Wireless Last Mile Final Report
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Executive Summary

The investigation considers whether there is a way forward to offering economic, ubiquitous broadband wireless access, given that previous solutions have had marginal business cases. The report time scale covers the next 10-20 years. The focus is fixed access, i.e. the local loop; mobile access is specifically excluded from the scope.

The first specific question to answer is: What is the future last mile wireless broadband requirement?

This really is a key question over the long time scale under consideration. We believe that the last mile requirement will increasingly be one in which there is a convergence of the services and platforms providing communications and entertainment to the home. We note that High Definition (HD) displays and services are set to play an increasing role in this future. Whilst we cannot predict the exact, future HD services, we can take HDTV as a proxy - future requirements can then be estimated over the next 10-20 years. It was found that whilst video codecs have typically improved two-fold each five years, this fails to take into account two things: Firstly, users’ quality demands will increase, secondly the amount of coding gain for a given codec depends on the quality and resolution of the source; at the highest quality and resolution, less coding gain is available. In conclusion, 10-15Mb/s of bandwidth is likely to be required, per channel, for HD services in 10-20 years time.

At first sight it may appear that the present-day ADSL service is close to what is required by HD services. This could not be further from the truth. In fact, examining a typical ADSL service advertised at ‘up to’ 8Mb/s results in two immediate problems:

- the bandwidth of 8Mb/s may only be available at up to 2 miles from the exchange. Only 20% of customers live this close. At five miles from the exchange, the rate will have fallen, perhaps to only 2Mb/s or even 512 kb/s
- the present day ADSL service is a contended service. BT wholesale provide two contention levels; 20:1 and 50:1. Even a home user close to the exchange, who may access 8Mb/s peak rate, may access only 160kb/s when the system is fully loaded

Hence present day contended ADSL is unsuited to deliver HDTV or even standard definition TV. In fact the requirements for HD services of at least 10Mb/s streaming is so vastly different to what contended ADSL presently provides, that we have termed the future bandwidth requirement ‘Broadband 2.0’, relative to today’s ‘Broadband 1.0’. This issue is summarised in Figure 1.

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1 This is clearly recognised by BT who have just begun to offer ‘Advanced Services’ over ADSL for their BT Vision customers. This provides a bigger share of the ADSL bandwidth pool for those users who are willing pay the premium. This approach is not scaleable to all users.
One obvious question then arises - can wireless address the needs of Broadband 2.0? It would have to do so at a competitive cost, which means preferring self install indoor systems and minimising base station numbers, perhaps by working at the lower frequencies of the UHF band. But before evaluating specific wireless technology approaches, benchmarking against access technologies in other countries was performed, with the following results.

1. It was quickly apparent that countries leading on bandwidth to the home are all using some form of fibre system. Whilst Japan/Korea are doing this with government sponsorship, Verizon and AT&T in the US have recently begun fibre roll-outs on a purely commercial basis. This is a watershed development for fibre in the local loop.

2. Interest in fibre is high in the EU too, but some operators have halted their roll-out plans due to the absence of an FCC-style forbearance on fibre unbundling within the EU.

3. Benchmarking against upcoming wireless standards showed these were biased towards small screen mobile content delivery, i.e. they are not attempting to address the challenge of the Broadband 2.0 requirements for delivery of HD services to the home.

Based on the requirements identified, the cost drivers and benchmarking, three fresh approaches to the physical technology are proposed. These are:

- Mesh and multihopping systems
- UHF/TV band working
- Hybrid schemes with fibre or Gb/s ‘wireless-fibre’

It was also appropriate to consider fresh approaches for:

- Licensing, including the licence mix
- Creating a nationally tetherless last mile
- Ubiquitous access, based on peering approaches

The subsequent evaluation of the technology approaches began by looking generally at the capacity-coverage trade-off involved in all point to multipoint wireless systems. We also looked in detail at WiMAX and 802.22 capacity planning. This provides a profound, if not entirely
unanticipated result - the practical, economic capability of wireless, while adequate to provide today’s Broadband 1.0, is very clearly inadequate for the very much more demanding Broadband 2.0. The capacity shortfall is about two orders of magnitude. For example, to provide even only an SDTV-capable uncontended streaming capacity to all subscribers would need 50x more base station resource than is needed to provide Broadband 1.0. This would either require 50x more spectrum allocation or 50x more base stations would need to be deployed. To provide HD services, this factor becomes 500x.

Applying this finding first to UHF and then to mesh working, in both cases we conclude that wireless cannot be expected to provide Broadband 2.0 in a cost-effective manner. It was noted further that our sister project\textsuperscript{2} also supports this view for frequencies over 30GHz.

