convenience for more mobile consumers. This is extremely difficult, and would perhaps limit the innovations that users themselves develop with technology. However, collaborating with businesses would allow for the HCI community to discover advertising and marketing strategies which balance the benefits of users' access to services and devices, businesses' profit, and the sustainability of the Internet.

4.5.4 Designing for sufficiency: meaningful and moderate use

The participants reported trawling through data they considered 'meaningless', 'wasting time' online, procrastinating from work and attempting to disconnect (e.g. through productivity tools, section 4.3.4; or in specific spaces, section 4.3.2). It is clear that they viewed this data consumption within some practices as less meaningful (where the elements of meaning are less valued [338]) than those for other activities such as communication with others (section 4.3.3)—suggesting some data is perhaps 'wasted' due to its lack of value to users. Similar wasteful scenarios can also be found in other studies, e.g. Khan et al. found that 49% of files stored in the cloud are forgotten about by users [185], and users sometimes only listen to video-streamed music [211, 298]; this highlights how Internet storage and content (and its energy impact) is not always fully utilised. Not *all* Internet uses are meaningless and frustrating for users, but our participants highlight that some interactions are; this is where opportunities lie for HCI to intervene, reducing data demand through creating more *moderate* device and service use in ways users *want* (or even need) whilst still maintaining *meaningful* interactions.

In sustainability, Hilty points to the need to avoid the trap that efficiency breeds growth (the 'rebound effect' known as Jevons paradox): we must create a condition of *"sufficiency"*, a ceiling at which capacity is reached and exponential growth stops [162, p. 1]. Given this, we must aim to create sufficient levels of Internet use—both for the environment and society—otherwise, it's clear that the growth in demand will continue unchecked. To do this, *sufficiency* should be debated and defined in HCI, to keep *"consumption within certain limits"* [162, p. 1]. Utilising this concept, we can better control the consumption of devices, the Internet, and their underlying environmental consequences (e.g. energy impact from data demand) and user effects (e.g. impact on work tasks). Adding to existing ideas around non-use (e.g. better balancing user engagement and control in social media apps [333]), slow design (e.g. creating meaningful experiences with digital content [261]), and designing meaningful interactions [214, 244], the HCI community should explore this design notion of *designing for sufficiency* through creating more moderate and meaningful uses of digital devices and online services—specifically creating changes which attribute value to the meaning elements of Internet-connected practices [338], as the more meaningful activities (e.g. communication) are not always the most data demanding.

By *"introducing constraints that respect given limits"* [162, p. 3] through HCI, we can improve design *for* users and create an experience which is appropriate to both their needs and the natural environment's. This will require challenging the addictive nature that current interface designs target, as well as the wider societal influences and practices that drive them (e.g. the marketing strategies adopted by service providers discussed in section 4.4.2). Yet, service providers and developers have already begun to develop and adopt services which aim to improve, or reduce, users' online consumption (e.g. Apple's [9] and Android's [373] digital wellbeing tools). Perhaps this user-focused initiative to reduce data demand may be more palatable to the technology industry than, for example, forcing limits on the data-intensive services we need to target (section 4.5.1).

The concept of what is sufficient has certainly appeared in other fields of energy and sustainability research [162, 386]—but how can we capitalise on this? How can we, as HCI researchers, investigate and debate digital sufficiency in different contexts? Walker et al. discuss that there is *"the potential for a growing proliferation of energy uses to become normal and needed over time"* [386, p.135]; regarding Internet and device use, how will what we regard as 'sufficient' usage change over time? And how can our HCI designs adapt to accommodate new norms about what usage is 'enough'? These are just some of the questions that the HCI community should consider when designing for sufficiency and maintaining meaning in digital interactions. An obvious next step for this work would be to further the findings presented in this chapter: what online interactions are meaningful to users, and what opportunities are available for reducing data demand in activities that users deem less meaningful. To outline what designs may be appropriate for this reduction agenda, *designing with users* would be a beneficial approach—aiming to find sufficient levels of service and device use that best align with digital experiences that are healthy and preferred.

4.6 Summary

In this chapter, I have provided a detailed overview of data demand for two datasets: a large dataset of 398 Android mobile devices running Device Analyzer, and a smaller (but more comprehensive) dataset of nine households' network flows. My contributions to the HCI community include providing this analysis of Internet use through time, by device and by service, as well as outlining users' digital experiences from their Internet connectivity. From this, I have discussed the challenges of exploring data demand in everyday life due to data access and business marketing strategies (section 4.4), and produced implications for the HCI community for reducing the impact of Internet traffic (section 4.5). HCI researchers and practitioners should target the most data-intensive activities (such as watching, gaming and social networking—section 4.5.1), and diminish the impact of updates data demand by shifting them off-peak or offering smaller, security-focused updates for services (section 4.5.2). They should seek collaborations with businesses and ISPs to overcome the challenges of data access and marketing (section 4.5.3). Furthermore, the HCI community should design for sufficient levels of data demand through creating more moderate and meaningful digital experiences with users (section 4.5.4). Two of the implications here (sections 4.5.1 and 4.5.4) are developed in the rest of this thesis. The next chapter (chapter 5) delves into the practice of watching—uncovering how this is transitioning in more data demanding directions, and how we can specifically target this data-intensive activity. Chapter 6 then explores ideas of designing for sufficiency by designing moderate and meaningful digital experiences with everyday users—producing specific design recommendations for the HCI community that aim to address overlapping concerns associated with digital device and online service use (e.g. digital wellbeing and data demand reduction).

Every song that I’ve ever heard
is playing at the same time, it’s absurd.
And it reminds me, we’ve got everything now.

—ARCADE FIRE

Chapter 5

Streaming, Multi-Screens and YouTube: The New Ways of Watching in the Home

'Watching' was found to be the most data demanding Internet activity in chapter 4, forming 21% of Android device data demand and 72% of household data demand. This corresponds with large-scale analyses of Internet traffic [78, 322]. The HCI community therefore need to target this data demanding activity to have a significant impact on reducing data demand growth (as highlighted in section 4.5.1). For this, we need to: understand more about how *watching specifically* is becoming increasingly data-intensive, so that distinct practices can be targeted; and uncover the opportunities available to adapt HCI designs for watching, reducing the data demand from video streaming in ways which work best for users *and* the environment (section 4.5.1).

This chapter therefore explores the practice of watching in more depth. I first describe a brief history of watching video content in the UK and outline the prior work on watching and video streaming in HCI; this is intended to provide an understanding of how watching has previously been conducted in everyday life, and how video streaming has become popular. I then present an in-depth understanding of the data demand associated with watching in the home from the household study (method outlined in section 3.2), and illustrate how video streaming is embedded within the everyday lives of the participants. In particular, I reveal the new ways in which watching is becoming unsustainable due to the fact it is increasingly facilitated through online means and additional screens. From this, I discuss opportunities for the HCI community to intervene, alongside the challenges they will face when developing interventions (i.e. HCI designs that aim to reduce data demand) to address streaming growth. I conclude with implications for HCI researchers and practitioners, as well as other stakeholders in society, to transition this data demanding practice in more sustainable ways.

5.1 A brief history of watching and prior research

In this section, I provide a brief overview of the history of watching television and video content. Specifically, I focus on watching in the UK in the past century; the UK context is relevant to the household study of nine UK households discussed in this chapter. The overview of watching is intended to be brief: highlighting the major changes to, and events which have shaped, this practice over time. This particularly shows how the activity of watching television changed from one TV per household with minimal channel options, to the vast collections of TV series, films and video clips which we have quick access to on many digital devices in 'the streaming era' of today. More in-depth histories and explorations of watching are provided in other works [1, 134, 142, 160, 198, 353]. From the brief history outlining significant shifts in watching in the UK (section 5.1.1), I then provide an detailed summary of watching and video streaming research in HCI (section 5.1.2).

5.1.1 Significant shifts in watching: a UK summary

The practice of watching has evolved significantly in the last 90 years. Black and white TV sets first became popular in British households between the 1930s–50s [15] with color TV gradually taking over since the late 1960s [16]. During this time period, UK households would traditionally have one television and access to three broadcast TV channels (BBC 1, BBC 2 and ITV); and additionally Channel 4 in 1982 [31], Channel 5 in 1997 [57], and the launch of Sky (the UK's first satellite TV service [350]) and Freeview between the late 1980s and early 2000s [334]. The arrival of pay-TV in the 1990s (e.g. Sky) and multiple digital TV channels led to the digital switchover (i.e. the switch from analogue to digital TV) in 2007, later completed in 2012 [275]. The increase in available channels coincided with a rise in TV ownership in UK households: 5.7 million households in 1956, to 16.9 in 1970, 21.5 in 1990, and 27.2 in January 2019 [19]. With the move to Digital Terrestrial Broadcast (DTB) and multiple channels, terrestrial TV faced added competition—this led terrestrial channels (notably the

BBC) to create more *"special event"* or *"visually exciting"* footage [142, p. 97].

Alongside the rise in the availability of broadcast content, the practice of watching shifted with the introduction of the Video Home System (VHS). Video recording e.g. via the Video Cassette Recorder (VCR) arrived in the 1970s [275], allowing users flexibility to record TV content onto VHS as a way to reschedule and time-shift video watching from the original broadcast time. Video rental stores (e.g. Blockbuster in 1985 [275]) became common on many UK high streets, with consumers able to schedule TV 'box set' (i.e. a collection of episodes from a TV series) and film watching at the availability of the local shop's stock. The 90s saw the change from VHS to Digital Versatile Disc (DVD) and VCRs to Personal Video Recorders (PVRs), leading to DVDs topping VHS sales in 2003 [97] and the end of this video era [379]. Blu-ray Discs shortly followed in this millenium, offering more storage and better compression than DVDs and therefore opportunities for higher quality video [101]. Netflix, now a prominent streaming service, originally started in 1998 as an online DVD rental company—sending DVDs to subscribers' homes using the postal service [34]. Shifted watching became even easier with the introduction of services such as Sky+ (with an in-built PVR) in 2001—allowing control for users to record, pause or rewind live TV [351]. Five years on, Sky+ HD was born [351], enabling PVR functionality with higher quality video.

The take-up of video-on-demand services and digital TV began in 2007 with the launch of BBC iPlayer; ITV Player and Freesat quickly followed (2008), alongside other prominent video streaming services today (YouView, 2010; Sky Go, 2011 [352]; Now TV, 2012 [352]; Netflix, 2012; Amazon Prime Video, 2014; Facebook Live, 2015; and YouTube Premium, 2018)—all of which have *"exponentially expanded consumers' choice of content"* [271, p. 25] and drive *"massive increases in fixed-line data use"* [271, p. 21]. In just four years, subscriptions to on-demand services have increased from 14% of UK households (2014), to 39.3% of households (2018) [273]. Subscriptions to streaming services (e.g. Netflix, Now TV) reached 19.1 million in 2018 (4.8 million more than pay-TV services e.g. Sky, Virgin Media) [275]. Broadcasters are even beginning to adapt to this change in viewing behaviour, with the BBC moving BBC Three to an online-only channel in 2016 and making the full 'box sets' for the TV programme 'Killing Eve' available on-demand after the first episode was broadcast [275]. The introduction and popularity of on-demand services has coincided with changes in device take-up: the share of UK households owning a digital television has increased (84% in 2008 to 95% in 2018), smart TVs have surged (5% in 2012 to

42% in 2018), and tablet ownership (a device easily used as a portable TV [240]) has also risen (2% in 2011 to 58% in 2018) [271].

These growth statistics also coincide with a decline in UK households owning DVD players (83% in 2008 to 64% in 2018) [271]. Streaming and downloads overcame DVD and Blu-ray Disc sales for the first time in 2017 [364], and DVD sales decreased by 30% between Christmas 2017 and the festive period the following year (forcing leading DVD seller 'HMV' into administration) [247]. Broadcast TV is also declining (falling again in 2017 for its sixth year in a row), with more than half of broadcast viewers being over-54 [273]. The BBC recently scrapped free TV licences for over-75s [388], which could perhaps further contribute to the decline in broadcast viewing. Yet important national events (e.g. the 2018 royal wedding, FIFA World Cup) can still captivate huge audiences [273]. In fact, catch-up viewing (rather than broadcast-facilitated watching) is more prominent for some genres than others: the most time-shifted genre is 'drama' (31.28% time-shifted in July 2019), with music the second (23.07%) [18]. Sports (9.81% time-shifted in July 2019), news/weather (2.96%) and party political broadcasts (1.83%) were some of least shifted in time [18]. In 2018—a year which brought the Winter Olympic and Paralympic Games, the Commonwealth Games, the FIFA World Cup and the Ryder Cup—97.1% of the UK population watched a sporting broadcast [20].

Prominent trends in watching have also seen the rise in high-fidelity viewing. The BBC began subscription-based high-definition (HD) broadcasts in 2006, which were followed by non-subscription HD channels on Freesat in 2008 [275]. In 2015, BT Sports Ultra HD became the first UK channel to offer ultra high-definition (UHD) (4K resolution) sports coverage [275]. Standard-definition (SD) TVs are now becoming insignificant with HD and UHD representing nearly 100% of sales, and 63% of TV households in 2017 accessed HD services [270]. Like high-fidelity video watching, 3D-TV was expected to become popular with the first 3D-TV set becoming available in the UK in 2010 [390] and Sky launching Europe's first 3D-TV channel the same year [275]. However, major 3D-TV set manufacturers (Samsung, LG and Sony) discontinued these products in 2016–17 due to lack of demand *"as consumers were not sold on the idea of sitting in their living rooms wearing a chunky pair of 3D glasses while watching TV"* [250]. As pointed out in this brief history, other watching trends have instead followed: increased availability of video content in higher-definitions, accessed at suitable times and places for consumers—enabled most recently by the prevalence of on-demand streaming services.

5.1.2 HCI and watching: prior research

In 2009, Barkhuus and Brown [22] highlighted that HCI had not previously deeply investigated TV watching; this was despite it being a popular entertainment activity, and therefore they conducted qualitative research with 21 household participants to better understand the practice. They found that *"time-shifting and location-independent technologies enable television watchers to structure their everyday life better"* [22, p. 15:19]. For example, participants who owned PVRs had moved almost entirely from watching live TV to pre-recorded shows—particularly to fit TV programmes into their schedules, avoid adverts, and collect multiple episodes of a series to watch in a sitting. Such reduction in watching live TV was also common with users who primarily watch via Internet downloads. Yet they note that TV watching is socially organised: PVR recording was really only used to provide *minimal* time-shifting, with viewers still wanting to watch content on the same day it was broadcast (primarily in the evening) potentially to avoid losing out on the 'water-cooler moment' [22] (i.e. discussing content with family, friends and colleagues [264]).

Barkhuus and Brown [22] further observed that: the change from broadcast TV watching meant viewers were no longer 'channel surfing' (i.e. searching through channels) and actually watching shows they wanted to watch; and that participants engaged in *"ambient watching"* i.e. having the TV on in the background during a different practice such as eating [22, p. 15:14]. DVDs were a prominent feature for repeatedly watching content, with participants viewing shows or films over and over again.

Saxbe et al. furthered this understanding of watching by looking at social and spatial contexts of TV viewing in the home with families—finding that 61% of watching was carried out with at least more than one person [326]. Linking their study to Barkhuus and Brown [22], Vanattenhoven and Geerts [382] studied watching in 2015 to see how the practice had changed since 2009. At this point, on-demand viewing had taken over PVRs and was usually for focused viewing rather than background, ambient content. Despite the decrease in broadcast TV watching, they found that there were still some important genres for watching live TV, including: football games, news, repeat broadcasts, and TV shows that *"generate quite a lot of buzz among friends, family or colleagues"* [382, p. 5]. Participants preferred movies and TV series in higher qualities, yet this was not as important for news. The authors produced a number of implications for content and TV providers, e.g. recommender systems should take into account *"the viewing situation"* (i.e. what types of content are preferred at different times of the day, and prioritising that content based on the time) [382, p. 8].

As Internet-based watching became more prominent, research into this activity increased. Specifically, studies have aimed to: analyse specific watching services (e.g. BBC iPlayer [181], YouTube [69], and Netflix [175]); uncover why users multitask digital media (i.e. use more than one digital device simultaneously), particularly alongside the TV [167, 170]; and design collaborative online interfaces [257] or 'second screen' apps [105, 120, 259] to enhance watching experiences. The rise of live streaming has captured the interest of researchers—leading to investigations of this activity on Twitch for gaming practices [348]; in China (a country in which this activity is extremely popular) [213]; and into reasons why viewers support streamers, financially or otherwise [397]. The growth of on-demand entertainment services has also led to recent works by Rigby et al., aiming to qualitatively uncover how, where and who partakes in streaming activities via two-week diary studies [309, 310]. All the work discussed here, however, does not take into account the data demand (and associated energy and carbon emissions) associated with streaming. In some cases, the problem of data demand will only become more prominent; e.g. the introduction of second screen apps (cf. [259]) creates an additional Internet service that wasn't previously used before, *adding to* the data demand from the video streaming itself.

However, the work carried out by some researchers that focuses on improving watching experiences for users *can* move the activity in more sustainable directions. To *"optimize binge-watching experiences"* [95, p. 65] or help parents transition their children away from devices [164], recommended designs have included prompts to users to stop watching or removing the auto-playing of video—the latter a feature which has contributed to the rise in streaming. To prevent users having to spend hours re-watching entire box sets before a new season is released, short summaries of TV series have been suggested as an alternative way to remind viewers of the plot [382]; this is obviously a preferred solution if the re-watching is currently facilitated by energy-intensive online streaming. Pre-downloading video content on fixed networks (e.g. a Wi-Fi broadband router) has been proposed for reducing buffering of mobile-accessed video for users during their daily commutes [180]; this is potentially a more sustainable solution due to the fact that fixed-access networks consume less energy than mobile (in 2015, accessing 100 MiB via Wi-Fi was approximately 15Wh less than by 3G/LTE [211]). Similarly, Nencioni et al. have developed a tool to predict users' video consumption—pre-recording broadcast shows to alleviate pressure on the Internet infrastructure [260].

In sustainability research, the environmental impact of this activity has come under scrutiny for example by comparing: the use phase of watching TV via broadcast channels and the BBC iPlayer, finding that broadcast channels with smaller audiences (e.g. BBC Parliament) can be more carbon intensive than video-on-demand [71]; and the impact of different qualities of service for video streaming on energy consumption, where 4K video can consume 30% more energy than HD at the client device [107]. In SHCI, however, there has been very limited work investigating video streaming. Preist et al. have touched on reducing the data demand associated with streaming, e.g. by suggesting 'video on/off' toggles on services (such as YouTube) [298] where users may only be listening to the watchable content they stream [211]. Such designs are required to remove unnecessarily streamed video, and have actually made an appearance on YouTube Red/Premium (a paid YouTube service)[1] by allowing users to listen to YouTube content 'in the background'. Preist et al. note that this action of streaming video for listening is 'digital waste', and highlight that turning video off for this activity on YouTube could create energy savings that compare to running a data centre on renewable energy [299]. More research is required in SHCI to: better understand how the practice of watching is composed; uncover what adaptations are required for more sustainable watching activities; and discover further opportunities for interaction designs that inhibit the highly data demanding activity of video streaming. Through this chapter, I explore the practice of watching more deeply, and discuss the roles of the HCI community and broader society (e.g. policy makers) on this matter. This analysis is based on quantitative and qualitative data collected from the home Internet study (method in section 3.2)—the findings of which I discuss next.

5.2 Watching: a quantitative overview

Revisiting the quantitative data for watching (section 4.2.1.1) in more detail: all households (and 82% of logged devices shown in table 4.1) accessed some form of watching content during the study (see table 5.1). As outlined in chapter 4, the services used for this activity (e.g. YouTube, Netflix, Now TV, Facebook Videos etc.) contributed to 72% (558.57 GiB) of the households' total data demand (777.09 GiB), highlighting this activity's prominence in everyday Internet use. Watching typically occurs every day of the week and throughout the day (see figure 5.1). There are peaks early morning (7am), lunchtime (1pm), and late at night (10pm), with an early evening peak at

[1]YouTube Red/Premium: `https://www.youtube.com/premium`, accessed October 2019.

H#	Avg. Daily MiB	No. of Days	Top Watching Services (Avg. Daily MiB, No. of Days)
H1	892	55	YouTube (803, 55), ITV Hub (184, 8), Akamai (128, 8)
H2	5	31	Facebook Videos (7, 17), YouTube (0.8, 26), Brightcove (2, 8)
H3	1287	36	Warner Bros UltraViolet (1962, 6), YouTube (310, 32), Watching Device Unknown IPs (964, 10)
H4	17	29	Brightcove (19, 10), YouTube (6, 28), BBC iPlayer (7, 11)
H5	2272	29	Now TV (3589, 13), Netflix (1658, 8), Facebook Videos (176, 27)
H6	5145	28	YouTube (4882, 28), Facebook Videos (79, 28), Sky Sports (2120, 1)
H7	1690	32	Sky (1472, 32), YouTube (286, 24), Facebook Videos (10, 5)
H8	2749	27	TV Player (2480, 17), All 4 (747, 15), ITV Hub (421, 14)
H9	5738	24	YouTube (3370, 24), Netflix (2285, 16), Twitch (910, 15)

Table 5.1: The households' watching demand and top watching services.

6pm. The majority of data demand occurs in traditional 'prime time' TV watching hours (8pm–10pm [374]); this prime time watching is facilitated by devices other than smartphones, tablets and laptops, as demand from portable devices dips at this time (see figure 5.3)—a trough consistent with mobile devices as found in chapter 4 (sections 4.1.1.1 and 4.2.1.1) [249, Fig. 7].

Device Type (No. of Devices)	Avg. GiB per device (total devices' GiB)	Contributing Households
Smartphone (18)	10.34 (186.17)	All households
Tablet (12)	6.96 (83.63)	All but H5
Laptop (7)	9.4 (65.85)	H2, H5, H6, H7, H8, H9
TV Box (5)	10.2 (51)	H1, H3, H7
TV Dongle (4)	20.46 (81.84)	H3, H6, H8
PC (4)	1.09 (4.37)	H1, H3, H5, H6
Smart TV (3)	2.23 (6.71)	H3, H6, H9
Games Console (1)	78.98 (78.98)	H9

Table 5.2: The households' watching data demand by device type. Note that the number of devices used for watching is less than those displayed in table 4.1, as 18% of all the households' logged devices were not used at all to access a watching domain.

Watching occurs across different device types (table 5.2). These ranged from mobile devices such as smartphones and tablets, to larger devices such as smart TVs or PCs, and more modern TV-based devices such as dongles (e.g. Amazon Fire TV Stick). Smartphones were the most commonly owned devices, 18 of which accessed watching

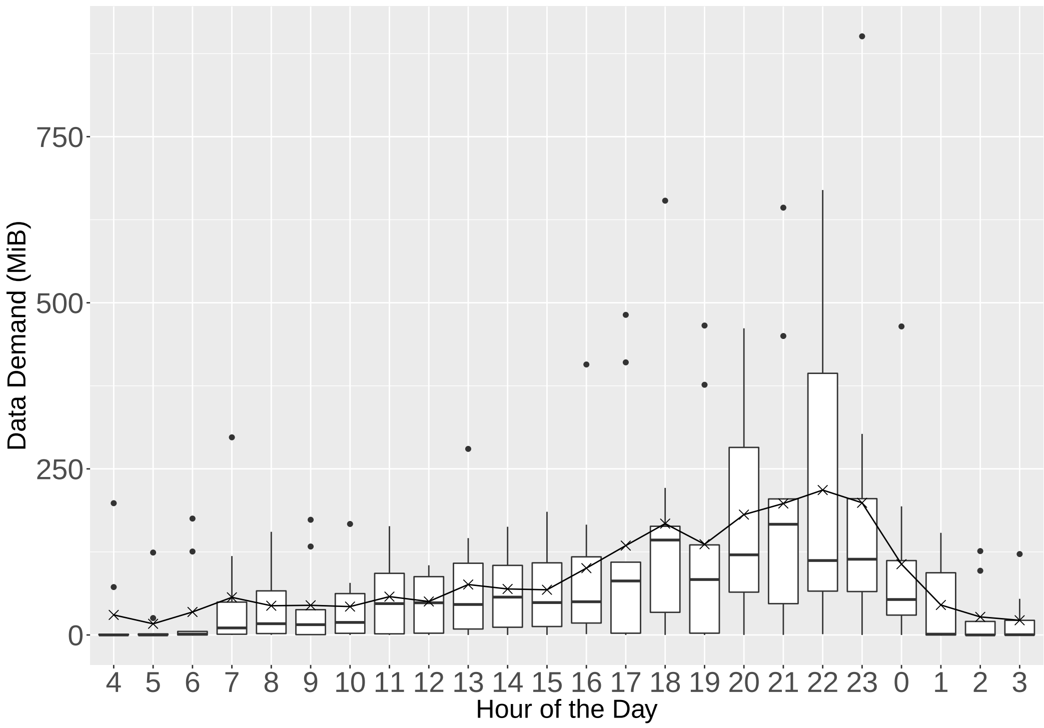


Figure 5.1: The households' average data demand for watching throughout the day. The overlaid line and crosses represent the mean; the dots represent the outliers. This figure is supported by nine months (at least one month in each household) of fine-grained network logs. Some samples lie outside the inter-quartile range because data demand is non-normally distributed.

content, contributing 186 GiB (33% of total watching data demand); merging this with the tablets' demand shows how prominent mobile devices have become for facilitating streaming, with just under 50% of total watching data being consumed on these devices. The most data-intensive devices for watching consist of H9's games console (79 GiB in the month-long study) and the TV dongles (avg. 20 GiB per device).

Figure 5.2 shows the top 10 services which compose a large share of watching data demand. YouTube was the most demanding service across households. Other significant services consisted of Now TV, Netflix, Sky TV and TV Player, followed by more social-related videos on Facebook and Twitch. Domain names for video from Akamai also made that CDN a top contributor. From this quantitative data I have uncovered: 1) when watching occurs; 2) the device types used; and 3) the streaming services accessed. But how is watching formed in everyday life? Why, and how, is this demanding activity growing, and what parts of it are most meaningful to users?

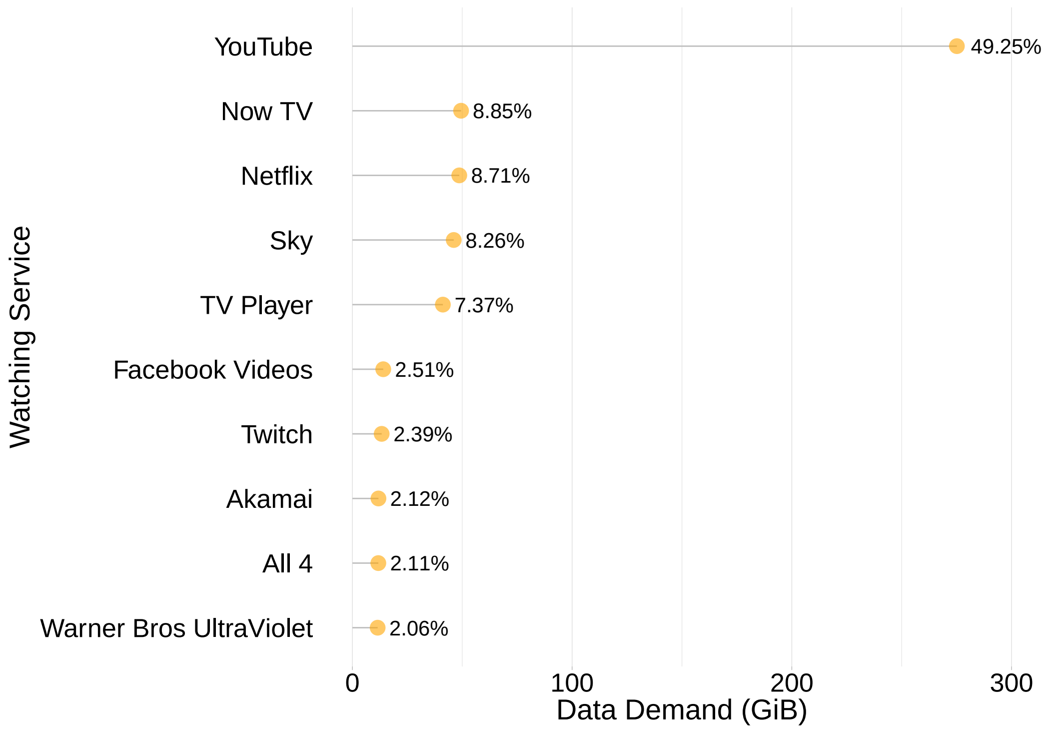


Figure 5.2: The households' total data demand for the top 10 watching services. Percentages represent services' share of watching demand. Other watching services totalled to 35.5 GiB (6.37%).

5.3 The new ways of watching

In this section, I uncover the new ways in which watching is being facilitated and how this links to the quantitative, logged data demand: 1) streaming is becoming the primary way of watching; 2) YouTube is the most data demanding watching service; 3) multi-watching is occurring in the home; 4) the growth in devices is leading to more watching demand; 5) media-multitasking is coupled with watching practices; and 6) participants can find the content they watch trivial. These are explored below.

5.3.1 Streaming as the primary way of watching

Video-on-demand provides a high level of flexibility for watching activities: users can often watch at a time and place which best suits them, on a multitude of devices, and view many clips, shows or films given the large variety of content available online. Subsequently, the nature of watching and what can be expected from this form of entertainment has changed, as Ella states below. Her household's watching is facilitated by their laptops, Google Chromecast and Now TV Box; since these *"constellations"* [25, p.1175] of devices for on-demand viewing entered their lives, the participants' ways of watching have become much more particular:

> *"Years ago you'd sit just for hours and watch Come Dine with Me or something on repeat on a Sunday, erm, but now we will start a series, if we don't like it after one or two episodes we will quit it and we'll start watching something else, and we're the same with movies, like we constantly just turn movies off half way through, and I never would've done that like a few years ago, I would've selected something, sat down and watched it, even if it was rubbish, erm because I wanted to see it through to the end [...] there's always something else that you could erm be watching"* (Ella, H5).

Ella and Kevin no longer have access to broadcast television and describe it as *"mundane"*. Instead they pay monthly subscriptions to access the *"massive amount of options"* on three popular streaming services: Netflix, Now TV and Amazon Prime. Whilst all other households had access to broadcast television, some of them showed signs of following the trajectories of H5: Rachel and Sally (H8) only have access to content provided by Amazon Fire TV Sticks in their bedrooms; H9 has access to broadcast TV but *"always stream*[s]*"*; Gemma (H1) believes *"you need the Internet for a telly"*; and Tim (H3) reflects on whether broadcast television is even needed:

> *"I'd still watch the same programs I watch I suppose [...] I sit down to put the telly on and I don't just watch whatever's on at the time. If there's nothing I wanna watch I just put something on on-demand. I suppose it wouldn't really matter if there was no broadcast telly."* (Tim, H3).

Furthermore, users may sometimes default to streaming TV programmes or films instead of accessing the same content through other available mediums. Alan (H4) tends to watch catch-up TV programmes rather than pre-recording them as it's *"just as easy"* to do; and in H6, Fred chooses to stream films rather than finding his own copy on disc from his large collection at home. These shifts show that Internet-enabled television is becoming the primary way to watch, and is breaking the links to the more traditional materials (e.g. televisions which can only show broadcast programmes, video discs) of watching practices [338] as these become the secondary, and increasingly obsolete, form of entertainment.

5.3.2 YouTube: the most demanding watching service

YouTube is used by all of the households and was found to be the largest contributor to data demand—consuming 49.25% (figure 5.2) of demand for watching across all households (275.12 GiB/558.57 GiB). Not only was it the highest contributor to watching demand, but it was over five times more data demanding than the next most demanding streaming service (Now TV at 8.85%). From the interviews with the participants, there were two clear reasons to why this data demand was so significant for YouTube: 1) YouTube is especially popular with younger audiences; and 2) YouTube videos are used for listening to music.

5.3.2.1 Popular amongst younger audiences

For personal devices (i.e. devices that are used solely by one participant), the average daily total data demand for YouTube was 648.25 MiB for Generation Z (participants born early 2000s onwards), 410.63 MiB for the Millennials (1980s–2000s), and 186.02 MiB for Generation X (roughly pre-1980s). This was evident in the interview discussions too for Ben (H1) and Xavier (H9) (Millennials), alongside Heather (H6), Nick (H7) and Sally (H8) (Generation X).

While Heather (H6) knew the study was about device and Internet use, she picked out YouTube to describe herself: *"I'm 13, I play with my cats a lot, I go to school, and I spend quite a lot of time on YouTube"*. This YouTube use was evident across her different devices (two tablets and a smartphone)—totalling to 66.90 GiB of data for YouTube during the study. Discussion in the second interviews with H6 also revealed that Heather will additionally watch YouTube videos on the family desktop PC and her mum's (Julie's) phone; if the YouTube demand from these devices was created by Heather's access alone, an additional 1.61 GiB would be added onto her total.

