Demand in My Pocket: Mobile Devices and the Data Connectivity Marshalled in Support of Everyday Practice

Carolynne Lord, Mike Hazas, Adrian K. Clear, Oliver Bates, Rosalind Whittam, Janine Morley, and Adrian Friday
Lancaster University, UK
{c.lord, m.hazas, a.clear, o.bates, r.whittam, j.morley, a.friday}@lancaster.ac.uk

ABSTRACT
This paper empirically explores the role that mobile devices have come to play in everyday practice, and how this links to demand for network connectivity and online services. After a preliminary device-logging period, thirteen participants were interviewed about how they use their iPhones or iPads. Our findings build a picture of how, through use of such devices, a variety of daily practices have come to depend upon a working data connection, which sometimes surges, but is at least always a trickle. This aims to inform the sustainable design of applications, services and infrastructures for smartphones and tablets. By focusing our analysis in this way, we highlight a little-explored challenge for sustainable HCI and discuss ideas for (re)designing around the principle of 'light-weight' data 'needs'.

Author Keywords
Sustainability; mobile devices; practices; energy; network demand

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: Miscellaneous

INTRODUCTION
"You have the power to create, shape, and share your life. It's right there in your hand. Or bag. Or pocket."

– iPhone 5S advert

There can be little doubt that the development, adoption and use of mobile computing technologies changes experiences of daily life, if only in subtle ways. A defining aspect is the 'connectivity', both social and network, that such mobile, ready-to-hand devices facilitate. Whilst there is a rich literature exploring consequences of social ('always on') connectivity for family life and wellbeing [29], there is little consideration of the environmental consequences of the increasingly intensive and extensive forms of mobile network connectivity that appear to be developing. In general, network traffic is significant from an energy perspective. By proportion, the energy required to operate the network and data centres is estimated to be about half that used to power domestic ICT goods [4, 30]. Some predict that this proportion will further increase as 'thinner' more efficient consumer devices become standard and as processing and storage functions are increasingly carried out 'in the cloud': from an estimated 25% of the total energy consumption associated with the production, network operation and in-home use of ICT and entertainment devices in 2012, to 50% by 2017 [4]. As this prediction indicates, the network aspects of ICT-related practices are changing. Expectations of what forms of content can be accessed, and when, are increasing, as pervasive high-bandwidth connectivity (e.g. public Wi-Fi, LTE) and services that make use of it, are instigated, marketed and used.

In this paper, we investigate the data demand associated with smartphones and tablets, as opposed to other computing technologies such as laptops, given that (1) these small, battery-powered devices allow data to be consumed at many places in and outside the home, alongside more conventional computing; (2) they require that modern mobile data networks (3G/LTE) be provisioned and able to handle demand at peak times; and (3) the energy demand arising from data associated with mobile devices is high, relative to the energy it takes to charge them.

Based on the assumption that energy and data are used primarily in the accomplishment of social practices (e.g. [20, 27]) we aim to develop a better understanding of the sources and patterns of demand through a practice-based analysis of mobile device use, supplemented with fine grained measures of network and application use. This frames critical challenges for the (re)design of mobile applications and services to foreground sustainability, specifically lighter-weight forms of network connectivity. We offer some suggestions of how this might be achieved.

RELATED WORK
Research into the environmental consequences of the growth of Internet traffic and 'cloud-based' services has

CHI 2015, April 18 - 23 2015, Seoul, Republic of Korea
Copyright 2015 ACM 978-1-4503-3145-6/15/04…$15.00
http://dx.doi.org/10.1145/2702123.2702162

largely focused on the challenge of quantifying the energy used (e.g. [5, 6, 22-24]) and exploring possible future trends (e.g. [4, 18]). However, much uncertainly remains: Coroama and Hilty [5] show four orders of magnitude (1000 times) difference among estimates of Internet-related energy demand, expressed in kilowatt-hours per gigabyte. More recent estimates focus on particular components of the Internet and the delivery of specific services, and tend to be more modest (e.g. 0.052kWh/GB in 2014 for core networks [22] compared with 7kWh/GB in 2008 for core, access and business servers [30]).

Yet, even modest estimates of the electricity intensity of Internet traffic reveal its significance. This is especially so for mobile devices, where the energy used by core networks, access networks and consumer routers to deliver digital content outweighs that used directly to charge the devices [22, 24]. In fact, mobile networks can be especially energy intensive when delivering video content [24]. Whilst there has been some discussion of how to manage and reduce the volumes of data more generally – including user feedback, reducing video resolution depending on context, improving web design and caching [18, 24] – this has not so far considered mobile devices in particular and how they are used.

One consideration for reducing data flows is the distinction between overall and peak demand [18]. The latter is growing for both mobile (cellular) and home (broadband) services as it co-evolves with service provisioning [21]. Because social networking and real-time ("on demand") streaming of content is rising, the largest peaks are becoming more pronounced. The most recent estimates have suggested that streaming makes up about 40% of the prime time traffic in Europe (home and mobile), and in the US (mobile); on US home networks, it is about 60% of the prime time traffic. "This continuing phenomena means network operators need to be doing their capacity planning around peak growth rates", instead of aggregate monthly consumption [21, p. 28].

Kawsar and Brush studied the use of mobile devices in 86 homes using aggregate router logs of networked applications, supplemented with surveys and interviews in a subset of the homes [11]. They explored how different factors (such as screen size) affect which device is chosen to perform a specific activity; and also where (living room, kitchen) and what time of day these activities tended to be performed. Whilst there was no report of the data demand associated with particular applications, they did show higher occurrences of most networked applications in the late afternoon and evening [11, fig.4].

