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Theoretical and Practical Survey of Backhaul Connectivity Options

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1 Introduction

The aim of the Portable Wireless LAN trial programme by JANET [1], under which this work is being carried out, is twofold. Firstly, we needed to develop a portable and easily carried Wireless LAN (WLAN) kit that should be able to provide local and global connectivity to the devices individuals carry for an academic study or module outdoors. In simple terms, the portable WLAN kit should provide local connectivity to devices around it, in the form of a 802.11b/g wireless network, and global connectivity with the aid of a backhaul connectivity option, such as a Satellite, 3G/UMTS or WiMAX link or by establishing its own connection to the Internet if that is feasible. We have successfully designed and developed a mobile and portable WLAN prototype that is able to satisfy the aforementioned requirements. Our design and implementation decisions, combined with our thorough tests are reported in the companion deliverable by Lancaster University, entitled "Developing a Portable Wireless LAN kit" [2]. Secondly, the project needed to study the backhaul connectivity options that could be utilized in the above context, so that we could identify and evaluate the suitability and applicability of the backhaul connectivity options that the Portable WLAN kit could utilize to establish a connection over.

Therefore, Section 2 of this document, studies theoretically three possible backhaul connectivity options, namely Cellular networks (Section 2.1), Satellite Communications (Section 2.2) and WiMAX network (Section 2.3) in an effort to give an insight of their characteristics. The report provides a brief discussion on how these technologies work and is by no means complete as these communication technologies are being evolved continuously and such a lengthy discussion would go beyond the goal of this project. However, the report focuses on the mobility characteristics of these backhaul options, which are of particular interest for this project. Section 3 that follows, provides a hands on experience on three different backhaul options that we tried and are applicable in the context of this project. To be specific, Section 3.1 reports networking tests from GRPS and HSDPA tests that we carried out, using the GSM modem that is part of our Portable WLAN prototype. Section 3.2 reports our deployment and networking tests of the Astra2Connect Satellite service which, even though not ideal, is a suitable backhaul connectivity option for the requirements of this project. Section 3.3 that follows reports similar deployment and networking tests' results of the Inmarsat service, using a small and lightweight BGAN terminal, the Explorer 500. Finally, Section 4 concludes this report and summarizes our thoughts on the availability and suitability of the backhaul connectivity options we examined theoretically and practically for the requirements of the Portable WLAN project.

2 Backhaul Connectivity Options : Theory

The idea of a network-enabling Portable WLAN kit is very valuable for an academic outdoor study or as part of outdoor experiments for a module of an academic course. Nowadays, during the course of an outdoor study module, individuals do not just carry their science specific tools, but have also a range of network enabled devices, such as laptops, netbooks, sensor nodes, cameras, GPS devices to aid them during their study. Being able to provide Internet connectivity to this range of devices as individuals move outdoors in regions with harsh morphology, is a challenging task that we hope our Portable WLAN kit is tackling efficiently. Although our kit is able to create local 802.11 and 802.15.4 wireless networks for the devices that individuals carry, it requires a backhaul connectivity link to transfer data out to the global Internet and vice versa. The available and suitable connectivity options have many different theoretical characteristics that make some of them more suitable and practical than others. This Section describes theoretically three different backhaul connectivity options, namely Cellular Networks, Satellite communications and WiMAX in respective Sections bellow, and focuses on their mobility related characteristics that are of particular interest of this project.

2.1 Cellular Networks

Cellular networks operate by dividing the coverage area into several cells where each of the cells is served by at least one fixed-location transceiver called a cell site or base station. The base station (BS) provides the coverage in the cell and communicates with the mobile users through signalling on two channels, one for receiving and one for sending data. The cellular networks are bandwidth limited but they operate using a frequency reuse technique which allows them to offer increased coverage and capacity [10, 11]. In addition, the mobile users gain access via different division techniques, such as the Frequency Division Multiple Access (FDMA), the Time Division Multiple Access (TDMA) or the Code Division Multiple Access (CDMA) [10]. There has been a series of generations of cellular networks that are trying to bring the state of the art of the cellular technology to the real world and enhance the Internet data rates and services users are experiencing.

2.1.1 Evolution of Cellular Networks Generations

The first generation of cellular mobile systems used FDMA technology and analogue modulation. The most widely deployed first generation standard was the Advanced Mobile Phone System (AMPS). In contrast to the first generation cellular standards, Second Generation (2G) systems provide data services such as short text messages and low speed data access. The Third Generation (3G) cellular systems support voice, data and multimedia services in an integrated environment [11].

In European countries, the Global System for Mobile Communications (GSM) was developed in early 1990s. The first GSM network operated in the 900 MHz frequency band. From then, many more advanced standards have been developed such as the General Packet Radio Services (GPRS) and the Enhanced Data rates for Global Evolution (EDGE). GPRS offers 40-160 Kbps data rates and it is suitable for non real-time applications such as email and web browsing, whereas EDGE is designed as an add-on of the existing digital systems to provide higher data rates. EDGE is able to handle multimedia content and services such as video calls and video conferences by offering up to 384

Kbps data rate. The tremendous growth of the 3G networks offer higher data rates (up to 14 Mbps on the downlink and 5.8 Mbps on the uplink) and flexible communication capabilities [43]. The 3G networks have been standardized by ITU and the standard is referred as International Mobile Telecommunications 2000 (IMT-2000). The Third Generation Partnership Project (3GPP) provides multimedia communications and integrated services [35]. The objective of the project is to be able to support a peak data rate of 100 Mbps in downlink and 50 Mbps in uplink. In order to achieve this, a MIMO (Multiple Input Multiple Output) antenna and OFDM are likely to be required and deployed [35]. Part of the 3GPP is the Universal Mobile Telecommunications System (UMTS) technology, defined in the IMT-2000 standard, which although technically is part of the 3G mobile telecommunications, it is also being developed into the fourth generation (4G) technology. UMTS uses a wideband CDMA (W-CDMA) and unlike EDGE and CDMA2000 it requires new base stations and new frequency allocations. However, it borrows and builds upon concepts from GSM and thus it is closely related to EDGE. Therefore most of the UMTS handsets also support GSM, allowing seamless dual-mode operation. UMTS that uses W-CDMA supports maximum theoretical data transfer rates of 21 Mbps (with HSPA), although in practice mobile R99 handsets can expect a transfer rate of up to 384 Kbps and HSDPA handsets can expect a 7.2 Mbps rate in the downlink connection [43, 12].

Apart from the bandwidth capabilities of the different generations of the cellular networks, Quality of Service (QoS) profiles are also very important as they take into account additional network characteristics such as delay, round trip times, error rate and others. According to [11], four Quality of Service (QoS) classes are defined for the cellular networks; conversational, streaming, interactive and background. Each class has its own delay tolerance, where the conversational class is very delay intolerant compared to the other three classes, because it carries real time application traffic (voice). The streaming class serves video streaming applications and its delay tolerance levels are almost similar to that of the conversational class. The interactive class includes web browsing and access to many more services and so is a much more delay tolerant class. Two important attributes for this class (interactive) are round trip times and error rates, where both should be very low. Email services are an application example of the background class, where its characteristics are less delay sensitivity and low error rate. Many difficulties emerge when trying to support different QoS profiles in cellular networks and thus many different schemes have been proposed for the newly evolved cellular generations. Examples of such QoS schemes are admission control [7], QoS guarantees [8], and prioritization [9].

2.1.2 LTE : Future Architecture

Third-generation (3G) wireless systems, based on Wideband Code-Division Multiple Access (W-CDMA) radio access technology, are now being deployed on a broad scale all over the world. However, at the same time, user and operator requirements and expectations are continuously evolving, and competing radio access technologies are also emerging. As described previously, the first step in the evolution of W-CDMA has already been done by the 3G Partnership Project (3GPP) through the introduction of High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA) [11]. These technologies provide 3GPP with a radio access technology that will enable faster link adaptation in the mid-term future. For a 10-year perspective and beyond, 3GPP has launched the project 3GPP **Long Term Evolution (LTE)** to improve UMTS access and cope with emergent requirements. These requirements include improving efficiency, lowering costs, improving services, making use of new spectrum opportunities, and better integration with other open standards. The LTE project is not a standard per se, but it will result in the new evolved release 8 of the UMTS standard, including mostly extensions and modifications of the UMTS system.

The LTE project has some generic goals, such as deploying the new technologies into the real world. However it also has set itself some specific goals, much of which are oriented around upgrading UMTS to a so-called fourth-generation (4G) mobile communications technology. The fourth generation of cellular networks is essentially a wireless broadband Internet system with reduced latency and cost so that it can support apart from voice, many more newly emerging services [11, 12]. Based on satisfying these requirements, the new system architecture is considered to have a reduced number of network nodes along the data path. This would reduce both the overall protocol-related processing as well as the number of interfaces that need to receive and forward data, which in turn would reduce the cost of interoperability. A reduction of the number of nodes in the architecture would also make possible the reduction of call setup times, as fewer nodes will be involved in the call setup procedure. Such a reduction also gives greater possibilities to merge control plane protocols, thereby potentially further reducing call setup times.

Figure 1 illustrates the current Rel-6 mobile system architecture (left) and a possible future architecture that allows evolution (right). [11] In Rel-6, Node B handles the lower layers of the wireless access, as this is the node with the antenna. The Radio Network Controller (RNC), being on the core wired infrastructure, handles radio resource management, mobility management (locally), call control and transport network optimization. It further acts as a termination point for the radio protocols. The gateway General Packet Radio Service (GPRS) support node (GGSN) acts as an anchor node in the home network. The serving GPRS support node (SGSN) acts as an anchor node in the visiting network and handles both mobility management and session management. Typically, all traffic is routed back to the home network so that a consistent service environment can be maintained while also allowing the operator to filter traffic and provide security to the end user (e.g. using firewall) [11].