Having thus concluded that neither today’s contended ADSL nor wireless can provide Broadband 2.0, then attention must focus on what could - and whether wireless has any contributing part to play within that solution. The Broadband 2.0 solution must be based on fibre, which must in future reach further into the access network, and potentially all the way to the customer premises. Fibre can solve the contention issues by increasing back haul capacity, and can solve the last mile issue by acting as a point to point solution alone, or as a feeder to DSL distribution technologies - thus effectively reducing the length of DSL lines required.

These findings are summarised by the broadband decision tree in Figure 2.

\textsuperscript{2} SES-2006-10 ‘Higher Frequency bands for Licence Exempt Applications’, to be published.
In addition we note that the desire to provide ubiquitous broadband access to the UK will probably be best met by a peering\(^3\) arrangement between legacy and future, fixed and mobile devices, rather than attempting to design a single last mile access scheme.

To find the Economic Value of wireless last mile access to the UK, we built on an earlier analysis\(^4\) based on increasing the range of base stations. We propose a counterfactual of the status quo and a factual consisting of

- fibre based access for urban customers at Broadband 2.0 level
- wireless based access for rural customers at Broadband 1.0 level

The resulting net benefit for wireless thus comes from rural customers alone and is estimated as an upper bound figure of £54M, which is relatively small. Further, from a social perspective we point out that there exists a clear danger of creating a new digital divide - those who can access applications which run only over Broadband 2.0 versus those who cannot.

In conclusion, this report has found that

- the future needs of fixed broadband will be driven by a convergence of the services and platforms providing communications and entertainment to the home, and in particular the use of HD displays and services. This demands access to streaming content at 10Mb/s and above. This is so far in excess of what today’s contended ADSL systems can support, that we have termed it Broadband 2.0
- an increase in back haul capability will be needed to support Broadband 2.0, irrespective of the access method used
- wireless cannot realistically compete with fibre for the provision of Broadband 2.0 over the whole of the last mile
- coverage of fibre may be below 100%, leaving some scope for wireless based Broadband 1.0 systems, probably in rural areas

Nonetheless, within Broadband 2.0, wireless does have application -

1. as a last mile feeder element, using Gb/s wireless as a fibre replacement
2. within the home, e.g. 802.11n

Finally, the key recommendations of this report are -

1. Fibre should be the foundation of a Broadband 2.0 capability for the UK.
2. In order to avoid a new digital divide, deployment of fibre would ideally extend to rural areas, although this may not be attractive as a wholly private venture.
3. In order to facilitate Broadband 1.0 in rural areas, spectrum should be made available at

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\(^3\) Coalition Peering Domains, to share all available heterogeneous access methods, are introduced in section 2.3.6.

\(^4\) “Understanding the Scope for a Power Increase for Wireless Broadband Access at 2.4GHz & 5.xGHz”, May 2006, from www.ofcom.org.uk
suitable frequencies, for example (i) within the UHF TV bands by re-allocation or sharing; or (ii) by sharing of underused cellular or military spectrum at UHF.

4. With respect to DSO spectrum, market forces are unlikely to promote rural broadband access, so an alternative approach may need to be considered.

5. In licence exempt spectrum, where technology neutrality is desired, both codes of practice and polite protocols should be pursued in preference to application specific bands.

6. Given that home wireless usage is likely to increase and the traffic is likely to move over to mainly streaming or real-time, it would seem appropriate to reconsider the likely amount of licence exempt spectrum required, given that some estimations performed recently have considered only bursty data traffic.

7. Both service and platform convergences are key trends in the broadband future. In other words, the distinction between fixed, portable and mobile devices and services is becoming increasingly blurred. Whilst this report has concentrated on fixed wireless broadband, we recommend that future studies enable an integrated evaluation of technology, licensing and spectrum considerations for broadband wireless.
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0 Introduction to report

The organisation of this report is as follows:

- Chapter 1 derives the last mile requirement and identifies cost drivers
- Chapter 2 benchmarks non-UK schemes and emerging standards. It also introduces our fresh approaches to the last mile problem
- Chapter 3 evaluates our fresh approaches, answers eight key Ofcom questions for a wireless last mile service and provides a technology decision tree for wireless broadband access systems
- Chapter 4 presents a cost benefit analysis
- Chapter 5 draws recommendations

Each section has a summary. A list of abbreviations and glossary is provided in Appendix B.

1 Last Mile Requirements and Cost Drivers

1.1 Review, future requirement setting and baseline

The last mile is usually taken to mean the connection from the local exchange to the user premises. But note that in the US, the last mile is often referred to as the first mile\(^5\) and the exchange as the central office.