The interviews with the Millennial and Generation X participants uncovered the types of videos watched on this site by younger generations. These include music videos (Heather, H6; Sally, H8) and specific channels that users will follow (Nick, H7; Xavier, H9). Nick (H7) described his favourite channels, which involved learning about science topics in a fun and engaging way: *"there's some, YouTube channels that I like watching, Demolition Ranch, Backyard Scientist, stuff like that, Daily Dose, they're all good YouTubers"*.

Connie and Tim's (H3) YouTube demand within the Millennials bracket is extended by their two children. As characterised by her parents, their daughter (aged 5) in

H3 enjoys watching *"these YouTube videos of, just videos of other kids making games or something"* (Tim, H3) or *"ridiculous things where people are like playing with dolls"* (Connie, H3). Their son (aged 3) also likes to watch YouTube videos. This shows how YouTube is now ingrained within everyday life for users at an early age—perhaps driving increased competencies for certain ways of watching than younger generations before—and provides an explanation of why younger generations consume more of this content.

5.3.2.2 'Watching' for listening

For all generations, music was a particularly popular video type: Tim (H3) sometimes watches music videos from his saved playlists with his family; Julie (H6) noted watching old music videos on a Saturday night during the study; and Sally (H8) mentioned that she likes to watch and sing along to new music videos: *"I let the music play and I sing to it"*. Yet, some participants do not always *watch* the YouTube music videos they stream. Whilst Heather (H6) does a *"bit of both"* watching and listening, Nick (H7) will only listen to music videos. This is facilitated by his phone whilst he plays on the household's Xbox or researches online for school work: *"I don't watch them I just put them aside to listen to music."* (Nick, H7).

Nick's listening of YouTube videos for music began when he got his first smartphone, but these habits can emerge in other ways. As briefly touched on in section 4.3.1.1: H1's free three-month trial to Apple Music, listened to through their two Sonos speakers, led Martin to develop a new norm of listening to music in the home. This was continued after the trial via a new Bluetooth speaker and streamed YouTube playlists to avoid paid subscriptions through Sonos:

> *"The Sonos system, I'm a bit disappointed with [. . .] you can't just stream things to it from Bluetooth, you've gotta pay for a subscription to a music service [. . .] you can't have the free Spotify one streaming through it, it's got to be the paid one, erm, which is a bit annoying [. . .] so we've got a cheaper music speaker in there [. . .] I was using my phone and sending it via Bluetooth to that speaker, and it was, and it was fine, from, on YouTube, which is pretty good."* (Martin, H1).

Martin went onto say that YouTube was *"more advantegeous"* than Apple Music because you get the music videos too; watching the videos was an after-thought, rather the YouTube playlist feature was the important aspect. Streaming YouTube playlists is a much more data-intensive way to listen to music due to the video content involved. Whilst audio-only options are available on YouTube Red/Premium, Martin highlighted that they *"don't listen to* [music] *frequently enough to pay a fee for it"*.

5.3.3 Multi-watching in the home

Watching separate content via different mediums at the same time (e.g. through broadcast TV, on-demand services, video disc etc.) is a common activity for households. I define this everyday life reality as *multi-watching*, i.e. *multiple, separate watching activities occurring simultaneously in a given space*. This is partly enabled by new material elements of watching as mobile devices (e.g. smartphones, tablets, laptops) exist in the home alongside the TV—for multi-watching to occur in previous eras of watching and TV, a household would've had to own multiple TVs (see section 5.1).

Multi-watching occurs in: different rooms of the home, e.g. Fred (H6) will stream Sky Go football on his study PC when the lounge TV is in use by his family; and in the same room, e.g. Fred described that Heather is *"happy sitting on the settee with us with her headphones in watching something on YouTube"*. Same room multi-watching has taken place in H3 too: Tim decided to stream a French football match via BT Sport on his laptop since his children were watching the TV. Household members are also *streaming* video for 'solo entertainment'. H5's Internet-only watching allows Ella and Kevin to sit separately for this activity—partially aided by Netflix's profiles feature:

> *"sometimes we just sit separately and do entertainment on our own as well [...] we'll watch different things in different rooms, depending on what kind of we're doing and what type of downtime we're having [...] we share the accounts but we both have, well we both have a profile on the Netflix"* (Ella, H5).

Table 5.3 shows each household's daily number of streamed multi-watching sessions; these occur when more than (any) one device is streaming from any watching domain at a given time. Sessions are concatenated if they occur within one minute of each other, and must be at least 30 seconds in duration (filtering out extremely short overlaps). Looking at this data, multi-watching is a rare or non-existent activity for some households (H1, H2, H4). However, it does happen at least once daily for other households (H3, H6, H7, H8, H9). This is partly related to the number of people living

Household	No. of Sessions per Day			Durations of Sessions (minutes)		
	Mean	Med	Max	Mean	Med	Max
H1	0.1	0	2	2.3	2.2	4.4
H3	10.1	8	54	112.3	32	853.4
H4	0.03	0	1	0.7	0.7	0.7
H5	1	0	6	6.9	4	41.5
H6	12.5	11.5	23	38.4	9.9	441.6
H7	16	16	43	27	13.3	323.2
H8	3.6	3	9	3.9	2.6	17.1
H9	4.7	4	14	30.5	4	198.6

Table 5.3: The households' daily number and durations of multi-watching sessions. Note that H2 did not multi-watch during the study so is omitted from the table, and H3's max duration means they streamed for a full day.

in the home: H3, H6 and H7 (the most frequent multi-watchers) have three or four occupants each. Yet multi-watching can also happen in a single-person household, as with Xavier in H9 (see table 5.3). Fred (H6) also discussed watching YouTube whilst watching TV—a data-intensive activity via his Amazon Fire TV Stick:

> *"I might be watching an episode or a film or something, if my phone's there I might every now and then go on and just look at Facebook or, I might look at YouTube or something because I've short attention span of watching..."* (Fred, H6).

Multi-watching via streaming is not yet routine for these households. However, as we are increasingly turning to online content for watching, it is reasonable to expect that multi-watching will be further accomplished by streaming in the future—particularly as Internet speeds grow and allow for even more simultaneous streams in higher qualities (for example, the UK Government aims for 15 million business, home and community premises to have 'full fibre' access i.e. fibre to the home by 2025 [137]).

5.3.4 More devices, more watching demand

The variety of devices available has created new possibilities for how and when watching can occur. Portable devices (i.e. mobile devices and laptops) are easily accessible and able to integrate *"in areas of the home where computing was previously unacceptable"* [356, p. 2642], allowing for watching activities to follow the same suit. *"Communality and Portability"* has been found to be the motivation behind mobile device

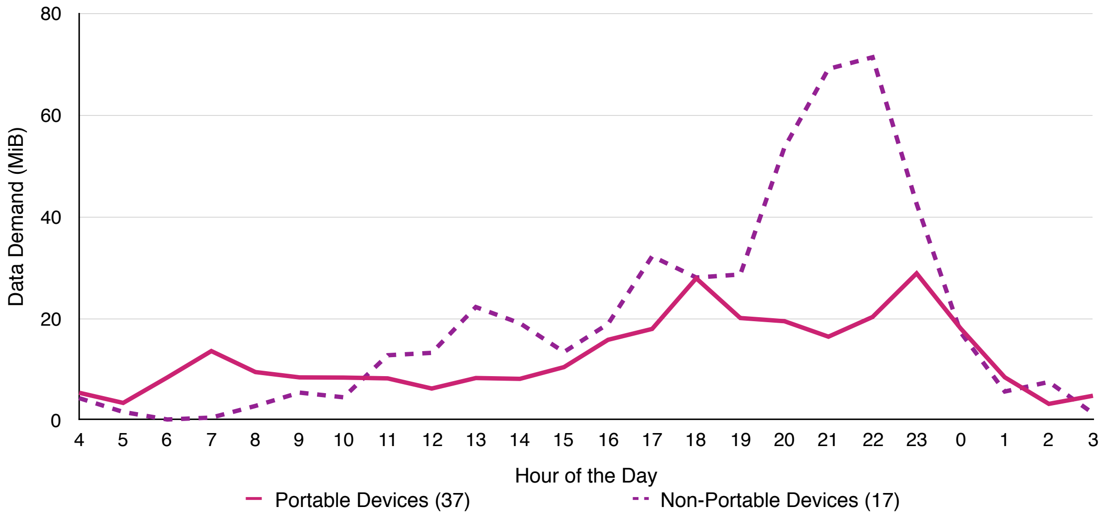


Figure 5.3: The household devices' average hourly data demand by device portability.

video watching [183, p. 633] and I extend this to laptops too; e.g. when asking Ella (H5) about her large data demand on Wednesdays, she responded with: *"you know what, Wednesday is my cleaning day, that sounds ridiculous, but erm I watch, I watch things while I'm tidying"*. This was facilitated by her laptop, which she carries round the house to 'wind down' when cleaning or doing other chores as she has a *"thousand things to do"*. Yet, she pointed out that this is a more frantic way to watch whilst she gets things done: *"if I really am winding down I'm down in the living room usually"*.

Watching demand is greatest at 8pm–10pm and is predominately provided by non-portable devices (see figure 5.3), yet there are points in the day where watching on portable devices is more prominent: 7am (when the participants were getting up and ready for work), 6pm (when the participants were arriving home, cooking or eating dinner), and 11pm (before the participants typically went to sleep). These times coincide with the mobile device watching demand peaks (see figure 4.3a in section 4.1.1). Watching here is not necessarily used to *fill* 'dead time' [211, 316] but rather to *spend* downtime. For example, Martin (H1) watches Sky News before bed on his iPad or iPhone; Nick (H7) watches YouTube often in the morning before going to school; and Fred has a particular YouTube routine on his phone:

> *"Usually when I get home from work I'll sit down for 10 minutes or so, about quarter of an hour, and just sort of like right, before I do anything else, have a choc ice* (laughs) *and go on YouTube for a bit."* (Fred, H6).

The characteristic of portability alongside device quality can lead users to borrow devices off others for watching; this is described by Kevin (H5) regarding his wife's streaming, despite Ella owning a laptop herself: *"Occasionally* [Ella would] *borrow my laptop to watch some Netflix thing whilst she's cooking, just cause it had a bigger and better screen."*

Other ways of watching can be more situational and spatially determined. Fred described how he usually watches his portable DVD player in the bath for an hour, yet if it's not charged, he replaces this offline watching with YouTube. Kevin (H5) described how his household *"crash out and watch telly"* more during the winter months to avoid going out in the cold. The log data indicated that Rachel's (H8) Amazon Fire TV Stick demands more data on Tuesdays and Wednesdays; when discussing this in the second interview with her, she explained that she goes to bed earlier on these two evenings. She uses the TV dongle located in her bedroom (rather than her lounge TV) due to regular activities in her weekly routine, and the need to keep warm in bed during the winter (similarly to Kevin):

> *"Tuesday, erm I don't see my boyfriend, he doesn't come round, so I go to bed when Sally goes to bed, and she comes in my bed for a bit and we watch telly, erm, and then Wednesday erm I go to my boyfriend's for tea and then we come back here and I don't see the point in sitting in the front room, especially in winter, so we just go to bed."* (Rachel, H8).

H3 arguably has the most complex watching setup of the households. Alongside their mobile devices, they own a Google Chromecast, an Android box, a smart LG TV and two YouView boxes—all of which facilitate H3's watching in some way at home (particularly the lounge, master bedroom and garage). Tim therefore has multiple options of how to watch the same TV programme or film, yet he chooses a particular device configuration in order to watch in HD:

> *"I get BT Sport, erm I only get standard-definition on the YouView player, high-definition on the mobile app, so I tend to watch high-definition channels by connecting* [my smartphone] *to the Google Chromecast and watching that on the telly in high-def."* (Tim, H3).

During the study, Tim only ever accessed BT Sport through his Google Chromecast and smartphone. These scenarios of how the participants go about watching sum up the complexity of device setups—yet it is clear that all these scenarios lead to more demand. Participants extend watching hours through portable devices (and hence embed watching more into their everyday lives); Ella will watch streamed content on larger devices; Fred will stream football matches instead of watching them on H6's (in-use) broadcast-enabled TV; Rachel will default to on-demand watching on specific days of the week in order to watch from the comfort of her bed; and Tim will use specific device configurations in order to watch in HD. These are examples of where the materials of watching (e.g. portable and HD devices) are, in part, transforming the practice in more data-intensive directions.

5.3.5 Media-multitasking

The TV has been described *"as a resource that can be dipped into and out of as different activities come to dominate"* [22, p. 15:14], allowing the accomplishment of other activities whilst the TV is on. More recently, *"media multi-tasking"* has become familiar; many users access their mobile devices whilst watching TV for both *"media-meshing"* i.e. mobile device use involving the TV program in view, and *"media-stacking"* i.e. mobile device use for other means unrelated to the TV [265, p. 4].

Daily media-multitasking activities were common for 14/20 participants, consisting of: viewing social media and communication notifications (Ella, H5); checking emails (Ian, H7); online shopping (Julie, H6); playing games (Sally, H8); gathering news updates (Alan, H4); searching for information on TV shows (Ella and Kevin, H5); smartphone use during TV adverts (Heather, H6); and other mobile device browsing (Laura, H2; H3; Denise, H4; Rachel, H8). Multi-watching (as described in section 5.3.3) is one particular form of this media-multitasking that the participants engaged in. Figure 5.4 shows the stacked hourly data demand for these common media-multitasking activities: social networking, shopping, communication, and news, weather and magazines. As shown by the plot, the majority of data demand for these categories occurs between 8pm–midnight with peaks at 10pm; this follows the evening patterns of watching data demand (figure 5.1).

Five of the participants (i.e. Martin, Laura, Connie, Fred, Sally) mentioned that their media-multitasking occurs due to their disengagement with what they, or their household members, are 'watching'. Such multi-tasks can even cause conflict between householders, as Ella said that *"Kevin tells* [her] *off all the time"* when she checks her social media and communication notifications during TV watching. However, some participants do not media-multitask; despite Alan (H4) having his iPad to hand while the TV is on, he points out that he is not using them simultaneously:

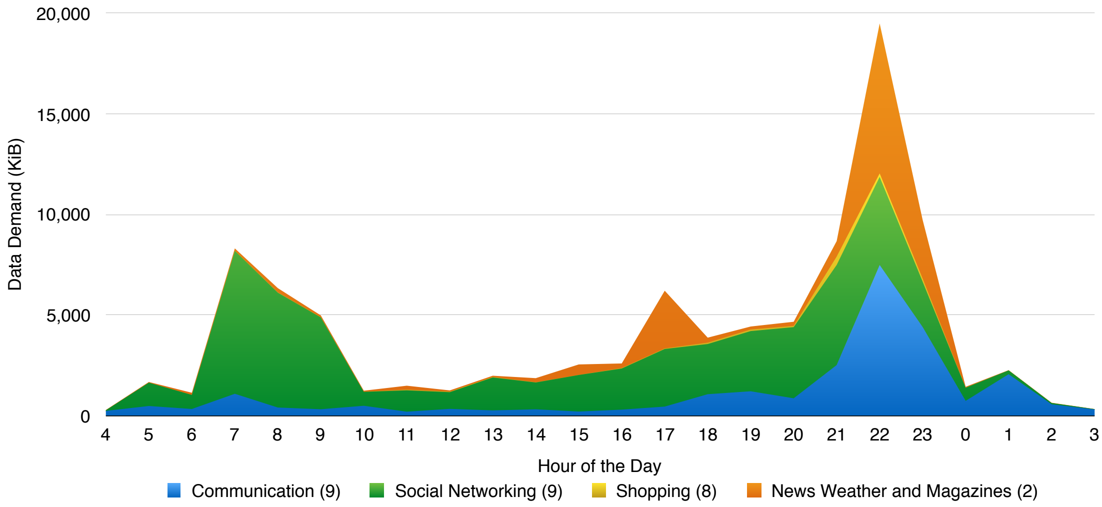


Figure 5.4: The households' stacked average hourly data demand for media-multitasking activities. Numbers in brackets represent the number of households contributing to the activity. As with figure 4.5c, H9's FaceTime data demand (daily average of 290.73 MiB) was omitted from the average hourly communication data.

> *"I'm not doing both, I can't multitask, so I might be concentrating perhaps on a newsfeed on the iPad and the television's on, or I'm watching the television and I'm just looking for an alternative source of information or something."* (Alan, H4).

Two H1 participants also specifically mentioned not partaking in second screening activities, implicitly describing their attention to either watching or device use. Ben (H1) stated that: *"if I'm watching something I'm watching"*, ensuring focus on the content he is viewing. Gemma (H1) even mentioned she has to have the TV turned off to *"concentrate"* on her online tasks:

> *"I don't even like the telly on when I'm, if I'm using* [my phone] *or texting cause it'll distract, the telly will distract me from doing it [. . .] it's a bit like reading the same, when somebody's talking to you and you're reading the same page of a book, it just gets annoying doesn't it?"* (Gemma, H1).

As media-multitasking overlaps data demand from other online activities (discussed in chapter 4), the demand linked to watching practices may actually be higher than I present here. Yet, the participant accounts highlight their disengagement with their video content and their need to focus on single online tasks—indicating that not all streamed content (and layered ‘other’ content e.g. social media use) will be fully absorbed or appreciated. Thus, much of this unnecessarily compounds watching *data demand*, as streaming is becoming more prominent in the home (section 5.3.1).

5.3.6 Trivial watching?

The participants have varying perspectives on what types of watching provides meaning to their lives. Ian (H7), for example, finds YouTube helpful when his children (Nick or Peter, H7) are learning to play a new piece of music; this is because they can watch videos of other people playing the music. Fred (H6) described multiple uses of how YouTube helps him in everyday life; such uses include finding new music artists he likes and learning songs on the guitar (like Ian’s children, H7). However, general YouTube viewing can be distracting for Fred:

> *“You can lose track of time sometimes [. . .] you go on* [YouTube] *for something to do and you realise you’ve been on there for half an hour because one video of funny cats lead to another [. . .] sometimes it’s easier just to watch another video, ‘oh I’ll do the ironing in a minute, oh there’s another video of cats, I’ll watch that’”* (Fred, H6).

In fact, when discussing how Fred would feel if his household’s Internet cap returned, he used the cat videos as a reference to diminish his ‘need’ for YouTube: *“we’d just have to adapt, we’ve had it before, the world’s not gunna end if I don’t watch another video of funny cats”*.

Despite Ben (H1) and Xavier (H9) regularly using YouTube, they seemed somewhat dissatisfied with the site’s content. For example, Xavier falls asleep while watching YouTube videos he describes as *“mundane”* and as *“background noise”*—the video content of which isn’t meaningful to him:

> *“Most of it’s just junk content, people playing games and then making jokes over the top of it [. . .] it’s almost like a podcasty thing, I don’t really watch it for the content itself but it’s more about the, the voice overs...”* (Xavier, H9).

Xavier further explains how this YouTube watching contrasts to Netflix (the households’ fifth demanding watching service—see figure 5.2): *“When I’m watching Netflix, I don’t really wanna go to sleep, I wanna watch the show”*. This shows how the different services available for watching can provide various meanings or trivialities in participants' lives. Like Xavier, Ben described how he is also more content with Netflix than YouTube:

> *"I noticed when I had the Netflix subscription that I was way more satisfied with the entertainment that I had, whereas YouTube entertainment is very like basic [. . .] it's a bit like a slot machine isn't it? Like yeah, it's a bit of a gamble, like 'you might get something good, you might not'"* (Ben, H1).

Ben reflected that services like YouTube are *"designed to hold your attention as long as possible"*. As a result (and as mentioned in section 4.3.4), he uses productivity tools and has edited a system file on his PC to block access to sites he finds distracting. Yet, video-based distractions are not limited to YouTube alone—Reddit can lead Kevin (H5) to watch many short videos on the site. He discussed how he can easily pass hours on the service, and then later wish he'd gone for a walk or done something *"much better"* for him instead. This 'binge-watching' can occur with longer forms of video too, as Ella points out with her Netflix streaming: *"I'll be like 'I'll just watch one more'"*. These accounts build upon the distracting Internet-connected interactions discussed in section 4.3.4—showing that trivial use of services, where weaker valuations are associated with practice meanings, can actually be quite data demanding when video streaming is involved.

5.4 Discussion

Considering how technology is impacting watching practices, I see two clear opportunities where the HCI community can challenge this data demanding activity: 1) targeting the new norms of watching, and 2) reducing the data demand of watching through HCI design. These are discussed in this section. However, such interventions do not come without difficulty; this discussion, therefore, also deliberates the challenges involved in this work going forward (section 5.4.3).

5.4.1 Targeting the new watching norms

Similarly to the suggestion in chapter 4 (section 4.5.1) to target the most data demanding user activities (e.g. watching, gaming, social networking), the HCI community should target *forms* of these activities where data is more intense. Specifically, HCI researchers and practitioners should focus on new norms, developing within practices, that are leading to increased device, data and service use. In this section, I summarise the new norms of watching—formed from changes in the underlying practice materials, competences and meanings—that require intervention.

5.4.1.1 Shifts towards streaming and YouTube generation gaps

The findings presented in this chapter, coinciding with UK [274] and US [357] statistics, show that there have been significant shifts towards streaming as a default way to watch TV programmes, films and video clips. H5 no longer have a TV license (a requirement by law in the UK to watch broadcast content on any device)[2]—with their access to the streaming services Now TV, Netflix and Amazon Prime replacing that void. With Fred and Alan, online content is emphasised as the primary medium for watching, with more traditional forms of viewing (i.e. broadcast TV, video discs) becoming a secondary, if not obsolete, form of entertainment. Unsurprisingly, the shift to streaming is more prominent with younger generations (Generation Z, Millennials) accessing YouTube. This coincides with larger scale studies, finding that younger UK viewers (16–34 years of age) watch more non-broadcast content and over an hour of YouTube on average per day [273]. These trends increase the difficulty of targeting streaming norms, as: 1) these generations have always known, or grown up with, the Internet and online services—and thus potentially have trouble envisioning ways of life where they are used less; and 2) YouTube is a particularly popular and demanding service, contributing significantly to watching traffic (just short of 50% in my study). It is also important to note that, despite these shifts towards streaming, the energy cost linked to older infrastructures (e.g. broadcast TV) is not removed; streaming norms create another layer of energy impact *on top of* more traditional forms of watching.

5.4.1.2 Watching as a distraction

Whilst watching adds value to users' lives in providing entertainment (Ella, Kevin, Fred, Nick), time together (H8), and skills development (Ian, Fred), it can become trivial. Users can become disappointed with the time they spend watching (Ben, Fred, Kevin). YouTube in particular, the most common [309] and demanding watching service, can sometimes only provide *"mundane"* or *"distracting"* entertainment (Xavier, Ben). Paid streaming services can provide 'better' content (Ben), yet they can also

[2]UK TV licence: `https://www.gov.uk/tv-licence`, accessed October 2019.

promote binge-watching (Ella) which drives watching-related data demand through encouraging *longer* streaming sessions. These examples show how different watching services, their content and the way in which they are used can greatly vary in meaning for users. This follows the participants' digital experiences explored in chapter 4, with users having to 'search' for meaningful content within services (section 4.3.3) and attempting to overcome the addictive designs that some services embody (section 4.3.4). We should be designing positive experiences (in this case, for watching) from the perspective of happiness rather than efficiency of output, as Hassenzahl et al. point out: *"It is not primarily about, for example,* [TV programme] *in high-definition, with stereo surround, but about watching the* [TV programme] *in a meaningful, satisfying way"* (e.g. together with family) [154, p. 29]. The HCI community should therefore target data demand reductions for watching practices that are causing distractions, or are not sensitive to the value added (cf. [126]), to users' everyday experiences.

5.4.1.3 A screen (or two), each, anytime of the day

In the past, TV viewing in family homes has primarily been found to be carried out in couples and groups [326]. Yet, as I have revealed in this chapter, the participants in shared houses illustrate how each person is becoming more focused on their own watching devices (H3, H6, H7, H8, H9). Users do, purposely, sit separately for their video entertainment (H5). This is even occurring whilst household members are the same room (H3, H6)—an activity that Ofcom found is happening (at least weekly) for a third of UK households [267]. The act of domestic multi-device watching, i.e. *multi-watching*, is contributing to exaggerated evening peaks in traffic (figure 5.1) and creating concurrent, overlaid data demand (table 5.3). HCI researchers and practitioners should therefore target the multiple layers of device use and streaming, occurring in the home. Perhaps the biggest challenge for HCI to overcome with tackling multi-watching, is that interactivity can be core in these experiences. Most online services aim to keep users engaged for longer, leading to more demand. Therefore, for this new norm of watching, the HCI community should adapt *multiple* services and devices to achieve data reductions.

5.4.2 Reducing the data demand of watching through HCI

Given the new norms of watching, there are a number of 'low-hanging fruit' options in which the HCI community could implement or consider, to reduce the data demand of watching: 1) limiting watching to the least demanding configurations; and 2) co-creating with users what amount of streaming is 'enough'. I detail these below.

5.4.2.1 Limiting watching to the least data demanding configurations

With a persuasive design approach, interventions could steer users away from the new watching possibilities that the multitude of household devices allow [25]. Take the example of Tim (H3) and his choices of either watching BT Sport in standard-definition on his YouView player, or in high-definition on his Google Chromecast via his smartphone: Tim chooses the latter, yet devices and services could be designed to encourage the former (less data-intensive) setup. Whilst previously discussed 'nudge' approaches for opt-in high-definition video [298] may encourage standard-definition viewing for some users, these are less likely to be effective for streaming *"connoisseurs"* [25, p. 1178] like Tim. As a result, further encouragement *across devices* will be required. This principle follows when considering other device choices that increase demand: device sizes (e.g. Ella, H5), and more situational aspects (e.g. Fred's streaming due to others watching the TV in H6, Rachel's streaming in bed on specific nights in H8).

Another approach for limiting watching could involve prompting users to interact with 'one digital medium at a time'. Media-multitasking could be avoided by prompting users to choose between watching and the secondary activity; and multi-watching could be removed by bringing household members together for group-only streaming [392], moving away from watching *"alone together"* [377]. Such designs would require a greater shared understanding of devices, their capabilities, and users' activities. The emergence of smart home devices could help with this: information on users' current Internet activities could be transferred between devices or made more visible (through displays, apps, or disaggregated views) in the household. Predictive algorithms could then be exploited to present options of what households could do or watch at a particular point in time, helping them to avoid any difficult activity choices or potential conflicts in content preferences between household members.

5.4.2.2 Co-creating what amount of streaming and data is 'enough'

As outlined in section 5.1, researchers have previously found that on-demand viewing was for *"focused viewing"* [382, p. 8] and broadcast was for *"ambient watching"* [22, p. 15:14]. As the participant accounts show in this chapter, streaming is now following in the steps of broadcast content for facilitating 'background' watching, and is even shadowed for other, layered online activities (particularly on mobile devices, e.g. for social networking, shopping or further watching). In addition, the participants can find the content they stream trivial or distracting, meaning users are not always fully watching or appreciating the video streamed. Given this, the HCI community should look to ways in which content is only streamed if users *want* to partake in their data demanding watching practices, and ideally only if it is adding meaning to their experiences.

HCI researchers and practitioners should co-create guidelines and technologies *with* users that define what amount of streaming is 'enough' in everyday life, highlighting what does and does not make watching practices important or *meaningful* to users (see section 4.5.4). Working with users in this way will not only create opportunities for transitioning streamed watching activities more sustainably, but will also help users find ways which work best for them. For example, designers could: investigate when streaming becomes 'distracting' and how users envision technology helping them avoid this; and discuss with users how they might be shifted back to watching via broadcast for ambient viewing. Such co-creation activities would also enable the opportunity to gauge users' thoughts on the design proposals for limiting watching to the least data demanding configurations, and finding out which choices (quality, device, time, content) are most important to maintain in their watching practices.

5.4.3 Challenges in implementing streaming interventions

Developing interactions for reducing streaming introduces a number of challenges for the HCI community. Not only do such streaming interventions conflict with many HCI designers' current research interests, but they also carry practical difficulties in actually *implementing* the adaptations required to technology. Furthermore, it could be argued that encouraging less streaming is potentially *worse* for the environment if users instead begin to engage in practices with a bigger environmental footprint (like driving). And more broadly, our society urgently needs to confront 'all-you-can-eat' and 'binge' watching marketing strategies that service providers adopt. I discuss each of these challenges below. However, it is worth noting upfront that, to tackle the wider societal challenges linking to this increasingly significant concern of streaming video, it is likely the HCI community will need to draw upon: political activism [192], radical societal transformation [191], and policy intervention [368], as these authors have previously pointed out for addressing issues in Sustainable HCI more generally.

5.4.3.1 Persuading HCI designers: innovation within limits

Section 5.4.2 outlined opportunities for the HCI community to intervene with the data-intensive video streaming norms growing in the home. However, I note that these data-limiting designs conflict with what the HCI community currently drive: researchers often push for increased data in watching by embedding more screens and actions into streaming (e.g. [259]), and service providers introduce interaction designs (e.g. auto-playing the next episode or a trailer; defaulting to the highest resolution possible [298]) that encourage longer, or more data-intensive, video streaming sessions. Therefore, these design recommendations are just as important for adapting *HCI designers'* practices as they are for streamers'. This is an issue that can be applied to SHCI research more generally, whereby the *"sometimes anti-technological implications"* from SHCI researchers can conflict with the broader HCI and UX community's view of novelty, invention and innovation [345, p. 67].

As I pointed out in chapter 4 (section 4.4.2): innovation should not be lost in HCI, but we must take a more responsible stance (cf. [27]) on *what to design* given our need to constrain the growth in Internet traffic. We must view innovation *differently* by creating enjoyable streaming experiences *within limits*, rather than assuming 'more' technology and data is always better—particularly since the participants *themselves* highlighted frustrations with their own watching activities. However, a possible way in which the HCI community could still design for more devices and data-intensive services in streaming activities, is to utilise temporalities of network demand (similar to technology forecasting peaks and troughs of renewable energy supply [346]; e.g. 'Low Tech Magazine', available only when there is enough solar energy to power the site [218]). For example, more restrictive designs could be enforced at times of peak traffic, and more data-intensive designs could be an option at traffic troughs; this is akin to the updates implication discussed in section 4.5.2. Softening restraints like this would also enable users to occasionally watch in data-intensive ways—allowing them to fully appreciate high-quality streaming during times where it is more sustainable and will not motivate future expansions in infrastructure, whilst perhaps reducing the streaming qualities of the more trivial watching activities noted by the participants.

5.4.3.2 Technical and implementation challenges

Another challenge in implementing these interventions in streaming practices (and Internet use in general) is whether they are *technically feasible* given current device and service design. Presently, services and devices generally (to the best of my knowledge) do not share data about their users' use (e.g. foreground application) outside of a given application container—nor can this data be logged in real-time in the 'background'. Without access to these controls, designs which aim to limit multi-tasking and multi-streaming in the home by applications *on* devices (section 5.4.2) will not be possible; this is because the current running services in the home would not be able to be identified in the first place for adaptation. Taking mobile operating systems as an case study: current restraints to preserve energy, ensure inter-application security and the privacy of user data, make such software increasingly difficult to implement. For example, only specific types of apps can run continuously (e.g. music players, location trackers) on Apple's iOS[3]—meaning logging device actions (e.g. screen on/off, user activity) in real-time is no longer possible unless 'disguised' as a permitted background-execution app (which would then be subsequently rejected from the App Store), or unless the standard operating system protections are broken (such as jailbreaking the devices).

Information of users' access to services could be provided at the home router-level (e.g. using OpenWrt routers,[4] as in this study). However, this introduces issues of its own, including: 1) the burden of *"digital plumbing"* [370] and deploying these types of routers in the home [367] (rather than pushing app-based services which can easily be disseminated via app stores); 2) the obsolescence (cf. [306]) of previously-owned routers by replacing them with routers that have logging and computational abilities; 3) differentiating users' *use* of services to traffic which is autonomously initiated by services in the background (as seen in section 4.3.5); and 4) the difficulty of mapping computer log data (i.e. network domain names) to human-interpretable services (as described in section 4.4.1). Future work aiming to develop technological interventions to streaming will, therefore, require innovative solutions that solve these challenges.

5.4.3.3 Rebound effects and when it's best *not* to intervene

In sustainability research, it is commonly known that energy savings from an intervention (e.g. user behaviour change, efficiency in technology) can actually lead to *increased* energy consumption due to 'rebound effects' [143, 162, 182]; these rebound

[3]Apple Developer documentation: `https://developer.apple.com/documentation/uikit/app_and_environment/scenes/preparing_your_ui_to_run_in_the_background/about_the_background_execution_sequence`, accessed October 2019.