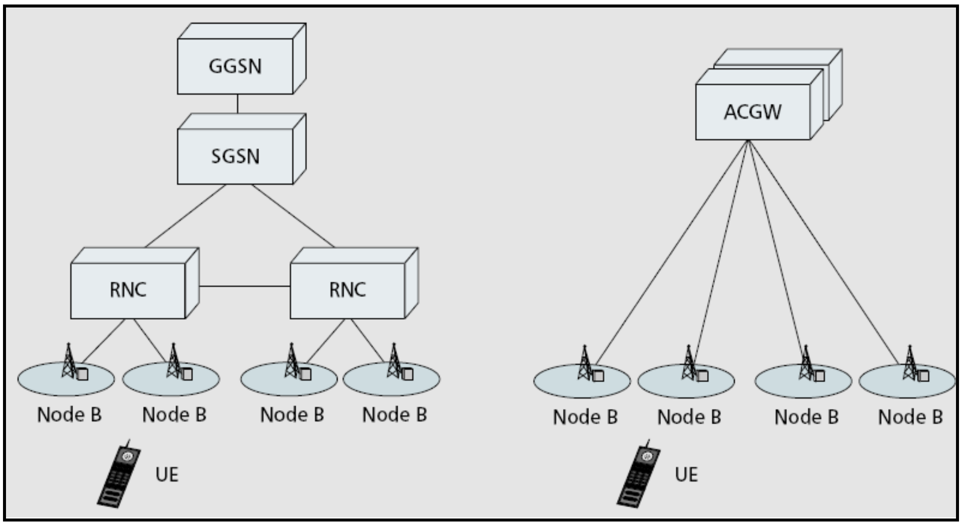

Figure 1 : 3GPP Release 6 Architecture (left) and Evolved 3G Access Architecture (right) [11]

In the proposed LTE architecture, the Rel-6 nodes GGSN, SGSN, and RNC are merged into a single central node, the access core gateway (ACGW) as shown in Figure 1 on the right. The ACGW terminates the control and user planes for the User Equipment (UE or MN), and handles the core network functions provided by the GGSN and SGSN in Rel-6. The control plane protocol for the UE will be similar to Radio Resource Control (RRC) in Rel-6, for example, handling mobility and radio bearer configuration. In the user plane, the ACGW will handle functions like header compression, ciphering, integrity protection, and automatic repeat request (ARQ) [11, 35].

In view of a brief evaluation of the LTE architecture, we summarize the advantages and disadvantages this new solution presents. LTE architecture presents the following advantages [11] :

1. **User-plane latency is reduced**, as there are fewer nodes, and less protocol packing/unpacking.
2. **Call/bearer setup time is reduced**, as there are fewer nodes involved in the setup procedure.
3. **Complexity is reduced**, as there are fewer interfaces data is traversing an thus less equipment should be set up and maintained. The amount of interoperability testing required is also reduced.
4. Placing an Automatic Repeat-reQuest (ARQ) protocol in the ACGW will provide both **robustness against lower-layer** losses and a simple way to **provide lossless mobility**.
5. Performing ciphering and integrity protection of control and user plane data in the ACGW allows for a **security** solution at least as strong as in Rel-6.
6. Support for **macro diversity** (i.e. several receiver/transmitter antennas are used for transferring the same signal) to combat the fading (i.e. distortion of telecommunication signal due to multipath propagation) can be provided with centralized radio control handling. This has been shown to give significant coverage and capacity gains.
7. There is no need for a direct Node B–Node B interface for mobility. Eliminating this interfaces decreases the operational burden for the operator (as no additional configuration and planning is required) and “strengthens” security.
8. A new function in the proposed architecture compared to Rel-6 is support for ACGW pooling. This allows for network **redundancy solutions** that increase the reliability of the network.

The LTE architecture has the following drawbacks:

1. LTE will require **completely new infrastructure equipment** that will impose a significant cost to mobile operators.
2. As several Rel-6 nodes are merged into the ACGW, **the reliability and performance of this single central node has a strong impact on the interconnection service** availability. It is apparent that a hot standby ACGW support is required.
3. The RAN transport layer is expected to remain an **expensive** part of the network and over provisioning of these links cannot generally be assumed. Therefore, packet losses due to congestion in the transport layer will occur despite deployment of enhanced flow control mechanisms.
4. In order to maximize the spectrum efficiency the new radio device **should sense and be aware of its operational environment** (i.e. self-configured) and intelligently adjust its radio operating parameters (i.e. self-optimized). Traditional radio equipment being used nowadays is not suitable for this new architecture.
5. Automatic Repeat-reQuest (ARQ) protocol could bring new problems to real-time flows and applications based on TCP [6].

2.1.3 Deployment Consideration

Under the light of the new emerging LTE architecture and the current efforts to deploy 3G telecommunication infrastructure world-wide, there are certain considerations that arise and will have a big impact on this deployment effort :

1. What will be the impact on either network equipment or user terminals due to the need of using more complex radio technology that would try to utilize the radio spectrum more effectively?
2. What will be the impact on handsets' weight and their batteries' autonomy?
3. It is necessary to ensure that cellular users are good citizens of the Internet. Therefore, implementers of cellular terminals that will be using 3GPP's architecture should be aware of this and define how to implement IPv6 in such cellular hosts [13].
4. The movement of cellular hosts within 3GPP networks is handled by link layer mechanisms [13]. There is a strong need to develop a cross-layer design between the link layer and upper layers to ensure efficient handovers.
5. Initially the coverage of the new architecture is expected to be poor due to the time it takes to upgrade the access network and thus interoperable solution should be utilized effectively.
6. For fully-fledged UMTS incorporating Video on Demand features, one base station needs to be set up every 1–1.5 km (0.62–0.93 mi). While this might be financially acceptable in urban areas, it is unacceptable in less populated suburban and rural areas. An effective solution might be to use a mesh-style IEEE 802.16 networking approach.
7. Since 2005, 3GPP systems were seeing deployment in the same markets as 3GPP2 systems. Industry commentators speculate constantly about these competing systems, and the outcome is unclear [11]. It also diminishes the economy of scale and does not bring benefit to the end users, which could have been benefited if these two systems had harmonized their regulations.

It is worth mentioning that on the light of the difficulties in deploying newly emerging cellular network technologies, there are other initiatives that are trying to bridge the gap until the new technologies are fully deployed. For example, there is an industry-led initiative, called Unlicensed Mobile Access [15], that provides roaming and handover services for users between GSM/UMTS, WLAN, and Bluetooth networks. Unlicensed Mobile Access is a mobile-centric solution and covers only handovers in the above-mentioned access network technologies. It is a 2G solution lacking support for a variety of services, for example, video sessions. This specification was communicated to 3GPP in 2005, which was considered very valuable and is now part of the 3GPP release 6 as the Generic Access Network (GAN). There are several other WLAN/3G integration architectures reported in [14], based on the interdependence of WLANs and 3G networks.

2.2 Satellite Communication

Satellites have been used to provide telecommunication services since the mid-1960s, but since then, they vastly evolved, as technology improved, to offer a variety of services in a reliable fashion. Key developments in transmission techniques, antennas, satellite payload technology and launch capabilities have helped in the emergence of a new generation of Satellite systems that provide a solution for broadband services that are easily deployed and available across a wide geographical coverage. Following these new Satellite systems, Mobile Satellite services have emerged around the early 1980s, to provide communications to the maritime sector. Since then many more communication services have been introduced with the use of Mobile Satellite services, such as aeronautical, land-mobile and personal communication services [16].

Satellites are categorized by their orbital type, and as far as Satellites are concerned there are four types of orbits to be considered ; geostationary orbit, highly elliptical orbit, low earth orbit (LEO) and medium earth orbit (MEO) [16]. The introduction of Satellite services was done by using geostationary Satellites and due to lack of technology some decades ago, geostationary Satellites were the only basis for providing Satellite services. However, the improvements in the geostationary Satellite's power and antenna gain characteristics combined with the improvements on the receiver's side have allowed to reduce the size of the receiver to the dimensions of a briefcase or a mobile hand-held device. Being able to provide Satellite services with such small and portable devices lead to the introduction of Satellite personal communication services which make use of non-geostationary Satellites that are placed at low or medium earth orbit. Nowadays, it is not very difficult to find dual-mode phones that are able to operate using both GSM and Satellite communication services. In addition, in recent years, mobile Satellite communication services are enjoying greater deployment as the receiver's technology is able to automate the alignment and synchronization process, even if the receiver is constantly moving, for example, is in a car, ship, helicopter, train or airplane. The following section discusses the mobile-satellite access network architecture and Section 2.2.2 discusses the major mobile Satellite service providers for the UK market under the light of this project's goal.

2.2.1 Mobile Satellite Access Network Architecture

The mobile Satellite access network architecture consists of three segments; **user** segment, **ground** segment and **space** segment (see Figure 2) [16].