Numerous studies have looked at particular aspects of smartphone usage, for example measuring and improving battery life by altering people's awareness and management of apps [1]; creating understandings of how mobiles and their apps have changed webpage visits [28]; how this might relate to social and economic status [19]; what time of day apps are typically opened and for how long [2]; and how smartphone usage differs in those who might be considered "at risk" to technological addiction [12]. These analyses have been presented in a primarily quantitative way, with implications pointing to ways to further enhance smartphone interaction, or otherwise to help manage it.

In contrast to previous discussions of reducing the environmental impacts of 'consumer' IT use (e.g. [20]) this paper focuses specifically on the impacts of, and demand for, data connectivity. It seeks to explore the basis of data demand in everyday life and hence offer new insights. This follows in the footsteps of practice-based studies in other areas (e.g. [3, 27]).

METHODS AND PARTICIPANTS

We recruited thirteen participants to take part in a mobile device-use study. The study focused on smartphone (Apple iPhone) use for six of them, and tablet (Apple iPad) use for the other seven. No participants were studied for both. Flyers were distributed throughout the university and then further participants were recruited through the researchers' social networks. Participants consisted of students, university administration staff, a teacher and a stay at home mother. There was no financial incentive for taking part in the study. Pseudonyms are used throughout.

The study consisted of two parts. In the first, a software logger was installed on each participant's device, which recorded minutely traces of the power state of the device, battery levels, mobile and Wi-Fi data usage, the foreground app, and the state of the screen. These were recorded locally on the device and transferred from it before the second study part. For each of the participants, the logger ran on their device, collecting data for at least two weeks (11 days for Sarah). Whilst this data allowed us to understand the types of activities that the participants carried out on their devices, it was not possible to explicitly link app use to specific practices and, as such, interviews were necessary to uncover how app use was situated in everyday life.

A semi-structured interview was carried out with each participant covering a number of topics related to mobile device usage, including: typical practices that included mobile device use, mobile and Wi-Fi connectivity management and use, power management and charging practices, and times of uses. The interview questions were tailored to account for differences between phone and tablet devices. Graphs of app use, charging times and connectivity were prepared and introduced towards the end to encourage further elicitation. These ranged from under twenty minutes to one hour. They were fully transcribed, and then independently open-coded by two researchers. These were then consolidated and re-coded for emerging themes.

Name	Device	Top 3 Apps by Foreground time (% network use)	Other significant network users (%)	Notable areas of practice (from interviews)	Wi-Fi (mobile) daily demand in megabytes	
					Median	Max
Joel	iPhone 4	Text Messaging (5.2%) Safari (5.1%), Twitter (2.6%)	Remote speaker (37.2%), NoApp (29.5%)	Social networking, boredom, email, news, shopping, cycling	76 (10)	445 (71)
Colin	iPhone 5	Orchestra (Todo's, 17.6%), Safari (7.9%), Phone (5.8%)	Own App (38.5%), NoApp (18.1%)	Work, communication, relaxing	32 (45)	299 (100)
Ben	iPhone 4	Email (6.6%), Phone (5.2%), Facebook (5.1%)	NoApp (58.2%)	Boredom, work, social networking	44 (12)	599 (32)
Martin	iPhone 4	Text Messaging (1.2%), Tumblr (73.5%), Safari (1.7%)		Communication, blogging, socialising	355 (0)	1592 (4)
Daniel	iPhone 4	Alarm (4%), Text Messaging (4%), Safari (9.1%)	Youtube (28.2%)	Social networking, browsing, online shopping	86 (6)	330 (21)
Sarah	iPhone 4	Text Messaging (7.8%), Phone (0.6%), Email (2.3%)	NoApp (46.6%)	Exercise, work, communication, email, killing time	25 (5)	97 (19)
Kathryn	iPad 3 (3G)	BBC News (4.8%), Alarm (0.3%), Gmail (4.2%)	NoApp (25%), Skype (40.5%)	Work, home, media, communication, gaming, email	95 (0)	1182 (32)
Pete	iPad 2	iBooks (6.4%), Dictaphone (6.4%) Safari (77.1%)		Table-top games, university	6 (0)	61 (0)
Mandy	iPad 2	Facebook (7.7%), Safari (13.8%), Youtube (38.3%)		Cooking, socializing, work	518	4388
Rebecca	iPad Mini 1	Amazon Player (8%), Safari (9.8%), Facebook (43.8%)	NoApp (23.1%)	Socialising, organisation, work,	95	460
Jenni	iPad Mini 1	Safari (15.5%), Words w/ Friends (0.3%), Email (4.9%)	Preferences (58.4%), NoApp (19.2%)	Home, Reading, Browsing	15	285
Bill	iPad 1	Imo (messaging, 9.2%), Safari (66%), NY Times (20.3%)		Work, research, browsing	33	952
Erica	iPad Mini 2	Safari (30%), YouTube (39.5%), Pinterest (0.7%)	NoApp (3.1%)	Communication, research, work, gaming, TV, browsing	130	1252

Table 1: Description of participants' uses of their devices

OVERVIEW OF DATA DEMAND AND DEVICE USE

The participants' uses of their devices has been summarised in Table 1. The top three apps were devised based on their time in the foreground; 'other' network uses relate to data needed for processes running in the background. 'NoApp' refers to the demand associated with in-app, and device updates which the user did not directly request.