[4]OpenWrt: `https://openwrt.org/`, accessed October 2019.

effects are generally unconsidered within environmental assessments of ICT [295]. This means that energy savings made from reducing streaming may, in some cases, lead to *more* carbon emissions. In the ideal scenario (and opposite to the 'Cornucopian paradigm' [298]): a HCI intervention would enable users to reduce their streaming consumption, putting less pressure on the Internet infrastructure to grow to meet this demand, and meaning efficiency potential in the infrastructure would be fully utilised.

However, there is the possibility that rebound effects would occur from reduced streaming. Taking a more carbon-extreme scenario: users may begin to spend less time video streaming, and more time driving in cars. In this case, streaming would be the environmentally-preferred way to spend downtime, and should even be *encouraged* over other practices (like fossil fuel-based travel) which are ultimately worse for the environment. Given this, when the HCI community is considering Internet interventions, it must not be forgotten that the end goal is to *address concerns of climate change*. To alleviate and combat rebound effects, streaming interventions will require careful deployment, testing and long-term evaluation [307]—ensuring that the developed HCI designs lead to less resource- and carbon-intensive ways of life.

5.4.3.4 Confronting 'all-you-can-eat' and 'binge-watching'

'All-you-can-eat' contracts for home broadband and cellular data have become common; these enable data to be demanded from multiple devices and allow for media-rich interactions. For example, BT's 'Broadband Unlimited'[5] and giffgaff's 'Always On' data plans[6] allow users to have constant, infinite Internet access. To make these options even more competitive, some contracts include unlimited data specifically for streaming (e.g. Three's 'Go Binge' deal[7] allows unlimited data volumes on Netflix and TV Player) and bundle media subscriptions with contracts (e.g. EE customers can get free BT Sport [277], and Sprint customers can access Hulu [48]); this encourages media consumption, further propagating default streaming norms and escalating data demand. 'Binge-watchers' and perhaps less disciplined consumers (e.g. Ella, Ben, Fred, Kevin) are aware that that they are ensnared by auto-play [95] and the infinite availability of video on YouTube, Netflix and other forums e.g. Reddit. Unlimited access

[5] BT's 'Broadband Unlimited': **https://www.productsandservices.bt.com/broadband/unlimited/**, accessed October 2019.

[6] giffgaff's 'Always On' data plan: **https://www.giffgaff.com/sim-only-plans/always-on**, accessed October 2019.

[7] Three's 'Go Binge' deal: **http://www.three.co.uk/go-binge**, accessed October 2019.

to these services therefore only adds to their streaming ‘addictions’. These coupled service deals for streaming relate to the marketing strategies discussed in chapter 4 (section 4.4.2), reiterating the influence of service providers’ business campaigns on data demand.

How is it that *excess* is valued as neutral or even positive, in this context? Taking health as an analogy (‘all-you-can-eat’ food/buffets, binge drinking), overload is seen negatively [2, 21, 201]. Yet, binge use drives major selling points of Internet and video streaming contracts. Ultimately, if binging is bad for our health (and perhaps the planet’s health), why are ISPs and service providers allowed to promote binge data? There is a real need to rethink regulations (e.g. caps) on what data demand or screen time providers can responsibly encourage, for the good of the user and the environment. Whilst previous HCI research has suggested that streaming services should help users gain more control over their watching sessions (e.g. by informing users when their ‘optimal’ viewing time has been reached or passed [95]), contributions to over-watching are much more pervasive than the design of a particular app. Building on section 4.4.2, the findings in this chapter point towards a need for a more responsible stance on the ‘all-you-can-eat’ philosophies and business models of ISPs and cellular providers—all of which enable the prevalence of streaming in everyday life.

5.5 Implications

From the discussion, there are clear opportunities that the HCI community could utilise, develop, test and evaluate to target data-intensive streaming norms and reduce the associated data demand. Taking these into account, alongside the associated challenges, I provide three implications for the HCI community going forward: 1) to re-think user experience (UX) and actively degrade Quality of Experience (QoE) through collaboration with network systems engineers; 2) to carry out interdisciplinary work with policy makers and policy researchers, specifically to balance net neutrality and more sustainable streaming activities; and 3) to develop a robust evidence base for policy makers, helping them create policies that technology providers should adopt for more sustainable Internet use.

5.5.1 Rethinking UX and QoE

Within HCI, media-multitasking is generally looked upon as a positive UX and is often used within the design of services for creating novel interactions with technology [105, 120, 259]. With the participants, this multitasking means that streamed content is not always fully utilised (or 'consumed') and makes watching more data demanding. As pointed out in the challenges discussion (section 5.4.3.1), here lies a tension [345]: HCI and UX promote innovative and improved user experience through increased data-intensities, whereas SHCI highlights the need to be conscious of the utilisation and promotion of data demanding services [298]. Whilst arguably many HCI researchers and practitioners would not want to lose data-intense innovation in HCI, we must take a more responsible stance on what to design; this follows calls on when it's best *not* to design [30], to *undesign* technology [289], and the implications from chapter 4 of this thesis. So what if Quality of Experience (QoE) considered reducing data demand?

There is an opportunity to actively degrade QoE as a HCI intervention—deterring the data demanding forms of watching I present (e.g. multitasking and multi-watching) and helping users think about negotiable forms of watching [26]. To do this, HCI could work more closely with network systems researchers who are experts in, and drive the agenda of, QoE [118, 119, 132]. Through this partnership, HCI researchers and practitioners could implement interfaces and services that nudge and shift users towards less demanding modes of watching [298]: targeting the new norms of watching (section 5.4.1) e.g. via the 'low-hanging fruit' options suggested in section 5.4.2.

Collaborations between network system engineers and HCI would also mean that HCI researchers and practitioners could be instrumental in promoting network infrastructure running from renewable energy (e.g. data centres [40]); and help create Internet standards that support sustainability via IETF[8] (Internet Engineering Task Force) and ISO[9] (International Organization for Standardization). This would specifically be useful for highlighting the data impact of interaction changes in digital services *prior* to implementation, preempting significant effects on network operators (e.g. the effect of Facebook introducing video auto-play [321]). Given the severity of the effect, HCI designs could be scrapped if they were deemed too data demanding against proposed Internet sustainability standards, or the designs could be introduced if the demand was offset by powering the associated network infrastructure by newly provisioned renew-

[8]IETF: **https://www.ietf.org/**, accessed October 2019.
[9]ISO: **https://www.iso.org/**, accessed October 2019.

able energy. Such processes would allow greater opportunity for the HCI community to create less data intensive online service designs, and these collaborations would better cater for the knowledge of networks needed for data-reducing interventions.

5.5.2 Sustainable streaming contravenes net neutrality

One of the key points from the findings and discussion in this chapter is that the HCI and networking communities might limit video traffic in different ways to create less data demand. Yet, this will have potentially profound impacts on society and social justice. For example, by limiting watching traffic and therefore the number of online video viewings, the revenues of content creators (e.g. on services such as YouTube and Twitch) would be negatively impacted. This could therefore significantly impact creators' abilities to earn a living income and provide for themselves, their homes and their families.

Traffic limits are clearly at odds with ideas of net neutrality; this takes all traffic as equal and at an equal cost, in the name of guaranteeing a fair level of access and service to all. The suggestions made for limiting video traffic might seem to dovetail with the net neutrality repeal in the US [35] and conflict with policies such as the EU's Open Internet [82]. This is an extremely difficult challenge, given the need to target streaming-related data demand for environmental sustainability. Whilst I am not against the social justice issues that EU policies protect, I argue that we need traffic limits for reasons of greater good (i.e. *environmental sustainability*) over increased profits for service providers (i.e. the usual driver against net neutrality). As a result, if video traffic should cost more to reflect its cost to the environment, these would have to be applied to *all* forms of video content; YouTube, Netflix, Twitch, Facebook and the like would all have the same quota or tariff on watching traffic.

In some contexts, videos may still have to be treated differently (e.g. the Emergency Broadcast System). This is a hard balance to maintain and cannot be resolved by HCI researchers alone. Policy makers are also required to consider the social, environmental and economic implications of surveilling, regulating and controlling portions of the Internet. HCI researchers should seek out policy makers for interdisciplinary investigations in this area—and I note I am not the first researcher in SHCI to point out the need for wider political and societal involvement [60, 100, 103, 368]. To do this, HCI researchers could begin by approaching relevant governmental departments (e.g. UK Department for Digital, Culture, Media, and Sport; US Department of Commerce's

Digital Economy Agenda), or look to how previous HCI researchers have communicated with policy makers (e.g. the International Policy Ideas Challenge [368]).

5.5.3 Developing a robust evidence base for policy makers

Internet policies drive 'superfast' and 'full fibre' access [137]; this may only be fuelling rises in data, as infrastructural capacity growth leads to an increase in demand [298, Fig. 1]. Economic benefits are often argued to be linked to Internet growth, e.g. broadband adoption leading to an average 0.3% rise in Gross Domestic Product (GDP) per annum across the OECD region [272]. However, there has not been a concrete link between *superfast* speeds and economic growth. Rather, access to faster Internet has been seen to positively correlate with the number of VoD subscriptions [249, Fig. 2].

From this standpoint, it is clear that policy makers have not made the connection between streaming, binge-watching, all-you-can-eat marketing, data demand and sustainability. Possibly blinded by the utility of Internet and the perceived economic benefits, there has been little discussion on the energy impact of the Internet and its services within public policy in the UK (perhaps only a recent report by Policy Connect [241]). Given this, how can HCI researchers help policy makers consider the growing environmental impacts associated with data demand?

HCI researchers need to build robust knowledge bases [355] and engage with the creation of more *responsible* policy when it comes to ICT. Not only should new norms of everyday data demand be considered (e.g. the new ways of watching presented in this chapter), but also the emerging Internet-based technologies (e.g. cryptocurrencies, IoT, smart homes and connected cars) and broader SHCI topics that require policy engagement [60, 100, 103, 368]. This will involve HCI researchers providing policy makers with ideas (e.g. designs, interventions), and evidence of their sustainable effect (with consideration of rebound effects, as discussed in section 5.4.3.3), that affect different aspects of HCI and Internet use. These aspects include users themselves, the interfaces HCI practitioners create, and subscription designs (sections 4.4.2 and 5.4.3.4) that service providers introduce. Such policy engagement will enable possibilities of data demand reduction where collaborations with businesses (as suggested in section 4.5.3) are not feasible—e.g. for companies who are not willing to adopt more sustainable service or marketing designs.

An avenue worthy of exploration could involve HCI researchers to investigate, and draw upon, how other places or countries (specifically developing countries) live or work with less reliance on Internet connectivity, faster speeds and online services—similar to HCI studies investigating Internet adoption in Cuba [106], mobile data practices in South Africa [233], or Internet disconnections in Bangladesh [44]. This includes understanding the users of, and business model designs for, 'Lite' versions of services which are purposely made to demand less data. For example, 'YouTube Go' (the 'Lite' version of YouTube) lets users be more conservative with their data plans by choosing the amount of data they use per video they watch.[10] By drawing upon the experience and practices of countries or places less reliant on connectivity, we can better propose alternative futures for our use of devices and services to policy makers.

How HCI researchers would then present these to policy makers is still in question, much like the net neutrality implication. Working in this interdisciplinary space takes significant time and effort: to understand policy documents and language [368], and to create structural events in HCI for policy (e.g. workshops) with different professionals crossing this space [355]. Perhaps the largest hurdle in HCI is finding the appropriate venues to promote these discussions and affect change in systems, interfaces and policies (rather than 'simply' publishing papers at HCI venues e.g. the Conference on Human Factors in Computing Systems (CHI)).

5.6 Summary

In this chapter, I have deeply explored the practice of watching (particularly involving video streaming) in the home for the household participants. New norms of watching are developing in data-intensive directions: streaming is becoming the default way to watch (phasing out broadcast TV and video discs); YouTube is a significantly popular online service; and the presence of multiple devices during watching activities (i.e. media-multitasking or multi-watching) is increasingly prominent. HCI needs to tackle these new norms of watching in order to have a significant impact on overall data demand; and I have provided 'low-hanging fruit' designs that the HCI community can implement and evaluate, to reduce the data growth and impact of video streaming.

I have also discussed the challenges that HCI researchers and practitioners will face when working in this area: the conflicting nature of UX, HCI and SHCI; technical challenges to implementing Internet interventions; considering rebound effects; and challenging 'all-you-can-eat' and binging business models. From this discussion,

[10] YouTube Go: `https://youtubego.com/`, accessed October 2019.

alongside the findings, I have provided three implications for the HCI community to: 1) rethink UX and QoE *with* network engineers, for forecasting and alleviating HCI impacts on the Internet infrastructure; 2) perform interdisciplinary work with policy makers and policy researchers, ensuring more sustainable streaming policies that consider net neutrality; and 3) create robust evidence bases for policy makers, pushing service providers and wider societal drivers to become more 'data responsible'.

In the next chapter, I explore the implication from section 4.5.4: creating 'sufficient' levels of Internet demand through designing for more moderate and meaningful use of digital devices and online services. By creating such experiences, we can reduce the amount of data demand associated with streaming and online activities that participants do not necessarily fully appreciate (e.g. the trivial watching described in section 5.3.6). This utilises the design workshop (method in section 3.3), and therefore builds on the co-creation consideration presented in this chapter—developing what amount of streaming or data is 'enough' (section 5.4.2.2).

And then he died in his lonely house, on the lonely street,
in that lonely part of the world.
You can go on his Facebook.

—THE 1975

Chapter 6

Designing for Moderate and Meaningful Digital Experiences

There are negative impacts associated with digital device use (outlined in section 2.2). As the household participants highlighted in chapter 4, users do not always enjoy their interactions with technology and even take steps to curtail their use of digital devices and online services. This means the demand for data does not always result in positive or meaningful experiences for users. Ideally, we would alleviate these negative effects by creating sufficient (cf. [162]) levels of digital device and online service use in everyday life: designing more moderate (and sustainable) uses of the Internet to benefit users, whilst maintaining their most meaningful interactions with devices and services (section 4.5.4). Through this, we can enhance value for the elements of meaning within Internet-connected practices. This chapter therefore explores this notion of designing for moderate and meaningful digital experiences.

HCI and design communities have discussed 'meaning' and 'meaningful use' of technologies e.g.: using 'Slow Design' for creating mindful and meaningful interactions that encourage product attachment [144]; ensuring devices add value to our lives through *"designing for meaningfulness"* [66, p. 96]; and designing meaningful and positive experiences from the perspective of happiness rather than efficiency of output [154]. Researchers have also explored interaction experiences—highlighting that HCI should prioritise those which are 'eudaimonic' i.e. are associated with ideas of fulfillment, long-term importance and meaningfulness [243]. To design for meaningful interactions, smartphone use has been studied [214]. Lukoff et al. found that the same application can provide different experiences of meaning based on the type of use the user engages in on the service; and suggests hiding cues that trigger usage habits, or designing for positive disengagement [214].

With concerns that HCI does not ground meaning making in theory [179] and potentially simplifies designing meaning, Mekler and Hornbæk [244] have used psychology literature to create a HCI framework of meaning. They define five components of meaning: connectedness (i.e. the links to *"aspects of the self and the world we are in"* [p. 4]); purpose (i.e. *"having a sense of direction"* [p. 4] or goals to meet); coherence (i.e. *"the extent to which one's experiences make sense"* [p. 5]); resonance (i.e. something immediately making sense without the need for reflections or explanations); and significance (i.e. *"the sense that our experiences and actions at a given moment feel important and worthwhile, yet also consequential and enduring"*) [244, p. 6]. They emphasise that it is difficult to empirically understand what interactions users experience as meaningful, and suggest that researchers in this area focus on measures from their framework *"that account for different components of meaning"* [244, p. 10].

Given this, I highlight the use of the terms 'meaning', 'meaningful', or 'meaningless' in this chapter link to the specific framework components 'purpose' and 'significance' [244]. Building on the discussion in section 4.5.4, I define the term 'moderate' in this chapter to mean *a reduced level of interaction with digital devices and online services*, and 'meaningful' as *digital device or service use that is deemed valuable, or too important to moderate, in users' lives*. But what interactions are meaningful to users, and what can we moderate through HCI digital device and online service design? How do users envision interventions, and to what extent can the HCI community address the negative environmental and societal effects of devices and services more holistically?

In this section, I analyse the digital experiences of participants from two design workshops (method in section 3.3). Specifically, I build on the findings from the household study participants (section 4.3) to further uncover: what is most meaningful to users in their interactions with devices and services, and what is most frustrating for them. I also reveal the findings from these design workshops to see how users envision meaningful and moderate Internet use. From this, I outline specific design recommendations for the HCI community to explore for moderate and meaningful digital interactions; these aim to reduce the environmental concerns of data demand, whilst also benefiting society through combating the negative effects that devices and services have on users' digital wellbeing, privacy, relationships and work productivity (section 2.2). I then summarise by discussing the challenges associated with these design recommendations, and highlighting the benefits of this holistic design approach.

6.1 Design workshop: digital experiences

In the household study, the participants discussed how they: find their use of online services trivial (section 5.3.6), become somewhat 'addicted' to services (section 4.3.4), and make efforts to search for meaningful interactions (section 4.3.3) or disconnect from devices and services (section 4.3.2). This means the demand for data is not always fully appreciated, and therefore an area of *"digital waste"* [298, p. 1330]. In this section, I build upon these findings through analysis of two design workshops I conducted with 13 participants (method in section 3.3). I further uncover both the interactions that users perceive meaningful and enjoyable, and those deemed frustrating.

Specifically, I draw from the discussions throughout the workshop whereby participants quote their experiences of digital device and online service use, alongside direct notes from the participants (through the post-it note exercise) to emphasise positive and negative online experiences. 61 out of the 107 post-it notes were found to be associated with positive experiences, 41 were negative, and five were neutral (i.e. participants did not include a positive or negative association). From this analysis, I found four themes that underpin whether an interaction is deemed as meaningful or frustrating, and compare these to the household study: 1) nuances of meaning within online social experiences; 2) the availability of online content (and its potentially overwhelming volume); 3) overuse: awareness and interventions; and 4) trust in online services and feeling tracked. These are discussed below, and a summary of the participants (including their demographic information, the workshop they attended, their table discussion topic, and their described typical Internet use) is provided for context in table 6.1.

6.1.1 Nuances of meaning within online social experiences

13 of the post-it notes (12% of total) focused on communication and connectivity as positive experiences by the participants, with these mainly focusing around the ability for users to connect with other people. Through online communication services (such as WhatsApp, Facebook Messenger, Discord, Skype etc.), participants enjoyed being able to send messages to their friends and family: *"Like the ability to immediately send a message to anyone I know"*, *"I like connecting with friends and family"* and *"It helps me to stay connected"*. This was most valued for the ability to communicate over long physical distances: *"makes the world a small place. Contact over distance is*

P#	Participant Pseudonym (Age Range, Gender, Occupation)	Workshop (Topic)	Typical Internet Use
1	Caleb (10s, M, UG Student)	W1 (SN)	Streaming video (Netflix)
2	Jasmine (20s, F, PhD Student)	W1 (SN)	Researching, social media (Facebook), streaming video (TED talks)
3	Isaac (30s, M, PhD Student)	W1 (SN)	Social media (Facebook, Twitter)
4	Samir (20s, M, PhD Student)	W1 (W)	Streaming music (Spotify) and video (Netflix)
5	Lola (20s, F, PhD Student)	W1 (W)	Streaming music and podcasts
6	Greg (30s, M, HR Training Assistant)	W1 (W)	Reading the news
7	Elijah (10s, M, UG Student)	W2 (SN)	Social media (SnapChat, Facebook, Instagram)
8	Balto (30s, M, Software Developer)	W2 (SN)	Social media, streaming video (Netflix)
9	Alex (10s, F, Secondary School Student)	W2 (SN)	Communication (Skype, Discord), social media
10	Zane (30s, M, PhD Student)	W2 (W)	Researching, education, entertainment, communication
11	Duke (40s, M, PhD Student)	W2 (W)	Researching, education, communication (Skype), streaming video (Netflix)
12	Felix (20s, M, PhD Student)	W2 (W)	Researching, streaming music (Spotify) and video (Netflix)
13	Ross (20s, M, UG Student)	W2 (W)	Online gaming, streaming video

Table 6.1: The workshop participants and their typical Internet use. W1 represents workshop one, W2 represents workshop two. Workshop brackets indicate table discussion topics: watching (W), and social networking (SN). As noted in section 3.3.1.3, these topics were selected as they are data-intensive categories of services that the HCI community needs to target for reducing data demand.

almost instant" and *"Like WhatsApp is a worldwide 'free-of-charge' service to connect anyone"*. Jasmine (W1) later emphasised that Facebook Messenger helps her to keep in contact with friends around the world, highlighting that: *"it'd be really really hard, I mean if you used email, the chances that you just lose contact with many of them is really high"*.

This communication was sometimes interlinked with other digital content and services, as Ross (W2) later discussed how streaming the UK TV hit show *'Bodyguard'* soon became *"a way of keeping up with* [his] *mum more than anything"* due to the communication they engaged in after each episode. Balto (W2) 'confessed' to using Tinder and Couchsurfing hangouts *"just to make some friends"* as he moves around the world. Duke (W2) also discussed how he was able to interact with his friends from home (an eight-hour time difference away) using both social media and YouTube: YouTube members would make videos available about his home country's news (for a short time period, as they would shortly be taken down due to copyright issues), which he would then watch in order to be able to discuss local news with his friends on social media. Duke stressed how he *"need*[s] *to get updated with all this stuff"*.

The participants did discuss negative experiences of communication and connectivity: these particularly revolved around social networking sites (e.g. Facebook, Instagram, Snapchat), rather than the instant communication apps available. Whilst Facebook Messenger allowed Jasmine (W1) to keep in contact with all her friends, she described Facebook as *"a love-hate relationship where you would like to go without but you can't"*. Lola (W1) mentioned how she hates having Facebook on her phone, stating that: *"as much as I love dogs, I don't really care about seeing them throughout the day"*. This rather less meaningful content was also present for Alex (W2); she tries to stay away from the main homepages of social media sites and just use them for messaging as *"just the things you see* (laughs) *like it's complete nonsense"*.

The variance in meaning between instant communication applications and social networking sites found here with the workshop participants, support the findings from the household study. Communication was key for many household participants—yet meaningful interactions within social media were less prominent (see section 4.3.3). However, the workshop discussions add to this by highlighting there is not necessarily *just* the communication applications that are useful for facilitating meaningful communication; as Duke, Balto and Ross point out, other services such as BBC iPlayer, YouTube, social networks and dating sites can also enhance elements of meaning in practices involving Internet connectivity.

6.1.2 Online content availability (and its potential to overwhelm)

Access to content, and it's timeliness, was an important aspect of Internet connectivity for the participants—forming 47 (77%) of the positive post-it notes. More specifically, 15 post-it notes were associated with positive experiences around gathering data and learning from it, including: *"Curiosity – always able to find answers to questions"*, *"Provides access to lots of information"*, and *"Great for educational purposes"*. Adding to these, eight post-its included the element of time, e.g.: *"I like being able to find things out 24/7"*, *"I like keeping updated about news and social trends"*, and *"Like having the answer to nearly any question nearly instantly"*. Zane (W2) pointed out that he finds access to, and notifications of, news *"within a few seconds"* particularly valuable.

Other positive experiences surrounding access to content included: the ease and availability of digital devices and services (eight post-its) e.g. *"simple extremely accessible and easy to use to help along with day-to-day tasks"* and *"Available in most places"*; the functionality of services (six post-its) e.g. *"Like online banking"* and *"Like the Internet for navigating around i.e. use Google Maps a lot when I don't know where I am going"*; and the range of entertainment available (10 post-its) e.g. *"is an incredible source of video, music [. . .] far better than CD/DVD ages"*, *"Great accessibility to services to build your own 'world' (e.g. entertainment)"*, and *"Like entertaining – there is a meme for everything"*. Associated with the latter, Lola (W1) discussed how the availability of content online for entertainment has helped with her insomnia: *"now, I can watch anything, it can be something exciting, it could be boring if I want to go to sleep [. . .] accessibility is good"*.

Only three post-it notes associated negative connotations to the availability and volume of content online: *"The sheer volume of information can be intimidating"*, *"Over-whelming (too much info/too many offers)"*, and *"The 'always on' nature of the Internet can be a bit intrusive"*. However, through the discussions, four workshop participants highlighted how this expanse of data can lead to some negative experiences. Felix (W2) recounted how he will watch entertainment online just because it's available, but questions whether he should be making better use of his time:

> *"sometimes I feel like I watch things when I don't want to watch them, cause they're available, I have this feeling constantly, that I might be like, using my time better reading a book or doing actual work, but no, here we are watching valuable series that they released"* (Felix, W2).

Felix went onto say that sometimes he wishes for series *"that last forever"* to be cancelled, as whilst it's still running, you want to keep up. This highlights aspects of the 'fear of missing out' (otherwise known as 'FOMO', a term only brought up in one post-it) due to the volume of online content available. To avoid missing out on social interactions surrounding online content, Jasmine (W1) felt social pressure into buying a Netflix subscription and described motivating herself to watch things that others had recommended. Greg (W6) also highlighted his experiences of FOMO:

> *"there's so much out there and you can get it whenever you want [. . .] you kind of feel like you're missing out if you're not constantly on the Internet and not constantly reading or watching to something [. . .] cause you could be doing, all sorts of different things, so it kind of feels like a waste to be doing nothing, even though it's a very good thing to do, to sit and do nothing for a bit"* (Greg, W1).

Earlier in the workshop discussion, Greg suggested whether the Internet makes it easier to switch entertainment off as it's always available at a later date—unlike historically, whereby a TV show would be shown once on broadcast media and *"you feel like, if you don't watch it, you might never watch it again"*. Yet his own experiences of switching off can cause him to feel like he has wasted his time. This feeling of wasting time links to Lola's (W1) worries about whether people (particularly children) know how to be bored anymore, due to the variety of content available on the Internet: *"everything's a possibility now so it's like would I ever be bored again? [. . .] I think* [boredom] *inspires things like creativity or going outside in the world"*.

The workshop uncovered that the availability of content is often linked to positive experiences for the participants. Users like the large amount of information that is easily available at anytime and anywhere. However, from the discussions, there are links between content availability and worries surrounding ideas that there is always 'something better' to be doing or 'other data' to be consuming. These concerns were not mentioned by participants in the household study (see section 4.3), and therefore extend my preliminary findings.

6.1.3 Overuse: awareness and interventions

The use of devices and services, and particularly their overuse, were highlighted within 13 of the 41 negatively themed post-its (32%), including: *"Easy to over-use by acci-*

dent", *"Distraction – not good, easy to get lot on other websites"*, *"Addition (can't go without)"* and *"Fear (Future to come) increase dependency"*. The discussions further unpacked issues of overuse. Five of the participants (Isaac, Elijah, Balto, Alex, Duke) implicated notifications in drawing users into their devices and services: *"when you get a notification, like you'll randomly check your phone"* (Elijah); and *"with the notifications, like if I see the green light blinking I'm like 'oh what's that?' and then I check it"* (Alex). Furthermore, Balto (W2) described how sometimes in the evening he finds himself *"scrolling"* in Instagram, and Alex (W2) discussed how YouTube wastes a lot of her time as *"you just get sucked into it, and go down a hole"*; Alex also added that this video content is meaningful if it is being used to educate you, but not if if it's *"just like useless, just entertainment"*. To overcome unwanted use of services, Duke silences his phone to avoid looking at notifications, and Isaac confines his social media use to the evening to avoid it interfering with his work hours.

Felix and Ross discussed how just by being on devices themselves can lead to potentially unwanted device or service use: Felix finds it easier to not watch content when he is doing non-technology related tasks, but that *"doing things on a device has a temptation [. . .] 'what if I don't work, but watch this instead?'"*; and Ross agreed with Felix: *"yeah it's the temptation when you're at a device isn't it [. . .] you could go to that computer or phone or whatever with wholehearted like [. . .] 'I'm gunna work' and then you're like [. . .] type N-E-T-F-L-I-X and then press enter and get on it and watch something in three seconds"*. This is similar to Caleb (W1), who attempts to control his social media use through having removed such applications on his smartphone, and only accessing his social networks via his laptop's web browser:

> *"so having the app there and just knowing I can click on it, is more, more of an incentive to do it and that's how it can become a little bit more addictive [. . .]. On the laptop, [. . .] you have got to take more steps to get onto the website"* (Caleb, W1).

As a participant who would've spent time growing up without constant Internet access, Greg (W1) discussed how he does *"sort of miss the phase where, there was only sort of one computer in the house"*. He did not mention that he has previously made any efforts to limit his own use online, however he contemplated whether this more traditional access to devices would help create more meaningful digital experiences:

> *"you'd have a specific purpose and you'd have to say, right I'm going to go sit at the computer and do this, and then when you're not doing that,*

you're doing something else, and the Internet's just out of your head and you're actually, switched on to the rest of the world" (Greg, W1).

This is similar to how Ross (W2) no longer takes his smartphone into his bedroom (specifically replacing his mobile phone alarm with an alarm clock) due to the time he would waste in the morning before work; he thinks *"the temptation surges when you have* [your device] *in front of you"*. Ross, alongside Lola (W1), also highlighted that *other* people's use of digital devices and online services can cause concern. Ross indicated frustrations with family members when he is trying to spend time with them, but they are *"just like addicted to taking a picture and putting it on Instagram or seeing what other people have put on Instagram"*. Lola, on the other hand, described her disbelief during an anecdotal experience on public transport with strangers—an experience in which she related to the Netflix TV series *'Black Mirror'*:

> *"I was on the bus at uni once and we were just leaving campus and I was just staring out of the window, like looking outside and I turned to look at the bus and literally everyone was just like a white screen in front of them and I was just sat there like, I don't, I didn't feel the need to, I just like enjoying looking outside because I wasn't at my office staring at a screen"* (Lola, W1).

The participants' perceived overuse of devices and services (Alex, Greg), and the attempts to regain control by time or access constraints (Isaac, Caleb), is similar to that of the eight household participants that discussed feeling 'trapped' in their device use (see section 4.3.4). The design workshop participants further highlight that it's the *type* of content accessed (Alex, Caleb), or *context* in which it is accessed (Isaac, Greg, Ross), that can help deem whether accessing online content is meaningful—building on the trivial use cases found for watching (section 5.3.6). Furthermore, similarly to how the household participants' devices and service use was influenced by their relationships (see section 4.3.2), Ross and Lola also highlight how the relationships with others and even weak ties [141] (e.g. interactions with people in different social groups) can lead to awareness or frustrations of digital overuse in everyday life.

6.1.4 Trust in online services and feeling tracked

Despite the fact participants emphasised the positive experiences associated with the availability of online content and forms of communication, the wide variety of content and users online enables issues of trust for some participants (14 post-its). These included lack of trust in other Internet users due to forms of technology misuse and abuse (three post-its: *"Dislike misuse of IT e.g. fraud, cyberbullying"*, *"Dislike abuse of people, intolerance"*, and *"Strongly Dislike the hostility and insularity of many social media political discussions"*), as well as the lack of trust in the data that is accessible (five post-its, e.g.: *"Dislike the quality of the content because it is free and open"*, and *"censorship 'fake news' faster to spread"*). Ross (W2) raised how serious this fake news can be: *"when they're talking about fake news has influenced the Brexit result or erm the US election, yeah, it's like pretty scary to think that democracy could be compromised in that way"*.

In addition, participants highlighted worries of privacy and security (six post-its), as they do not always trust the online services to handle their data with care: *"Security compromised?"*, *"Worry about where all my data goes and what it is used for!"* and *"Dislike how accessible our information is (vulnerable feeling)"*. This seeped into worries of being tracked online (*"Dislike constant background feeling of being tracked and monitored"*) and the use of this data to then predict what should be shown to them (*"Dislike social media & entertainment apps that collect data and predict preferences"*). Samir (W1) later highlighted that we: *"have accounts on all of our devices that record everything we're doing [. . .] Google account"*; Elijah (W2) gave the example of Android apps, e.g. Flashlight, asking for permissions it wouldn't need for the app's functionality prior to GDPR (General Data Protection Regulation). Furthermore, Jasmine (W1) described Facebook as a *"nightmare"* for privacy: *"I'm pretty sure they use all the information that I type to like, sell it someone to, sell me something that I don't need or want"*. This *"surveillance culture"* was a particularly an issue for Caleb (W1) and his use of social media, who tries to avoid such sites due to the lack of transparency for how data is being shared online for advertisements:

> *"...sponsored ads are okay cause they're a company and they need to sponsor themselves somehow, but it's the ads like you say that follow you [. . .] if you see an ad, something that you've researched before, your brain will go 'oh okay, they've used that information, then how else have they maybe used it?' and you don't know"* (Caleb, W1).

Whilst Jasmine (W1) joked of the idea of removing all personal data from her Facebook page and instead using a flower as her profile picture (rather than herself), Isaac (W1) discussed how he has already made efforts to change his social media use for reasons of privacy: he and his family no longer share photos or visual media on Facebook, but instead use it for textual information. Counteracting this, he described how he's noticed a trend from his friendship group shifting their shared personal posts from Facebook to Instagram: *"I don't know if it's secure or something, but somehow the trend has changed in the past year or so"*; this is despite Facebook owning Instagram.