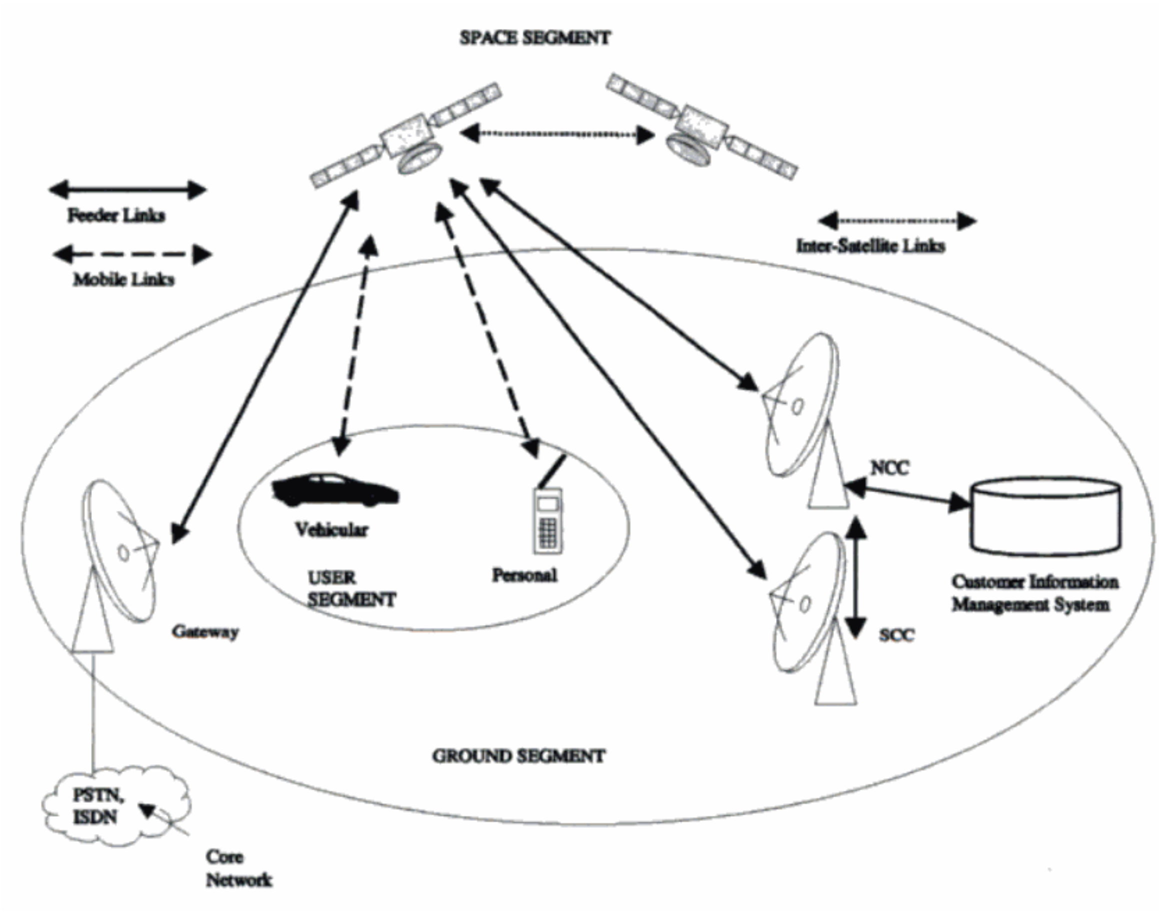

Figure 2 : Satellite Network Architecture [16]

The **user segment** comprises of user terminals, of whose characteristics are directly related to the application and operational environment they are used in. User terminals are divided into two main classes; mobile terminals, that support full mobility operation, and portable terminals which are easily carried but do not support operation while mobile [16, 37]. Mobile terminals are further subdivided into mobile personal terminals that refer to hand-held mobile devices with Satellite communication capabilities or small compact units for printed circuit boards (PCB), and mobile group terminals that are designed to support group mobility and are usually installed on a car, ship, train, bus or aircraft.

The **ground segment** of the mobile Satellite access network architecture consists of fixed earth stations (gateways), network control centres (NCC) and Satellite control centres (SCC) [37]. The fixed earth gateways provide fixed entry points for the users' terminals to the existing fixed core network, such as the public switched telephone network (PSTN), via the Satellite link. The network control centre, also known as network management station, is responsible to coordinate access to the Satellite resource and also provides network management and control functions, such as congestion control, enforcement of call traffic profiles, system resource management, inter-station signalling and others. Finally the Satellite control centre monitors the performance of the Satellite constellation and is responsible to control the position of a Satellite in the sky by receiving important data from it and by monitoring and processing its telemetry [16, 37, 36]

Finally the **space segment** consists of the Satellites that are responsible to provide the connection between the users of the network and the gateways. Nowadays, direct connections between users via the space segment is also achievable if the latest generation of Satellites and users' terminals are being used. The space segment of an operator may have one or more constellation of Satellites each with an associated set of orbital and individual Satellite parameters to facilitate the use of certain services [37].

2.2.2 Mobile Satellite Services Providers

As the Satellite technology evolved vastly during the recent decades, Mobile Satellite services providers were introduced to provide easy access to Satellite communication that usually includes voice and data (Internet) services. The user's terminals that these providers offer to their customers are usually small, portable and lightweight and are essentially ideal for the goals of this project, as the portable WLAN kit could very easily use them as a backhaul connectivity option. In addition, these terminals are normally very easy to set up and some of them are aligned to the appropriate Satellites constellation automatically without any user intervention and thus no networking staff at hand is needed. For this reason we list mobile Satellite services providers bellow :

1) **Globalstar** [5] offers Satellite phone and low speed data communication from a low earth orbit Satellite constellation. The Globalstar services are offered from a total of forty Satellites that are connected to public switch telephone networks with the use of gateways. Globalstar's Satellites do not employ inter-Satellite links, therefore the user can get Satellite access to the services only when a Globalstar Satellite is in view [17].
2) **Iridium** [4], similar to Globalstar, provides Satellite access to voice and data services. Iridium uses microwave, not optical, inter-Satellite communications links. The links are unique for their Satellite telephone services and contrary to other providers, they relay data between Satellites. Iridium voice services support 1100 voice calls using TDMA and FDMA based systems [19].
3) **Inmarsat** [3] is a British Satellite telecommunication company that offers global, mobile services with a history of more than 30 years. Inmarsat offers voice and data services with portable and mobile user terminals that support full duplex reliable and easy to use

communication. Inmarsat uses 11 geosynchronous telecommunications Satellites that support both real and non real-time applications [3]. However, in the recent years, Inmarsat introduced the Broadband Global Area Network (BGAN) which is a global Satellite Internet Network that supports small (laptop size) terminals from anywhere around the word (if linke-of-site to the Satellite exists). The value of BGAN terminals is that it does not require bulky and heavy Satellite dishes and that speeds are up to 492Kbps for downloading, and 300-400Kbps for uploading according to Inmarsat's standards. Currently, there are four Inmarsat standards (Inmarsat-A, Inmarsat-B, Inmarsat-C and Inmarsat-M), each of which supports different data rate and mobile services. We are in the advantageous position to have an Inmarsat BGAN terminal, the Explorer 500, which we will be putting to test and report results in Section 3.3.

4) **Hispasat** [18] offers telecommunication services for military or civil purposes, broadcasting, broadband multimedia communication and many more. Hispasat Satellite constellation are at geostationary orbit and are able to support VoIP, P2P file exchange, video conferencing and real time applications [20]. Hispasat uses the DVB-RCS standard which is specifically for digital television broadcasting.
5) **SES Astra** [25] is one of Europe's first private Satellite operators and owns the Astra series of geostationary communication Satellites that provide various services from TV to Radio and Internet to millions of households. SES Astra is not a Satellite Mobile network operator per se, but we list it here because in 2007 they lunched Astra2Connect service that provides broadband Internet services over their Satellites using portable equipment which can be set up easily in a matter of minutes without networking staff at hand. Astra2Connect basically targets households in remote and rural areas that cannot get broadband access from landlines but can also provide temporary backhaul link to the Internet if needed, for example in an emergency scenario such as the aftermath of an earthquake. We will provide an insight of the Astra2Connect service in Section 3.2, as we possess the appropriate Astra2Connect equipment and we put it to test for the requirements of this project.

2.3 WiMAX

IEEE 802.16 is a series of wireless broadband standards that have been commercialized under the name "Worldwide Interoperability for Microwave Access" or WiMAX in short. WiMAX is commonly used to refer to the interoperable implementations of the telecommunications protocol[1] that provides fixed and mobile Internet Access in high speeds in a Wireless Metropolitan Area Network (WMAN) setting. The 802.16-2004 (i.e. 802.16d) and 802.16-2005 (i.e. 802.16e) revisions of WiMAX provide up to 40Mbps with the first being known as "Fixed WiMAX" and the later being known as "Mobile WiMAX" as it adds support for mobile users. The 802.16m revision of WiMAX (which is work in progress) is expected to offer up to 100Mbps for mobile users and up to 1Gbps for fixed terminals [39, 38]. WiMAX's bandwidth and range capabilities make it suitable for a variety of applications such as providing portable and mobile broadband connectivity across cities (and sometimes across countries) through a variety of devices or offering an alternative to cable and DSL broadband access, especially for remote and rural areas where fixed infrastructures is costly. Its range capabilities also make it an alternative for cellular phone technologies such as GSM and CDMA in developed and poor nations [21]. Furthermore, its bandwidth capacity makes it suitable for not only providing high-speed broadband Internet access but also providing additional services such as VoIP and IPTV with relative ease [39].

[1] As Wi-Fi refers to the interoperable implementations of the IEEE 802.11 Wireless LAN standard.