\(^5\) Hence 802.3’s EFM – Ethernet in the First Mile, is a last mile solution
The terms ‘distribution’ and ‘feeder’ will also be defined and used in this report: It is convenient to separate the last mile distribution part from any feeder part which may be used to connect to the existing back haul. An example would be a last mile distribution provided by UHF wireless, connected via a last mile feeder of Gb/s wireless to the exchange, see Figure 4.

Another example of a feeder part in the last mile would be the legacy link from the Exchange to the Primary Connection Point in BT’s access network, although in this case the same copper pair technology is used all the way to the consumer.

Throughout this study the wireless technologies are assessed against a fixed line baseline. The chosen baseline is ADSL+WiFi, due to its market leading position in the UK. Other countries however have different delivery issues and hence different delivery methods. It is expected that much can be learnt from examining these, with the aim of cherry-picking those approaches which might translate well to the UK (see section 2).

This section begins to set the scene by looking at existing fixed broadband delivery methods in the UK. It then identifies the coverage percentage of the most popular method, ADSL, for customers versus their distance from the exchange. This shows that the majority of customers are further than 2km from an exchange, even within major cities – the importance of this will become clear when ADSL bandwidth versus distance is covered later in the report. The universal service obligation is also reviewed; one danger moving forward is that the digital divide may be deepened between those who have broadband and those who have only lesser access.

The latter part of the section moves on to discuss service quality and types of service, in terms of what the future requirements may be. It is suggested that quality of service (QoS) will become a greater focus than simply increased bandwidth, due to the evolution and convergence of the service
mix towards more multimedia content, for example IPTV. Finally we note that our given base line itself, ADSL+WiFi, is unlikely to satisfy future demand as an integrated service delivery platform, in its present form. Moreover the DSL technology roadmap is looking very flat into the future.

The project scope specifically excludes mobile broadband - in particular the future service requirements will differ between mobile and fixed. Hence, the report findings should not necessarily be expected to apply to mobile broadband.

1.1.1 Existing UK delivery methods

The methods of last mile delivery in the UK include the following, in order of popularity. Note that ADSL and cable are by far the two most popular delivery methods [Ofcom 2006]. Wireless, in its various forms, is reviewed last.

xDSL

Last mile communications traditionally referred to the copper lines between the telephone exchange and customer premises. Today this legacy of copper still dominates the provision of telecommunications lines to the end user. The copper lines are largely buried in the UK and originally were used for analogue telephony. Today, through digitisation and the development of ADSL techniques, those same lines are being used to deliver bit rates of several Mb/s.

The pre-existence of copper based ADSL provides a barrier to competition from alternative last mile delivery methods which must bear new installation costs.

However, ADSL limitations include the facts that

- ADSL is carried over a dedicated twisted pair copper cable from the exchange to the subscriber, however from the exchange to the core, ADSL is subject to bandwidth contention (50:1 or 20:1 for BT IPStream)
- ADSL bit rates fall off with distance from the exchange

The various forms of DSL were/are promoted for standardisation by the DSL Forum. DSL is available with symmetric (e.g. SDSL) or asymmetric\(^6\) (e.g. ADSL, VDSL) bandwidth and with a wide range of speeds, e.g. from 250kb/s to 20Mbs and more. Range and speed may be traded off, within limits. ADSL is the most common UK broadband delivery vehicle, priced at a monthly rate similar to the price of a monthly mobile phone contract; hence it is suitable for residential applications. Unfortunately, many rural applications tend to be out of range, since the so called last mile can in fact be several miles.

EFM – IEEE 802.3’s last mile solution based on Ethernet frames is similar to DSL in its approach.

Cable

Data transport over CATV uses methods specified in DOCSIS (Data Over Cable Interface Specification), which is a closed specification within the cable industry. Transport is typically two-way with asymmetry in preference of downstream data. There are some problems with sharing out the limited available bandwidth amongst many users, which also translates to a poor bandwidth upgrade potential. The up link is restricted to a shared, low capacity. Cable is a commercially viable broadband delivery method only when paired with cable Internet/TV from the same network provider. It is the second most common UK broadband delivery vehicle, at a similar price point to ADSL.

FTTx

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\(^6\) i.e. with respect to transmission direction, the down link having the higher capability.
Fibre to the home/office/curb\textsuperscript{7} has been a suggested delivery method for the last 15 years or more. Capital expense issues with equipment are part of the barrier; along with the installation expense (whilst there is dark fibre\textsuperscript{8} in the core there is very little fibre already in the local loop). Ways to reduce CapEx have included reducing the number of active optical devices by operating a Passive Optical Network (PON), but this compromises the big advantage offered by fibre, namely bandwidth. Fibre is used when the bandwidth required justifies the expense (businesses) or when a new build is under way (no additional installation costs). In the UK, numbers of installations are relatively low and prices are necessarily set at business to business levels, far above what a consumer would pay. On the other hand, other countries are installing mass FTTx today, e.g. Korea, plus Verizon and AT&T in the US have also begun some FTTx roll-out, see section 2.1.3. BT’s future plans for 21CN show fibre being pulled into the local loop.