These issues of trust and privacy were more prominent in the design workshop than in the household study. For the households, worries around data, and the lack of understanding to how it is shared, mostly arose from showing the participants their quantitative log data (see section 4.3.5); and issues of trust were linked to operating system and service updates (section 4.3.6). However, the awareness of online service tracking for the workshop participants does align with the tech-savvy participants, Xander (H9) and Kevin (H5), in the household study.

6.1.5 Summary: from experiences, to designs

To summarise, the workshop uncovered additional detail surrounding the meaningful and frustrating digital experiences that users have. There are nuances of meaning within online social experiences and users' everyday practices, with different services (e.g. video streaming) adding to meaningful communication. The participants enjoy the availability of content, particularly how easy and timely they can access information—although there are cases where this volume of data is overwhelming. Workshop participants also deal with overuse of online services and digital devices, as like the household participants; yet issues of trust and feeling tracked were more prominent in the workshop. To build upon these findings, I now reveal the designs from the design session. These uncover how devices and services can be designed to: 1) create more moderate interactions with the Internet, and therefore more sustainable data demand; as well as to 2) overcome the negative experiences the participants describe, and maintain users' most meaningful digital interactions.

6.2 Designing moderate and meaningful UX

In this section, I describe the different interventions from the two workshops' design sessions. As I note in section 3.3, participants were asked to design for moderate and meaningful use of the Internet (via digital devices and online services) for a group of hypothetical users who *want* to moderate their use. However, participants did build upon their own experiences of interactions with digital devices and services (see section 6.1) through the design process, and so I utilise these narratives. The designs were independently analysed into themes by myself and another researcher, then discussed until a consensus was made (see method in section 3.3.2); I summarise the resulting design groups in table 6.2. I also conclude this section by revealing the challenges that the participants associated with the embedding of each design in today's society.

D#	Design Group	Design
1	Feedback: awareness and alternatives	Awareness of use
		Providing moments of reflection
		Suggesting alternatives
2	Setting limits	Limited, yet flexible, access
		Limiting usage sessions
		Limits at specific moments of everyday life
3	Physical and spatial aspects	User senses and device sensors
		Location data and movement
4	Merging virtual and real-world experiences	Encouraging real-world interaction and support
		Gamification and competition
		Incentives and rewards
5	Reducing user experience	Modifying colour, brightness and imagery
		Preventing interactions
		Producing finite content and feelings of sufficiency
6	Integrative designs	Combinations of design groups 1-5

Table 6.2: The designs from the design workshops, designed with participants and analysed into groups by myself and another researcher (see method in section 3.3.2).

6.2.1 Feedback: awareness and alternatives

Throughout both workshops, my analysis uncovered that a prominent design idea from the participants revolved around giving feedback to the user. This consisted of making users aware of their own device and service use, providing moments in which users can reflect on this information, and suggesting alternatives to such use.

6.2.1.1 Awareness of use

10 of the participants (Caleb, Jasmine, Isaac, Lola, Greg, Elijah, Alex, Balto, Duke, Ross) emphasised that designs for moderate and meaningful use of devices and services could raise awareness of *how, when* or *what* they use such technologies for. As

Caleb (W1) describes: *"being aware this is how much time you're spending, and also you can make that choice whether to continue using the platform the way you have been using it"*. Elijah (W2) pointed out that these measures would be *"more subtle"* and may be best suited for users who are already self-motivated. These ideas were based on experiences of the participants themselves: Greg (W1) discussed how sometimes *"you notice the time in the corner of your phone, and you think 'oh it's been an hour, okay' [...] 'I should stop'"*; Ross (W2) mentioned how an app on his browser measures his time on different sites and that *"it suddenly makes* [him] *feel very bad"* if his time on the entertainment sites (e.g. Reddit) is much more prominent than his time on sites for work (e.g. Overleaf); and Isaac (W1) spoke about his experience of using the iOS tools: *"when I get a notification from my phone [...] that you know 'you've been using the phone for like 10-11 hours' [...] at times I do take it seriously"*.

Isaac envisioned this information in current service designs—e.g. Facebook *"have that side bar where it used to have updates on who's doing what so, it could have an update side bar which tells you what you have been doing"*; Duke, however, envisioned information feedback as monthly, weekly or daily reports via email (see figure 6.1a). Duke, Alex and Ross (W2) also mentioned potentially using forecasted estimates of use to persuade users to moderate their use (e.g. *"'in the next 30 years, the amount of time you've spent on Netflix is going to be like 10 years or something'"*, Ross).

For such designs, the participants noted that trackers would be needed to log users' Internet activities to display a quantitative understanding of their use (Lola, W1); this becomes tricky if a service provides different meaning across activities, as Duke points out: *"it's called Netflix or YouTube, but the thing is that, I don't know how could you classify if this is for entertaining, or for indicative purposes"*. Potentially even more difficult to track, is the *service provider's use of user data*, rather than the *user's use of services*. Whilst he was the only participant to suggest this, Caleb proposed that if people were aware how their data was being used, *"then it would make them less inclined not only perhaps to use social media but then maybe* [their] *course of the Internet in general"*.

6.2.1.2 Providing moments of reflection

For the watching table in W1, the idea of 'mindfulness' was a favoured concept for helping users create more moderate and meaningful experiences online. This was mostly down to the fact that Samir, Lola and Greg wanted to focus on *positive* ways to moderate, providing *"more carrots instead of less, and less sticks"* (Lola). They saw this mindfulness experience as *"a means to think about how you act in a world of how you react to things"* (Lola) and a way in which digital tools can give users the chance to *"sit down and think to themselves how much they want to use this"* (Greg)—raising awareness of their device and service use in order to make digitally-mediated decisions *"more deliberate"* (Greg). They discussed how *"adding an element of mindfulness to the process"* (Greg) would help users think about what's meaningful when it comes to their Internet usage, *"rather than* [the designers] *dictating to someone what is right and what is wrong"* (Lola)—overcoming the subjectivity around moderate and meaningful use across users. Lola highlighted that you can already get apps for mindfulness, but that they do not specifically focus on Internet usage or online behaviours that users may deem negative.

Similarly to the usage trackers described above, this trio (alongside their workshop organiser) designed an app which enabled users to consider, and then track, what they were most interested in for moderating their online service use. Topics included: for bettering mental health, reducing online carbon footprint, and creating more meaningful time online. Based on the option the user selected, they would be given: different ideas for how they could moderate their use (e.g. 'Reduce Netflix to two hours a day', W1 storyboard), moments to reflect on their use (e.g. *"'oh I actually have been happier since I've reduced X'"*, Lola), and even various visualisations of meeting this goal over time (e.g. change of CO2 emissions over time). From this, they hoped that the process of moderating Internet use would be personalised and therefore users would be positively motivated, as Samir highlights: *"as long as it's all green numbers going up then people will be pleased"*.

Rather than a separate app for thinking about device or service use, the social media table in W1 discussed embedding reminders into these services to promote moments of reflection. Caleb suggested raising users' awareness of *why* they might be using (or overusing) a service in a particular way: *"perhaps you could be reminded by an email or something, or notification, okay, 'this is just, erm a withdrawal symptom, this is your brain telling you you need it, cause your brain wants it, it's not you that wants it'"*. Building on this, both Caleb and Jasmine proposed the idea of providing *"motivating or demotivating messages, if the user wants this [...] some quotes and like any of them can feel meaningful to them"* (Jasmine); these would give users the chance to reflect on whether they are achieving their digital wellbeing goal, and potentially re-motivate users if required.

6.2.1.3 Suggesting alternatives

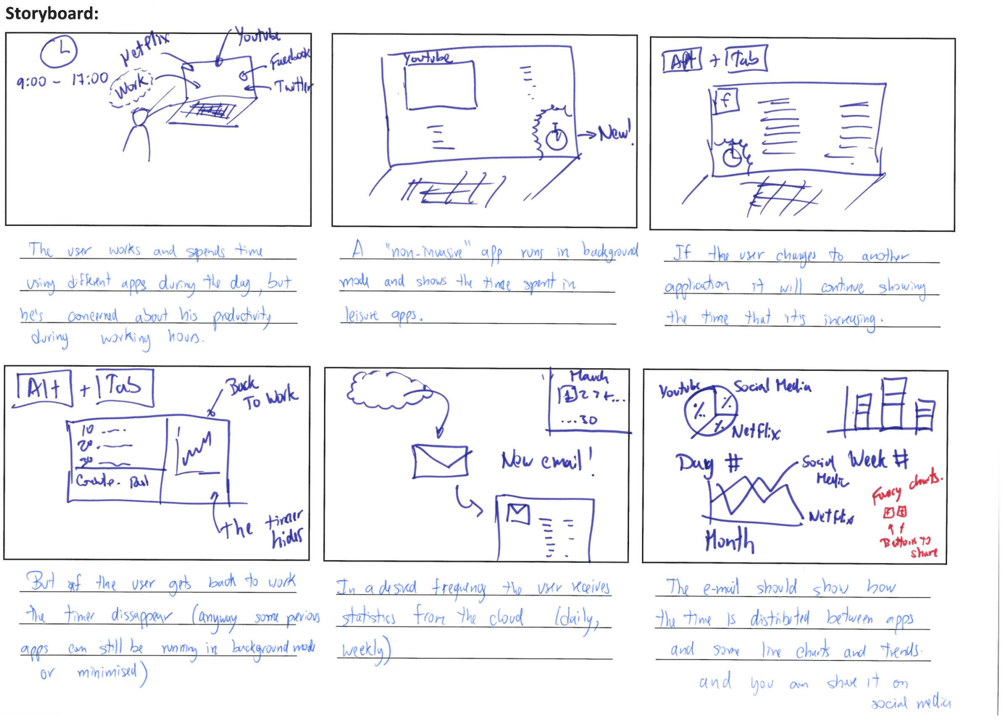
An element of providing awareness of use included providing examples or suggestions to how users may have, or could, 'better spend' their time, as Felix (W2) highlights: *"maybe it's not how much you're spending how much you watch, but what you're missing out"*. Lola (W1) linked to this idea as users could learn a language on Duolingo instead of *"learning absolutely nothing"* scrolling on Twitter; Elijah's (W2) Internet moderation design included how much a user could've achieved fitness-wise, or how much salary they could've earned, if they had been exercising or working instead of spending time on their device; and Alex (W2) suggested that hobbies or alternative online services could be suggested when users are looking to be entertained: *"instead of scrolling on Facebook you go listen to an audio book, you're still on your phone, you're still being entertained, but you're not just endlessly mindlessly scrolling"*. This latter point by Alex links to how Zane (W2) imagines moderating Internet use:

> *"it's replacing the benefits that people get by using it [. . .] so there's an end product, which is entertainment or fun, or just killing boredom, or something like that, so [. . .] for example, if the person has to go out with friends or has to go out running or has to like, there has to be something else to occupy, that time and that space"* (Zane, W2).

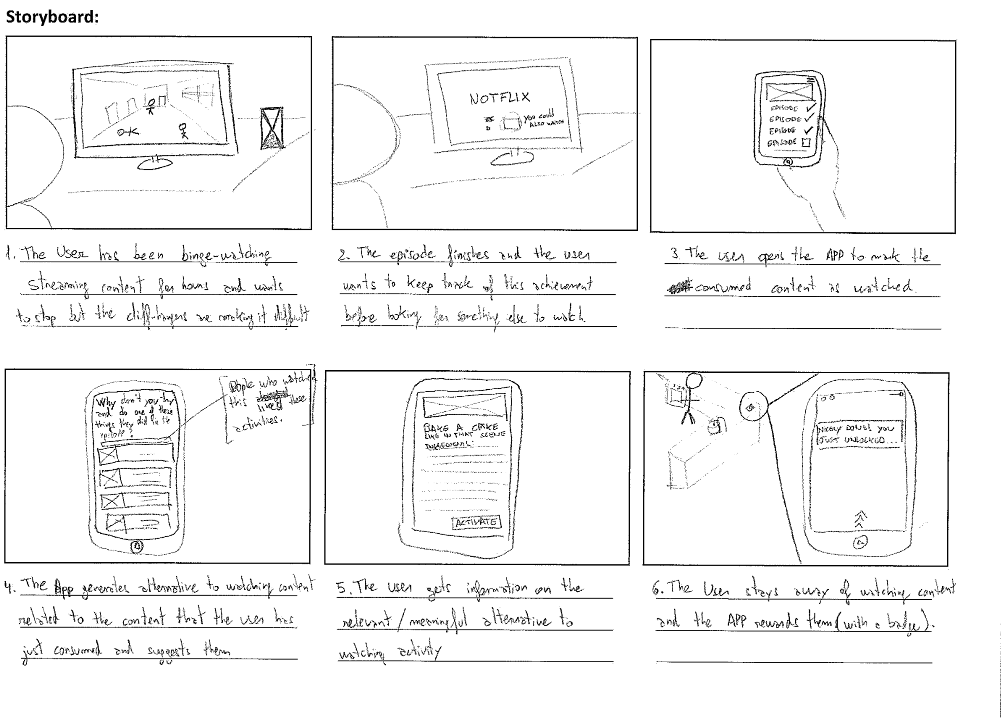
Zane outlined the potential for services to inform users of social events occurring locally right now, which would *"occupy your time and then take you away from your screen"*. Felix then extended Zane's idea to link an alternative activity to the online content that the user is engaged with—in this case, video streaming. As a user of a tracker app which enables him to monitor what he watches online, he discussed how this app regularly recommends content for him to watch. He proposed that other activities could be recommended based on what he has already watched for *"breaking the momentum of the* [streaming] *consumption"*; for example, fans of the *'Great British Bake Off'* (a UK cooking show) could be provided with recipes to make that have appeared on the show (see figure 6.1b). As a result, this area of design focuses on providing awareness of what *else* users could do, rather than what they have done.

6.2.2 Setting limits

A popular intervention discussed by the participants consisted of making tools available that allow users to set specific limits on their device and service use. Providing



(a) Duke's awareness of use prototype (section 6.2.1.1).



(b) Felix's suggestions prototype (section 6.2.1.3).

Figure 6.1: Example storyboards for feedback designs (section 6.2.1).

such facilities, rather than imposing limits upon users, *"gives people the power to make the decision to moderate"* (Lola, W1), is *"a lot less pressurable than having a social credit style way of enforcing it"* (Greg, W1), and *"can be a starter"* to someone who is willing to cut down their access to devices or services (Isaac, W1). This follows similar ideas to the digital wellbeing tools introduced by Apple [9] and Android [373], whereby users can set time limits on their use of specific applications. I explore three variations of limits that were prominent in the workshop designs; these are detailed below.

6.2.2.1 Limited, yet flexible, access

One form of limiting Internet use that the participants suggested (Isaac, Zane, Duke, Ross) relates to having a specific amount of time that a user could have access to an online service. This limited access would be flexible, meaning users could dip in and out of a given service until an overarching limit is reached. Isaac (W1) described how this would make certain service use a *"privilege"*, avoiding unlimited access that might cause 'excessive' usages such as *"check*[ing] *your status like every 10 minutes"*. Through such tools, users may be provided with feedback on their limit through a progress bar (Duke, W2) and can gradually, over time, discover the limited time set which users find meaningful (Isaac). These type of restrictions were mostly related to running on a 24-hour period, which Isaac linked to online games: *"you have those games and you have lives, if you finish those lives you have to wait for a certain time [...] to get those lives back"*.

Participants also envisioned these designs being deployed within online services themselves, rather than as separate applications that control the use of all services. Zane (W2) highlighted this could be deployed in Netflix in relation to watching a number of hours of movies (e.g. *"for three hours or more or five hours"*), whereby Netflix would then be inaccessible for a longer period of time (e.g. *"five hours or eight hours"*). He mentioned that the user would be unable to workaround this hard limit, *"unless of course* [they] *create another account"*. Whilst the watching table group in W2 discussed the challenges of a company, like Netflix, introducing these designs, Ross made a link to gambling websites and the public relations or marketing strategies that companies can promote:

> *"you can set a limit on Sky Bet, which I think is maybe a legal requirement now that gambling companies have to do [...] you could kind of have a*

> *similar thing on Netflix [...] 'I'm only allowed to watch for two hours a day' [...] maybe it would be a positive thing, you know you could say 'Netflix is helping people stopping binge watching'"* (Ross, W2).

These participants mostly focused on flexible limits in terms of *time spent* on services. However, Isaac offered data usage as a limit—building upon his experience of having a 2 GiB/month bandwidth quota whilst at university. He noted how *"you were forced not to use it more often"* and associated these restrictions to pre-paid SIM connections whereby *"you have limited data to consume"*. With his university quota, Internet speeds became slower after the 2 GiB was met. Utilising this, Isaac and a workshop facilitator designed two versions of his limiting design for social media access (see figure 6.2): 1) 'Hard Limit' (see figure 6.2a), whereby the user can no longer access a service after a given amount of time; and 2) 'Hard Limit 2.0' (see figure 6.2b), whereby the user can access a 'Lite', text-based version of a service after a given time limit, with all the 'fun' (pictures, videos) from the service removed.

6.2.2.2 Limiting usage sessions

Rather than having a time limit to using services throughout a given period, participants also suggested restrictions for specific *sessions* of use. For example, Zane (W2) describes this as *"a timer to keep track of what you're doing"*: users would set their preference for how long they want to engage with a given service for that particular usage session, and would then be reminded of their limit as an alarm or warning. Isaac (W1) linked this to parental control systems available on televisions, and Alex (W2) used the example of Spotify's podcast 'sleep timer': *"you can set a sleep timer [...] the next episode doesn't play, or you turn it off after an hour, or five minutes"*.

Given these per-session ideas of limits, more novel approaches (as opposed to time) were discussed. Elijah (W2) discussed blocking the number of times a user could refresh their content. Alex suggested how screen length (*"assuming like a screen's about like, I don't know, about four inches"*) could be utilised as a limit to a usage session; users would then have a maximum *distance* in which they could 'scroll' (e.g. on social media). She described that limit notifications could be introduced and combined with distances in real life, as like fitness equipment: *"you know how like treadmills sometimes have that like 'oh you've ran like erm the whole perimeter of Manhattan'"*. Similarly, Balto (W2) described how limits could be imposed on *"compulsive"* session use based on scrolling speeds:

> *"scrolling, in a very fast and compulsive way, maybe we could put a limit on that or a trigger on that to kind of erm, like, keep from scrolling erm fast, Instagram, probably it's not, it's not meaningful to me and is only making stress and erm, maybe we could [...] moderate the intensity of how much we are using it..."* (Balto, W2).

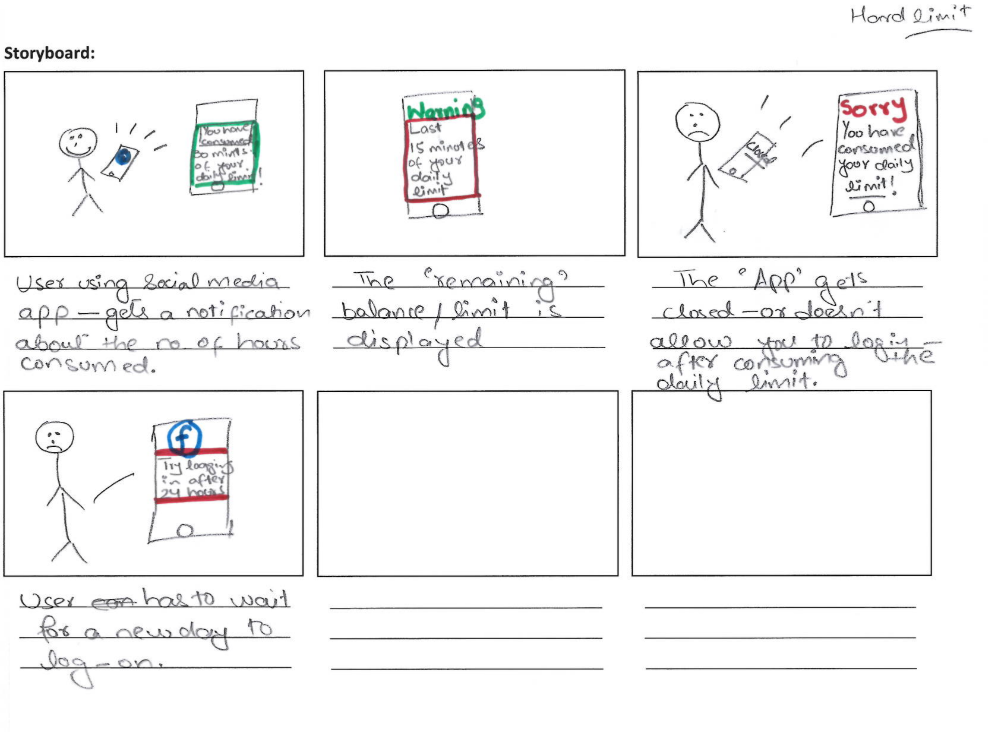
6.2.2.3 Limits at specific moments of everyday life

Another, more complex aspect for user-set limits involved a broader understanding of other events or activities occurring within the users' lives. Within the discussions, these other events surrounded considering users' work tasks and productivity. For example, Lola (W1) explained how users could impose limits at specific times of the day based on her experience of friends using similar tools already available: *"I know people who used to do this when they were doing like university work, they would, there was a program for the computer where they could like block your rubbish sites like social media, and stuff like that"* (Lola).

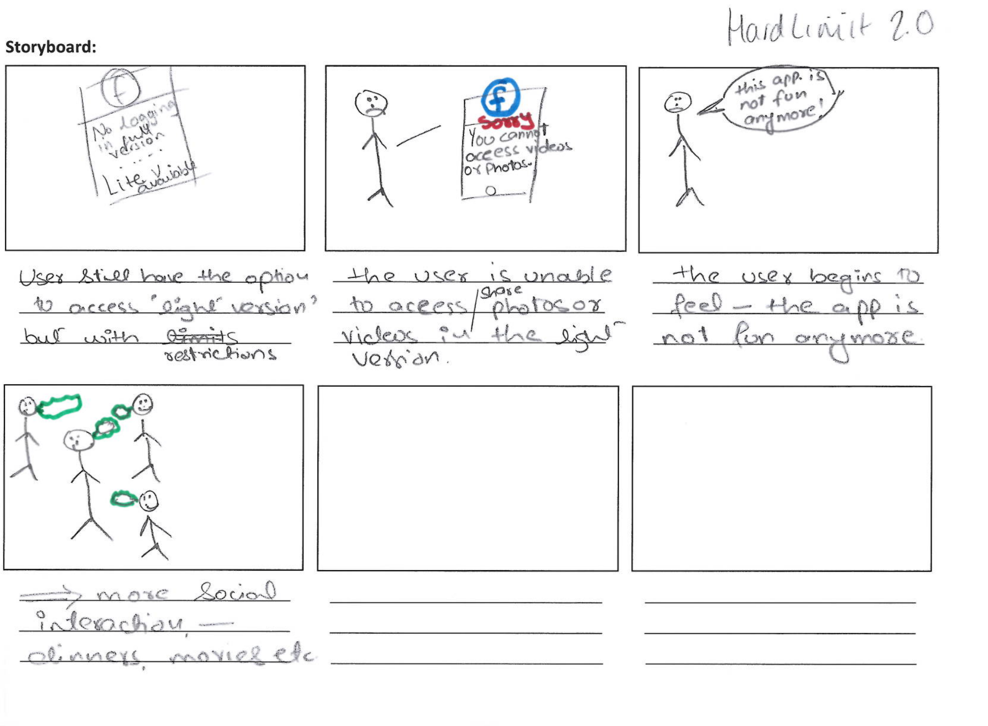
Within the discussions of the watching table in W2, the participants discussed ideas of watching for entertainment (Felix, Zane, Ross, Duke), and watching for procrastination to avoid work and deadlines (Felix, Ross). Given this, the organiser of the table suggested whether machine learning algorithms could be utilised to determine whether users were on-time with their work deadlines: *"make sure that if I'm still on time with my deadline, if not I get this thing like 'you can't watch anything anymore'"*. Following this design idea, Ross exclaimed how this might actually help him manage his video streaming and university deadlines: *"yeah cause I guess a lot of the time when I'm working towards a deadline, it's kind of on guess work you know, how close to the deadline will I need to work"*. As a result, users could set limits to their own interactions with digital devices or online services during specific time periods, and could even have additional aid from the digital tool itself as it 'learns' the rate at which a user works, the time left for a deadline, and the amount of streaming or Internet use that could be 'acceptable' given these working constraints.

6.2.3 Physical and spatial aspects

To create moderate and meaningful digital device and online service use, six of the participants (Caleb, Samir, Greg, Elijah, Balto, Alex) suggested using different aspects of users' bodies, sensors present on devices, and spatial data of the users' location.



(a) Isaac's 'Hard Limit' prototype.



(b) Isaac's 'Hard Limit 2.0' prototype.

Figure 6.2: Isaac's storyboards for his flexible limits designs (section 6.2.2.1).

6.2.3.1 User senses and device sensors

Using the human senses and physicality was a more playful aspect of design that the participants discussed. Jokingly, Samir (W1) suggested *"gloves you wear that makes it hard for you to use your phone"* to moderate smartphone use. Yet, using this idea of touch, Alex (W2) designed a 'fidget toy smartphone case' (see figure 6.3a) that included distracting *"clicky rocker switches and then little buttons"* as a *"'Bop It' phone"* or *"sensory ASMR"* (Autonomous Sensory Meridian Response). She discussed how her device case (which would require software on the device), would give users something to do with their hands instead of scrolling online:

> *"It would be plugged into your phone through like the, your typical like charging port [. . .] then it'd be like 'oh take a break' and then 'beat your personal best at like this game' [. . .] there's like different kind of switches and spinny bits and buttons and a maze [. . .] it would just kind of make you turn it off and do something else maybe if you're bored and scrolling because you're bored rather than scrolling for content"* (Alex, W2).

Balto (W2) comically described a scenario of smartphone use that happens to him regularly: dropping his smartphone on his face in bed as he starts falling asleep during his device use session. He used this specific scenario to use both a device's accelerometer to detect this type of movement, as well as light sensors to measure when a room is dark, to design a moderation tool which displays alerts on the device that encourage users to get some sleep: *"'hey give yourself some rest, erm, you already crashed on, with your head once'"*. This use of device sensors extended into a design idea from Elijah (W2); he suggested that face recognition on devices could be used to track whether a user has been *"looking at* [their] *device for a long time"* whilst walking, *"maybe you could have a suggestion that you should look up"*. Similarly, an organiser involved in the watching discussion suggested the use of gaze tracking to ensure users are actually focusing on the content they are watching; if not, the screen would turn off. Whilst these designs are scenario-based, they highlight the potential of using more sensory aspects of both users and devices for moderate device and service use.

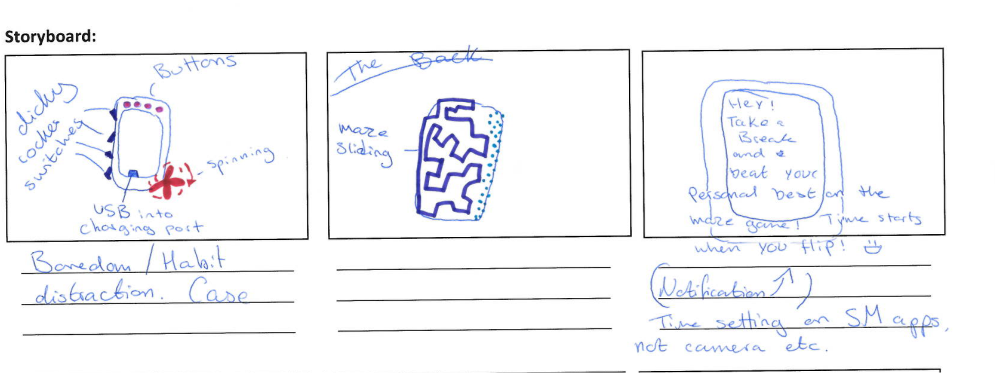
6.2.3.2 Location data and movement

Adding to the ideas of using sensory data, four participants (Caleb, Greg, Elijah, Balto) proposed the use of locations and movement detection to aid moderate and meaningful digital device and service use. Elijah (W2) described this, in the case of social media, as specific zones in which you can access these services: *"fine if I'm using social media at home,* [if I'm in a] *lecture theatre meant to be in a lecture then maybe no"*. Like Elijah, both Balto (W2) and Caleb (W1) suggested utilising the workplace as a location for moderate device and service use: Balto suggested *"while we are going near the job location, we can erm, kind of mute some notifications or some notification of some apps"*; and Caleb discussed blocking Internet access in a workplace's break spaces *"people would be forced to talk to one another [...] it would strengthen the teamwork aspect [...] in the utopian scenario"* (Caleb). Other locations for moderating device use that participants suggested were dangerous roads (Balto) or at home, as Greg (W1) describes: *"you can only use the Internet on a PC in a separate room"* (perhaps linking to his nostalgia of 1990s computing norms described in section 6.1.3).

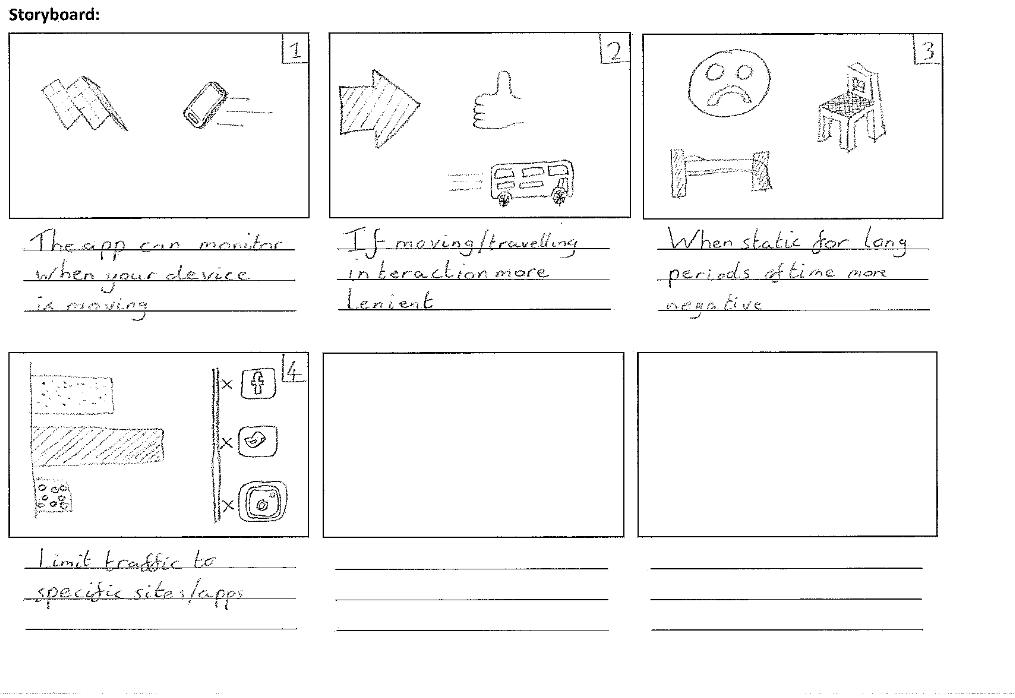
Elijah also discussed the idea of using movement to determine whether to moderate device or service interactions: *"if you're moving, be more lenient [...] if you're a passenger in a car, bus, or whatever, you're generally not doing much productive anyway so, it's probably fair enough to be checking your phone for 20, 30 minutes"* (see figure 6.3b). Somewhat contradictory to this idea, he also suggested using different types of movement as way of detecting meaningful use: *"if I'm stuck on the bus, I'm probably more likely to just read or look at my Facebook or Instagram feed or Twitter feed, whereas if I'm kind of on the go and doing other stuff I'm only likely to read, or respond to notifications that I'm interested in"*. This highlights the complexities and trade-off between managing boredom and maintaining meaningful interactions. Instead of using movement to *detect* meaningful use or opportunities for moderation, Balto highlighted how movement (using devices' GPS (Global Positioning System)) could be used as a technique for *implementing* moderate device or service interactions: *"'hey walk for 300 metres and then you can use it again'"*. Such a design could therefore potentially link digital wellbeing to physical wellbeing through exercise.

6.2.4 Merging virtual and real-world experiences

Utilising social influences within the 'real-world' (i.e. physical world) were a way in which the participants discussed that device and service interactions could be moderated and made more meaningful. These included: social experiences and support in the real-world, creating competition with others through gamification, and developing incentives and rewards.



(a) Alex's fidget case prototype (section 6.2.3.1).



(b) Elijah's device movement prototype (section 6.2.3.2).

Figure 6.3: Example storyboards for designs involving physical and spatial aspects (section 6.2.3).