2.3.1 How does it work?

WiMAX uses a "connection-oriented" MAC protocol that uses a request-grant scheme. Therefore, the mechanism provides a communication model where the Subscriber Stations (SSs) requests bandwidth from the Base Station (BS) using a BW-request PDU and the BS is responsible to process this request and reply to the SS. There are two modes to transmit BW-request PDUs, namely contention mode and contention-free mode (e.g. polling). Contention-free mode is suitable for QoS-sensitive applications because the experienced delay is predictable and can be taken into account when transmitting data. Furthermore, the MAC layer of WiMAX supports Grant Per SS mode (GPSS) of bandwidth allocation in which a portion of the available bandwidth is granted to each of the SS, and each SS is responsible for allocating the bandwidth among its corresponding connections [38].

WiMAX's physical layer is using different access technologies over the different revisions of the protocol. 802.16-2004 (i.e. 802.16d) is using Orthogonal Frequency-Division Multiplexing (OFDM) with 256 sub-carriers (of which 200 are used). 802.16-2005 (i.e. 802.16e), which added mobility support, uses a scalable version of the OFDM, called Scalable Orthogonal Frequency-Division Multiple Access (SOFDMA) [40]. More advanced versions, such as the 802.16e bring additional physical layer access technologies into play, and also include different antenna technologies, such as the multiple antenna support through MIMO which offers extra benefits in terms of coverage, power consumption, frequency re-use and coverage [38, 39]. WiMAX can operate in two "visibility" modes as well, which are a line of-sight (LOS) and non-line-of-sight (NLOS) and they work over licensed spectrum. The LOS mode is usually used among BSs, for example when a WiMAX BS is directly connected to another WiMAX BS using a microwave link. The NLOS mode is usually used between the BS and the terminal receivers, for example communication between the BS and the antenna of a laptop or a handheld device (see Figure 3).

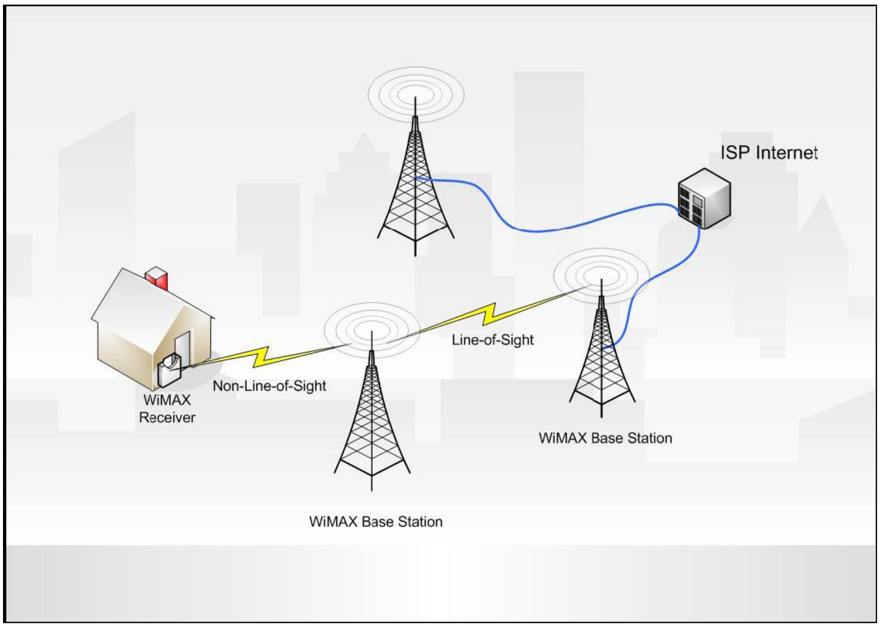

Figure 3 : Line of Sight and Non-Line of Sight modes of WiMAX

In addition to the single-hop point-to-multipoint operation scenario that WiMAX is designed to follow, the 802.16-2004 standard also defines signalling flows and message formats for multihop mesh networking among the SS (i.e., client mesh). In this scenario, several BSs can communicate with each other. Data traffic from an SS is transmitted through several BSs along the route in the mesh network to the destination BS or an Internet gateway (i.e. Point of Presence), as one can see in Figure 4 [38, 39, 40].

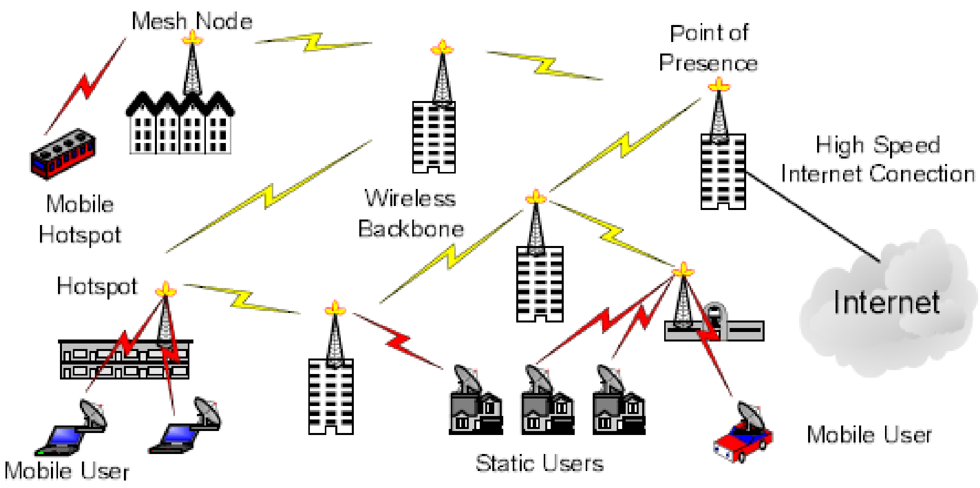

Figure 4 : WiMAX MESH Topology

In urban areas, mesh networks can decrease the cost of running several hotspots, since they only require a single point of presence to a broadband connection for the whole network. In addition, mesh networks can also be used to provide the wireless last mile in rural areas where it is impractical to provide wired connectivity due to the sparseness of customers. This is the idea behind rooftop networks, where each house has a mesh node connecting it to neighbouring houses while providing wireless access to the devices in the house [38].

2.3.2 Mobile WiMAX and Support for Mobility

IEEE 802.16e-2005 (i.e. 802.16e) was designed to add mobility support to 802.16d and is known as Mobile WiMAX. In addition to fixed broadband access, mobile WiMAX envisions four mobility usage scenarios [22, 40] :

- **Nomadic** : The user is allowed to take a fixed subscriber station and reconnect from a different point of attachment.
- **Portable** : Nomadic access is provided to a portable device, such as a PC card, with expectation of a best-effort handover.
- **Simple mobility** : The subscriber may move at speeds up to 60km/h with brief interruptions (less than 1 sec) during handoff.
- **Full mobility** : Up to 120km/h mobility and seamless handoff (less than 50 ms latency and <1% packet loss) is supported.

It is likely that WiMAX networks will initially be deployed for fixed and nomadic applications. Then, it will evolve to support portability to full mobility. The IEEE 802.16e-2005 standard defines a framework for supporting mobility management. In particular, it defines signalling mechanisms for tracking subscriber stations as they move from the coverage range of one base station to another being active, or as they move from one paging group to another being idle. The standard also has protocols to enable seamless handover of ongoing connections from one base station to another.

The WiMAX Forum has used the framework defined in IEEE 802.16e-2005 to develop further mobility management within an end-to-end network architecture framework. The architecture supports IP-layer mobility using Mobile IP [22]. Furthermore, 802.16e uses at the link layer both ARQ and HARQ protocols in a similar way as they are used at the link layer of 3G networks [40].

Three handoff methods are supported in 802.16e, one is mandatory and the other two are optional [22]. The mandatory handoff method is called the hard handover (HHO) and is the only handover method that was initially implemented in Mobile WiMAX. HHO implies an abrupt transfer of connection from one BS to another. The handoff decisions are made by the BS, Mobile Station (MS), or another entity, based on measurement results reported by the MS. The MS periodically does a Radio Frequency (RF) scan and measures the signal quality of neighbouring base stations. Scanning is performed during specific scanning intervals allocated by the BS. During these intervals, the MS is also allowed to perform optionally initial ranging and to associate with one or more neighbouring base stations. Once a handover decision is made, the MS begins synchronization with the downlink transmission of the target BS, performs ranging (if it was not done while scanning), and then terminates the connection with the previous BS. Any undelivered PDUs at the BS are retained until a timer expires [40].

The two optional handoff methods supported in 802.16e are Fast Base Station Switching (FBSS) and Macro Diversity Handover (MDHO). In these two methods, the MS maintains a valid connection simultaneously with more than one BS. Both previous methods offer superior performance than HHO does, but they require that several base stations be synchronized, use the same carrier frequency, and share network entry–related information. Support for FBHH and MDHO in WiMAX networks is not fully developed yet and is not part of the WiMAX Forum Release 1 network specifications [22].

2.3.3 Deployment Analysis and Critical View of WiMAX

In the recent years users are restricted to homes/offices for using the Internet; additional wireless “freedom” is given to them using Wi-Fi-based WLAN services via numerous hotspots being deployed in homes/offices/cafes and other places. For wider area mobility, customers normally rely on cellular communications technology. However, the relatively low data rate and higher pricing plans for cellular technology have been serious obstacles to the widespread use of mobile Internet [23]. On the other hand, although Wi-Fi technology provides higher speed rates at an affordable price it covers only a small region. This calls for another technology, such as WiMAX, to fill the gap between cellular and WLAN services and fulfil the future vision of ubiquitous Internet access. The 802.16e and 802.16m, designed for mobile users, can be a true alternative to 3G cellular networks whilst the IEEE 802.20 standard is being developed [40].