Medians typically ranged from the tens to hundreds of megabytes; and daily maximums stretched from hundreds of megabytes, to over four gigabytes. On average, these levels of data flow seem to be within typical bounds for European users at the time of the research (2014): reported as 13.3 MB per day on mobile networks and 705.7 MB per day on fixed networks (which includes other domestic Internet access) [21].

Our participants' devices had daily direct energy demand due to charging from around 1.8Wh (Sarah) to 4.2Wh (Ben) for phones, and 2.5Wh (Rebecca) to 25.8Wh (Kathryn) for tablets, due to their larger screens and batteries.

To put these data demands into an energy context, we apply a modest estimate of electricity intensity for accessing these services via the Internet. In the absence of a current and general purpose estimate, we use a figure of 0.2 kWh/GB (a composite from [22, 23, 24] which reflects data centre, access and core networks, and assumes a mix of text and video traffic). A daily use of 100MB might equate to 20Wh via Wi-Fi (approximately double that, 35Wh, over 3G/LTE). For phones and small tablet in particular, this is an order of magnitude greater than the typical daily charging energy we observed.

Yet, if the energy per GB estimate is realistic, it might take several years for data connectivity to exceed the impacts of manufacturing and transporting the mobile devices. These range from 29 (iPhone 4)[1] to 60 kgCO2e (iPhone 5) for phones, and from 75 (iPad 2 and iPad Mini 1) to 135 kgCO2e (iPad 3 and Mini 2) for tablets. To put that in energy terms, equivalent emissions from the UK electricity

[1] Apple. 2010-2014. iPhone and iPad Environmental Reports, https://www.apple.com/uk/environment/reports/, last accessed 15th January 2015.

grid correspond to 50–200 kWh (depending on device model).

FINDINGS: DATA DEMAND IN CONTEXT

The findings are structured as follows, (1) most dominant use of the mobile device, practices of non-traditional communication – or filling time; (2) the supporting of other non-IT related practices; (3) an investigation of those practices where the mobile device was unable to stabilize as a material element of that practice; (4) more traditional practices associated with that device and (5) other, non-practice data demand findings.

Keeping up with the world …or filling time?

The logging data and supplementary interviews revealed the wide variety of platforms and techniques to stay in contact with social networks. The discussion of more 'traditional' communication (i.e. phone calls and SMS messages) will be dealt with later.

Whilst iPad participants – Mandy, Erica and Rebecca – all reported an increase in the number of platforms used for social networking or email; they had all originally used at least one of these platforms before acquiring the device. Mandy, Rebecca, Kathryn and Erica noted that their use of these had increased since acquiring their iPads. Whilst for Kathryn this meant that her device had led her to develop an '*auto email-checking reflex*', others discussed the way in which their devices allowed them to easily and quickly access and use their social media platforms, which had then impacted on the frequency of their use.

"sometimes I'll get bored, and say that I'm going on my iPad for 10 minutes to check something and I'll be there 45 minutes, because something's led me to something else, and something else and something else" (Mandy, iPad)

The combination of notifications and ease of access to these platforms meant that for these participants, it had become easier and quicker to check these accounts; to satisfy the expectation of knowing what was happening online. This has paradoxically been said to be the result of too much frequent checking; which forms a habit [28].

Investigation into those participants that owned an iPhone, however, revealed that whilst there was certainly evidence to suggest that non-traditional communication was carried out through these devices, it was with a different motivation to that which was evident with the iPad users. Here, participants noted the way in which social media and email notifications were dealt with; activating what would otherwise be 'dead time'. Dead time has been defined as the "small pockets of time not focused on one specific activity and often perceived as 'unproductive time', like waiting for the bus or commuting" [20]. Whilst this 'dead' time has always existed, it is the increased possibility of being able to use this time 'productively' which has repainted it as dead; as it is in moments where we are unable to use time 'effectively' in which they are perceived as dead, or empty.

Smart mobile devices are hugely powerful information and entertainment devices, placing the World Wide Web, social networks, media and games in the user's pocket. They are designed and marketed to be always to hand, and quickly and easily drawn upon. Given that smartphones are designed to be carried around it is no surprise then that one of their most prevalent places in everyday life has come to be one of filling this otherwise 'dead' time.

"Uh I suppose when I'm out and about I probably use my social networks more, 'cause I'm bored" (Colin, iPhone)

They are frequently unsheathed in life's periods of transition; while waiting, bored, or travelling. It is because of their multifaceted nature, however, that the use of dead time was not restricted to non-traditional communication and some participants such as Daniel noted the use of other apps, like YouTube for the filling of this dead time.

The use of the device to fill dead time was not limited to the iPhone, and similarities were seen in those participants who owned an iPad. Despite this, the scales of time that our participants reported to fill with mobile device usage differed, and ranged from a few minutes to an hour. This led to variation in the activity carried out. iPad participants could be seen to speak of filling larger chunks of time (up to an hour), and this practice was quite structured and routine: in Pete's case, it involved filling time between scheduled university lectures:

"I do that if I've got an hour free… I mean not now, I'm doing coursework, but usually I'd have, say an hour between lectures, I'd get my iPad out, go on Wikipedia, Or TV Tropes, perhaps, as that's my weakness (laughs). Erm, and… just sort of peruse that for a while." (Pete, iPad)

In contrast, the iPhone participants spoke about using their mobile devices to stimulate themselves for a few spare minutes when periods of free time or boredom arose. Some examples of such periods that participants listed are: times when they are waiting, coffee breaks, and social situations that were not stimulating enough.