6.2.4.1 Encouraging real-world interaction and support

When it comes to helping users make their use of devices and services more moderate and meaningful, three participants (Caleb, Isaac, Balto) turned to ideas surrounding real-world social interaction and support. Caleb (W1) highlighted that if you're trying to moderate your use at the same time as a friend or family member, *"you can support each other"* in that process. Isaac (W2) built upon this idea, suggesting that *"this Internet use and social media use, so addicted to it I mean these days that this withdrawing thing needs to have a special six-months intensive training programme"*. Through further discussions with Isaac, he designed (with a workshop organiser) *'The Healthy Internet Programme'*; this was in the form of an app which would provide the user with different tasks, challenges and activities that help users moderate their use of a given device or service. One of these activities or *"very small small steps that you can take"* Isaac suggested included sending physical greeting cards, rather than an e-greeting or social media post—a task he was once given by a teacher for wishing friends and family a 'Happy New Year'. He explained how the app would also link the user to other users going through similar goals:

> *"if you have similar people who are undergoing a similar situation, [...] you can share your experiences [...] you can hear how each of the members is doing to feel more motivated [...] not a competition but comparative"* (Isaac, W1).

In a similar, and more playful, design, Balto (W2) discussed the idea of integrating support from family and friends into social media moderation. He suggested that if a user *"continues to scroll and you know abuse of the social network on the smartphone"*, then the device could post a photo of the user to their friends with the caption *"'Please help me, call me, let's go out for a beer, I have an issue with social networks'"*. Although Balto and the workshop group acknowledged the privacy implications for this, they discussed how it would be a humorous, consent-driven design and could possibly only be sent to a few supportive friends that the user selects.

6.2.4.2 Gamification and competition

Seven of the participants (Caleb, Isaac, Lola, Elijah, Balto, Felix, Ross) suggested gamification or competition as a fun way of helping users create more moderate and meaningful experiences online. For Isaac (W1) and Ross (W2), these were suggestions based on their own experiences of engagement in competition with family members for step challenges on the FitBit (*"I will start walking again [...] because I know I'm losing* [the challenge]*"*, Isaac) and for the football score guessing app 'Super 6' (*"my mum doesn't care about football at all but she does it just for the 'I want more points than everyone else'"*, Ross). To link this competition to the idea of moderating device and service use, ideas were suggested where a family could monitor their use of social media and the highest user would have to pay for a big family meal (Caleb, W1) or donate money to a given charity (Isaac). Through discussing complexities surrounding abilities to make such payments, Caleb created *'The Forefeit Incentive'* application whereby a group of users (in this case, friends in a shared flat) would commit to a given forfeit instead of a monetary 'fine':

> *"I just imagined the idea to be the bins, it could be anything else, it could be washing up or, or hoovering, or I dunno something like that [...] as an incentive but also a competition in a way to help people to moderate their use as a collective"* (Caleb, W1).

Rather than creating real-world rewards for competitions like these, Duke (W2) suggested gamification by users gaining 'badges' associated with certain milestones of device or service non-use. Furthermore, Ross (W2) proposed the idea of creating virtual money for online activities. His design to help make these online activities more meaningful consisted of an application that allowed the user to set a 'negative' or 'positive' association against different services; from this, the user would gain money based on the use of positive services, and have money charged to their total based on the use of negative ones (see figure 6.4a). Through these totals, the competition element would consist of family or friends comparing scores: *"'oh I've got more than you today cause I've done more productive stuff'"* (Ross). He also imagined that the designs of services could adapt to how much money the user had:

> *"if you don't have any money in your account, it would start not refreshing content, if it was like YouTube, you would see all the same recommended stuff that you'd been recommended, or if it was Netflix it would stop auto-playing and you'd have to click play again every time rather than it just automatically loading"* (Ross, W2).

Elijah (W2) also suggested a similar 'token system' (comparing this to the game 'Candy Crush') whereby a user would earn tokens as they spend time away from specific services or devices that the user themselves has selected; these points could then be 'spent' for time on the device or service, with the user being blocked from further use if they had consumed all their points. Whilst this didn't include an element of competition, his design still gamified the experience of creating moderate and meaningful use of devices and services.

6.2.4.3 Incentives and rewards

In some way similar to the incentives associated with gamification and competition, eight of the participants (Caleb, Isaac, Samir, Greg, Lola, Duke, Felix, Ross) discussed the need to incentivise and reward people with their moderate and meaningful use of digital devices and services. Samir (W1) used the example of how the makers of the game 'World of Warcraft' *"rejigged the numbers"* so that instead of degrading the user experience after users had been playing for a certain amount of time, users would instead receive a 'well-rested' bonus: *"now it was a thing being given to the users, rather than a thing being taken away, and suddenly they loved it"*. Greg (W1) backed up this argument: *"the fact you've been given something just makes it, people much more likely to do it, much happier about it"*. Such rewards were seen as a way *"to get people motivated"* (Caleb, W1), and change habits rather than just being aware of usage data: *"why would I change if I see the data? Data informs me and communicates, but it doesn't affect* [me]*"* (Felix, W2).

In W1, Caleb talked about his friend's app which will *"pay you for walking"* where users might receive a small *"discount off something"*. Both Caleb and Isaac (W1) mentioned that having a financial incentive or reward like this (e.g. as a voucher) could motivate users to moderate their use online (see figure 6.4b).[1] However, they speculated that it might not necessarily have to be monetary-based, linking to user experiences of the FitBit (*"as like* [Isaac] *was saying about erm the FitBit, and if you get to 10,000 steps, you know, there's no economic benefit for that but people feel pretty good about themselves"*, Caleb) and search engines *"that plant a tree or something"* (Caleb). In W2, Felix and Ross had a similar discussion for rewarding users in their successful moderate and meaningful online experiences. From this conversation, Felix discussed users potentially receiving *"something like, you know, Nectar points [. . .] the value*

[1] The participants did not mention the app, but the 'Hold' app (`https://www.hold.app/`, accessed October 2019) allows users to gain points from spending time away from their smartphones. These can then be spent on free or discounted products or services in the real-world (e.g. free popcorn at the Vue cinema).

of Nectar points isn't significant but then people keep collecting them and get upset when they remove them". Such designs would need buy-in from companies, yet the participants stressed that such rewards could potentially be important for motivating moderate interactions with devices and services.

6.2.5 Reducing the user experience

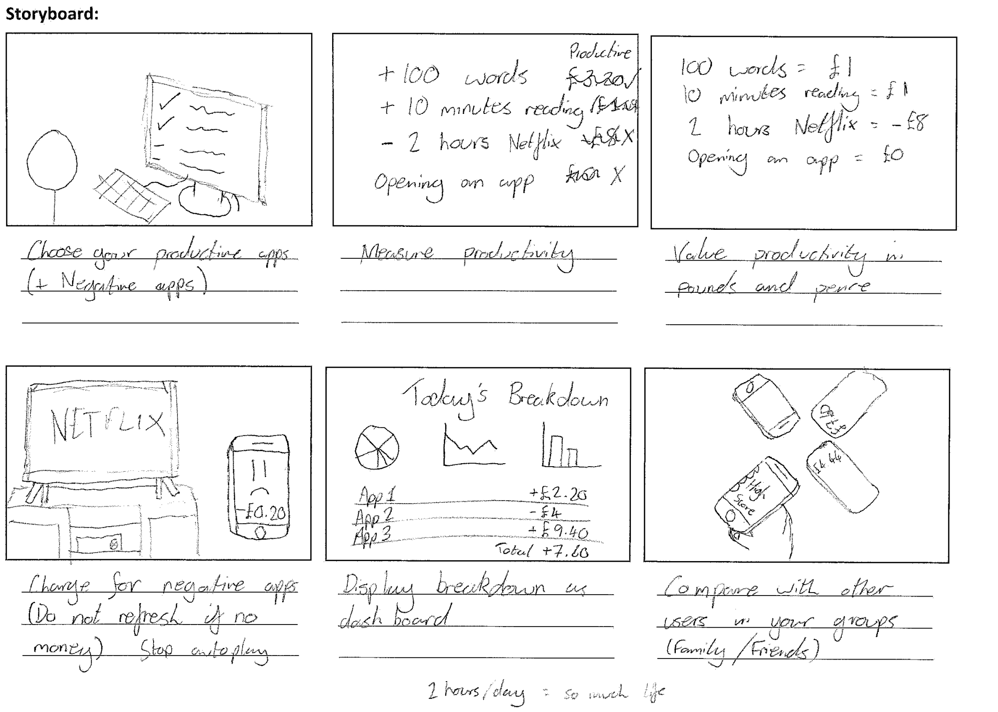
Rather than developing separate apps or devices that help users create more moderate and meaningful use of their digital devices and online services, the participants had the idea of reducing the user experience for such device and service use. In other words, interventions to use would be *embedded within* interactions, instead of layering interventions on top of 'excessive' or 'meaningless' uses. The participants identified a number of ways in which this could be facilitated: modifying colour, brightness and imagery; preventing interactions; and producing finite content.

6.2.5.1 Modifying colour, brightness and imagery

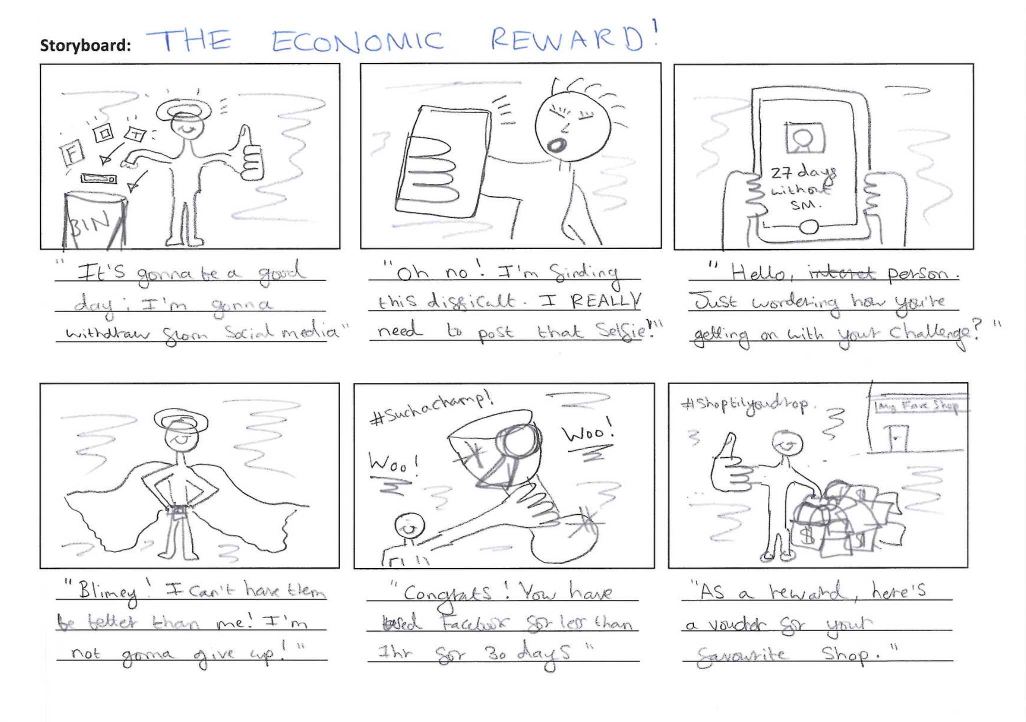
To reduce the user experience and therefore the time in which users spend on their devices or services, Jasmine (W1), Caleb (W1) and Alex (W2) all suggested modifying the colour or brightness of a screen. Caleb explained the 'science' behind this idea that he had previously found on a website providing tips to reduce your social media use:

> *"When you have the colour on your device, it kicks in, or helps, it hacks the reward system of the brain so releasing dopamine, so anything with colour, we're more likely to get addicted to, so if you reduce, the erm, well if you turn it into black and white, it'll neurologically be less of an incentive to use that device"* (Caleb, W1).

Jasmine saw this removal of colour as a *"good compromise"* between reducing the user's experience and making them frustrated (see figure 6.5a). She imagined this being deployed by *"either just displaying in black and white or gradually removing colour"* the longer that users spend time on the service or device. Alex also suggested this concept with turning down the screen's brightness. Adding to this, Isaac (W1) discussed how a research study he was aware of found that pictures and videos can enhance student experiences within teaching materials: *"if you have more funky things, within your PowerPoints, they might help retain the attention"*. His 'Hard Limit 2.0'



(a) Ross's competition prototype (section 6.2.4.2).



(b) Caleb's incentive prototype (section 6.2.4.3).

Figure 6.4: Example storyboards for designs merging the virtual and real-world (section 6.2.4).

design (described in section 6.2.2.1, shown in figure 6.2b) utilised these ideas of losing users' attention: *"you can still access a lighter version of the app where you don't have access to photos or videos or something dynamic, just a static content, that might eventually reduce your interest in an app"* (Isaac). Such designs would still allow for the 'important' and meaningful data to be accessed online, as Elijah points out: *"images tend to be more either promotional from companies or just random social stuff, messages tend to be like the text seems to be more important"*.

6.2.5.2 Preventing interactions

As described in section 6.1.3, participants indicated that devices or services can be tempting to use due to notifications pulling users in (Isaac, Elijah, Balto, Alex, Duke) or the ease of access to devices or services (Caleb, Felix, Ross). Therefore, to design moderate and meaningful device and service interactions, Balto (W2) suggested that notifications could be muted or delayed (e.g. during users' sleeping patterns), and Caleb and Jasmine (W1) discussed together that designers could make it *"tricky to get to the website"* (Caleb) to avoid ease of access. One way in which this 'tricky' access could be deployed involved slowing Internet connections, as Jasmine describes:

> *"So I think one thing that makes me use things less is if they're slow, they could do this option of making the website go slower, load slower after a certain amount of time that you define yourself, so whenever my Internet connection's bad then I just can't be bothered, because it takes forever to load"* (Jasmine, W1).

Whilst Zane or Balto didn't suggest this as a design, Zane (W2) did describe how sometimes his *"Internet connection is not that good so it's not refreshing so you just decide 'well, it's not worth it'"* in relation to his Twitter usage, and Balto mentioned falling asleep within *"little loading moments or the buffering"* for Netflix. Elijah (W2) *did* suggest slowing Internet speeds as a design, yet he perceived these being deployed after a user has *"been using it for a certain period of time"*, highlighting that this could be a *"stronger barrier"* to use for *"people who live constantly on their phones"*. In a similar notion, Jasmine suggested that devices or services could *"just close the app after a certain amount of time, you could re-open it [...] but maybe just this closing thing would be like 'oh right, maybe not, I should actually go and do something else'"*. She saw this as a *"less intrusive"* form of creating moderate and meaningful device use than blocking a user from a service or device entirely. Despite thinking about intrusive designs, Jasmine also suggested that access to social media could drain more of your battery: *"if you see the battery decreasing then you might stop because you want to use your phone for something else that day"* (see figure 6.5b). She highlighted the caveat of users needing a lot of motivation to install such services, and that they might just end up carrying a charger—however, such a design could prevent the temptations of overuse whilst still allowing users to access services.

6.2.5.3 Producing finite content and feelings of sufficiency

To create more moderate and meaningful interactions with devices and services, Balto and Zane (W2) proposed adapting online content to become more *finite* instead of infinite. This was mostly linked to ideas of 'endlessly scrolling' on news articles (Samir, W1) and on Facebook (Balto, Zane). Balto suggested less elements could be loaded *"to slow down, for example, the scroll"*, and Zane described how your social news feed could be filled with *"older stuff more and more, with very little new content"*:

> *"so when you keep scrolling, you keep seeing things you've seen maybe 30 minutes ago, 40 minutes ago, the past one hour, those are the things that keep repeating so you don't see the need to keep staying up on Facebook"* (Zane, W2).

This idea of finite content is available in the design of other social media services as Elijah (W2) points out: *"Instagram has a feature where it does 'you're all caught up' so obviously that wouldn't work with Facebook because Facebook's goal just seems to be endless"*, and "[Twitter] *tells you like there's so many messages like 100 messages, 80 messages and I can't be bothered reading that, so I normally just press 'up' like the little button that takes you to the top and I'll read the last 3, 4, 5, kind of thing"*. Elijah and a workshop organiser discussed how scrolling could be made automatic (like screensavers) to slow the pace of scrolling through infinite content, as the organiser describes: *"maybe there's an intermediary kind of stage where it's just like you get* [new content] *every 20 seconds [. . .] it kind of drip feeds you"*. This is less restrictive than just showing old content (as Zane in W2 suggested) but may still lead users to gain feelings of 'having had enough' content.

Similar designs for sufficiency (i.e. in this case, the feeling that users have had an adequate amount of device and service use) seeped into the watching discussions. Felix

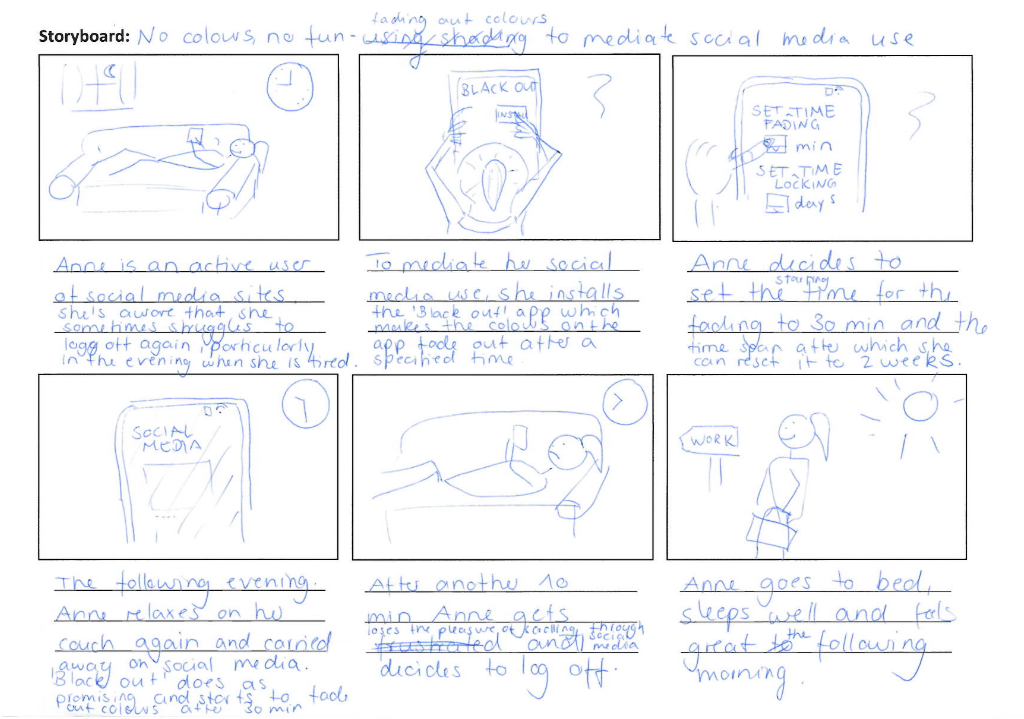
(W2) said that *“maybe* [Netflix] *need to stop releasing the whole season”* at a time, to avoid negative effects e.g. binge-watching. Furthermore, like Elijah, Felix was aware of Instagram’s service design: *“I remember that Instagram did this test years ago that was when you were caught up, they did display ‘oh here is the new things and from here on is things that you’ve already seen’”*. Using this idea, Felix suggested service designs could be adapted to ‘trick’ the user into thinking there is no new content:

> *“ ‘oh you’ve spent so many minutes there, beyond that it’s not healthy [. . .] we’re going to make a trick of rearranging things, here’s what you’ve looked at, the next one is something that you’ve already seen’, then later there’s something new but you don’t know that, you’re misleading the user for the greater good”* (Felix, W2).

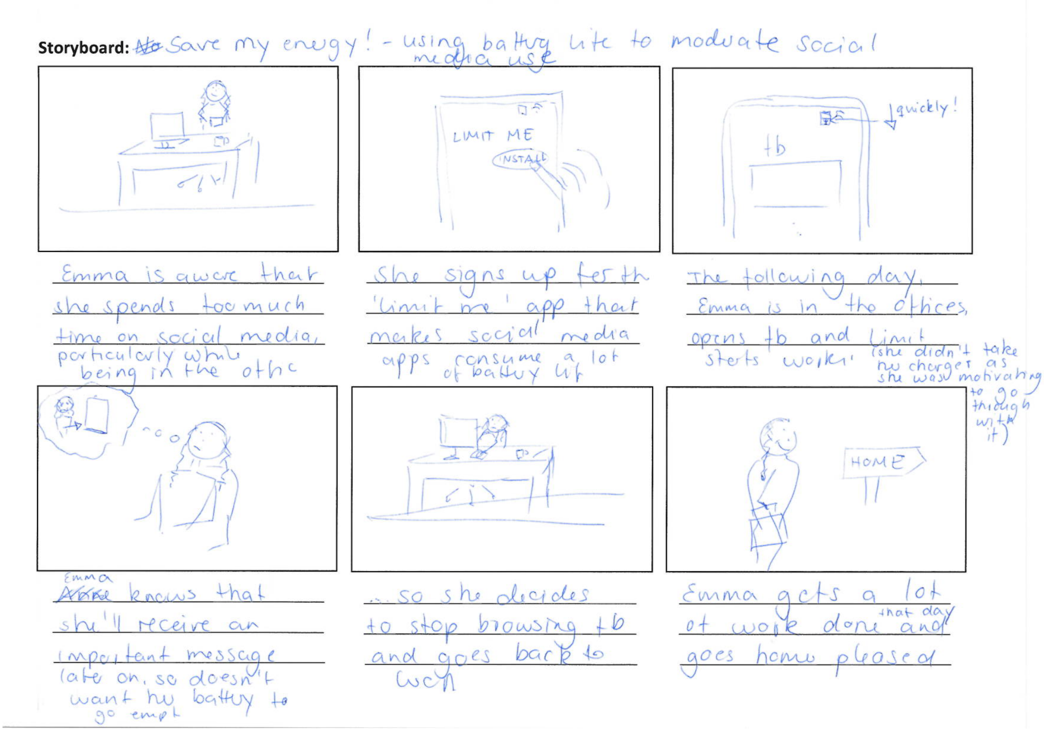
Ross (W2) added to this discussion to say that he likes *“the idea of fooling* [the user] *rather than outright telling them it’s not refreshing it”*, and Felix replied with *“but doesn’t that come from Psychology? If you forbid me to do something, I want, I really want to do it”*. In this sense, users can still access content if it is providing meaning to them and are not being ‘forced’ into moderating their use—yet, it may avoid the ‘endless’ and ‘infinite’ content cycles that the participants describe.

6.2.6 Integrative designs

To create more moderate and meaningful interactions with digital devices and services for users, six of the participants (Isaac, Lola, Greg, Elijah, Balto, Alex) specifically suggested that the designs described in the workshops (and this section of the chapter) could be merged to develop a more robust and complete intervention. For example, both Isaac (W1) and Elijah (W2) discussed the potential of raising users’ awareness through reminders (section 6.2.1.1) of their usage limits (section 6.2.2). Furthermore, Isaac suggested limits (section 6.2.2.1) and rewards (section 6.2.4.3) could be combined; Alex (W1) discussed that Balto’s movement design (section 6.2.3.2) could be linked to Elijah’s token system (section 6.2.4.2); and Balto (W1) proposed combining the best features of his table’s designs whereby his accelerometer use for detecting users dropping their phones could *“at the same time we can include some points, some of the implication stuff, or some spinner, spinner revolutions”* (i.e. Alex’s fidget spinner phone case—section 6.2.3.1). In W1, both Lola and Greg envisioned that Isaac’s reduced image content design would merge well with Caleb’s and Jasmine’s colour



(a) Jasmine's colourless prototype (section 6.2.5.1).



(b) Jasmine's battery drain prototype (section 6.2.5.2).

Figure 6.5: Example storyboards for reduced user experience designs (section 6.2.5).

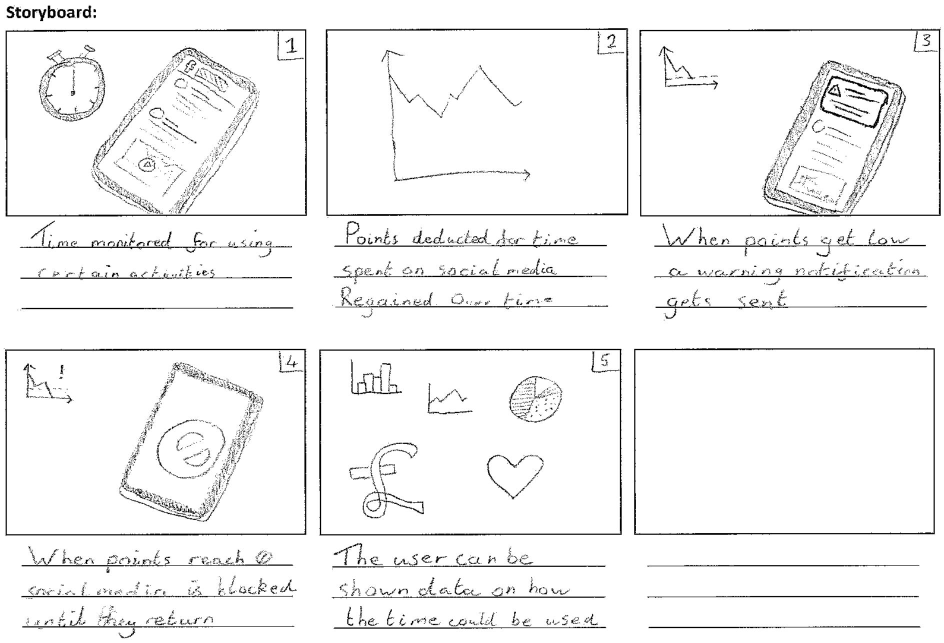


Figure 6.6: Elijah's storyboard for his integrative design (section 6.2.6).

fading idea (section 6.2.5.1), and Greg also saw that this could link to the target setting design that his group discussed (section 6.2.1.2).

At the end of W2, Elijah had produced a complex intervention (see figure 6.6) that merged four of the five core design groups I have highlighted in this chapter (summarised in table 6.2). In this intervention, users could accrue points for not accessing certain apps and lose them when they did (gamification—section 6.2.4.2). Once points were diminished, users' bandwidth would be slowed on specific services (preventing interactions—section 6.2.5.2) or the use of those services would be restricted (limited, yet flexible, access—section 6.2.2.1). Users would also receive a summary of their use (awareness of use—section 6.2.1.1) and what they could've done instead if they had put their time into something else, e.g. what they could've earnt on their salary (suggesting alternatives—section 6.2.1.3). Elijah's idea, alongside the comments from the other participants, suggest that integrating *multiple* design ideas *together* could be a more rounded and successful approach for creating moderate and meaningful digital experiences.

6.2.7 Summary and challenges

As I have outlined, the participants were active and innovative in the workshops and as a result were able to develop many different design ideas (summarised in table 6.2). However, they did often battle with aspects of their ideas in relation to the designs working in the real-world. They discussed the difficulties in bringing businesses on board to these designs (Caleb, Jasmine, Isaac, Elijah, Felix, Ross), and the need for regulation changes (Greg) that do not lead to inequalities of use across users (Samir). Furthermore, they worried about the users themselves: ensuring users are not being controlled (Caleb, Jasmine, Samir, Felix); that they don't have 'extra work' to do (Jasmine, Greg) and can still access their devices in emergencies (Caleb, Jasmine, Greg, Elijah, Ross); and they also highlighted the privacy implications of designs requiring some form of tracking (Isaac, Samir, Lola, Greg, Elijah, Balto, Alex, Felix, Ross).

Furthermore, the participants discussed the challenges surrounding the subjective nature of meaningful device and service use across users (Jasmine, Samir, Lola, Greg, Balto, Felix, Ross), and the scenarios of users creating workarounds, or 'cheats', to continue their current usage patterns (Caleb, Jasmine, Isaac, Samir, Lola, Greg, Elijah, Balto, Alex, Zane). Finally, they highlighted concerns regarding the implementation of these designs: the potentially counter-intuitive nature of creating devices or services to moderate other digital interactions (Lola, Greg) or rebound effects of potentially creating more use of the Internet or digital devices (Caleb, Samir, Lola, Alex, Felix); and the technical challenges for creating moderate interaction designs across devices, services and activities (Caleb, Jasmine, Isaac, Samir, Alex, Elijah).

In the next section (section 6.3), I build upon the findings in this chapter, alongside the the household participants' digital experiences (section 4.3), to propose recommendations for the HCI community to design for more moderate and meaningful use of digital devices and online services. However, as the participants noted here, I understand that there are rather obvious societal or economical challenges to this area of HCI design; I therefore follow my design recommendations with a discussion of the challenges with opportunities to overcome them (section 6.4).

6.3 Design recommendations

Considering the findings from the household study and the workshop (sections 4.3 and 6.1), as well as the participants' designs (section 6.2) *and* related work, I propose design recommendations for the HCI community. These are specifically for researchers who are aiming to mitigate the negative effects of digital devices and online services *through design*; these are therefore applicable to researchers that seek to reduce data demand growth (the core drive of this thesis), *as well as* address other areas surrounding digital technology's effects on users (outlined in section 2.2). Furthermore, the designs are non-specific to services, and therefore could be applied to online services beyond the watching and social media categories discussed in the workshop.

6.3.1 Frictions and flows

The participants can find it difficult to break away from their use of digital devices and online services (see sections 4.3.4 and 6.1.3). Given this, I consider two potential design areas: 1) 'Internet speed bumps' as a barrier to (re-)entry, creating frictions to use; and 2) increasing ease of exit, concerning the fluidity of disconnecting from use sessions. These are *"self-inhibiting"* design options [289, p. 961] which devices and services could incorporate to help users moderate their digital interactions. This is the opposite to how HCI generally operates, as service providers use persuasive designs to motivate users to access their services and carry out specific behaviour [123].

6.3.1.1 Internet speed bumps

The participants' accounts show that they find it 'too easy' to access, and become distracted by, digital devices and online services (sections 4.3.4 and 6.1.3). In fact, some purposefully try to avoid going on certain services as they then find it difficult to end the activity (Gemma, Ella, Isaac, Duke, Caleb), and have even introduced processes (Caleb, Ross) or software blocking tools (Ella, Kevin, Ben) to reinforce entry barriers.

Similar findings have been found in work productivity research, as workers create *"micro-boundaries"* to accessing their email [67, p. 3996]; these micro-boundaries are defined as *"a small obstacle prior to an interaction that prevents us rushing from one context to another"* [90, p. 1392]. Such micro-boundaries could be utilised to create moments of reflection (section 6.2.1.2) to create more moderate and meaningful interactions with online services by enabling users to rethink if they actually need or want to carry out the interaction. This would enable users to think about whether they actually need or want to carry out the interaction—just as Ben (H1) described (section 4.3.4). Barriers would be particularly important for deployment at specific moments of users' everyday lives, e.g. as work deadlines approach (section 6.2.2.3).

Furthermore, as Tim, Elijah and Alex discussed, and as prior sustainability work points out [211]: users often deal with checking reflexes for using their device or specific services, e.g. just because devices are 'there' (as found in section 6.1.3), or perhaps due to fears of missing out on online content (section 6.1.2). Barriers to *re-entry* may harness data reduction opportunities by removing the ability to continuously refresh content in application revisitations [178]. This could be implemented by using location and contextual data (e.g. user movement via GPS tracking, section 6.2.3.2)—echoing a call made by Roffarello et al. for digital wellbeing tools, where behaviours (such as going for a walk) could be suggested for users to form new habits (instead of existing ones, such as browsing Facebook) [248].

Prior work has tested frictions through asking users to carry out cognitive tasks before accessing specific apps [188, 286]—aiming to engage users in *"cost-benefit analysis for self-regulating frequent app use"* [188, p. 9]. As a barrier to re-entry, Park et al. [286] increased the complexity of the cognitive task based on shorter interval times between app visits. However, these interventions focus on smartphone applications, and concerns surrounding digital device and service use go beyond these mobile devices. I suggest that boundaries on device and service use could exist through *Internet speed bumps* (e.g. at the router-level). These would slow down the rate of data transmission or service accesses, and automate services' loading screens—creating an opportunity for mindful digital interactions on all devices. This preventative measure for device and service interaction was a design that the workshop participants discussed (section 6.2.5.2), allowing for users to still have Internet access whilst filtering actions that are less meaningful or important. Furthermore, Kovacs et al. found that work productivity tools on one device do not redistribute procrastination onto other devices [197], but this may not be the case for the other HCI domains I discuss (e.g. digital wellbeing). As Internet speed bumps would target all devices; switching devices to avoid the friction would not be an available option to users.

Internet speed bumps could also be more physical; much like the avoidance of devices on holiday (as like Connie, Alan and Laura) or areas in the home (as with H7, section 4.3.2; Ross and the nostalgia felt by Greg, section 6.1.3), as well as the design suggestion of utilising workplace locations for disconnection (Elijah, Balto and Caleb—section 6.2.3.2). Deliberate 'Internet dead zones' could be introduced in spatial areas crossing users' lives (e.g. quiet zones or break spaces at work, family collocations in the home [263]). The speed bump here would be the requirement for the user and their device to physically move out of the location of a black spot, for the consumption of Internet connectivity. Yet, it is important to note that these Internet-free zones would require challenging the user expectations of 'always on', easily accessible devices (as with Martin and Ben in H1)—an aspect that the workshop participants deemed important (section 6.1.2).