WiMAX can also be a feasible and efficient alternative for DSL subscribers. For example, a research study in Germany, showed that there are three main reasons why Internet customers cannot get access to broadband Internet using Digital Subscriber Lines (DSL) [24]:

1. The distance between the customer and Digital Subscriber Line Access Multiplexer (DSLAM) is greater than 5 km and thus DSL technology cannot be used.
2. The customer density per DSLAM is too low in certain scenarios and thus DSL lines are not an affordable option.
3. Some regions in Germany have local loops based on a special hybrid fibre copper cable, where DSL Technology is not applicable.

The first two aforementioned reasons prove that density is very important for DSL usage. This coverage problem typically occurs in rural areas and several providers are interested to fill this coverage gap using wireless technologies. WiMAX is a viable and very good solution to these situations and can cover "the last mile" customers by providing broadband services to remote users without having to set up a lot of expensive equipment. However, in order to solve the problem effectively and so experience full WiMAX deployment, the 802.16 mesh topology (described in Section 2.3.1), which is ideally fitted in such scenarios, should be rapidly evolved to include security and QoS features.

WiMAX can be a good broadband connection option as it offers higher data rates to Internet customers and can support many more services than are undoubtedly needed nowadays from DSL subscribers. Cable operators are successfully offering today telephone services, TV services and broadband Internet over their DSL lines. However, the increment of the number of services subsequently increases the throughput and delay requirements that customers have from their service. Hopefully, this will act as a drive to push telecommunication companies to actively participate in the evolution of WiMAX and adopt it as fast as possible as it offers high network capacity and wireless coverage. The different and competitive broadband access technologies that have emerged, hopefully, will lead to cheaper connection fees and better quality of service that will benefit the customer.

The network capacity and broad wireless range converge of WiMAX are very promising for making it the prevalent technology for ubiquitous access for mobile users. WiMAX can support a broad range of applications from email and web browsing to IPTV and voice and video conferencing very efficiently. There is a strong emphasis nowadays, from both academia and enterprises, to improve the handoffs of WiMAX, as supporting just hard handoffs is not enough to cope with the requirements of demanding applications. Interestingly, the bigger goal, if handoffs are improved very effectively, would be to provide VoIP communication over WiMAX in a similar quality to GSM. This would help immensely the deployment of WiMAX technologies as telecommunication companies would try to get a share of Voice services using WiMAX equipment and therefore induce benefits to customers who would have the opportunity to enjoy lower cost voice services in addition to Internet mobile connectivity wherever they are.

One of the major problems in the deployment of WiMAX is that it operates on a broad frequency spectrum and this has already created disunity among terminal manufacturers and communication regulators. For example, there are WiMAX ready laptops in the market that run using the 2.5Ghz WiMAX Forum profile [33] in an effort to be able to support both Wi-Fi and WiMAX from the same hardware. This would essentially lead to cost effective terminals and would help the broad deployment of WiMAX. However, communication regulators (e.g. OFCOM for the UK) are trying to split the frequency spectrum that WiMAX is using into zones and put them in auction for mobile operators. Unfortunately, the current frequency range that regulators are auctioning and licensing is not in accordance with the hardware equipment that manufacturers already have in the market. This not only creates an impediment in the current deployment of WiMAX technologies, but also creates further problems as manufacturers would now have to solve interoperability issues between WiMAX equipment that run on different frequency range. This also creates a huge problem for telecommunication providers as it increases significantly the cost for buying not only equipment for a certain frequency range, but also for paying a large amount of money to buy the frequency band license for this range. Another problem from the frequency split that regulators are imposing is that even if a telecommunication company buys a certain frequency band license and installs all the appropriate network equipment for it, all its customers should buy certain WiMAX equipment that operates on the company's frequency band and would be tight with that company unless the buy new WiMAX equipment in the future. Unfortunately, all these problems do not help the large scale deployment of WiMAX which admittedly has a lot of benefits to bring to both telecommunication companies and the end-users.

3 Backhaul Connectivity Options : Hands on Experience

The theoretical merits of the backhaul connectivity options that were discussed in the previous Section are undoubtedly challenged in practice. Real-life deployment of any backhaul options and the different scenario that each is tested under, usually provide significant findings and a practical insight that is very important if they are to be used every-day. Therefore, this Section provides our hands on experience on three different backhaul connectivity options that we put to test, namely GPRS/HSDPA tests with O2 (Section 3.1), Astra2Connect Satellite tests (Section 3.2) and Inmarsat Satellite tests (Section 3.3). We detail not only our networking testing results but also our deployment and logistics experience that, hopefully, will give a more complete overview of their suitability and applicability for the requirements of this project.

3.1 GPRS/HSDPA tests with O2

One of the most popular backhaul connectivity options that quite a few mobile users are using is the GPRS/EDGE/HSDPA network from their GSM telecommunications provider. The portable WLAN kit that we designed at Lancaster University (see Figure 5) consists of its own O2 GSM modem so that it can establish and utilize a 3G connection when no other is available. The mobile router with the aid of the software that we implemented is able to identify the best suited connectivity option and utilized it according to the requirements of the scenario. To avoid repeating information, the reader is referred to [2] for full details on our design and implementation decisions.

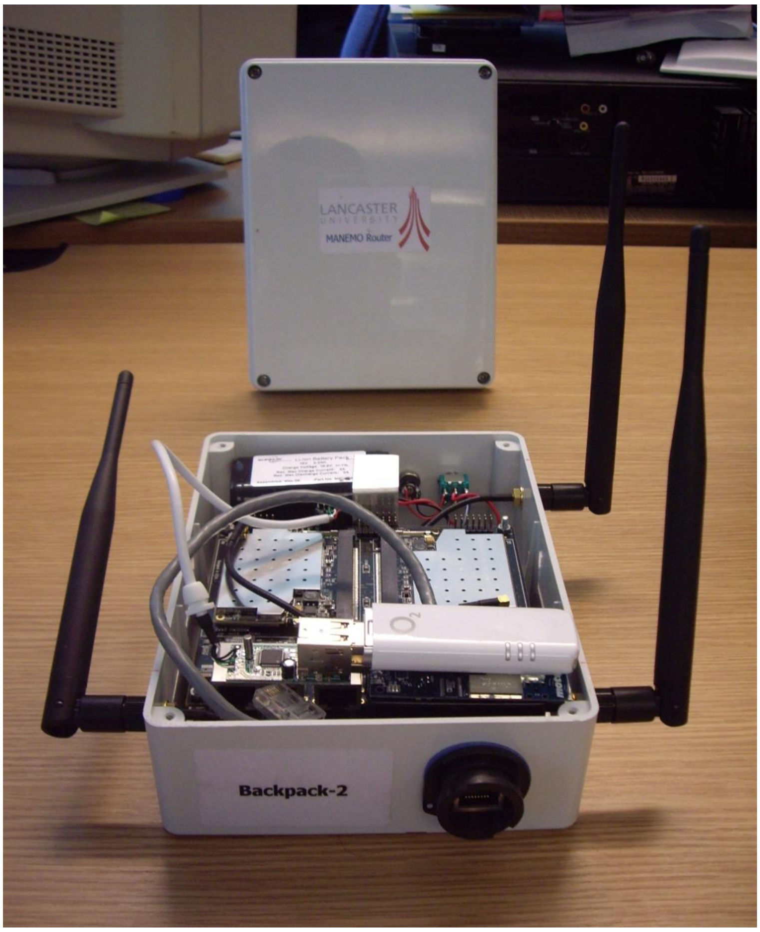

Figure 5 : Portable WLAN kit designed at Lancaster University

Since the O2 GSM modem of our Portable WLAN can establish its own backhaul connection to the Internet we decided to test it by connecting a laptop to the router with an Ethernet cable and communicate with the modem over a secure shell (ssh) and minicom. During our tests in the lab at Lancaster University, we found out that we had full HSDPA coverage by O2. After setting a globally reachable iperf server in our lab we run uplink tests from the mobile router using its HSDPA O2 connection to the Internet. Our results showed that TCP flows could get an average uplink speed rate of 390 Kbps, whereas UDP packets could get an average uplink speed rate of 340 kbps, recording roughly 20% packet loss and 4 ms jitter, which are very satisfying results.

To test the Portable WLAN kit in the environment more similar to the one that is intended for use, we decided to go to Flookburgh (Grange-over-Sands, UK, see Figure 6) and do some outdoor tests with identical setup as previously. However, we noticed that the O2 GSM modem could not establish an HSDPA connection, so it resorted to establishing a GPRS one. Running similar tests as before, we recorded that uplink TCP flows (using iperf) were maximized at 29Kbps, whereas UDP flows were maximized at 30Kpbs with significant loss. Using an Open-VPN server that we have set up at Lancaster University, we were able to test also IPV6 connectivity successfully, albeit with high latency, namely 780 ms (which was expected over the GPRS link).