As this indicates, dead time can occur during the enactment of existing practices, like travelling or cooking. Both Joel and Pete used their mobile devices during bus journeys to browse the Internet or check for updates. In Pete's case, this practice was enabled by the availability of Wi-Fi on the bus. For many participants, the mobile device had come to play an important bedtime role, being called upon last thing before sleeping and first thing in the morning. And, for Joel, mobile device use made the mundane activity of cooking more bearable:

"But then sometimes… especially when I'm in my kitchen, cooking and I'm waiting for something to cook, I'll be constantly refreshing it because I'm bored and I want some… stimulation." (Joel, iPhone)

From our participants' accounts, it is clear that, aside from the affordances of the mobile device itself, the design of mobile applications and models for presenting and accessing content play a major role in data demand for filling time. Certain applications are conducive to a quick distraction. For example, the abundance of free games in the App Store that can be easily browsed, installed, played once, and forgotten about thereafter. Social networking applications like Twitter and Facebook can be relied upon for almost constant updates of content that can be quickly and easily accessed. Not only do such applications promise immediate relief from boredom, but also they are conducive to feelings of needing to stay in touch and updated. Without regular attention, content builds up, becomes unmanageable, potentially missed, and dated.

Supporting practices in new ways

In this section we shall explore those practices which were previously non-IT related, to demonstrate – as others have done [20] – how the integration of mobile devices can be seen to increase the energy, or data intensity, of that practice. Various participants discussed the way they had incorporated their devices into practices that they previously enacted without the use of a technology. Sarah reported her use of the Strava app to log her running times and distances, which then allowed her to share this data with her friends – something which she felt was an important motivating factor for the enactment of this practice.

"yeah the social side of it really helps because you're kind of held a bit more accountable because your friends can see whether you've been or not, and they comment on the fact that you've not been in a while or they can help you motivate yourself, saying 'You did really well', or 'You did it really quickly.'" (Sarah, iPhone)

From this, we can see that not only has the iPhone been successfully incorporated into the practice of running for Sarah, but this was a conscious desire on her part; trying out various apps to enable this incorporation. Pete, on the other hand, had incorporated his iPad into his learning practices by audio recording his lectures, which in turn allowed him to revise by listening back over these lectures. Whilst this integration could not be said to transform the practice beyond recognition, new features had been added to Pete's enactment of this. The iPad – and the functionalities it provides – had enabled a new way of working and Pete talked of its uses in understanding notes he had made earlier in the year, which could otherwise be confusing.

"It's why I have them on there really. It's so, when I look back at my notes I've got stuff that I've got written down at the time…which doesn't always makes sense […] whatever I've actually got there, can then be delivered in context to how it was given." (Pete, iPad)

Others, however, could be seen to use their devices in a more supportive role. Joel used his phone to navigate and track his cycling routes, and to stream music from a music library server during the cycling practice. This supportive role was more prevalent in the discussions with iPad users who noted the importance of its screen size and the convenience it offered to this type of use. One such usage was that of background noise. Mandy, who described herself as a sociable person, recounted the way in which she had begun to use her iPad as a source of background noise to support domestic practices, like cooking, eating, studying, and sleeping, in an otherwise quiet home. This was mostly with YouTube, the total demand for which was 10GB over 5 weeks. This use of the iPad had extended to support her working practices, increasing the sense of comfort and convenience.

"[…] I'll be writing an essay on my laptop and have a film or something on my iPad playing, so I don't have to switch tabs so I can constantly be on my laptop." (Mandy, iPad)

Other examples, where the practice itself was transformed by the integration of the device, included Mandy's use of her iPad as a second screen for lecture slides when she was working on essays on her laptop; or Rebecca's use of her iPad for additional entertainment when watching TV she did not enjoy with her parents.

Migrated practices

So far we have seen how the new ubiquitous functionalities provided by mobile devices have increased data demand by extending or supporting existing practices to enable new forms of these. There are, however, practices which would have previously have been carried out through other IT means, and had now migrated over to mobile devices, such as video calling (i.e. Skype) and media watching. Colin, who could be seen to have a 24-hour connection to his work life, discussed the way in which his iPhone had allowed him to use Skype on the go. Further investigation revealed that use of this particular app, however, was restricted to the instant messaging abilities, and any video calls were carried out through what he felt was a suitable device, a PC. For Kathryn, however, her iPad and its mobile data connection had allowed her to use Skype outside of Wi-Fi areas. This, however, was limited to special occasions.

"That would have been when I Skyped my dad form the hospital, 'cause he couldn't make it over to see the baby. So everyone was there, and I sent to my Mam 'Get Dad on Skype', and I put him on so that he could see a video of the baby" (Kathryn, iPad)

On this occasion almost 800MB of mobile data was consumed, in making the half-an-hour Skype video call.

Given the way in which mobile devices have been positioned by their manufacturers, and the surrounding advertising campaigns and discourses, as ideal devices for media watching and listening, it was surprising that the participants reported only using their devices for these, under specific conditions. Whilst those iPhone participants only reported the use of their devices for media when they were out and about, to fill dead time, the iPad participants found that their devices were only used when convenience was necessitated over comfort. When there was a more 'suitable' device available, these resources were usually drawn upon. For example, Kathryn – who worked away from home for long periods of time – found that her iPad was ideal to stream media from online services, rather than taking her heavier laptop away with her too.