6.3.1.2 Increasing ease of exit

As some of the participants find they become trapped within applications (Kevin, Ella, Ben, Xavier, Alex, Balto—sections 4.3.4 and 6.1.3), it's important that there are mechanisms for users to easily exit their use of these online services—encouraging users to leave services after their original purpose has been achieved [214]. The design workshop pointed out different design approaches that such 'flows' could be introduced, making it easier for a user to end a usage session. Deploying these may be particularly useful for when users seem to be disengaged in the content that they are interacting with e.g. scrolling too fast to really fully concentrate on online media (section 6.2.2.2), or dropping devices from falling asleep (section 6.2.3.1).

An explicit approach could include auto-closing apps (section 6.2.5.2), or deploying timers and scrolling limits (if applicable) to be placed on sessions of use (section 6.2.2.2). Such *"self-defined limits"* e.g. *"natural stopping points"* to device use have been recommended by Hiniker et al. in regards to transitioning children away from their device use [164, p. 657]. As I highlight in this chapter, such limit designs would be useful for other users (i.e. not *just* for children). Another example in HCI research which increases the 'ease of exit' consists of the negative reinforcement vibrations that Okeke et al. have explored during Facebook overuse [278]. Interventions like these are an important area for HCI researchers to design ease of exit flows—particularly for services that the participants describe as addictive (e.g. Facebook, Buzzfeed, Reddit, Instagram, YouTube—sections 4.3.4 and 6.1.3), or categories that are data-intensive (e.g. watching, chapter 5).

However, the workshop also highlighted less explicit ways, or 'softened' ways, in which 'ease of exit' designs could be introduced. By reducing the user experience from using such services (section 6.2.5), users may find the interfaces less 'addictive' and therefore make it easier for them to exit their usage sessions. Such flows could be introduced over time by gradually removing colour or imagery (section 6.2.5.1), increasing loading times as more and more content is requested (section 6.2.5.2), or even producing the same content that users have already seen (section 6.2.5.3).

6.3.2 Providing degrees of service

The participants exchanged worries about their privacy online (sections 4.3.5 and 6.1.4), and also discussed their need to moderate their interactions with online services (sections 4.3.4 and 6.1.3) whilst emphasising their desire to always be in contact with others (sections 4.3.3 and 6.1.1). Although these concerns differ, I highlight that online applications could introduce various degrees of service to better cater for users' needs: 1) stripping back layers of service, to remove meaningless or useless content displayed to users; and 2) adding analytic layers that run on top of services, to help users manage their use and online privacy.

6.3.2.1 Stripping back layers of service

As the studies revealed, the Internet provides an abundance of information which can be extremely helpful to users in their everyday lives (section 6.1.2). However, particularly for social networking sites, a lot of useless or meaningless content can also be present (sections 4.3.3 and 6.1.1). For the household participants: Kevin described having to trawl through rubbish content to access what is important, Olivia discussed the difference in content quality between Twitter (informative) and Facebook (non-informative), and Xavier has even stopped using Facebook as he claimed it is full of advertisements. For the workshop participants, Lola and Alex mentioned the useless information they are exposed to on social media. What was most important within these services for the participants was communicating with friends and family.

Given this, I suggest that HCI researchers and practitioners look to ways in which 'layers' of services can be 'stripped back' to only contain what content is most meaningful to the user. For example, in the case of Facebook, layers of imagery (images, videos, advertisements) could be removed (as the participants suggested in section 6.2.5.1) to leave only a layer of textual or informative posts from friends or family. This would keep the 'core of the service' for users, enabling them to engage in the communication they expressed as paramount (particularly in emergencies or for maintaining overseas relationships—sections 4.3.3 and 6.1.1).

This stripping back of layers could be introduced *after* a usage limit has been reached on accessing the original full-service version (section 6.2.2.1). Such lower layers of service would act similarly to the 'Lite' versions of apps that currently exist for countries with limited data access. HCI researchers could experiment whether imagery would be removed in its entirety, or whether users could 'click to load' elements (similar to Twitter Lite's *"data saver"* mode)[2] after a limit has been reached; the latter allowing for users to subjectively make decisions with purpose about what content is significant [244] or preferential [216] to them to view. Maintaining users' online privacy may also play a role here, as users would have better control of what visual content they view and therefore potentially more control of how they are tracked online (a concern that the participants had—sections 4.3.5 and 6.1.4).

Stripping back layers of services in this way may be difficult for some services (e.g. Instagram which is image-focused), however alternative forms could be introduced. For example, summaries of information could be provided rather than detailed accounts e.g. BBC's news summaries designed to be read in five minutes. Such reductions in the amount of information available may help users who experience FOMO (section 6.1.2) as they can access the 'most important' details quickly. Furthermore, HD streaming could be stripped back to SD streaming e.g. imposing limits or celebratory-only instances (cf. [121]) of HD streaming but more access to SD; enabling users to still stream content in meaningful ways (e.g. with family and friends [154]) without putting as much pressure on the Internet infrastructure or potentially causing significant 'digital waste' (e.g. as users use YouTube to listen to music [211, 299]). This again follows ideas utilised by 'Lite' versions of apps: as noted in section 5.5.3, YouTube Go enables users to select the different qualities or data use for each video they watch.[3] Such designs would moderate Internet use whilst strengthening the value associated with meaning elements in Internet-connected practices.

6.3.2.2 Adding metadata layers

Workshop participants were aware of the online privacy issues occurring in society today: they questioned whether service providers should be trusted, and they were conscious of being tracked online (section 6.1.4). Similarly, the household participants were confused about what their devices were actually doing in the background (section 4.3.5): it was unclear to them why their logged network data didn't seem to coincide with their use of devices and services (Gemma, Martin, Ben, Julie, Heather, Nick, Peter), and the domain names that the devices accessed were often unknown (Fred, Ian, Olivia, Rachel, Sally). From these misunderstandings, household participants were then asking questions about *their own* devices' data access that they wanted *me, the*

[2]Twitter Lite: **https://play.google.com/store/apps/details?id=com.twitter.android.lite&hl=en_GB**, accessed October 2019.
[3]YouTube Go: **https://youtubego.com/**, accessed October 2019.

researcher, to answer (e.g. Rachel). As I note in section 3.2.3.1, even participant recruitment for the household study in the first place was difficult: the fact that the study would log and see their network data, particularly the domains they accessed, was very off-putting for some households. Yet, ISPs already have access to this sensitive data.

The lack of awareness or understanding about data transmission and its accountability is concerning. This is not a shortcoming of the participants. Rather, it is an outcome of the design goals and abstractions made in digital system design (see section 4.4.1). There are a number of calls for increasing transparency and control within design to promote privacy [115, 122, 242, 381], ensuring that users are *"better positioned to make decisions that meet their privacy and functionality expectations"* [396, p. 10] or fully informed about privacy and security issues when purchasing devices [108]. With this in mind, I suggest that layers could be *added* onto services to provide 'metadata' about what information is being captured from users' interactions with online services—providing *"notice"* of what the service is doing [205, p. 8] in the moment. This would help alleviate the confusion and concerns that the participants faced, and create greater trust between service providers and users through openness.

Inspired by the design workshop, feedback layers could be implemented that facilitate awareness and reflection (section 6.2.1), showing what data the service provider now has (and how they might use it) based on the user's interaction. Designs following this idea would need to ensure they work across services, as service providers share data across their platforms; this therefore may require displaying full network traces as a user-friendly 'step-by-step' guide on how the data might have been shared across linked platforms. Creating metadata layers would also be useful beyond improving users' online privacy. With more information of how users use their services, as well as how services utilise this information, users can be empowered to better control their usage overall. As Caleb highlights (section 6.2.1.1), making data more open may lead to users potentially becoming less inclined to use the service. This could then have benefits for preventing overuse (sections 4.3.4 and 6.1.3) and promoting the use of services solely when the interaction is important or adds value to elements of meaning in their digitally-enabled practices [338] (sections 4.3.3 and 6.1.1).

6.3.3 Creating more carrots, and less sticks

The workshop participants were mindful of creating designs that promoted moderate and meaningful interactions with devices and services in a way which *gave* something to the users ('carrots'), rather than taking something away from them ('sticks'). This idea of carrots, rather than sticks, was an important aspect to Samir, Lola and Greg when they were designing for moderate interactions with services (section 6.2.1.2). In addition, designing for carrots is most apparent in section 6.2.4, where the participants focused on: providing users with the benefits of real-world interaction and support (section 6.2.4.1), creating fun games and healthy competition (section 6.2.4.2), and rewarding users with incentives and gifts (section 6.2.4.3). Increased *"social-supporting techniques"* have been called for in digital wellbeing tools [248, p. 12], and so these positive designs are an obvious starting point for improving such tools.

Given the importance of positive framing for the participants, I suggest that HCI researchers and practitioners looking to create more moderate interactions with devices and services should focus on designs that emphasise the *"mores"* that they bring, rather than the *"limits"* they create [146]. This need for positivity has been suggested within sustainability literature [224], and I echo this for additional research areas: digital wellbeing, relationships, work productivity, and online privacy. This may 'simply' mean creating and testing some of the designs the participants outline in section 6.2.4; or even the feedback designs in section 6.2.1, as they empower users with the tools to think and make decisions *themselves* rather than having decisions made by technology on their behalf (e.g. section 6.2.5).

However, there are other examples where a positive framing might enable further adoption of such designs—particularly in regards to designs utilising contextual data (e.g. section 6.2.3). For instance, Balto's design incorporating contextual information of device use whilst falling asleep (section 6.2.3.1) would be a way in which technology can be shown to 'help users sleep'; and Alex's fidget spinner design (section 6.2.3.1) would help users manage their use of devices and services in a way that doesn't necessarily require further trackers or software on their devices—a potential win for both user privacy and Internet sustainability, avoiding additional data demand from transferring and storing users' use of online services and digital devices.

Furthermore, the participants highlighted that designs which were spatially and temporally-aware could reduce procrastination (section 6.2.2.3), as well as improve co-worker relationships, teamwork and productivity (section 6.2.3.2). Carefully designed interactions that utilise awareness for these contexts may therefore be a prime opportunity for reducing the negative impacts of devices and services, without causing inconveniences for users; e.g. technologies that defer notifications in the presence of others can reduce social interruptions, yet the delay is mostly unnoticeable [285].

6.3.4 Embracing benevolent deception: dark patterns for good?

To create moderate and meaningful digital interactions, the workshop participants suggested designs that involve forms of 'trickery' or deception to the user. These feature in section 6.2.5 (e.g. colour modification, increased battery draining), most specifically with the designs to produce finite content and feelings of sufficiency (section 6.2.5.3). The participants recommended that services could show users content they have already seen, particularly as they spend more time on their devices or services. This was discussed in terms of scrolling on social media, as well as for homepages on services where the user would have to potentially 'search' for new content rather than having the content displayed to them directly (e.g. the next episode on a streaming service may not be advertised, although it is available). Ross and Felix considered that users may feel less entitled to their use of devices and services if they are *not informed* of the design restrictions.

Research in HCI has produced recommendations and guidelines for encouraging changes in behaviour through technology design, predominantly by creating *"persuasive designs"* [123]. Design of modern day services can turn those strategies against users by subversively promoting behaviour that is undesirable in the long term for the user, but profitable for the provider. Inspired by Alexander's pattern language [5], Brignull coined the term *"dark patterns"* [55] and collected such intentionally unethical design patterns [56]. For example, in the design of games, dark patterns have been noted to cause users to spend more or less time or money on a game than they would expect, or even utilise social experiences to promote a game and encourage use that isn't always wanted (e.g. users using a game as they feel socially obligated) [402].

Yet, given the design ideas the participants highlighted, I contemplate whether 'dark patterns' could be used for users' 'greater good'—helping combat the negative effects I have highlighted in the related work (section 2.2) and findings (sections 4.3 and 6.1). And if they were used for positive reasons (e.g. preventing perceived overuse of technologies [145], avoiding binge-watching [95]), then would they still be classed as 'dark' patterns? Such designs would indeed trick users into a certain behaviour, but for their own good—therefore, while still being deceptive, some form of benevolent deception; a dark pattern 'for good'. Cox et al. [90] have pointed out that 'micro-boundaries' contrast with dark patterns, as they do not aim to push undesired use of devices or services. However, the design frictions that Cox et al. discuss (e.g. users taking photographs of food to support healthier dietary decisions [403]; users using different mail clients to avoid work email out of hours [67]; and testing interface lock-outs to improve data input accuracy [136]) all involve the user being aware of the intervention and interacting with it. This was not necessarily the case for the interventions that the participants discussed. Instead, users would be tricked or deceived; therefore I see stronger links to dark design patterns than this prior work.

6.4 Challenges beyond UX

From both the household study and the workshop, there are lots of opportunities for HCI to combat the negative effects of digital devices and online services through more moderate and meaningful interactions—noting the design recommendations I see most viable. However, as I have noted in prior chapters (e.g. sections 4.4 and 5.4.3), there are many challenges to facilitating these designs that go beyond 'just' user experience; some of which were highlighted by the participants themselves (see section 6.2.7).

6.4.1 Who has the power?

The designs discussed in this chapter have obvious contradictions with how business models currently work. Businesses typically want you to spend more time on their services, and often create hooks (or *"triggers"* [123, p. 3]) to draw users into performing a particular action (e.g. buying a product, viewing an advert). This makes it difficult to design for moderate and meaningful digital interactions, as designs are unlikely to be adopted if they act against profit and business stability. It also takes power away from the HCI community to *really* make significant changes towards mitigating the negative effects of devices and services—similar to how current marketing strategies raise difficulties for reducing data demand (section 4.4.2). Given this, I see a number of options going forward for the HCI community to recapture such power: 1) collaboration with businesses; 2) developing 'add-on' technology; and 3) intervening through policy.

Firstly (and building on my implication in section 4.5.3), we will need to collaborate with companies to discover how moderate device and service design can work for their business and for users. This would allow for the different compromises between businesses and users to be established, and highlight what specific designs can or cannot be deployed. Tools (cf. [157]) and research calls to push a digital wellbeing agenda forward have been made by service providers (e.g. Facebook research's focus on understanding Instagram users' wellbeing [116]), and I encourage the HCI community to leverage these opportunities for holistically designing against the *multiple* negative effects associated with devices and services. Furthermore, to overcome the marketing challenge discussed earlier in this thesis (section 4.4.2), there is potential in using reasons for moderate use of devices and services as a compelling advertising approach for businesses. For example, data privacy has become an effective marketing strategy [229], despite data mining providing businesses with in-depth information about users (especially for targeted adverts). This is also inline with the responsible gambling strategies Ross mentioned (section 6.2.2.1).[4]

Secondly, we can achieve some of the designs through 'add-on' technology, rather than directly modifying the devices or services themselves. This is similar to: how previous HCI researchers have deployed interventions to digital consumption [278], how productivity tools (e.g. StayFocusd, Forest) currently work, and how some of the participants designs could be envisioned (e.g. section 6.2.4); they are tools to prevent the use of *other* services. Taking the example of Internet speed bumps (section 6.3.1), blocking Internet use at specific locations may require separate signal blockers that can be located through the home or workplace; these would exist instead of location-triggered throttling of bandwidth on devices. Yet, I acknowledge that, in some cases, it may be better not to design added technology at all [30, 289] e.g. the signal blockers could have implications for sustainability if they become obsolete [84, 306].

Finally (and building on my implications in chapter 5), I note the importance of policy intervention for this topic to enforce businesses to comply with ethical technology designs. There have already been calls for online services and the Internet to be legislated in the UK [11, 228], and the HCI community should take advantage of these for the development of this work. However, as highlighted in section 5.5.3, engaging with policy comes with its own challenges as HCI researchers may then need to: create robust evidence bases [355], spend significant time and effort understanding policy documents and language [368], and create structural events in HCI for policy (e.g. workshops) with different professionals in this space [355].

6.4.2 Workarounds and cheating the system

As the participants noted, users may find ways to workaround any designs which aim to moderate their digital interactions. For example, Jasmine's battery draining design

[4]Sky Bet's 'Responsible Gambling' tools: `https://m.skybet.com/lp/responsible-gambling`, accessed October 2019.

(section 6.2.5.2) could lead to users carrying around chargers or battery packs. Additionally, if a user had exceeded a device or service limit, they may uninstall the limiting design or even create alternate accounts to start a 'fresh' record (as Zane discussed, section 6.2.2.1). Users may also find ways to cheat designs involving gamification and incentives: e.g. if users were given incentives or involved in competitions to spend time offline (section 6.2.4), they may find ways of accessing online services through devices which are not theirs or are not logged.

The ability to find workarounds and cheat the system soon becomes an issue of how much control we give to technology instead of users. We certainly *do not* want to take autonomy from users, but rather help them create a level of device and service use that is most positive and beneficial for them long-term. This is an extremely tricky tension to balance, particularly as the technology we create today can lead to developments in the future that would've previously been seen as unacceptable or unnecessary [290]—and so in that sense, through interventions like these, we are perhaps enabling technology to have more control in the future. In fact, I contemplate whether there's a limit to what moderate and meaningful digital experience designs can achieve: if the user ultimately chooses to uninstall a design, or even to just ignore the design, it is ultimately *their decision* to do so.

However, to avoid addictive behaviour, constant checking and technology overuse (sections 4.3.4 and 6.1.3), *and* the associated data demand, I suggest that: if the user has consented, software could potentially override user decisions in the short-term (e.g. an hour). Future work would benefit from exploring the issue of autonomy and control in relation to moderate and meaningful digital experiences, particularly to find out what kinds of control are most acceptable for users. HCI researchers and practitioners also need to understand exactly what device and service use is deemed negative by users in the moment—adapting for different temporal and spatial contexts, and ensuring that the intervention actually targets addictive behaviour rather than *"simply parroting an addiction narrative"* present in the media [204, p. 180:3]. Regardless of the intervention, the HCI community should be careful to ensure that users can always access emergency services or contact friends and family (sections 4.3.3 and 6.1.1).

6.4.3 Complexity and unintended effects

There are a number of complexities, and potentially unintended effects, when designing against the negative impacts of devices and services—some of which can seem contradictory. For example, as the participants highlighted, it may seem somewhat silly to introduce *more* devices or services when users are trying to cut down on their use of these technologies (e.g. the gamification designs usually involved creating another app for users to use—section 6.2.4.2). Furthermore, adding metadata layers may be worse for data demand and sustainability if the addition of transferring privacy information does not lead to significant reductions in overall service use. Similar to the discussion in section 5.4.3.3: these designs could therefore be adding to the problems I have highlighted, causing negative unintended effects that rebound on users, society or the environment. Such contradictory notions and trade-offs have been found in sustainability work: giving users smart energy monitors to better manage their energy consumption can actually lead users to view their energy access as unlimited, or make them feel that they are entitled to such use [151, 362]. My consideration of this work is perhaps a reason why I argue for design recommendations (section 6.3) that focus on adapting current interaction designs, rather than creating more devices or services for users to manage.

As the designs and the HCI themes I target are tightly interwoven, I am conscious that unintended effects or conflicts can be created across concerns I discuss (i.e. digital wellbeing, work productivity, relationships, online privacy, environmental sustainability). For example, the participants' gamification designs (section 6.2.4.2) focus on improving users' wellbeing and their relationships through healthy competition. However, such gamification could potentially cause rifts between families or friends as they compete—damaging relationships instead of encouraging users to spend more time together. Moreover, unintended effects could occur at a societal level—particularly with privacy. For example, the location-based designs (section 6.2.3.2) suggest the use of physical spaces to determine whether the user can access devices or services; this could require 'big brother' tracking that may potentially be used for other (and perhaps unethical) purposes by service providers, or even by governments (e.g. in social credit systems [209]).

This challenge of mitigating negative unintended effects is worth considering when designing for moderate and meaningful digital experiences. A possible avenue forward would be to anticipate [360] and acknowledge any potential unintended effects of the design recommendations as they are initially tested and evaluated in future work [307]. These can then be followed by longer-term studies with the most successful designs to attempt to anticipate, or alleviate, any unintended effects [401].

6.5 Holistic design for overlapping HCI concerns

As I have highlighted in this chapter, there are a number of HCI themes that overlap when designing for moderate and meaningful digital experiences. This means that many of the negative effects of devices or services (including the sustainability of data demand) could potentially be diminished by the same (or similar) designs. In table 6.3, I provide an overview of the design recommendations and how they link to the different HCI themes I have investigated; each design has 'primary targets' (i.e. HCI themes they closely link to and would most likely affect) and 'secondary targets' (i.e. themes that could still potentially be affected by the design). This is based on the strength in which each design recommendation (section 6.3) links to the participants experiences (sections 4.3 and 6.1) and therefore the HCI themes I explore. I suggest that researchers conducting future work in this area should choose the designs based on their primary target, and ensure that they also evaluate the other themes in order of their prominence. For example, researchers working in privacy could look to creating the 'adding metadata layers' recommendation; from this, they can also scrutinise how the design affects wellbeing, before evaluating the secondary targets (productivity, sustainability, and relationships).

Design recommendation	Primary targets	Secondary targets
Barriers to entry	Relationships, wellbeing, productivity	Sustainability, privacy
Ease of exit	Wellbeing, productivity, relationships	Sustainability, privacy
Stripping back services	Sustainability, wellbeing, privacy	Productivity, relationships
Adding metadata	Privacy, wellbeing	Productivity, sustainability, relationships
More carrots, less sticks	Relationships, wellbeing, productivity	Sustainability, privacy
Dark patterns for good	Wellbeing, productivity, sustainability	Relationships, privacy

Table 6.3: The design recommendations and the primary or secondary HCI themes that they target. Themes are also ordered in terms of prominence to the design.

Extending beyond creating moderate and meaningful digital experiences, I urge the community to embrace holistic approaches to design for overlapping concerns in HCI, i.e. to consider multiple concerns at the same time during design processes. This follows calls for holistic approaches *within* specific subject areas [25]; yet I suggest broader approaches *across* HCI themes (e.g. privacy, wellbeing, sustainability) are required. To encourage holistic approaches, research paper submissions (e.g. for the top HCI conference, CHI) could include a mandatory 'holistic assessment' paragraph—detailing how the research overlaps or impacts other HCI themes. This builds upon a previous suggestion from the ACM's Future of Computing Academy to ensure users think about the negative impacts of their research,[5] and will drive researchers to think more broadly about the implications of their work. Such considerations would be particularly useful for sustainability: SHCI is often seen as segregated from HCI [345], therefore embedding this review of sustainability into other HCI themes is a positive step forward for ensuring *all* computing innovators think about climate change.

Adding to this systemic change, I suggest that the HCI community should look to ways in which we can make it easier for researchers to use holistic evaluation processes, such as that defined by Remy et al. [307]. They offer a five-step model to guide the process of evaluation, which involves identifying 'mechanisms' that designs affect, as well as the 'scope' for those mechanisms in the evaluation process [307]. To avoid potentially repeated work (i.e. many researchers investigating all mechanisms), I suggest that future work could involve creating literature-style reviews which provide an inventory of the implications crossing different themes in HCI, as well as the frameworks or evaluation techniques within these areas (e.g. the 'Motivation, Engagement and Thriving in User Experience' model discussed in digital wellbeing [288], Mekler and Hornbæk's meaning framework [244]). This would include the work I have explored (e.g. productivity, privacy, relationships, sustainability, meaning) as well as other themes (e.g. health, aging, social justice). Whilst this would be an extremely difficult and time-consuming task, it could be beneficial for catching and mitigating interwoven issues in HCI—such as designing for moderate and meaningful device and service interactions.

6.6 Summary

In this chapter, I have explored the notion of designing for moderate and meaningful digital experiences. Through this, the HCI community can create device and service interactions that reduce data demand in ways that users want—combating the negative impacts technology has on environmental sustainability as well as users themselves

[5] ACM Future of Computing Academy blog: `https://acm-fca.org/2018/03/29/negativeimpacts/`, accessed October 2019.

(e.g. on users' digital wellbeing, work productivity, relationships and privacy). Specifically, I have: built on the findings in section 4.3 to further uncover users' current digital experiences and highlight where users attribute value to the meanings behind their everyday practices involving technology; and designed with users ways in which we may create more moderate and meaningful uses of digital devices and online services. From this, I have outlined a number of specific design recommendations that the HCI community can develop and evaluate: putting up barriers to users (re-)entering devices or services through Internet speed bumps, and ensuring easier exits to device and service use; stripping back layers of service to retain users' most meaningful actions online, or adding layers to provide metadata on their interactions; providing more 'carrots' and less 'sticks' when designing for moderate interactions with digital devices and services; and deceiving users for reasons of their greater good, perhaps through 'dark patterns for good'.

Furthermore, I have highlighted the challenges (building on prior discussion in chapters 4 and 5) that HCI researchers and practitioners will encounter when working in this space, and suggest a number of avenues to overcome these difficulties in future work. Given the potential impact of my design recommendations across HCI themes, I emphasise the importance of embracing a holistic approach to designing for overlapping concerns in HCI. By working across HCI themes (e.g. sustainability, digital wellbeing, etc.) we can create device and service interactions that work best for both the environment and society.

They say I’m a nihilist ’cause I can’t see any
decent rhyme or reason for the life of you and me.
But I believe in what I’m feeling,
and I’m firing for you.
This world is gonna end, but till then
I’ll give you everything I’ve got.

—SAM FENDER

Chapter 7

Conclusion and Future Work

Through the PhD—over three years of intense, but exciting, research—I have deeply investigated the demand for Internet data, and sought opportunities for reducing its impacts through HCI design. This chapter concludes this work, and marks an end to a significant point in my career. I provide a review of the aims of this thesis and a summary of the contributions of my research; this highlights how I have been able to add to academic knowledge in HCI. I then summarise the discussion and implications from chapters 4, 5 and 6, presenting next steps for those in the HCI community that aim to further understand, and mitigate, both the societal and environmental impacts of Internet demand in everyday life.

7.1 Review of research aims and contributions

Prior to this thesis, the HCI community had a limited understanding of how data demand is formed in everyday life. While large-scale statistics of network traffic exist, they do not uncover nuances needed for transitioning and mitigating the environmental, and user, impacts of data demand through HCI design. As a result, the overall goal for my thesis was *to better understand the impact of data demand and how we may reduce reliance upon it in everyday life for a more sustainable, and desirable, future for society* (chapter 1). Given this, the aims of my research were as follows:

1. Explore home and mobile device network traffic to understand how devices and online services are used both spatially and temporally in everyday life, and discover how this Internet connectivity supports people in meaningful ways.

2. Discover opportunities for the SHCI community and broader stakeholders (e.g. policy makers), to reduce Internet demand whilst positively affecting society.

Throughout this thesis, I have met these aims by contributing to academic knowledge in each chapter. In chapter 4, I provide a detailed overview of data demand through analysing both a large quantitative Android dataset of mobile devices (smartphones and tablets), and a mixed-methods study of home Internet demand. From this, my contributions are as follows:

- I provide the most comprehensive quantitative and qualitative understanding of data demand in everyday life to date; revealing how data traffic occurs through time, in the home and on-the-go, on different devices (e.g. mobile devices, smart TVs, laptops, games consoles), for different activities (e.g. watching, communication), on both large-scale and fine-grained datasets.
- I have demonstrated that watching is the largest category of data demand (72% of household traffic, 21% of Android device traffic) for users' Internet-connected devices. I also reveal the other data demanding online activities in users' everyday practices: gaming, social networking, communication and listening. I argue that these are the traffic categories that the HCI community needs to investigate and target for mitigating the environmental impacts of users' online service use.
- I uncovered that updates and installs for software and applications are contributing significantly to Internet demand in the home (5.2% of household traffic and the second most demanding category); these mostly occur during users' waking hours and my participants pointed out that they do not always want to install their updates due to issues of trust. I have presented opportunities for the HCI community to shift and reduce the data demand from updates through interface design changes and introducing multiple, concurrent update streams.
- I highlight the issues associated with researching data demand and aiming to mitigate it in everyday life. I express the need for the HCI community to seek collaborations with businesses and ISPs, in order to gain a complete picture of traffic and discover how reduced data demand can be incorporated into business models.
- I have revealed my participants' perceptions and experiences with digital devices and online services, and shown that there are aspects of Internet use that users

find more meaningful (e.g. communication) or frustrating (e.g. social media) than others. Some of my participants already voluntarily constrain their Internet use for reasons of wellbeing and work productivity. I present the notion of designing for sufficiency by creating more moderate and meaningful digital experiences—aiming to reduce data demand in ways that users may appreciate.

In chapter 5, I build on this exploration of data demand by delving into the practice of *watching* via video streaming in the home. Specifically, I contribute the following:

- I have analysed both the quantitative and qualitative data from the household Internet study to reveal the new ways of watching films, TV programmes and video clips in the home—all contributing to an unsustainable growth in data. I have identified new norms of watching that the HCI community need to target: streaming (and particularly YouTube) are becoming the default ways to watch content; users often engage in multiple online activities concurrently across devices through media multi-tasking and multi-watching; and users are not always enjoying, or fully paying attention to, the content they stream.

- I have discussed opportunities for the HCI community to target and mitigate the data demand impacts from the new norms of watching: limiting watching to the least-demanding configurations (e.g. to more traditional modes such as broadcast and DVDs, to lower quality streams, or by encouraging users to engage with one digital medium at a time); and co-creating what level of video streaming is 'enough' with users to facilitate watching experiences that are meaningful and fully appreciated.

- Given the numerous (and obvious) challenges to developing Internet interventions for video streaming, I add to the discussion of challenges in chapter 4 and provide insights on how these may be confronted. These include the conflicting nature of HCI and SHCI research; the technical and implementation challenges to limiting Internet use; potential rebound effects on the environment if users were to stop streaming; and the difficulty of reducing data whilst all-you-can-eat and binge-watching subscription models exist.

- I have highlighted how HCI researchers and practitioners need to engage wider stakeholders: 1) network engineers, to better discern the network impacts of service design and recommend SHCI changes to remove significantly data-intense designs; and 2) policy makers, to ensure they are better positioned to introduce regulation for data-intensive service design—particularly since promoting more sustainable video streaming would seem to contradict net neutrality.

Through a workshop that explores the idea of 'sufficient' Internet use by designing for moderate and meaningful digital experiences, I produce the following contributions in chapter 6:

- Building on the participants' experiences outlined in chapter 4, I further explain how there is a variance in meaning for users' digital device and online service use. I have shown how my participants enjoy the availability of content, yet that there is potential for the Internet to overwhelm, drive overuse, and raise issues of trust or feeling tracked. These confirm the potential to reduce data demand in ways users may actually want.

- I present numerous Internet intervention ideas that have been *designed with users*. These followed categories surrounding: presenting feedback and enabling awareness of users' device and service use; setting limits to such use; utilising users' physical and spatial awareness; merging virtual and real-world experiences; reducing the user experience of device and service designs; and integrating multiple of these design categories for a more cohesive intervention.

- Adding to the challenges in chapters 4 and 5, I discuss the problems (and the potential solutions) for creating moderate and meaningful digital experiences: the difficulties of ensuring businesses co-operate with this notion; ensuring users' autonomy for cheating Internet interventions, whilst also controlling users' device and service use through usage restrictions; and the unintended effects of introducing moderate and meaningful digital experiences, particularly those effects which contradict the initial purpose of the design.

- I establish the importance of embracing holistic design for overlapping concerns in HCI, specifically for the issues that Internet connectivity brings to users' well-being, work productivity, privacy, relationships with family and friends, and environmental sustainability. I provide specific design recommendations that aim to address all of these societal and environmental concerns—a novel, holistic approach to prior work in this domain. These recommendations, building on subject-specific work, consist of: creating Internet frictions to device and service use, and flows for ending use; providing 'degrees of service'; creating 'more carrots and less sticks'; and embracing benevolent deception in design through 'dark patterns for good'. I encourage the HCI community to embrace this holistic design approach and offer suggestions for evaluating this design space.

7.2 Future work

In this section, I utilise my findings, discussions and implications across chapters 4, 5 and 6 to provide suggestions for future work. These are opportunities—beyond the scope and contribution of this PhD thesis—for the HCI community to explore to further understand and mitigate data demand in everyday life.

7.2.1 Target other data-intensive activities

In chapter 4, I provided a detailed overview of data demand in everyday life. This identified specific data demanding activities that we need to target in SHCI for reducing the continuous growth and environmental impacts of the Internet: watching, gaming, social networking, communication, and listening. Given that watching was the most significant contributor, I delved into this practice in chapter 5 to uncover the new norms and ways that this activity is becoming more data-intensive in everyday life. Whilst the design recommendations in both chapter 5 and 6 will, and do, apply to data demanding activities other than watching, it's important that HCI researchers and practitioners gather a complete picture of how these other activities (i.e. gaming, social networking, communication and listening) are transitioning in more data demanding directions.