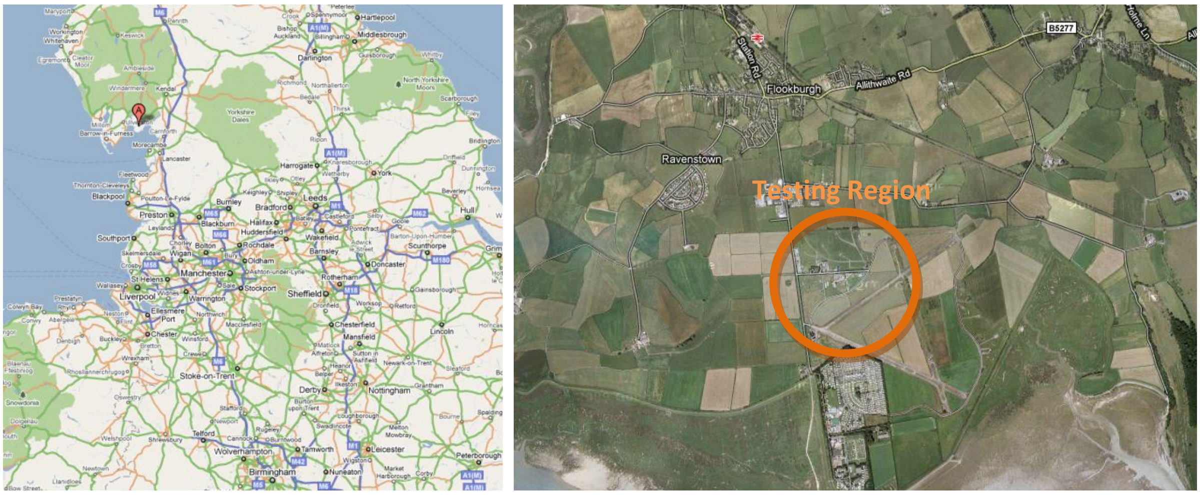

Figure 6 : Undertaking O2 GSM tests at Flookburgh (Grangre-over-Sands, UK)

Using the O2 GSM modem as a backhaul connectivity option for the purpose of Portable WLAN is considered as a suitable option, although establishing a HSDPA connection is highly preferable compared to a GPRS one due to its better throughput and lower latency. The GPRS connection can be considered as the last option if no other is available, and with the use of the Handover Manager software that we implemented (the reader is referred to [2] for more details) we can direct the portable WLAN kit to use it only if no other is available.

Following these GPRS and HSDPA results with O2, we believe that it would be useful to do similar future tests with the other GSM telecommunication providers such as Vodafone, Orange, T-Mobile and 3, especially because the capacity of their network differs and also because the achieved throughput depends heavily on the coverage that each company has on a certain region. In our future plans we will do more tests especially with Vodafone, which currently is the only UK provider that claims partial HSPA+ coverage that can theoretically offer 56 Mbps downlink and 22 Mbps uplink [41, 42].

3.2 Satellite Communication Tests with SES Astra in Field

SES Astra [25] was formed in 1985 and was Europe's first private Satellite operator. It owns and operates the Astra series of geostationary communication Satellites, which provide digital TV and radio channels to more than 125 million households across Europe and North Africa [26]. Following their success on providing TV and radio services, they lunched Astra2Connect in March 2007 to offer Internet broadband services [27]. Astra2Connect is a two-way Satellite broadband Internet service available across Europe, being able to provide high-speed Internet access (up to 4Mbps) at a flat rate cost to end users. It uses the Astra 1E communications Satellite at the 23.5° east orbital position to handle uplinks and downlinks in both directions [25]. Astra2Connect can also provide VoIP and IPTV services without any requirement for a landline, making the service very attractive for homes in rural locations or otherwise beyond the reach of existing broadband services. As we examined in Section 2.3.3 there are many reasons why still today, many hundreds of households cannot obtain broadband access through landlines [26] and thus the Astra2Connet is a very promising solution.

In our opinion, Astra2Connect is a suitable solution for getting backhaul connectivity for the purpose of the Portable WLAN trial. Its equipment is of moderate weight and can be set up without any networking expertise in 5 to 10 minutes. It provides a reliable service with sufficient throughput for long-hour in field tests for academic or research purposes and could provide a backhaul connectivity link for our scenario by connecting the satellite receiver (IPmodem) directly to our PWLAN prototype (described in [2]). It has to be noted though, that Astra2Connect cannot be considered as a convenient and truly mobile backhaul connection, as it requires mains power and cannot be used while in motion. However, for the nature of the Portable WLAN trial, Astra2Connect can be set up immediately before an academic outdoor experiment starts and provide a backhaul option throughout its duration and thus is considered as a suitable solution that we wanted to put to test.

We obtained an Astra2Connect Satellite kit that was comprised of a Satellite dish, a two-way interactive LNB (iLNB) and an IP modem (see Figure 7 and Figure 8). The Satellite dish is of an offset design with an 80 cm diameter solid steel reflector that can be fitted with an altazimuth mount on a tripod. The assembly of the equipment is straightforward and the user does not have to have networking or engineering expertise to do it. Briefly, the dish should be mounted on the tripod and then the iLNB should be fitted on its feed arm that should be attached to the masthead that holds the dish. Then the user should connect the iLNB with the IPmodem using a coaxial cable and connect a laptop or the portable WLAN kit to the IPmodem using a normal Ethernet cable (see Figure 7 and Figure 8).

Figure 7 : Astra2Connect equipment being fully set up (back side of dish)

Figure 8 : Astra2Connect equipment being fully set up (front side of dish)

For the purpose of testing the networking capabilities of the Astra2Connect service under the scope of this project, we decided to go on a remote and rural region, where an academic field study or a module related experiment could be carried out. For this reason, we chose the region around Buttermere (Lake District, UK, see Figure 9 - left) and specifically the Rannerdale Car Park on the East shore of Crummock Water (see Figure 9 - right) and carried out a deployment and networking test of our Satellite equipment in dry and rainy conditions. Figure 10 gives an impression of the terrain tests were performed in.

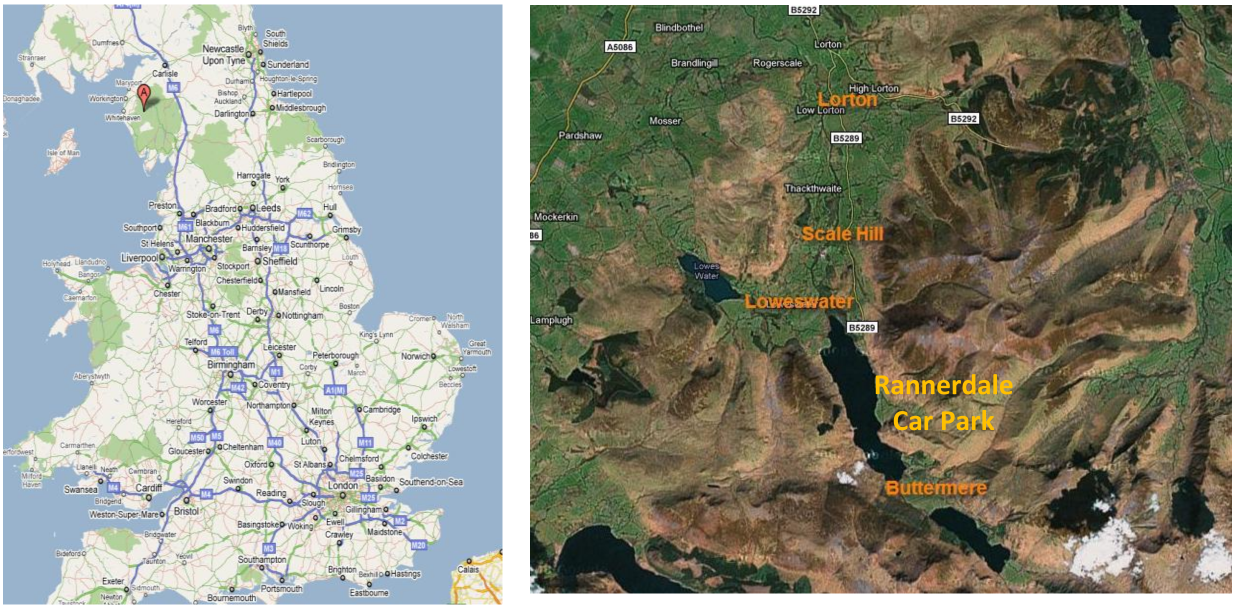

Figure 9 : Location of Astra2Connect tests (Rannerdale, Buttermere, Lake District)

We used the 80cm SES Astra Satellite dish to create a connection to the global Internet using the Astra2Connect service and aligned the dish to the Astra 1E Satellite at 23.5°E (see Figure 10, Figure 11 and Figure 12). We initially had some problems in establishing the connection with the Satellite due to high winds and the morphology of the ground making the synchronisation with the Satellite more difficult and time consuming. High-winds can often disrupt the synchronisation with the Satellite as the dish has a tendency to move regardless of how securely it is fixed to its mounting pole. However, one interesting observation we noted was that even though initial synchronisation can be problematic, once the Satellite receiver is synchronised, the connection remains stable even in the presence of those high winds. As we have carried out tests in other locations we can conclude by saying that the Satellite connection can be established from scratch in an average time of between 5 and 10 minutes, depending on the actual location that the test is being carried out. This variation depends mainly on the Satellite footprint of the area and also whether there are any obstacles (such as high trees or protruding rocks) blocking the line of sight of the dish to the Satellite.

Our Rannerdale testing also demonstrated that the Satellite dish we used is waterproof, however, this cannot be stated for the receiver that comes with it and is mandatory for its use. Therefore, some extra consideration must be given as how best to weatherproof this specific piece of equipment if it is to be used outdoors. During our tests, we powered the receiver of the Satellite dish with a portable generator. This was an acceptable solution for undertaking our tests, however carrying and setting up a generator (see Figure 10) might not be considered practical for other experiments, and therefore power is an important concern when using Astra2Connect.