By contrast, Bill reported the most use of his iPad's media capabilities; employing its use mostly as a music player. This, however, was again in those times where his more suitable, and specific music devices, were unavailable or unsuitable i.e. when his iPod ran out of battery or when he wanted to play music through speakers. This type of use was also seen to be employed by Rebecca:

"Sometimes I'll listen to it on the bus too, like for music, but that's only if my iPod has ran out of battery or, I have something on my iPad which isn't on my iPod like I have Amazon Music on my iPad. I've been using that quite a lot recently, which is not what I'd normally use, because I've just bought an album and it's taking ages to send to me – in the post– so I have it on Amazon Music and was just accessing it through that." (Rebecca, iPad)

Here, data demand can be seen to be increased by the availability of online services such as Amazon Cloud Player which now offer the possibility of listening to music which has been ordered in a physical form from the online marketplace, whilst the customer waits for the order to be delivered. Although the total demand for this app was relatively small at 88MB, it must be considered that this was in addition to energy arising from manufacture and transport of the physical CD, and simply supported listening to the music while waiting for the CD to arrive.

Enduring practices

Interestingly, by contrast, we also saw practices that did not comfortably extend to the mobile environment in spite of functionality being available to support them. Almost all participants related a practice that their mobile device was capable of playing a part in, but the device was deemed inadequate in some way. Internet browsing was one of the most common examples across smartphone participants. There were various reasons for this, and they were always linked to the availability (close proximity in time and space) of a more suitable laptop or PC. Sarah found connection speeds to be too slow on her phone and the screen size too small for comfortable browsing. Joel had a similar opinion but spoke of particular content (e.g. for comparison purposes) that was unsuitable for phone browsing.

One particular form of browsing that usually did not take place on iPhone devices was online shopping. Again, constraints of the device were linked to the amount of content from various sources that was being consumed, and also the amount of clicks that this process usually involved. Online shopping on eBay was an exception to this. This is partly due to the app being considered well-designed for mobile use, but also because the auctioning model of shopping that it supports – where auctions could end at any time of the day and where the end point required, or attracted, the most attention, i.e. raising bids – was more suited to mobile use and sporadic interaction. Whilst the iPad participants did not discuss this particular problem, possibly due to the bigger screen size; they did note another limitation which had impacted on the devices incorporation into practices. Whilst seven of the participants owned iPads, only one had a mobile data enabled tablet; the others only supported a Wi-Fi connection and, as such, were spatially bound to areas that had a connection. This can be seen to not only affect the use of the device, but the expectations of its user. Rebecca could be seen to be frustrated at its inability to allow her to make use of the dead time, on her commute. Meanwhile Kathryn – whose iPad was mobile enabled – discussed the way in which it allowed for more 'flexibility'. This flexibility, however, was not understood to be the same as a phone and the management of data connection was stricter here, to avoid incurring additional charges. The others – when questioned about their lack of a mobile data plan – cited economic factors as a reason for their avoidance of these particular models and it could be said that given the ubiquity of smartphones – and the cost of a data plan – an additional data plan for their iPad was not perceived to be a necessity.

Many of participants – iPhone and iPad – considered their mobile devices to be unsuitable for lengthy textual correspondence. While text messages and social network chatter were comfortably received and responded to on the go using mobile devices, email was done single-facedly: incoming emails were read, often in response to push notifications, but replies were usually composed on a more suitable typing device. Although the iPad's onscreen keyboard is larger than the iPhone's, this was echoed by Kathryn, who – dependent on time – would answer her emails on her laptop.

"So I guess I'd probably also switch to the laptop if I didn't have a lot of time, or I wanted to do some emails quickly or something. Quite often I'll read the emails on the iPad, and then I'll unread them, so it highlights, and [I'll] answer [them] on the laptop." (Kathryn, iPad)

More 'traditional' uses of the device

The interview data revealed that despite the many ways in which the participants had incorporated their iPhones into their previously established configurations of practices, they were still highly valued for their ability to send and receive traditional phone calls and SMS messages. For example, Sarah, who had been seen to incorporate her iPhone into the practice of running – in what could be described as a data-intensive way – reported phone calls and texts to be the *'thing [she'd] miss the most'*, if she lost her phone, given that her other technologies did not allow this.

Given that the discussion of the findings has revealed that iPads are not similar to iPhones; in either their use, or meaning, we are positioning the traditional use of this as an eBook Reader. This is the consequence of most of the iPad participants noting this particular use, and the form of the device itself lending it to direct comparisons to e-Readers. Pete used his device the most in this way, having downloaded rule books for tabletop games, which allowed him and his friends to refer to these during gameplay.

"For gaming, you tend to have just a whole selection of source books on there which just… so maybe just to share around the group, "This is what you've got," "this is what you're trying to do," etc. I'll hand it over to them because someone in my group, has a character that does various things, they don't exactly know the wording of it […] and we've got this tablet to share so everyone's got what they need, all the time." (Pete, iPad)

Similarly, Kathryn discussed her use of the iPad for this. Although again, the use here could be described as somewhat of a portal to resources. Her work in an archive meant that she was unable to physically move the documents outside of her place of work and the iPad allowed her access to these, through the use of the online service Dropbox.

App and device maintenance

Having discussed the everyday practices into which mobile devices were (un)successfully incorporated, or used to support, we will now move on to discuss other data demand findings related to the management of these devices, i.e. their apps and data use. There were various participants, such as Martin, Ben and Colin, who exhibited an awareness of the data demand associated with app updates and notifications, although they noted this in terms of constraints associated with their data allowance plans. Whilst some actively managed their connectivity to avoid exceeding their allowances – which will be discussed in more detail in the following section – there was evidence to suggest that others enabled automatic updates and notifications for the added functionality that it brought to the app. For example, Sarah discussed the way in which her Strava app updated to sync her running data to her profile, which was enabled by her mobile data plan.