Investigating data demand for specific practices would provide a more in-depth, nuanced understanding of how data may be reduced in these areas. It would also enable opportunities for SHCI researchers to better analyse the histories of these practices and prior HCI work surrounding them—highlighting how reductions may be embedded in this work and, somewhat strategically, 'force' the wider HCI community researching these categories (like streaming or gaming) to consider publications from this SHCI work. Reflecting on my two CHI publications: my CHI 2017 paper [392] providing an overview of data demand speaks heavily to SHCI; whereas my CHI 2019 paper on watching [393] is directly relevant to wider set of work in HCI investigating streaming. As previous work [345] and my thesis has highlighted, HCI and SHCI often conflict and at times exist as separate research areas. Deeply investigating other digitally-reliant practices and how these link to broader HCI research is therefore a valuable avenue for future work.

7.2.2 Collaborate with wider stakeholders

Throughout this thesis, it has become apparent that the HCI community needs to collaborate with stakeholders to truly understand and mitigate the impacts of Internet use. To gain a complete picture of data demand, we need to work with businesses[1] and ISPs (chapter 4) to continuously gather real-time trends of Internet use for many users; this will uncover how the demand for data is transitioning in more intensive directions over time. We also need to work with companies to ensure that current and new technologies are developed and marketed responsibly (chapters 4 and 5), finding ways that devices and services can work better for business, society and the environment (chapter 6). In addition to companies, network engineers who facilitate and steer QoE should be involved heavily in new HCI designs (chapter 5)—helping unravel the potential network impacts of services, and enabling closer consideration of the overlap between the network infrastructure, online services and HCI design. As the issue of reducing data demand will no doubt always conflict with business models in some way, the HCI community should also develop robust evidence bases and engage with policy makers (chapter 5) to take better control over the Internet's unbounded growth and its impacts on users and the environment (chapter 6).

As I have highlighted in chapters 4 and 6, HCI academics should aim to pursue project opportunities that involve partners who are significant contributors to the development and promotion of digital devices, online services and the Internet infrastructure (e.g. Google, Amazon, Facebook, Netflix, BT, Three). This may mean carrying out a research project focusing on one specific concern (e.g. Facebook's request for well-being research for Instagram [116]), and holistically researching *other* concerns, like sustainability, as they overlap (chapter 6). Other opportunities (e.g. competitions [368], impact workshops) with government bodies would also be useful for research into regulating the Internet—a call that technology pioneers themselves are arguing for [11]. Given this, the HCI community has never been better positioned for reasoning the need for further investigations into the negative impacts of the Internet.

[1] Businesses that work on the development of IT and Internet services.

7.2.3 Develop and evaluate Internet interventions

This thesis has provided a number of design recommendations for the HCI community, all aiming to intervene with the demand for Internet connectivity. Chapter 4 suggests how to shift and reduce the data demand from updates, chapter 5 offers opportunities to reduce the growing demand for video streaming, and chapter 6 provides a selection of designs that aim to promote both moderate and meaningful use of digital devices and online services. There is an obvious next step for the HCI community to trial and test these [299] *in-situ* with users—much like prior ubiquitous intervention studies in both HCI and Sustainable HCI (e.g. [51, 74, 80, 89, 278, 347]).

HCI researchers and practitioners need to develop concrete, and evaluative, studies that uncover: *what* the most effective interventions are for reducing the negative impacts of technology; *who* is most suited to different interventions, highlighting their experiences of moderation and meaning; and *where* and *when* they are most appropriate to deploy, both from a societal and an environmental standpoint. As in my home Internet study (section 3.2), mixed-methods approaches to these intervention studies would be a valuable methodology for exposing this detail—allowing for an in-depth qualitative understanding of how users perceive interventions, as well as a quantitative assessment of how the design *actually* impacted their device and service use.

Initial short-term studies should be trialled e.g. for two to three weeks (including an analysis of any potential rebound effects [307]) before attempting the much needed, longer-term studies (e.g. three to six months) with the most successful interventions; this will help overcome issues of users' workarounds and rebound effects (as outlined in chapter 6). In these later studies, the HCI community should research the following: multiple user groups; the variation in needs between these user groups; and how users change their habitual use of devices, services and interventions over time—this will help overcome the previously highlighted concerns with SHCI research [60].

7.2.4 Moving beyond the 'now', to the future

Gauging an understanding of data demand in HCI has so far focused on current, domestic use—both in prior work [25, 211] and this thesis. Whilst the demand for data is considerably formed from video streaming (chapter 5) and other data-intensive online activities (chapter 4), there are additional technologies and movements which will only add to these concerns of data demand: the Internet of Things; smart homes; delivery drones; connected cars; smart cities; and cryptocurrencies like Bitcoin [96]. These are technologies that are still emerging and may become more prominent in the future, therefore it's important we understand the *future implications* of data demand.

This futures-based understanding is also required for the user impacts of technology. For example, digital wellbeing research is relatively new (cf. [68, 248]), and major technology firms have 'only just' (in the last few years) started to combat the negative impacts that their technologies and online services have introduced to users' mental health [9, 373]—this is despite smartphone use and Internet connectivity becoming the norm in the last decade [271]. But will the introduction of digital wellbeing apps be enough? Will these enable new ways for technology to take control of humans? How will innovation in technology impact our wellbeing in the future? How will IoT, for example, add or alleviate mental health concerns? We are arguably so busy focusing on understanding and fixing today's problems, that we may miss tomorrow's.

Given this, I suggest that research should investigate and mitigate *future negative impacts of technology* on users and the environment. Whilst it is difficult to predict the consequences of an ever-changing and innovative sector, the HCI community working in this space could take a much more futures-orientated approach. This may require: scoping government aims for the future of the technology sector (e.g. the UK Government's Digital Strategy);[2] using ideas of design fiction [49, 99, 104, 359], scenario-based speculations [290] or futures studies [282]; or even building on the imaginings from recent film media (e.g. Netflix's *'Black Mirror'*,[3] The BBC series *'Years and Years'*)[4] that implicate and probe the potential (often radical) futures of technology. I suggest that HCI researchers and practitioners design studies that aim to better anticipate the societal and environmental impacts of emerging technologies and concerns. This will involve working with different participatory groups over time (e.g. technologists, innovators, designers, companies, avid and sceptical users of devices or services) to question them about their current *and* future aims, concerns or viewpoints associated with technology. Through this, the HCI community can aim to 'catch' issues of design or technology concerns early, helping *prevent* any potential negative impacts on users and the environment.

[2] UK Digital Strategy: **https://www.gov.uk/government/publications/uk-digital-strategy**, accessed October 2019.

[3] Black Mirror: **https://www.netflix.com/gb/title/70264888**, accessed October 2019.

[4] Years and Years: **https://www.bbc.co.uk/programmes/m000539g**, accessed October 2019.

7.2.5 Promote holistic approaches to overlapping concerns in HCI

As I have highlighted in this thesis, there is an opportunity for the HCI community to develop design solutions that aim to address *multiple* issues associated with the use of digital devices and online services (chapter 6). This raises an obvious opportunity for future work in the HCI community: promote, and engage in, holistic approaches to overlapping concerns in HCI. By stepping out of subject-specific fields (e.g. health, wellbeing, privacy, sustainability), HCI researchers and practitioners will be able to learn more from different perspectives of their work, as well as have more discussions and outcomes that speak to broader audiences in HCI. Previous work in SHCI has pointed out the link between, or the need to engage, sustainability and broader HCI themes [28, 114, 193, 345]. However, I want to highlight that this future work recommendation goes beyond 'just' embedding sustainability, and beyond Internet use and the scope of research in this thesis. *Any* HCI research area or concern that overlaps and interlinks with another, should require the researcher to acknowledge, consider and evaluate broader impacts of the work.

This is perhaps the trickiest recommendation for future work that I outline: considering and evaluating perhaps 'every' concern linked to an initial research intention will be incredibly difficult to do in practice. This becomes especially challenging if incorporating other HCI themes leads to a 'domino effect', requiring *more* themes to be considered. As I discussed in section 6.5, the HCI community would therefore appreciate more methodological research into addressing overlapping concerns, as well as literature reviews for designing and evaluating work across subject areas. To make this approach more feasible and accessible, HCI researchers and practitioners from different research areas are likely going to need to work together and collaboratively develop solutions. A workshop at CHI or another HCI-related conference (e.g. Designing Interactive Systems or UbiComp) would be a reasonable next step to initiate this process with experts across subject areas within HCI.

7.2.6 Action responsible thinking, development and research

The environmental impact of data demand mostly goes unnoticed by Internet users, with my participants' understanding of their technology energy use focusing on charging or powering devices. As a personal reflection from my PhD, I have had to frequently explain both at work, and in my home life, what this 'hidden' issue is. My research, and the work of others, has begun to appear in the media [208, 212, 239, 361], helping the awareness of data demand reach a broader audience. But we need to do more impactful work as a community to ensure users fully understand the implications of their digital device and online service use. For raising awareness of data demand issues, researchers have suggested adding environmental ratings to different online services and content [344]—in the hope that users will consider to demand more sustainable content. Following this notion, the HCI community should look for ways of enabling and encouraging more responsible knowledge, and reflection, during the use of technology. This crucially also applies to the technologists who *develop such devices and services in the first place.*

Given this, an obvious next step is for the HCI community is to engage in *impact* work surrounding the societal and environmental impacts of technology. This may involve collaboration with other computer scientists and educators, alongside software engineers, to: 1) engage in teaching activities that promote the knowledge of societal and environmental impacts of technology; and 2) create development processes or tools so that technology can be created more responsibly. For the former, we need to devise courses for schools, colleges, universities and post-education training (e.g. through the Interaction Design Foundation)[5] that inform the current, and next, generations of the ICT sector about the broader impacts of technology—similar to how researchers have already begun to ingrain issues of sustainability into higher education [113, 163]. Regarding the latter, researchers in HCI or software engineering could work to develop tools, or processes, that inform programmers and designers of the potential implications of their technologies under development—following a requirements engineering approach for embedding sustainability within software design [39]. In this sense, developing new devices or services should undergo rigorous decision-making, meaning the impacts of the technology are considered and alleviated *before* a product or software hits the market. Through both of these impact-focused directions, we can drive more responsible [27] thinking, development and research in the future of technology.

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Appendix A

Home Internet Demand Study: Participant Information Sheet

Participant Information Sheet: Informative Study
Transitions in everyday practice and Internet intensity

We are conducting a study into Internet and device usage at Lancaster University and would like to invite you and your household to participate. This sheet will inform you about the study and what participation will involve. We hope this sheet provides you with a full understanding of the study and your household participation, but if you have any questions then please do not hesitate to contact the researcher: k.v.widdicks@lancaster.ac.uk. For further information about how Lancaster University processes personal data for research purposes and your data rights please visit the following webpage: www.lancaster.ac.uk/research/data-protection.

1. Aim of the research:

The aim of this research is to understand Internet and device use both in, and out of, the home in everyday life. Through the deployment of a router logging tool, mobile device logging software and socket monitoring technology alongside qualitative data capture, we aim to discover ways in which peoples' use of the Internet and devices can be adapted to reduce the associated energy demands and therefore become more sustainable.

2. Study involvement:

It is completely your household's decision whether you all participate within this study. You and your household may withdraw at any point during the study, and up to 3 months after the study, without giving any reason. By withdrawing from the study, any data logging equipment (see section 3) deployed in your home or on your devices will be removed. All data collected during your study will also be deleted; this will involve shredding all physical copies of your data and deleting all electronic copies of your data (e.g. interview audio files and the transcriptions – see section 3) from any storage media we use in the study (i.e. the secure, password-protected server, the researchers' encrypted, password-protected laptop, or the logging equipment). However, if you decide to withdraw once a submission for a publication is made, it may not be possible to remove your anonymised data from such publications (see section 6.2). Furthermore, the withdrawal cut-off point is 3 months, as it is highly likely that your anonymised data will have been made public through publications, presentations, or discussions with other researchers and colleagues in the field or at Lancaster University by this time.

If during the study you, or your household, require more information or clarification, then please contact the researcher via the email address given in this document where they will be more than happy to help.

With this information sheet, yourself alongside the rest of your household members will be asked to each sign a consent form ensuring you understand what is involved with the study, and that you are willing to participate. Household members under the age of 18 will require a guardian to sign their consent form for them. On the consent form, you may give a pseudonym for yourself (or participants under the age of 18 which you have signed for) to be referred to in any research paper or work that follows from this study. If one is not given, the researcher will provide one for you.

Your form of participation in the study will vary based on the types of devices you own, therefore there are parts of the consent form that may not be relevant to you; for example, if you do not own a mobile device, then you will not partake in the mobile device logging (see section 3) and so you will not have to provide your consent to the mobile device logging conditions. You should have been informed by the researcher of the form sections to which you need to consent to and these will be highlighted to you on the consent form itself; these sections are described within the "Study procedure and the participant's role" part of this information sheet. Your household should have also been given a Deployment Inventory form which lists your household devices and the software or hardware deployed for their logging within the study.

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3. Study procedure and the participant's role:
If your household decides to participate in the study, we will set up an initial meeting with at least one of you to deploy the appropriate software and hardware within your home and on your device(s). Please refer to your consent form, or to the researcher, to confirm the technology which will be used within this logging phase. These may consist of the following:

- **Home router recording.** To understand your household's use of the Internet within the home, home router logging technology will be deployed to collect quantitative data surrounding Internet use of all devices. Details of the data logged via home router recording is shown in appendix 12.1.
- **Socket monitoring.** To collect data surrounding the use of other devices in the home, for example a TV, socket monitoring technology will be deployed. These will consist of smart plugs (one per device), connected to a small, Wi-Fi connected computer which we will leave running within your home. The smart plugs work similarly to travel adapters as they fit between the socket and the plug. You may use your sockets as you normally would, however we may require that some of these are left on for the duration of the study for the system to work. Details of the data logged via socket monitoring is shown in appendix 12.2.
- **Mobile device logging.** To gather information relating to your household's use of mobile devices and the Internet on-the-go, logging apps will be installed on each participant's smart Android or iOS devices, i.e. smartphones or tablets. These will either be installed via an app store, or installed directly by the researcher. Details of the data logged, along with any specific information about the logging tools to be used, is shown in appendix 12.3 for Android mobile devices (using the Device Analyzer logging app) and appendix 12.4 for iOS mobile devices (using the Squirrel logging app).

Updates to the versions of software or hardware deployed may be necessary during the study, which could involve meeting if this cannot be done remotely. We require that the software and hardware specified for the study should be deployed for at least one month to fully understand your household's Internet and device use. Over this period, in order for data to be collected, any logging software must not be stopped or paused at any point. For logs to be stored on mobile devices, you should make sure that there is at least 10MB of space free on each device daily. Furthermore, if any Android device(s) in the home will involve using the Device Analyzer logging tool, you must allow the log data to be uploaded to the University of Cambridge's secure server periodically; this is because the University of Cambridge created the application, and we will access your data via their secure server.

As well as this quantitative data logging, we will also ask you to participate in at least one qualitative data gathering method. These consist of: questionnaires, a visual diary exercise, and individual and group semi-structured interviews. Any questionnaires (maximum 2) given to you during the study will be fairly short, i.e. will take less than 10 minutes each to complete, and may be completed online or in-person. The questions will focus on details about your home, your Internet and device use, and your everyday practices.

We may invite you to take part in the visual diary exercise during the logging phase. This will involve lending your household a camera for at least one week of your logging period. The camera can be optionally used to take photos or videos of anything considered important surrounding your household use of devices and the Internet. The camera, and any media on it, will be collected when the rest of the logging equipment is removed. Any media collected on the camera will be anonymised and can be deleted both before and after sharing it with the researchers.

Both before and after the deployment of logging software, we will invite you to participate in a semi-structured interview. These individual interviews will be informal, semi-structured video interviews, scheduled at a time and place that is suitable for you, and lasng approximately one-hour. During each interview, you have the right to withdraw and leave at any time without giving reason, where from this we will not use any discussion prior to your withdrawal and delete any recordings. The interview will focus on your everyday activities, exploring how your devices and Internet use are incorporated within them. Previous data captured may also be drawn upon in the interviews in order to initiate and support discussion, e.g. logged data, visual diary media and questionnaire responses. If you do not wish to participate in a video interview, then it will be audio recorded instead; you can specify your choice of recording on the consent form. The justification for interviews to be videoed is so that any clips from your video interviews can be presented to academics, policy makers and other stakeholders. Videos are generally more presentable, accessible and easier to digest by wider audiences, and therefore may enable the study findings to have a larger impact within the research field. Further details about the use of your video interviews and other visual media is described in section 4.

You may also be invited to group interviews (before and/ or after the logging period) with the rest of your household members; these will be similar to that of the individual interviews. However, the discussions will focus on sharing devices, and everyday activities and Internet use as a group. Furthermore, the whole household will have had to consent to being videoed, otherwise the interview will only be audio recorded. As with the individual interviews, you have the right to withdraw and leave at any time without giving reason, where from this we will not use any discussion prior to your withdrawal and delete any recordings. Within this group interview, we may wish to use your study data specifically when initiating or supporting discussion around device or Internet use within the household. However, you will be notified of this individually beforehand, and will have the ability to request for any information to not be shared with your household.

4. Confidentiality and anonymity:

All physical and electronic copies of your identifiable log files, questionnaires, interview transcriptions and analysed data collected in this study will be treated with the utmost confidentiality. Only members of the research team will be able to directly associate this data to you as it will be made anonymous to anyone outside of the research team; this anonymization will be achieved through the removal of any names, identifiers, or other personal information, and through the use of pseudonyms. Anonymised data may be made public through publications, presentations, or discussions with other researchers and colleagues in the field or at Lancaster University. Whist we will not anonymise audio recordings (e.g. by removing spoken names), their file names will be anonymised and they will be kept confidential as only the research team will be able to access them. In the case of videos and photos, these cannot be made anonymous if publicised with your consent; this is because these types of media may contain identifiable information, such as your physical appearance. The risks to your anonymity, and the ways in which we can maintain your anonymity, are described in section 6.1.

5. Data use and protection:

Under the EU's General Data Protection Regulation (GDPR) and the UK's Data Protection Act 2018, the lawful basis for this research is that this is a *"task in the public interest"* (see: http://www.lancaster.ac.uk/research/participate-in-research/data-protection-for-research-participants/)). It is important to note that the data collected and analysed from your study will be used in accordance with the Data Protection Act 1998. The study data will only be accessible by members of the research team but may be used in, or indefinitely kept for, future publications and presentations created by the research team. Data which is publicised will be made anonymous where possible, i.e. all data except for video or photographic media with identifiable content. We will keep your contact details for a maximum of 10 years so that we can contact you about this study or follow up studies; however, this information will not be passed onto anyone outside of the research team. You will only be contacted about follow up studies if you are happy for us to do so. After we remove your contact details, we will no longer be able to contact you for your consent for the use of your video or photographic media. As a result, we will remove any of this media which is identifiable at the same time as your contact information.

The security of data, through storage and transportation, will be maintained. Electronically stored data will be kept on a secure, password-protected server or the researchers' encrypted, password-protected laptop, and physical copies of the data will be kept in a locked draw in a locked office on Lancaster University campus. Any media stored on cameras, Dictaphones or other data capturing tools will be transferred to the secure, password-protected server, or the researchers' encrypted, password-protected laptop, as soon as the data is physically collected by the researcher (i.e. at the end of the logging phase for log data along with media from the visual diary exercise, and at the end of the interviews for audio or video recordings), and then immediately wiped from the tool.

Data transfer between devices (e.g. a laptop to a memory stick) will be encrypted or password-protected. Video or audio recordings will always be encrypted when stored, and where possible, encrypted during data transfer. If the Android logging tool 'Device Analyzer' has been used during your study, any data logged through the app will be stored electronically on the University of Cambridge's secure server; however, this will be made anonymous.

6. Risks of participation:

6.1 Identifiable data. All logged data, questionnaires, interview quotations and analysed data collected within the study and used within publications will be anonymised, therefore it is unlikely that it will be attributable to you or your household. However, it is possible that people who know you very well could identify you, e.g. through quantitatively gathered Internet usage patterns or qualitatively collected interview quotations. Visual media (i.e. the video interviews, photos from the visual diary study) will only be used for informing academics, policy makers or other stakeholders, and appropriate measures to anonymise your recorded media will be taken. These will consist of making sure you are referred to via your pseudonym, and removing any identifiable information shown or spoken such as yours or your households' names. As a result, people outside the research team may know details about your household Internet or device use alongside your physical appearance, but they should not be able to contact you or your household. Furthermore, if we wish publicise any of your visual media (i.e. videos), you will be contacted before it is made public to double check that you are happy for it to be used. You will then be able to refuse the use of your media, or request for it to be blurred appropriately. However, there is still a risk that you and your household may be able to be recognised visually or audibly once the visual media is used. It is also possible that people who view of such media may be able to link your visual profile to data presented and discussed in publications; for example, if a quote from your video interview is written into a publication, then people who watch both the video and read the publication may be able to link your face and/or voice to your anonymised data in the publication (e.g. your device or Internet usage summaries from the quantitative data logs). It is important that you are aware of these risks, so you can make an informed decision regarding your consent to video or audio-only interviews on the consent form.

6.2 Study withdrawal. You are welcome to withdraw from the study at any point during the study, and within 3 months after the study. By withdrawing from the study, any data logging equipment (e.g. home router recording software and hardware) deployed in your home or on your devices will be removed. All data collected during your study will also be deleted; this will involve shredding all physical copies of your data and deleting all electronic copies of your data (e.g. interview audio files and the transcriptions) from any storage media we use in the study (i.e. the secure, password-protected server, the researchers' encrypted, password-protected laptop, or the logging equipment). However, if you decide to withdraw from the study once a submission for a publication is made, it may not be possible to remove your anonymised data from such publications. Furthermore, the withdrawal cut-off point is 3 months, as it is highly likely that your anonymised data will have been made public through publications, presentations, or discussions with other researchers and colleagues in the field or at Lancaster University by this time.

6.3 Logged data. Although the data collected will include the names of applications or URLs of websites you are using, no detailed or explicit information about their use or their content will be logged. Therefore, it will be impossible to identify, for example, any searches you have made or any videos you have watched. This is similar to the logging of communications data: phone numbers stored through mobile device logging will be anonymised, but no contact names of those contacted by phone or SMS will be saved. While it will be possible to see that they have been used, the explicit use of social networking or IM applications will not be logged.

6.4 Group interview. If you are to participate in a group interview, we may wish to use your study data specifically when initiating or supporting discussion around device or Internet use within the household. You may consider this data personal and may feel that conversation within the group interview around this data is of a sensitive matter. However, before the group interview, you will be notified individually if any of your data is to be used during the group discussion; here you will have the ability to request for any information to not be shared with your household.

6.5 Household guests. If guests (i.e. non-household members who have not consented to the study) are present in your home at any point during the study and they use the deployed smart plugs or your home Internet connection, then their use of devices and the Internet will be logged. However, we will then remove any data from the dataset which is identifiable of guests in the house, unless their written authorisation is given to use it. It is your responsibility to make sure that guests are aware of the study.

6.6 Mobile device logging. If your study involves logging your usage of your mobile device(s), there is the risk that the logging application could have an adverse effect on battery life or running speed while the app is running in the background. Whilst the logging apps used in the study have been tested prior to installation and this impact has found to be negligible, it is possible that you may notice a difference. We do ask, however, that participants keep 10MB of storage space free daily on each mobile device for the duration of the study, to ensure that the app is able to store the log files, and in the case of the Device Analyzer, allow the data to be uploaded to the University of Cambridge's secure server so it can be removed from the phone. This could interfere with your usual device usage if you normally use up all available space.

6.7 Device Analyzer. If your study involves using the Android logging tool 'Device Analyzer' and you allow other researchers to access your data online, then your data is added to the University of Cambridge's online dataset after you have had 3 months to review it. Therefore, if you do not request for your data to be removed from the dataset via the opt-out facility on the Device Analyzer interface, other researchers may access and use your logged data anonymously. If you wish to opt-out but do not know how to do this on the app by yourself, you can request clear instructions from the researcher.

7. Benefits:

[One of the following paragraphs will be selected based on whether incentives will be provided, the other paragraph will be deleted]:

1. Whilst there are no financial incentives to your participation in this study, you will be able to more easily discover, and reflect on, your Internet and device patterns; this may enable you to make choices for energy or financial savings through reducing your mobile data or home broadband plans. Furthermore, your participation will help design choices within technology that aims to reduce the energy consumed through Internet use whilst also having a positive effect on peoples' everyday lives.

2. Through this study, you will be able to more easily discover, and reflect on, your Internet and device patterns; this may enable you to make choices for energy or financial savings through reducing your mobile data or home broadband plans. Furthermore, your participation will help design choices within technology that aims to reduce the energy consumed through Internet use whilst also having a positive effect on peoples' everyday lives. You will also be provided with a financial incentive to participate in this study. This will be in the form of a £20 voucher per participant (maximum £100 per household) and will be given to you after the study is complete (i.e. after the second interview with each participant) as a thank you for your time.

8. Project review:
This study has been reviewed and approved by the Faculty of Science and Technology Research Ethics Committee at Lancaster University.

9. About the researchers:
The research team are based in the School of Computing and Communications (SCC), Sociology, and Lancaster Environment Centre (LEC) at Lancaster University, and Aarhus University in Denmark.

Research Team:

Kelly Widdicks (PhD student, SCC)
Matthew Marsden (PhD student, SCC)
Christina Bremer (PhD student, SCC)
Adam Tyler (PhD student, SCC)
Kathlyne New (PhD student, SCC)
Dr Christian Remy (Assistant Professor, Aarhus University)
Dr Oliver Bates (SCC)
Dr Alexandra Gormally (LEC)
Dr Janine Morley (SCC and Sociology)
Dr Mike Hazas (SCC)
Professor Adrian Friday (SCC)

10. Contact details:
If you have any further questions about the study and your participation, please contact Kelly Widdicks (k.v.widdicks@lancaster.ac.uk), Dr Mike Hazas (m.hazas@lancaster.ac.uk) or Professor Adrian Friday (a.friday@lancaster.ac.uk).

11. Complaints:
If you wish to make a complaint or raise concerns about any aspect of this study and do not want to speak to the researcher, you can contact:

Professor Adrian Friday (Head of Department)
Tel: +44 (0)1524 510326
Email: a.friday@lancaster.ac.uk
School of Computing and Communications
InfoLab 21
Lancaster University
Lancaster
LA1 4WA

Thank you for taking the time to read this information sheet.

12. Appendix
In this section, details around the data logged by each data collection facility are presented.

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12.1 Home router recording.
The data recorded by this home router recording is as follows:

- Source and destination IP addresses and port numbers
- URLs/ domain names of any website accessed by each device and active time on these
- The amount of data transferred between external hosts and internal devices (MAC address, IP address and device name)
- The time and date of each log
- Error handling information

12.2 Socket monitoring:
The data recorded by this socket monitoring is as follows:

- When an appliance or device is on standby, on or off
- The amount of energy used by the appliance or device
- The MAC address of each smart plug
- The time and date of each log
- Error handling information

12.3 Device Analyzer (Android device logger):
The Device Analyzer app is a free logging tool, created by the University of Cambridge. It can be downloaded remotely from the Google Play store, where you log onto the app with a user code given to you by the researcher. The privacy section of the app allows you to choose whether to enable or disable logging GSM (Global System for Mobile Communications) cell IDs, your location based on the network cell you are connected to, or your installed and running applications. For this study, please enable the logging of installed and running applications. Your data logged is uploaded to the University of Cambridge's secure server periodically. If you do not opt-out, your data will be added to the Device Analyzer dataset after 3 months. The data recorded by this logger (by category) is as follows:
Device:

- When you turn your phone on and off
- The times when the screen is turned on and off or your device is unlocked
- The version of the operating system and the type of device
- The time and date
- The volume of the different audio streams (ringer, media volume, etc.)
- The times at which the phone is charging
- The battery level and voltage
- The brightness level of the screen and whether brightness is dynamically adjusted
- Periodic sensor readings, such as brightness, acceleration, air pressure (depending on availability)
- When the alarm clock is triggered
- When you place the device in a dock or attach a headset

Applications:

- Which parts of the logging app you use (if a user interface exists) as well as internal logging and crash reporting
- A list of markets where at least one application was installed from
- A list of installed applications and which market they were installed from **(opt-in required for the study)**
- Updates and removals of applications
- When you clear the data of an application
- The running processes and their memory and CPU usage as well as their importance
- The 10 most recently started tasks
- How much data each application transferred

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Location:
- Location based on the network cell you are connected to **(ability to opt-out)**

Phone/SMS/Contacts:
- Whether your phone is ringing normally, is silent or on vibrate
- The times when phone calls are made and text messages are sent and received as well as the number of characters per text message
- Values for the phone numbers involved (anonymised), as well as whether the number is local or international, and if it comes from a contact
- The number of contacts, and how many email and phone numbers are stored for each contact

Photos/Media/Files:
- The amount of free internal and external storage
- When the external storage card is inserted or removed
- The times when you take pictures and how many pictures you have

Connection Information:
- When you enable and disable airplane mode
- Which mode of network connectivity is available
- Whether the phone is roaming or not
- Cellular signal strength
- The amount of data transferred over 3G and Wi-Fi
- When you enable and disable Bluetooth and Wi-Fi
- Data about Wi-Fi networks (anonymised) that are in range
- Data about Bluetooth devices (anonymised) in the vicinity if another application initiates a Bluetooth scan (the logging app will not initiate a scan by itself)
- When you enable tethering or the mobile hotspot

Identifiers:
- The identifier (anonymised) of the inserted SIM card
- Anonymised GSM (Global System for Mobile Communications) cell IDs **(ability to opt-out)**

12.4 Squirrel (iOS device logger):

This app requires direct install by the researcher. The data recorded by this logger is as follows:
- The battery level
- The charging state (Phone is plugged in and charging, phone is full, phone is not charging)
- Whether or not Wi-Fi or Mobile Data (2G, 3G and LET) is active at a given point
- The number of Kilobytes of Wi-Fi and Mobile Data sent and received over the logging period
- The screen state (on or off)
- Whether or not audio is playing (from music player, video, games, alarms or ring tones)
- The audio output method (built-in speaker, headphones, external speakers or AirPlay)
- Use of external accessories and screens
- The current foreground app
- Any background processes

Appendix B

Home Internet Demand Study: Participant Consent Form

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Participant Consent Form: Informative Study
Transitions in everyday practice and Internet intensity
The purpose of this consent form is to check that you understand what will be required of you and your household if you agree to take part in the study and how any information you give will be used.

Household: ______________________ **Name of participant:** ______________________

Pseudonym to be used in research: ______________________
(Please leave blank if you prefer the researcher to select a pseudonym)

1. **General:**

Please fill out this part of the consent form.

1.1 I confirm that I have read and understood the participant information sheet for the above study. ☐

1.2 I have had the opportunity to consider the information, ask questions about the research and have had these answered satisfactorily. ☐

1.3 I agree to participate in this study and I understand that my participation is voluntary. ☐

1.4 I understand that I have the right to withdraw, without giving any explanation, at any point during the study and up to 3 months after the study has ended. ☐

1.5 I understand that I can request for any of my data to be deleted from my withdrawal from the study, but that this may not be possible if my anonymised data has been used in publications or for other research purposes. ☐

1.6 I understand that I can request that any of my data is not shown to the rest of the household within group interviews. ☐

1.7 I agree for any interviews I give to be recorded via: Video ☐ Audio ☐

1.8 I agree that any data collected in the study which can be anonymised, e.g. logged data or quotations from any interview, can and may be used in publications or for other research purposes. I understand that this data will be anonymised, and any identifiers will be removed. ☐

1.9 I understand that, if I partake in any video interviews or photos or videos from the visual diary exercise, my media may be used to inform academics, policy makers and other stakeholders; however, before this media is made public, I will be contacted so that I can refuse use of my media, or request for it to be blurred. ☐

1.10 I understand that, if I consent to the sharing of any of my video interviews or photos or videos from the visual diary exercise, people may recognise my appearance and link such media content to my anonymised data in publications or other research documents. ☐

1.11 I understand my participation in the visual diary exercise is optional, and that I must return any technology used within the study to the researcher at the end of the study. ☐

1.12 I understand that any forms of my data collected through the study (e.g. network log data, interview transcription files) will be stored on a secure, password-protected server, or the researchers' encrypted, password-protected laptop. ☐

1.13 I understand that any personal data I provide will be retained and processed by the researcher in accordance with the Data Protection Act 1998. ☐

1.14 I understand that, under the EU's General Data Protection Regulation (GDPR) and the UK's Data Protection Act 2018, the lawful basis for this research is that this is a *"task in the public interest" (see: http://www.lancaster.ac.uk/research/participate-in-research/data-protection-for-research-participants/)*. ☐

1.15 I understand what software or hardware will be deployed in my home or on my mobile device(s) based on the 'Deployment Inventory' form. ☐

1.16 I understand that it is my responsibility to ensure household guests are aware of the study, and that any data from the dataset which is identifiable of guests in the house will be removed unless their written authorisation is given to use it. ☐

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2. Home router recording:

The study will involve home router logging (to be circled by the researcher) **YES / NO**

If yes, the please fill out this part of the form. If no, please move onto the next section of the form.