Figure 10 : Astra2Connect Satellite tests with Grasmoor in Background

Results from our tests in regard to the connection provided from the Satellite dish are very promising. Although the Lake District is on the edge of the Satellite coverage footprint, we achieved an average downlink rate of around 990Kbps and an average uplink rate of around 244 Kbps in our tests. Taking into consideration that our service's theoretical capabilities were 2Mbps and 256Kbps for downlink and upstream respectively and the fact that we were at the edge of the footprint we believe that the achieved throughput is very good and shows high potential of the service. Round-trip times between the mountainous location and Lancaster University (traversing Luxembourg which is where the terrestrial receiver of the Astra2Connect service is and then GEANT) averaged at around 600ms which is adequate for many applications. The Satellite service provided by SES Astra is only IPv4 enabled at present, however under a special agreement we obtained from their DHCP pool a global IPv4 address so that we could do IPv6 performance testing using an IPv6-in-IPv4 tunnelling technique. When using IPv6, an IPv6-in-IPv4 tunnel was established using the Hurricane Electric tunnel broker service [34], and round-trip times increased to around 1000ms whereas downlink and uplink rates were around the same levels as with IPv4.

Figure 11 : Astra2Connect Satellite tests at Rannerdale Car Park

Figure 12 : Astra2Connect Satellite tests at Rannerdale Car Park

Taking into account all our Satellite testing with Astra2Connect, we feel that it is a good backhaul solution that can satisfy requirements that a research experiment outdoors in a field may have. The throughput and delay capabilities of the link are enough to satisfy most applications' needs. Generally the Satellite link tests demonstrated that Astra2Connect service is suitable for use for the communication needs of this project. However, aside from the networking considerations, it was the logistic factors that provided the most problems. Setting up the equipment can be a bit problematic especially under bad weather conditions (e.g. high winds and rain) and also the person setting up the dish should have a rough idea of how to align it. As we mentioned before, it is not a difficult process but it takes some time and it might be likely that researchers or students would not like to do it before they start a study outdoors. In addition, the equipments' need for mains power is an important consideration, as in order to power the equipment a generator is needed.

For all these reasons we decided that testing a true mobile and ubiquitous mobile satellite service would provide very interesting comparative results both from the deployment but also from the networking point of view. Therefore, we purchased an Inmarsat BGAN Satellite terminal and undertook similar tests that are reported in the following section.

3.3 Satellite Communication Tests with Inmarsat

Section 2.2.2 mentioned Inmarsat as one of the mobile satellite service providers. Inmarsat is a British Satellite telecommunications company that offers true mobile Satellite services for more than 30 years. Inmarsat has created the Broadband Global Area Network (BGAN) that is a Satellite Internet Network with telephony using portable terminals. BGAN uses a constellation of three geostationary Satellites called I4, which provides almost global coverage (see Figure 13) [29, 30]. The value of BGAN terminals is unlike of other Satellite Internet services that require bulky and heavy Satellite dishes to connect, so it is much smaller and lighter than the Astra2Connect equipment. A BGAN terminal is small (around the size of a netbook) and lightweight (see Figure 14) and can be carried easily and connect almost automatically to the BGAN network and provide Internet, voice and telephony services to end-users. BGAN terminals can offer speeds up to 492kbps for both download and upload, although upload speeds are usually a bit lower. All the packets that travel via geosynchronous Satellite connections, have to travel a great distance before they reach the Internet and thus the experienced latency is usually around 1 to 1.5 seconds round trip for BGAN terminals [29, 3]. BGAN terminals are the future for true mobile Satellite Internet communication, although their high price makes them unapproachable for the ordinary end user.

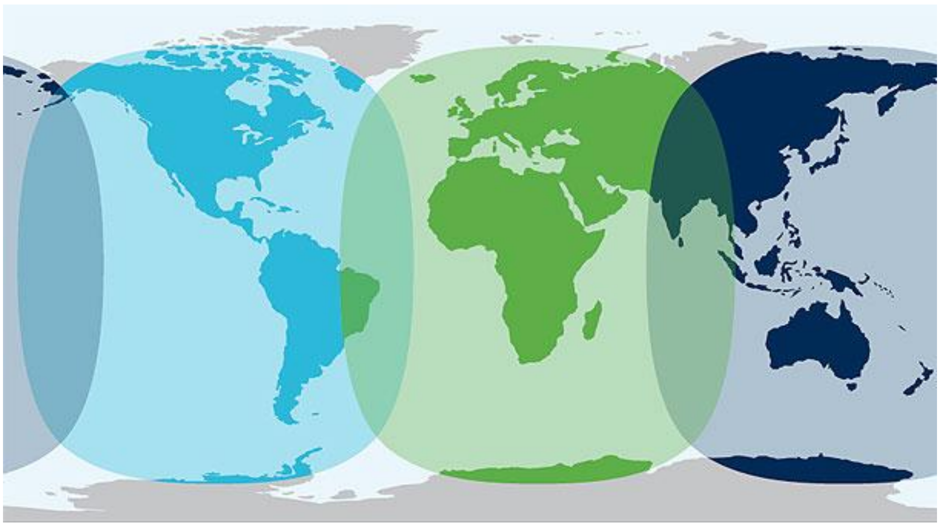

Figure 13 : BGAN I4 Satellite coverage [30]

Having tested the Astra2Connect backhaul Satellite connectivity option, we were very enthusiastic to try out a BGAN terminal and experience the Satellite Internet service offered by Inmarsat. Therefore, we purchased the Explorer 500 BGAN terminal [32] (see Figure 14), manufactured by Thrane & Thrane, to test it outdoors and see how easily it is deployed and its network capabilities. Theoretically, the Explorer 500 offers 464 kbps on the downlink and uplink and up to 128 kbps for streaming IP [32]. Its dimensions are 218 by 217 by 52 mm, its weight is less than 1.5 kg and it has a recharchable Lithium-ion battery, therefore not needing mains power when used outdoors. It provides a USB, a Bluetooth and an Ethernet port and we have to admit that its manufacture quality is high. Its Ingress Protection is marked with 54 which means that "splashing water against the enclosure from any direction should have no harmful effect" [32]. However all the above merits come with a high price that is approximately 2.720 pounds for the Explorer 500 terminal and 980 pounds for an annual fee allowing just a 255 MB traffic allowance. Other traffic allowance plans are offered by Inmarsat, but they are more expensive.

Figure 14 : Our Inmarsat BGAN terminal ; Explorer 500

We undertook our tests on campus at Lancaster University outside the InfoLab21 building (see Figure 15 and Figure 16). Before we mention our networking testing results, it is worth emphasizing the ease at which BGAN is deployed and synchronized with the Satellite. It literally took us less than 90 seconds from the moment that we placed BGAN on the ground, turned it on, connect it to a laptop using an Ethernet cable and be able to surf the web. From the moment you turn on Explorer 500 it starts searching for Satellites and gives an indication on its LCD screen (or over the web interface on the connected laptop) of the signal strength with the Satellite it has on sight. If the user is satisfied with the reported signal strength, he can choose to accept it and so the terminal carries on and synchronizes with the Satellite in a number of seconds. Any IP device that is connected to the Ethernet port of the Explorer 500 (a laptop in our tests) gets a private IPv4 address in the 192.168.0.x range.

Regarding the networking tests we used Speedtest.net online tool to test the download and upload capabilities of our BGAN terminal and we achieved 360Kbps and 120 Kbps respectively. In addition we pinged various servers at Lancaster and also Google.com and we recorded roundtrip times approximately 850ms to 1200 ms which is very reasonable for a service using geostationary satellites. UDP iperf sessions also reported higher uplink throughput when we carried out tests with a server at Lancaster University.

Overall we were very impressed with the Explorer 500 BGAN terminal as it is a high portable device that can be used within seconds almost everywhere in the world. Its networking capabilities are suitable for a range of applications and we think it is a very suitable backhaul option for the purpose of this project. The size, weight, dimensions and ease of use of the device makes it ideal for outdoor experiments, although it has to be noted that the terminal's price and annual tariffs can be considered too high, especially for ordinary end-users.