"It tends to happen while I'm out, because I hit stop on the app and then it sends it straight away so it syncs." (Sarah, iPhone)

Although it is difficult to compare, given that no iPhone participant left their device unpowered for more than a night, participants who left their iPads off for more than a few hours were seen to incur data demand peaks after having recharged, and powered them up. For example, having left her device unpowered for eight consecutive days, the logs demonstrated that upon powering up and staying on the Home screen (no foreground app), Erica's iPad consumed 800MB of Wi-Fi data.

Whilst the data demand associated with updating an app and its notifications is relatively small, when these have accumulated after a period of a few days; over many apps, they amass to a small peak in data demand.

Connectivity management

Management of data usage and connectivity varied across participants. Generally, smartphone participants always had at least Wi-Fi or mobile data switched on, and sometimes both. The actual data configuration employed was linked to convenience or cost. Three participants (Sarah, Ben, and Daniel) left both their mobile and Wi-Fi data switched on all the time so that they automatically connect as required. Martin switched Wi-Fi off when his battery is low, but otherwise left it constantly always on, whereas mobile data was on infrequently to ensure that he did not get charged. By contrast, Joel regularly switched Wi-Fi off to avoid being automatically connected to public hotspots that required him to enable connectivity through a log in screen. He preferred to use mobile data as an alternative, finding this more convenient.

Out of the seven participants who owned an iPad, only Kathryn had a mobile data contract associated with her device. This allowed her to avoid the strict pre-planning of downloads for their use on the go. Most iPad participants were Wi-Fi only and did not see the value in managing this connection; leaving it on and ready to use, for those times where they found themselves in an area which was Wi-Fi enabled. None of these participants turned their devices off, when not in use and left them in standby, citing good battery life and convenience as their reasoning behind this.

IMPLICATIONS FOR DESIGN

Our findings point to a number of ways that interaction designers might shift or reduce data demand associated with smartphones and tablets, without targeting the way these devices are currently configured within practice, nor raising questions about whether it should be this way.

Low-bandwidth options for background noise

Some participants used video streaming to provide background noise (Mandy) or to listen to the music associated with video (Pete). We might envision an audio-only option for streamed video content. Apps might locally cache a selection of previously streamed media, and offer it as an "instant" option for listening only. As others have suggested [18], such caching might also help to 'time shift' downloads to non-peak times.

Smaller and more strategic app updates

Recently in the news, the release of iOS 8 caused a 10% rise in traffic creating a record high for Virgin Media in the UK.[2] And in the cases of our tablet participants that

[2] http://www.engadget.com/2014/09/19/ios-8-virgin-media-record/, last accessed 15th January 2015.

switched off the tablet for a few days at a time, we observed spikes in throughput, as the device powered up and began downloading app updates. This points to a need for a more directed strategy in handling how and when apps are updated. App deployers might stagger update downloads across times of low network traffic. Before broadband Internet became widely available in homes, applications developers prioritised smaller patches which would take little bandwidth, yet would still apply the changes required to that application. We might return to such patches, far reducing app updates from the tens or hundreds of megabytes that are common now.

Additionally, many of our participants (Joel, Ben, Kathryn, Mandy, Erica) had more than twenty apps installed, yet from their interviews and device logs, only a small amount of these were used regularly. Devices might offer to update only the apps that have been used recently, instead of auto-downloading or offering to update everything installed on the device (e.g. "Update All" in the App Store).

Screen off, Network off

With each participant, we observed a significant amount (typically hundreds of megabytes per week) of demand during times that no app was in the foreground, and the screen was switched off (i.e. the device was not in active use). In these cases, the data demand generated was certainly not timed with practice, and in fact may not have been necessary at all (e.g. for push notifications later picked up on another device).

Such cases can be easily detected by a device operating system, which could suppress Wi-Fi and mobile data when the device is not being used. For iOS in particular, the "Background App Refresh" option might default to "off", or ask for permission to conduct network activity while in the background, much as prompts for location services do. For those truly concerned about getting timely push notifications during instances when they do not want to be interrupted, the "ringer off" or "Do not disturb" modes for notifications might instead switch off Wi-Fi/data.

IMPLICATIONS FOR UNDESIGN

These findings show that addressing data demand is not just a question of encouraging certain behavioral changes from users [18] but of how 'always-on' connectivity and data intensive transfers are designed into services, applications and even devices. So while the strategies outlined above might lead to measurable reductions, we view the data demand of mobile devices as part of a wider assumption (shared by users, designers and providers) that devices have access to certain intensities and continuities of network service. Data to the home and over cellular networks has been rising for years [21]. For specific areas one might make arguments, for example about whether it is more sustainable to stream content over a network, or distribute through physical transport networks on DVD or CD [30]. When it comes down to it, streamed media and mobile devices have resulted in more diverse forms of watching, and more watching overall. Social networks and photo sharing have created demand where there was little demand before. And the constantly changing requirements for apps, and expectations that they stay current to the changing designs of hardware, operating system and UIs, have increased the amount of network needed to maintain the functionality and usability of the device and the apps that run on it.

"Concerns with environmental sustainability in HCI exemplify a design imperative for undesigning" [17]. What would be ways of undesigning the data demand of mobile devices? Our findings lend some specific insights.

Social networks stay local

The social networking apps used by participants, and the fitness apps used by Sarah and Ben, relied on relatively local connectivity – most often to communicate with others in UK. And yet, these apps connected to data centres. We might envision social networking, social fitness training, and social gaming which are peer-to-peer by design. The meanings and competencies derived from this kind sharing could still go on, but without relying on big data centres and traversing many hops over edge and metro networks. The peer-to-peer networking and security technologies to make such things feasible already exist; but a challenge would be to shift ideas of what normal social networking is.