2.1 I understand that software and hardware will be installed in my home that will monitor and record the 'Home router recording' data listed within the participant information sheet for the duration of the study. ☐

2.2 I understand that no data will be collected concerning the content of websites visited (e.g. searches made, messages sent, videos watched etc.) ☐

2.3 I understand that to ensure successful data collection from the router recording, I must leave the deployed software and hardware running for the duration of the study. ☐

2.4 I understand that logged data will be stored locally, and possibly uploaded to a secure, password-protected server periodically. ☐

3. Socket monitoring:

The study will involve socket monitoring (to be circled by the researcher) **YES / NO**

If yes, the please fill out this part of the form. If no, please move onto the next section of the form.

3.1 I understand that software and hardware will be installed in my home that will monitor and record the 'Socket monitoring' data listed within the participant information sheet for the duration of the study. ☐

3.2 I understand that to ensure successful data collection from the socket monitoring, I must leave the deployed software and hardware running for the duration of the study. ☐

3.3 I understand that logged data will be stored locally, and possibly uploaded to a secure, password-protected server periodically. ☐

4. Mobile device logging:

The study will involve mobile device logging (to be circled by the researcher) **YES / NO**

If yes, the please fill out this part of the form. If no, please sign and date the form.

4.1 I understand that software will be installed on my mobile device(s) that will monitor and record the appropriate 'Mobile device logging' data listed within the participant information sheet for my mobile device operating system (Android or iOS) for the duration of the study. ☐

4.2 I understand that no data will be collected on any of the following through my mobile device(s): personal contacts or communications personal data (e.g. the number of contacts with the number of emails and the number of phone numbers stored for each contact will be logged if the Device Analyzer is used, along with hashed phone numbers for calls, but the actual contact personal data such as their name and email will not be logged by either mobile logging app); the content of data sent or received (e.g. searches made on websites); or the specific content of app usage (e.g. specific videos watched with any app). ☐

4.3 I understand that to ensure successful data collection from the logger, I must keep at least 10MB free daily for log storage purposes and the logging app open in the background without pause for the duration of the study. ☐

4.4 I understand that logged data will be stored locally, and possibly uploaded to a secure, password-protected server periodically. ☐

4.5 If I am using the Android device logger 'Device Analyzer', I understand that:

4.5.1 I must allow the log data to be uploaded onto the University of Cambridge's secure server periodically. ☐

4.5.2 I can opt-out on the application logging my location based on the network cell I am connected to and my anonymised GSM (Global System for Mobile Communications) cell ID, but for this study I must opt-in for logging a list of installed applications and which market they were installed from. ☐

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4.5.3 The data collected will be used anonymously within the University of Cambridge and can be shared with other researchers worldwide if I wish to do so, but that I can withdraw from future data collection and request for all historic data to be deleted. ☐

Participant's signature: ________________________

Researcher's signature: ________________________

Date: ________________________

Appendix C

Home Internet Demand Study: Participant Consent Form for Guardians

Participant Consent Form for Guardians: Informative Study
Transitions in everyday practice and Internet intensity

Within this document, the person for which the guardian is consenting is referred to as the participant. The purpose of this consent form is to check that you understand what will be required of the participant if you agree on their behalf for them to take part in the study and how any information they give will be used.

Household: ________________________

Name of guardian: ________________________ **Name of participant:** ________________________

Pseudonym for the participant to be used in research: ________________________
(Please leave blank if you prefer the researcher to select a pseudonym for the participant)

1. General:

Please fill out this part of the consent form.

1.1 I confirm that I have read and understood the participant information sheet for the above study. ☐

1.2 I have had the opportunity to consider the information, ask questions about the research and have had these answered satisfactorily. ☐

1.3 I agree that the participant can participate in this study and I understand that their participation is voluntary. ☐

1.4 I understand that the participant has the right to withdraw, without giving any explanation, at any point during the study and up to 3 months after the study has ended. ☐

1.5 I understand that I can request for any of the participant's data to be deleted from their withdrawal from the study, but that this may not be possible if their anonymised data has been used in publications or for other research purposes. ☐

1.6 I understand that I can request that any of the participant's data is not shown to the rest of the household within group interviews. ☐

1.7 I agree for any interviews the participant gives to be recorded via: Video ☐ Audio ☐

1.8 I agree that any data collected in the participant's study which can be anonymised, e.g. logged data or quotations from any interview, can and may be used in publications or for other research purposes. I understand that this data will be anonymised, and any identifiers will be removed. ☐

1.9 I understand that, if the participant partakes in any video interviews or photos or videos from the visual diary exercise, their media may be used to inform academics, policy makers and other stakeholders; however, before this media is made public, they will be contacted so that they can refuse use of their media, or request for it to be blurred. ☐

1.10 I understand that, if the participant consents to the sharing of any of their video interviews or photos or videos from the visual diary exercise, people may recognise their appearance and link such media content to their anonymised data in publications or other research documents. ☐

1.11 I understand that their participation in the visual diary exercise is optional, and that they must return any technology used within the study to the researcher at the end of the study. ☐

1.12 I understand that any forms of the participant's data collected through the study (e.g. network log data, interview transcription files) will be stored on a secure, password-protected server, or the researchers' encrypted, password-protected laptop. ☐

1.13 I understand that any personal data provided by the participant will be retained and processed by the researcher in accordance with the Data Protection Act 1998. ☐

1.14 I understand that, under the EU's General Data Protection Regulation (GDPR) and the UK's Data Protection Act 2018, the lawful basis for this research is that this is a *"task in the public interest" (see: http://www.lancaster.ac.uk/research/participate-in-research/data-protection-for-research-participants/).* ☐

1.15 I understand what software or hardware will be deployed in the participant's home or on their mobile device(s) based on the 'Deployment Inventory' form. ☐

1.16 I understand that it is the participant's responsibility to ensure household guests are aware of the study, and that any data from the dataset which is identifiable of guests in the house will be removed unless their written authorisation is given to use it. ☐

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2. Home router recording:

The study will involve home router logging (to be circled by the researcher) **YES / NO**

If yes, the please fill out this part of the form. If no, please move onto the next section of the form.

2.1 I understand that software and hardware will be installed in the participant's home that will monitor and record the 'Home router recording' data listed within the participant information sheet for the duration of the study. ☐

2.2 I understand that no data will be collected concerning the content of websites visited (e.g. searches made, messages sent, videos watched etc.) ☐

2.3 I understand that to ensure successful data collection from the router recording, the participant must leave the deployed software and hardware running for the duration of the study. ☐

2.4 I understand that logged data will be stored locally, and possibly uploaded to a secure, password-protected server periodically. ☐

3. Socket monitoring:

The study will involve socket monitoring (to be circled by the researcher) **YES / NO**

If yes, the please fill out this part of the form. If no, please move onto the next section of the form.

3.1 I understand that software and hardware will be installed in the participant's home that will monitor and record the 'Socket monitoring' data listed within the participant information sheet for the duration of the study. ☐

3.2 I understand that to ensure successful data collection from the socket monitoring, the participant must leave the deployed software and hardware running for the duration of the study. ☐

3.3 I understand that logged data will be stored locally, and possibly uploaded to a secure, password-protected server periodically. ☐

4. Mobile device logging:

The study will involve mobile device logging (to be circled by the researcher) **YES / NO**

If yes, the please fill out this part of the form. If no, please sign and date the form.

4.1 I understand that software will be installed on the participant's mobile device(s) that will monitor and record the appropriate 'Mobile device logging' data listed within the participant information sheet for their mobile device operating system (Android or iOS) for the duration of the study. ☐

4.2 I understand that no data will be collected on any of the following through the participant's mobile device(s): personal contacts or communications personal data (e.g. the number of contacts with the number of emails and the number of phone numbers stored for each contact, along with hashed phone numbers for calls, will be logged if the Device Analyzer is used but the actual contact personal data such as their name and email will not be logged by either mobile logging app); the content of data sent or received (e.g. searches made on websites); or the specific content of app usage (e.g. specific videos watched with any app). ☐

4.3 I understand that to ensure successful data collection from the logger, the participant must keep at least 10MB free daily for log storage purposes and the logging app open in the background without pause for the duration of the study. ☐

4.4 I understand that logged data will be stored locally, and possibly uploaded to a secure, password-protected server periodically. ☐

4.5 If the participant is using the Android device logger 'Device Analyzer', I understand that:

4.5.1 They must allow the log data to be uploaded onto the University of Cambridge's secure server periodically. ☐

4.5.2 They can opt-out on the application logging my location based on the network cell they are connected to and their anonymised GSM (Global System for Mobile ☐

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Communications) cell ID, but for this study they must opt-in for logging a list of installed applications and which market they were installed from.

4.5.3 The data collected will be used anonymously within the University of Cambridge and can be shared with other researchers worldwide if they wish to do so, but that they can withdraw from future data collection and request for all historic data to be deleted. ☐

Guardian's signature: ______________________

Researcher's signature: ______________________

Date: ______________________

Appendix D

Home Internet Demand Study: Interview 1 Schedule

Introduction

- Briefly introduce the interviewer(s) and describe the schedule of the interview
- Remind the user about what the study is for
- Remind the user that all data will be anonymised and that the interview will be either audio or video recorded based on the recording option they chose on their consent form

The Participant and the Home

- Can you briefly describe yourself? For example: age, occupation, hobbies
- Living arrangements (house, flat, shared accommodation, own or rent)
- Other members in the home (if any), including details such as:
    - Age
    - Occupation
    - Relation to participant
- Approximate amount of time spent in the home

The Internet in the Home

- Who is your Internet Service Provider?
- What home broadband plan do you have? Speed? Cost?
- Would you class this as cheap/expensive?
- How many people in the house use the Internet? Do you split access costs?
- Would you say you spend a lot of time on the Internet?
- Would you say other household members spend a lot of time on the Internet? Why? Demographic?
- Do you allow guests to use your Wi-Fi connection? Why/why not? Is this a regular occurrence?
- Do you think your Internet use has changed over the past two years? Five years? 10 years? Why? How?
- Have you had any Internet problems in the past? Has this bothered you in any way?

Understanding the Devices and Other Technologies

- What device(s) do you have?
    - Phone, tablet, laptop, home computer?
    - Android, iOS, other?
    - Data plans?
    - Monthly cost?

- What other technologies do you have in the home?
    - TVs, Smart TVs, HD, 4K?
    - Games consoles? Gaming accessories?
    - Speakers, headphones?
    - Radios?
    - Smart home technology? Smart meter?

Topics of discussion for the devices/other technologies:

- When and why did you get the devices?
- What is classed as the ‘main’ device?
- Are any of the devices shared with household members? Or friends?
- Have you integrated the devices in any way? e.g. shared contacts
- Have you integrated the devices/other technologies in any way? e.g. speaker to iPad
- Are your devices always connected to the Internet? e.g. is Wi-Fi always on? Is mobile data, if applicable, turned on and off?
- How often do you charge your devices? Would you find it stressful if you ran out of battery?
- How often do you update the software on your devices?
    - Why do you update?
    - When do you update?
    - Automatic, manual?
- How often do you update the applications on your devices?
    - Why do you update?
    - When do you update?
    - Automatic, manual?
- If you lost any of your devices, would you replace them immediately? Why?
- Have you considered upgrading any of your devices?
    - Data plans?
    - Hardware?

Understanding General Use of Devices/Other Technologies

- What are the main functions you use your devices/technologies for? How do you ‘see’ them?
    - Music player?
    - Video on-demand player?
    - Social, work?

- Do you have any subscriptions? e.g. Spotify, Netflix. Do you pay for these? Are they shared amongst household members? - Can you describe a typical weekday use?
- Can you describe a typical weekend use?
- Are there any specific times at which you would use your device? e.g. morning routine?
- Any specific times this typical use may change? e.g. due to a holiday?
- Do you feel you your devices to their full capabilities?
- If you had some free time, would you use any of your devices? Why this device over others? Would it change to a different device based on the amount of time you had free? e.g. one hour, 30 minutes, 10 minutes, five minutes?
- Where do you mainly use this device?
    - At home: which rooms?
    - On the go: in what context?
    - At work: what for?
- Are devices/technologies ever used at the same time? e.g. watching TV whilst playing on a tablet. If so, why? When?
- Are devices/technologies ever used habitually after one another? If so, why? When?
- Has the use of your devices/technologies changed in any way since you got each device/technology?

Use During Practices/Activities

- **App/website use**:
    - What apps/websites do you think you use the most?
    - If apps, do you regularly visit the app store to update them?
    - When are you likely to use each app/website? For what activities?
        - Watching
        - Listening
        - Social networking
        - Communication
        - Online dating
        - Online shopping
        - Work
        - Speciality (e.g. bird watching)
- **For each activity:**
    - What type of activity is this? e.g. entertainment, mandatory etc.

- When are you likely to do this? e.g. a habit when bored, or regularly on a weekday/weekend? How long for?
- Where are you likely to do this? e.g. at home, elsewhere?
- How do your devices/the Internet support this? Are there any particular features you like?
- Any subscriptions which support this? What? How?
- Any cloud services which support this? e.g. Dropbox. What? How?
- Is this activity carried out with anyone else? e.g. household, friends?
- Have you thought about integrating any more devices into this activity?
- Why this way over other ways? e.g. SMS over social networking?

Constraints and Feelings

- Do you feel that you use your devices to their full capacity?
- Is there anything that you'd like to be able to do with your devices that you can't? If yes, what are the reasons: operating system constraints, there's no app for that, don't know how to do it?
- Do you find the form/design of any of your devices constraining in anyway? Or alternatively, do they allow you to do things that you couldn't do with your other technologies?
- Do you find your use of your devices frustrating in any way? e.g. too much time on the device/the Internet?
- Would you change something about your device? If so, what would it be?
- How would you feel if your use of the Internet and/or devices was constrained? Is this positive or negative?
    - At particular times
    - At particular places
    - With others
- Would you be happy to share your use of devices and the Internet with other household members?
- Are you interested in making savings by reducing data plans or home broadband plans? Do you think technology could help you do this? How? Why?

Summary

- Anything you want to say/know/questions?
- Thank the participant

Appendix E

Home Internet Demand Study: Interview 2 Schedule

Introduction

- Briefly introduce the interviewer(s) and describe the schedule of the interview
- Remind the user about what the study is for
- Remind the user that all data will be anonymised and that the interview will be either audio or video recorded based on the recording option they chose on their consent form
- Briefly discuss their Internet use as described in the pre-study interview:
    - Devices
    - Times of day
    - Days of week
    - Services
    - Practices

Understanding Changes in Device Use/the Internet

- Do you feel like your Internet use or use of devices has changed since the beginning of the study?
- New practices?
- New subscription services?
- Spatial changes: rooms in the home, on-the-go, work?
- Frequency of use changes: weekday, weekend, particular times?

Understanding the Quantitative Log Data and the Qualitative Visuals

- Discuss notes made around top demanding domains
- Discuss if the following participant only graphs are similar to use, asking questions about interesting peaks/troughs:
    - 'Daily Average % Distribution of Data Demand per Device' pie chart
    - 'Average Hourly Data Demand per Device' stacked bar chart
    - 'Average Data Demand per Device Each Day of the Week' stacked bar chart
    - For each device:
        - 'Data Demand Over the Study' line graph
        - 'Data Demand Peaks' line graph (highlighting dates)
- Discuss if the following shared household graphs are similar to use, asking questions about interesting peaks/troughs:
    - 'Household's Average Hourly Data Demand' stacked bar chart
    - 'Household's Average Data Demand per Device Each Day of the Week'
    - For each shared device:

- ‘Data Demand Over the Study’ line graph

Impacts of the Study

- Has the data we’ve shown you surprised you at all?
- Has the study impacted your Internet use in any way?
- Has the study impacted you in any other way?
- Has it made you think differently about your Internet use/device use?
- Were there any graphs in particular that you did/did not find interesting/helpful for discussion?
- Are you still/still not interested in making savings by reducing data plans or home broadband plans?

Summary

- Anything else you want to say/know/questions?
- Thank the participant

Appendix F

Home Internet Demand Study: Manual Mapping Amendments

Device	Before Amendment: Category, Service	After Amendment: Category, Service	MiB	No. Flows	Cause of Error
H1 P1 PC	Gaming, Xbox Live	Unknown, Unknown IPs	0.21	5	Reverse DNS lookup
H2 P1 Work Laptop	Gaming, Xbox Live	Unknown, Unknown IPs	0.01	2	Reverse DNS lookup
H3 P1 Android Phone	Gaming, PlayStation	Unknown, Unknown IPs	0.01	2	Reverse DNS lookup
H6 H6 PC	Gaming, Xbox Live	Unknown, Unknown IPs	0.06	21	Reverse DNS lookup
H6 P3 Android Tablet 1	Gaming, Xbox Live	Unknown, Unknown IPs	0.73	164	Reverse DNS lookup
H6 P3 Android Tablet 2	Gaming, Xbox Live	Unknown, Unknown IPs	0.64	68	Reverse DNS lookup
H7 P2 Laptop	Gaming, Xbox Live	Unknown, Unknown IPs	0.07	58	Mapping to Xbox lookups
H8 P1 Amazon Fire Stick	Office, Work and Tools, Microsoft Office	Unknown IPs for Watching Device, Watching	3.25	8	Reverse DNS lookup
H8 P1 Laptop	Gaming, Xbox Live	Unknown, Unknown IPs	0.01	4	Reverse DNS lookup
H9 P1 iPad	Gaming, PlayStation	Unknown, Unknown IPs	0.03	10	Mapping to H9's PlayStation DNS lookups
H9 P1 iPhone	Gaming, PlayStation	Unknown, Unknown IPs	0.01	8	Mapping to H9's PlayStation DNS lookups
H9 P1 MacBook Pro	Gaming, PlayStation	Unknown, Unknown IPs	0.02	8	Mapping to H9's PlayStation DNS lookups

Table F.1: A list of the manual mapping amendments made in the household study (as discussed in section 3.2). Incorrect mappings (i.e. errors) were potentially caused by either an incorrect DNS lookup due to domains changing over time, or an incorrect match to another DNS request from a different device in the home. For each household, the percentages of affected flows, and the percentages of affected data demand, from each household's overall totals were less than 0.0%.

Appendix G

Design Workshop: Call for Participation

Workshop call for participation: Designing for a Changing Internet

In the School of Computing and Communications at Lancaster University, we are conducting a study into everyday use of the Internet, and how this might be shaped for the future.

The workshop will involve:

- Reflecting on your use of the Internet, particularly for watching, listening and social networking activities
- Discussing and designing solutions with other participants for adapting our use of the Internet

Please join us on Lancaster University campus (Science and Technology building A076) at one of the following times:
Friday 1st March 2019 9am-12pm *or* Monday 4th March 2019 6pm-9pm.

As a thank you for your time, a £10 Amazon voucher will be given to you.
Coffee, tea and biscuits will also be provided.

If you are interested in attending one of the workshop sessions, please contact the workshop organiser:
Kelly Widdicks
k.v.widdicks@lancaster.ac.uk

Appendix H

Design Workshop: Participant Information Sheet

Participant Information Sheet: Design Workshop
Transitions in everyday practice and Internet intensity

We are conducting a study into Internet and device usage at Lancaster University and would like to invite you to participate. This sheet will inform you about the study and what participation will involve. We have also provided you with a workshop schedule so you understand what activities the workshop will include. We hope this provides you with a full understanding of the study participation, but if you have any questions then please do not hesitate to contact the researcher: k.v.widdicks@lancaster.ac.uk. For further information about how Lancaster University processes personal data for research purposes and your data rights please visit the following webpage: www.lancaster.ac.uk/research/data-protection.

1. Aim of the research:

The aim of this research is to better design Internet use in everyday life. Through this co-design workshop, we aim to discover ways in which peoples' use of the Internet and devices can be adapted to benefit users and reduce the associated energy demands with Internet use – creating Internet usage which is more sustainable. We aim to co-design Internet interventions and designs with you and others in groups within the workshop; activities to do this in the workshop have been provided to you within the workshop schedule document.

2. Study involvement:

It is completely your decision whether you all participate within this study. You may withdraw at any point during the study, and up to 3 months after the study, without giving any reason. By withdrawing from the study, all of your individual data collected during your study will be deleted; this will involve shredding all physical copies of your data and deleting all electronic copies of your data that can be identified as yours from any storage media we use in the study (i.e. the secure, password-protected server, the researchers' encrypted, password-protected laptop, or the logging equipment). However, if you decide to withdraw once a submission for a publication is made, it may not be possible to remove your anonymised data from such publications (see section 6.2). Furthermore, the withdrawal cut-off point is 3 months, as it is highly likely that your anonymised data will have been made public through publications, presentations, or discussions with other researchers and colleagues in the field or at Lancaster University by this time. In addition, it may not be possible to remove your input from the workshop if it cannot be attributed to you individually; more information about study withdrawal is outlined in section 6.2. In addition, if you decide to withdraw before the end of the study, you will not be provided with any financial incentives as these are only provided after the study has ended (see section 7).

If at any point you require more information or clarification, then please contact the researcher via the email address given in this document where they will be more than happy to help.

With this information sheet, you will be asked to each sign a consent form ensuring you understand what is involved with the study, and that you are willing to participate. Participants under the age of 18 will require a guardian to sign their consent form for them. On the consent form, you may give a pseudonym for yourself (or participants under the age of 18 which you have signed for) to be referred to in any research paper or work that follows from this study. If one is not given, the researcher will provide one for you.

3. Study procedure and the participant's role:

If you decide to participate in the study, we will ask you to attend a design workshop which will involve co-designing Internet interventions/ designs with other participants and experts in human-computer interaction (e.g. members of the research team). This workshop will involve a number of discussions and exercises with other participants to design these interventions (outlined in the workshop schedule document you have been provided), and will last 3 hours. The

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workshops will be audio-recorded, and photos and videos will also be taken throughout the workshop. You may also be asked to fill in two surveys: 1) to collect your demographic information; and 2) to gather your feedback on the workshop after you have attended.

The justification for the workshop to be videoed and photographed is so that the media can be presented to academics, policy makers and other stakeholders. Visual media is generally more presentable, accessible and easier to digest by wider audiences, and therefore may enable the study findings to have a larger impact within the research field. Further details about the use of your visual media is described in section 4.

You have the right to withdraw and leave the workshop at any time without giving reason, where from this we will not use any of your individual data prior to your withdrawal. However, it may not be possible to remove all your input to any discussion or design if it is difficult to distinguish your contribution from that of the workshop group. Further details about this risk is outlined in section 6.

4. Confidentiality and anonymity:
All physical and electronic copies of workshop data, audio files, transcriptions, visual media of your workshop output (e.g. designs of Internet interventions) and analysed data collected in this study will be treated with the utmost confidentiality. Only members of the research team will be able to directly associate this data to you as it will be made anonymous to anyone outside of the research team; this anonymization will be achieved through the removal of any names, identifiers, or other personal information, and through the use of pseudonyms. Anonymised data may be made public through publications, presentations, or discussions with other researchers and colleagues in the field or at Lancaster University. Whilst we will not anonymise audio recordings (e.g. by removing spoken names), their file names will be anonymised and they will be kept confidential as only the research team will be able to access them. In the case of videos and photos of yourself, these cannot be made anonymous if publicised with your consent; this is because these types of media may contain identifiable information, such as your physical appearance. The risks to your anonymity, and the ways in which we can maintain your anonymity, are described in section 6.1.

5. Data use and protection:
Under the EU's General Data Protection Regulation (GDPR) and the UK's Data Protection Act 2018, the lawful basis for this research is that this is a *"task in the public interest"* (see: http://www.lancaster.ac.uk/research/participate-in-research/data-protection-for-research-participants/). It is important to note that the data collected and analysed from your study will be used in accordance with the Data Protection Act 1998. The study data will only be accessible by members of the research team but may be used in, or indefinitely kept for, future publications and presentations created by the research team. Data which is publicised will be made anonymous where possible, i.e. all data except for video or photographic media with identifiable content. We will keep your contact details for a maximum of 10 years so that we can contact you about this study or follow up studies; however, this information will not be passed onto anyone outside of the research team. You will only be contacted about follow up studies if you are happy for us to do so. After we remove your contact details, we will no longer be able to contact you for your consent for the use of your video or photographic media. As a result, we will remove any of this media which is identifiable at the same time as your contact information.

The security of data, through storage and transportation, will be maintained. Electronically stored data will be kept on a secure, password-protected server or the researchers' encrypted, password-protected laptop, and physical copies of the data will be kept in a locked draw in a locked office on Lancaster University campus. Any media stored on cameras, Dictaphones or other data capturing tools will be transferred to the secure, password-protected server, or the

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researchers' encrypted, password-protected laptop, as soon as the data is physically collected by the researcher (i.e. after the workshop), and then immediately wiped from the tool.

Data transfer between devices (e.g. a laptop to a memory stick) will be encrypted or password-protected. Video or audio recordings will always be encrypted when stored, and where possible, encrypted during data transfer.

6. Risks of participation:

6.1 Identifiable data. All workshop outputs (e.g. designs), audio-recorded quotations, survey responses, visual media of workshop outputs and analysed data collected within the study and used within publications will be anonymised, therefore it is unlikely that it will be attributable to you. However, it is possible that people who know you very well could identify you, e.g. through qualitatively collected quotations. Visual media of yourself (i.e. videos and photos taken of you in the workshop) will only be used for informing academics, policy makers or other stakeholders, and appropriate measures to anonymise your recorded media will be taken. These will consist of making sure you are referred to via your pseudonym, and removing any identifiable information shown or spoken such as your name. As a result, people outside the research team may know details about your workshop involvement alongside your physical appearance, but they should not be able to contact you. Furthermore, if we wish publicise any of your visual media (i.e. videos/ photos of you), you will be contacted before it is made public to double check that you are happy for it to be used. You will then be able to refuse the use of your media, or request for it to be blurred appropriately. However, there is still a risk that you may be able to be recognised visually or audibly once the visual media is used. It is also possible that people who view of such media may be able to link your visual profile to data presented and discussed in publications; for example, if a quote from you're the workshop is written into a publication, then people who view visual media from the workshop and read the publication may be able to link your face and/or voice to your anonymised data in the publication. It is important that you are aware of these risks, so you can make an informed decision regarding your consent to visual media capture of yourself on the consent form.

6.2 Study withdrawal. You are welcome to withdraw from the study at any point during the study, and within 3 months after the study. By withdrawing from the study, any data that can be individually attributed to you will be removed and deleted; this will involve shredding all physical copies of your individual data and deleting all electronic copies of your individual data (e.g. your workshop involvement such as your audio-recorded quotations) from any storage media we use in the study (i.e. the secure, password-protected server, the researchers' encrypted, password-protected laptop, or the logging equipment). However, if you decide to withdraw from the study once a submission for a publication is made, it may not be possible to remove your anonymised data from such publications. Furthermore, the withdrawal cut-off point is 3 months, as it is highly likely that your anonymised data will have been made public through publications, presentations, or discussions with other researchers and colleagues in the field or at Lancaster University by this time. It is also important to point out that it may not be possible to remove all your input from the workshop after you have begun participating. This is because the workshop exercises will be carried out in a group, and therefore it may not be possible to distinguish your contribution from the ideas and outputs of others. In addition, if you decide to withdraw before the end of the study, you will not be provided with any financial incentives as these are only provided after the study has ended (see section 7).

7. Benefits:

Through this study, your participation will help design technology interactions that aim to reduce the energy consumed through Internet use whilst also having a positive effect on peoples' everyday lives. You will also be provided with a financial incentive to participate in this study. This will be in the form of a £10 Amazon voucher per participant and will be given to you after the workshop is complete as a thank you for your time. However, if you decide to withdraw from the study before it has ended, you will not receive this financial incentive.

8. Project review:
This study has been reviewed and approved by the Faculty of Science and Technology Research Ethics Committee at Lancaster University.

9. About the researchers:
The research team are based in the School of Computing and Communications (SCC), Sociology, and Lancaster Environment Centre (LEC) at Lancaster University, and Aarhus University in Denmark.

Research Team:

Kelly Widdicks (PhD student, SCC)
Matthew Marsden (PhD student, SCC)
Christina Bremer (PhD student, SCC)
Adam Tyler (PhD student, SCC)
Kathlyne New (PhD student, SCC)
Dr Christian Remy (Assistant Professor, Aarhus University)
Dr Oliver Bates (SCC)
Dr Alexandra Gormally (LEC)
Dr Janine Morley (SCC and Sociology)
Dr Mike Hazas (SCC)
Professor Adrian Friday (SCC)

10. Contact details:
If you have any further questions about the study and your participation, please contact Kelly Widdicks (k.v.widdicks@lancaster.ac.uk), Dr Mike Hazas (m.hazas@lancaster.ac.uk) or Professor Adrian Friday (a.friday@lancaster.ac.uk).

11. Complaints:
If you wish to make a complaint or raise concerns about any aspect of this study and do not want to speak to the researcher, you can contact:

Professor Adrian Friday (Head of Department)
Tel: +44 (0)1524 510326
Email: a.friday@lancaster.ac.uk
School of Computing and Communications
InfoLab 21
Lancaster University
Lancaster
LA1 4WA

Thank you for taking the time to read this information sheet.

Appendix I

Design Workshop: Participant Consent Form

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Participant Consent Form: Design Workshop
Transitions in everyday practice and Internet intensity

The purpose of this consent form is to check that you understand what will be required of you if you agree to take part in the study and how any information you give will be used.

Name of participant: ____________________ **Pseudonym to be used in research:** ______________________
(Please leave blank if you prefer the researcher to select a pseudonym)

1.1 I confirm that I have read and understood the participant information sheet for the above study. ☐

1.2 I have been provided a workshop schedule and understand what the workshop involves. ☐

1.3 I have had the opportunity to consider the information, ask questions about the research and have had these answered satisfactorily. ☐

1.4 I agree to participate in this study and I understand that my participation is voluntary. ☐

1.5 I understand that I have the right to withdraw, without giving any explanation, at any point during the study and up to 3 months after the study has ended. ☐

1.6 I understand that I can request for any of my individual data to be deleted from my withdrawal from the study, but that this may not be possible if my anonymised data has been used in publications or for other research purposes. ☐

1.7 I understand that, if I withdraw from the study, it may not be possible to remove all my input from the workshop if it is difficult to distinguish my contribution to that of other participants. ☐

1.8 I agree for the workshop to be audio-recorded. ☐

1.9 I agree for photos and videos of artefacts (e.g. design prototypes) to be taken during the workshop ☐

1.10 I understand I can opt-in or opt-out for photos and videos to be taken of myself during the workshop, and I: Opt-in ☐ Opt-out ☐

1.11 I agree that any data collected in the study which can be anonymised, e.g. quotations from the workshop, can and may be used in publications or for other research purposes. I understand that this data will be anonymised, and any identifiers will be removed. ☐

1.12 I understand that, if I partake in photos or videos, my media may be used to inform academics, policy makers and other stakeholders; however, before this media is made public, I will be contacted so that I can refuse use of my media, or request for it to be blurred. ☐

1.13 I understand that, if I consent to the sharing of any of my visual media at the workshop (i.e. photos or videos of myself), people may recognise my appearance and link such media content to my anonymised data in publications or other research documents. ☐

1.14 I understand that any forms of my data collected through the study (e.g. workshop audio transcription files) will be stored on a secure, password-protected server, or the researchers' encrypted, password-protected laptop. ☐

1.15 I understand that any personal data I provide will be retained and processed by the researcher in accordance with the Data Protection Act 1998. ☐

1.16 I understand that, under the EU's General Data Protection Regulation (GDPR) and the UK's Data Protection Act 2018, the lawful basis for this research is that this is a *"task in the public interest" (see: http://www.lancaster.ac.uk/research/participate-in-research/data-protection-for-research-participants/).* ☐

Participant's signature: ______________________

Researcher's signature: ______________________

Date: ______________________

Appendix J

Design Workshop: Workshop Schedule

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Workshop Schedule
Designing for a Changing Internet

Activity	Duration
Welcome and introduction	15 mins
Post-it note exercise: An activity to get us thinking about our Internet use.	15 mins
Table discussions: An activity to discuss, in groups, our Internet use.	15 mins
Design session: Design, in groups, ways in which we may redesign Internet services for moderate and meaningful use.	45 mins
Coffee break	15 mins
Rapid prototyping: Prototype the design created in the design session.	45 mins
Evaluation: An opportunity for each group to discuss their design with the rest of the participants and evaluate each other's design prototypes.	30 mins