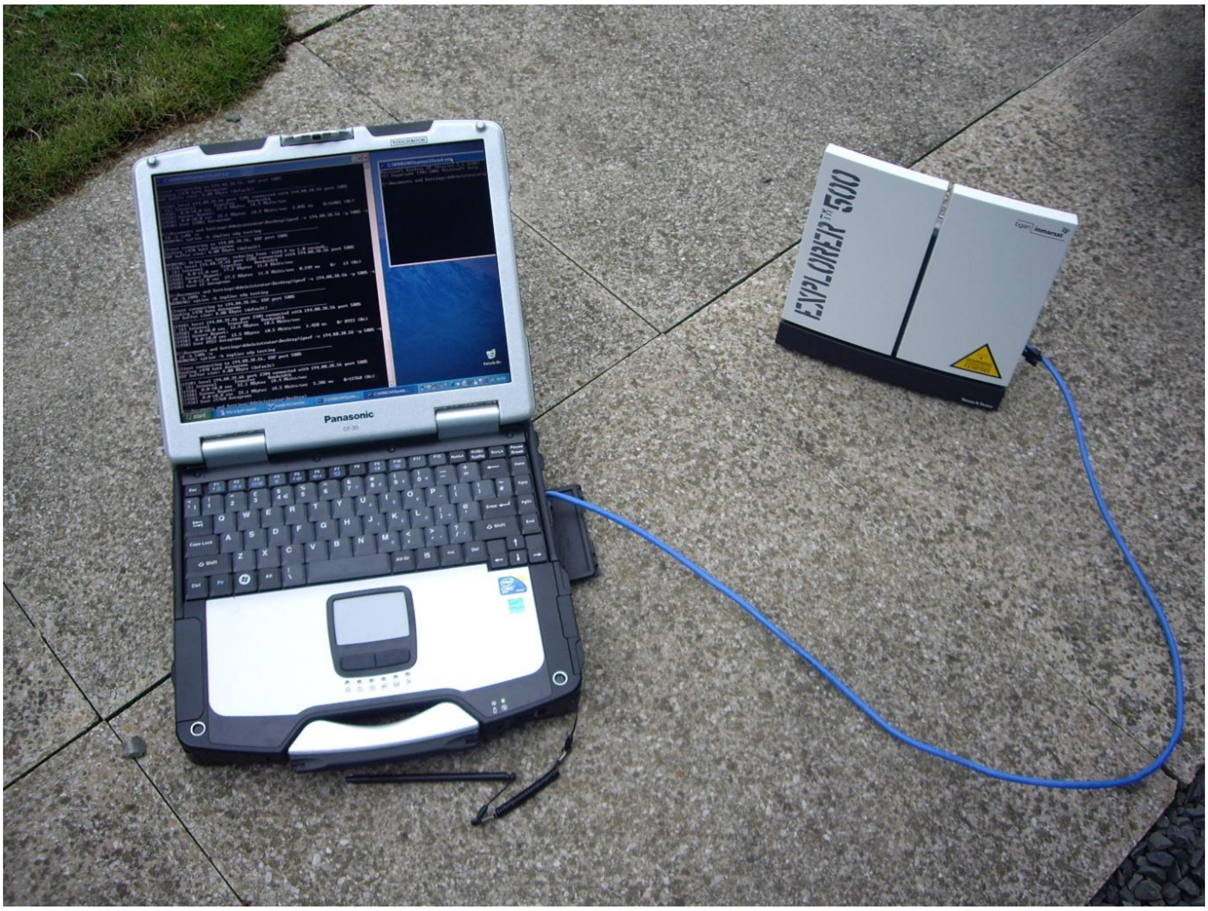

Figure 15 : Outdoor network tests of the Explorer 500 using a Panasonic Toughbook

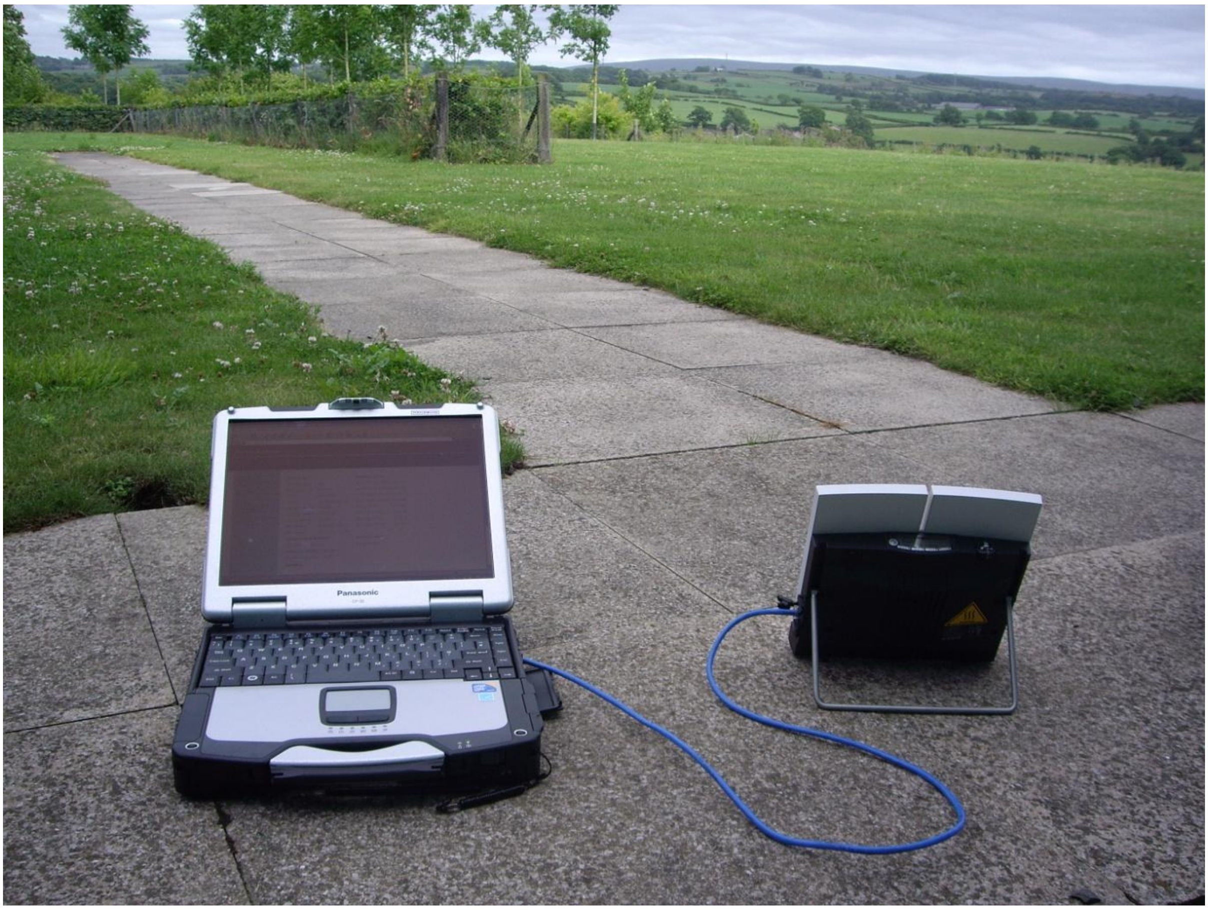

Figure 16 : Outdoors network tests of the Explorer 500 using a Panasonic Toughbook

4 Conclusion

The aim of this report was to theoretically and practically examine the backhaul connectivity options that are available and suitable in the context of Portable WLAN. Section 2 described the theoretical characteristics of Cellular, Satellite and WiMAX networks. It is apparent that Cellular networks are having the biggest deployment amongst backhaul connectivity options and end-users are currently experiencing Internet connectivity over GRPS/EDGE/HSDPA using their handheld devices (mobile phones) or laptops with GSM USB dongles. Although Internet connectivity over Cellular networks is prevalent in developed countries it still lacks high downlink and uplink rates which are highly affected from the coverage the network operator has over the respective region the user is in. It is without doubt that the technological advances of the 3G and 4G cellular networks will be able to offer higher throughput and lower latency to end users in the near future, but it is doubtful if Cellular providers will follow this evolution quickly and update their networks soon due to financial reasons. Our practical evaluation of GRPS and HSDPA on the O2 network shows that cellular networks are a good suitable backhaul connectivity option for the needs of Portable WLAN. Throughput levels were up to 390 Kbps with low latency when HSDPA coverage was apparent, which although might not be sufficient for the networking needs of many devices, but it is a valuable backup option when no other is available, especially as our Portable WLAN kit has the ability to form its own 3G connection without external input.

On the other end, Satellite Networks have started to offer broadband services with higher throughput but also with higher latency compared to Cellular networks, due to the long distance packets have to travel before they are routed to the Internet. Broadband Internet Satellite services are experiencing more deployment in the recent years and seem to be a very suitable connectivity option for users in rural areas that have difficulties in getting broadband Internet over landlines. Installing a permanent Satellite dish on the roof of a house could provide constant throughput up to 4Mbps if the user is within the Satellites' footprint. As we described, Satellite telecommunication companies are nowadays providing Mobile Satellite services with compact, lightweight and portable equipment that can be set up within minutes. Although this equipment is usually very expensive, we believe that in the upcoming years its price will be more affordable for the end-user and thus mobile Satellite services will enjoy more widespread deployment. Our hands on experience with Astra2Connect Satellite service proved the theoretical merits of this backhaul connectivity option. We were able to get approximately 1Mbps download speed and 256 Kbps upload speed with reasonable rountrip times (approximately 600 ms) although we were on a remote and rural region at the edge of the Satellite's footprint. We experienced some logistic problems on setting up and synchronizing the Astra2Connect Satellite equipment, mainly due to bad weather conditions and the equipments' power requirements (either mains or power from a generator is required). On the other hand, our experience with a true mobile Satellite service by Inmarsat, showed that it could overcome the difficulties and problems we had with Astra2Connect. The BGAN Explorer 500 terminal is a small, lightweight and portable receiver that can establish an Internet connection in less than 90 seconds from almost anywhere around the world. However, its throughput and latency capabilities were worse than the Astra2Connect service (i.e. less throughput and higher latency). The BGAN terminal is fully mobile and water resistant and is very suitable and applicable for the requirements of Portable WLAN, although its price and service tariffs might be a consideration for frequent use.

WiMAX communication is coming to fill the gap between the cheap and high capacity Wi-FI networks and expensive and less capacity Cellular Networks. The benefits that WiMAX technology has to offer are numerous, from higher bandwidth and less latency to covering long-distance areas with smaller number of antennas. WiMAX is a very promising technology that could benefit both telecommunication providers and end-users, however it seems that frequency regulators are not “releasing” the full benefits of WiMAX. On the one hand, they have split the frequency spectrum into divisions and are creating interoperability problems among WiMAX equipment and on the other hand, a license for such a frequency division is very costly. As WiMAX is encountering deployment difficulties, which we discussed in Section 2.3.3, we did not have the chance to get WiMAX equipment and perform deployment and networking tests. However, we feel that when WiMAX is widely deployed it would be a very suitable and applicable solution for the requirements of the Portable WLAN trial programme.

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