Already, those with mobile devices experience disruption: batteries run out, and network connectivity is lost. If social networking were peer-to-peer, outages in communication would become more common, occurring whenever either peer lost power or network. But, from what our participant accounts indicate it is the daily or weekly contact with others that is important, not that such contact is guaranteed to be instant, reliable or constant. If such expectations were to change, then this would also allow social network apps to time-shift their traffic to times of low network load. Push notifications, no longer explicitly *instant*, could be batched together and delivered during network troughs. In many cases it was the *textual* communication which was important; short messages could be sent via the traditional channel of SMS.[3]

Tune in to broadcast media

Radios have historically supported music listening and "background noise" (Mandy) very well; and analogue and digital radios remain easy to come by. We could certainly envision mobile devices with radio tuners implemented alongside the more complex Bluetooth, Wi-Fi and GSM protocols. As above, the challenge to overcome would be to shift expectations away from "on demand" songs and the

[3] SMS delivery is not guaranteed, nor is necessarily timely. Moreover, in areas where mobile data-driven social networking has risen, SMS is now underutilised.

type of playlists created by services such as Spotify. And yet, listening to live broadcast radio remains well within many people's experience. It is still relied upon in many homes worldwide, and where data connectivity is patchy (e.g. long car journeys).

Similarly, a built-in TV tuner might also support video watching on mobile devices. Or a local network connection to smart TVs or a set-top box could be used. These would no longer rely on network connectivity far afield, nor data centres and content distribution networks. As a result, such video would no longer be "on demand" in the sense that it is now, but rather locally stored for time-shifted watching similar to VCRs and PVRs. As with modern PVRs, there could still always be "something to watch", but it wouldn't necessarily support watching multiple episodes from the same TV series in a row (Mandy). Rather, forms of watching might return to those of the pre-streaming era.

Emphasise dead time as slow time

All of our participants discussed using their mobile devices during short windows of 'dead time' [20], waiting for something else to happen, or moments of boredom. These networked interactions were rarely characterised as particularly meaningful; at times they seemed simply compulsive (Kathryn) or stressful (Ben, Colin). Instead of pushing the latest news articles or social network chatter, we might work towards apps that are 'counterfunctional' [16] to this trend, making for more meaningful and data-free short periods of time as has been called for, elsewhere [13]. This could be through the promotion of 'ludic activities' [7], e.g. e-reader apps that provide compilations of short pieces of text (short stories, poems); or "slow" apps designed for anticipation of content [14] or that "promote moments of reflection and mental rest" [8] by guiding short meditation or relaxation exercises.

Reflecting on practice, as a practice

During the interviews, some of our participants expressed doubt or frustration about the way that their time-use of mobile devices had developed. This manifested in a number of ways: checking the device too often (Ben, Kathryn, Daniel); wasted time playing games (Jenny, Pete); the "buildup" of social networking and news updates (Mandy, Colin, Kathryn); all the new social networks and other services one signed up for after first getting a smartphone or tablet (Kathryn, Mandy, Rebecca, Erica); apps downloaded once and then never used again (Erica, Mandy).

In the spirit of 'reflective design' [23], we might envision apps which actually help us reflect on how we spend time with our mobile device: which apps are used at particular times of day, how much time we spend with each app, and which apps seem to be sitting around, unused. Whilst there are currently commercial options available, there has been some research which has examined the effects of different functionalities on the user. Like the Affective Diary [10], the reflection app might include a diary functionality to allow the person to annotate what took place in each session, identifying its relevance to everyday life. Annotations might be provided for periodic review, to help a person reflect on the persistence in ways of digital doing, and changes over time.

Preist and Shabajee [18] also suggest that data-based feedback could help to raise awareness and promote greater care over media consumption amongst those who are already environmentally focused. Indeed, amongst our interviewees there were a few concerns about battery life and data quota (Kathryn, Martin) but none made the connection between data and energy. This could be another goal for a diary app for mobile devices: it could provide tallies of the aggregate amounts and burst data rates for each app. Alongside, setting limits on time-use and times-of-use of certain apps (like plugins available for some browsers), the app could apply limits to data use. Primarily, however, we envisage that it is not data intensity but time-use that will engage users.

CONCLUSION

Mobile data demand is the product of an interconnected system that extends far beyond a practitioner and their mobile device. The functionality that defines these devices as 'smart' requires data connectivity. And, hence, the supporting mobile data and Wi-Fi infrastructures, with provision ranging through large multinational telephone companies to local coffee shops and transport companies. Interaction designers creating mobile apps draw on this infrastructure to promote novel and attractive uses of these devices; these in turn rely on publishers of digital data feeds and content generated by end-users. In this paper, we have described the product of this system in terms of its impact on (disrupted, enhanced, occasioned) everyday practices of end-users, and we have drawn attention to the increasingly intensive data demands of these.

There is a pressing need to foreground sustainability in mobile computing, and to start considering "undesign" as the most promising route to this. Mobile devices and their data connectivity have brought about new ways of being and doing, and images evoking these have made their way out of developed nations (where their use is most intense) across the world [9]. At each turn, HCI researchers and practitioners would do well to consider how we might move away from escalating data connectivity, and what genuine advantages this might also afford for quality of life [26].

ACKNOWLEDGEMENTS

This work has been funded by the UK research councils and supported by a PhD CASE studentship funded by the EPSRC and Microsoft Research. We would like to thank our participants and our CHI reviewers, the quality of whose feedback was exemplary.

REFERENCES

1. Athukorala, K., Lagerspetz, E., von Kügelgen, M., Jylhä, A., Oliner, A., Tarkoma, S., and Jacucci, G. 2014. How carat affects user behavior: implications for mobile battery awareness applications. *Proc. CHI*. 1029-1038.
2. Böhmer, M., Hecht, B., Schöning, J., Krüger, A., & Bauer, G. 2011. Falling asleep with Angry Birds, Facebook and Kindle: a large scale study on mobile application usage. *Proc. CHI*. 47- 56.
3. Clear, A., Morley, J., Hazas, M., Friday, A., and Bates, O. 2013. Understanding Thermal Comfort: New Directions for Ubicomp. *Proc. UbiComp,* 113–122.
4. Corcoran, P., & Andrae, A. 2013. Emerging trends in electricity consumption for consumer ICT. http://vmserver14.nuigalway.ie/xmlui/handle/10379/3563. Accessed September 2014.
5. Coroama, V. and Hilty, L. 2014. Assessing Internet energy intensity: A review of methods and results, *Environmental Impact Assessment Review* 45, 63–68.
6. Coroama, V., Schien, D., Preist, C., and Hilty, L. 2014. The Energy Intensity of the Internet: Home and Access Networks. In *ICT Innovations for Sustainability*, Aebischer and Hilty (eds.), Springer. 137–155.
7. Gaver, W.W., Bowers, J., Boucher, A., et al. 2004. The Drift Table: Designing for Ludic Engagement. *CHI EA '04*. 885–900.
8. Hallnäs, L. and Redström, J. 2001. Slow Technology – Designing for Reflection. *Personal Ubiquitous Comput*. *5*, 3. 201–212.
9. Harmon, E. and Mazmanian, M. 2013. Stories of the smartphone in everyday discourse: Conflict, tension and instability. *Proc. CHI*. 1051–1060.
10. Höök, K., Ståhl, A., Sundström, P., and Laaksolaahti, J. 2008. Interactional Empowerment. *Proc*. *CHI*. 647–656.
11. Kawsar, F. and Brush, A.J. 2013. Home computing unplugged: Why, where and when people use different connected devices at home. *Proc. UbiComp*. 627–636.
12. Lee, U., Lee, J., Ko, M., et al. 2014. Hooked on smartphones: an exploratory study on smartphone overuse among college students. *Proc. CHI*. 2327–2336.
13. Leshed, G. and Sengers, P. 2011. I lie to myself about the freedom in my own schedule: productivity tools and the experiences of busyness. *Proc. CHI.* 905 – 914.
14. Odom, W.T., Sellen, A.J., Banks, R., et al. 2014. Designing for Slowness, Anticipation and Re-visitation: A Long Term Field Study of the Photobox. *Pro*. *CHI*. 1961–1970.
15. Oulasvirta, A., Rattenbury, T., Ma, L., Raita, E. 2012. Habits make smartphone use more pervasive. *Pervasive and Ubiquitous Computing.* 16. 105–114.
16. Pierce, J. and Paulos, E. 2014. Counterfunctional Things: Exploring Possibilities in Designing Digital Limitations. *Proc*. *DIS*. 375–384.
17. Pierce, J. 2014. Undesigning interaction. *Interactions* 21, 4. 36–39.
18. Preist, C. and Shabajee, P. 2010. Energy Use in the Media Cloud: Behaviour Change, or Technofix? *Proc. CloudCom*. 581–586.
19. Rahmati, A., Tossell, C., Shepard, C., Kortum, P., and Zhong, L. 2012. Exploring iPhone usage: the influence of socioeconomic differences on smartphone adoption, usage and usability. *Proc MobileHCI*. 11–20.
20. Røpke, I., and Christensen, T. H. 2012. Energy impacts of ICT – insights from an everyday life perspective. *Telematics and Informatics* 29, 4. 348–361.
21. Sandvine. 1h 2014. *Global internet phenomenon report.* Sandvine Incorporated ULC.
22. Schien, D., Shabajee, P., Yearworth, M. and Preist, C. 2013. Modeling and assessing variability in energy consumption during the use stage of online multimedia services. *Journal of Industrial Ecology*, 17, 6. 800–813.
23. Schien, D. and Preist, C. 2014. A review of top-down models of internet network energy intensity. *ICT4S.* 87 – 94.
24. Schien, D., Coroama, V. C., Hilty, L. M. and Preist, C. 2015. The energy intensity of the Internet: edge and core networks. In: *ICT Innovations for Sustainability.* Springer. 157 –170.
25. Sengers, P., Boehner, K., David, S., and Kaye, J. 2005. Reflective Design. *Pro*. *CC*. 49–58.
26. Sengers, P. 2011. What I learned on Change Islands: reflections on IT and pace of life. *Interactions* 18, 2. 40–48.
27. Strengers, Y. 2011. Designing Eco-feedback Systems for Everyday Life. *Proc. CHI.* 2135–2144.
28. Tossell, C., Kortum, P., Rahmati, A., Shepard, C., & Zhong, L. 2012. Characterizing web use on smartphones. *Proc. CHI*. 2769–2778.
29. Turkle, S. 2011. *Alone Together: Why do we expect more from technology and less from each other?* New York: Basic Books.
30. Weber, C. L., Koomey, J. G. and Matthews, H. S. 2010. The energy and climate change implications of different music delivery methods. *Journal of Industrial Ecology*, 14, 5. 754–769.
31. Willum, O., 2008. Residential ICT related energy consumption which is not registered at the electric meters in the residences. *Willum Consult and DTU Management Engineering*. Copenhagen.