**Antenna remoting**

This is the practice of sending the relevant RF band down fibre by directly amplitude modulating a laser. The approach eliminates the need for digital conversion equipment when needing to site an antenna remotely from a transmitter. It is a very useful technique as part of a larger solution as it allows architectures which were previously uneconomic. The limitation is usually one of dynamic range due to noise and compression.

**FSO and microwave hybrids**

Free space optics has a niche market. It offers many of the advantages of a microwave link, with higher bandwidth and no licensing aspect. Issues include attenuation which depends on the weather (but in ways complementary to some microwave links, so hybrid optical-microwave links provide high reliability at a cost), safety issues depending on the optical transmitter used and ease of installation issues. Whilst the installation does require an alignment step and a cable link from outside to inside a building, this is clearly a quicker option than digging up the roadway. FSO satisfies a niche very well, but in situations where any other schemes could be used (DSL, leased line), then these are invariably more cost effective and reliable. Pricing is high, as befits a niche product. Strictly speaking, FSO is a wireless technology, moreover it is unlicensed.

**Satellite**

Two way satellite communications with a medium sized dish is aimed at businesses. Consumer satellite broadband is typically a small dish, one way, broadcast-like service, although multicasts are often created with reduced throughput. In the consumer case, the phone line is typically the return path. Clearly this creates a logical problem; if the phone line is there, then why not use ADSL? In some cases the answer will involve too large a distance. In such cases what results is a highly asymmetric bandwidth offering, which is also expensive to install and operate.

**Wireless**

Currently, mobile cellular networks lag behind DSL speeds and even HSDPA is not expected to close an increasing gap. Wireless LANs alone are not considered as relevant delivery methods in themselves due to their short range, but when augmented by back haul (i.e. precisely as in a community network) they can be a key component. WiMAX is a development of earlier broadcast LMDS (Local Multipoint Distribution Service) approaches and is now suitable for two-way, medium distance applications, with a mobile variant on the horizon. The prime issues with wireless are the performance due to the environment versus the service requirements, the availability of spectrum, equipment cost and transmitter siting. By applying network ideas from other fields (e.g. meshing, taken from the wired Internet) however, the capability set of wireless

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\textsuperscript{7} the curb means the last distribution point i.e. the street cabinet  
\textsuperscript{8} dark or unlit fibre is present in the ducts for future use, but is unconnected to any equipment
can be varied. Because of existing copper circuits, radio solutions offering only similar performance\(^9\) are not generally cost effective. However in the absence of existing circuits, radio becomes an option which may prove cheaper than digging trenches and laying copper or fibre lines. For remote locations radio clearly becomes the cheaper solution and BT have used radio point to point to reach remote locations in order to satisfy the Universal Service Obligation (see section 1.1.3).

Radio point to multipoint will have lower costs per subscriber as the distribution is being shared between many. There are examples such as UK Broadband Ltd who offer broadband service via radio currently in areas where new premises require service but also in areas where competition with legacy circuits is high, e.g. Reading.

**High microwave**

At 60GHz, weather limits the useful range to 1.5km or less. Lower frequency microwaves are however very useful for back haul, e.g. up to around 10km at 28 or 38GHz. These are intrinsically point to point links. Recent interest has re-focussed on 60/70/80GHz links since the available spectrum is large and Gb/s rates are possible, see section 2.3.3.

**UWB (Ultra Wide band)**

It is considered that UWB is of limited relevance to this project. The applications which are foreseen are primarily very short range, typically eliminating cables within rooms. However the technology is capable of trading bit rate and range so that it may be possible to use UWB in situations more akin to WiFi. Unless there is a significant under provision of LE (licence exempt) spectrum it would seem unlikely that UWB would be used in this way to any great extent.

### 1.1.2 BT's copper line coverage statistics

The coverage capability of BT’s copper lines is critical for ADSL delivery, which is the prime broadband delivery method, and the base line for comparison in this report.

As part of its Research and Market Data work, Ofcom produces reports on the state of the Communications Market, including ‘The Communications Market: Nations and Regions - Research Report’ [Ofcom 2006]. This report provides details of coverage and capabilities of commercially deployed services. Section 5.4 gives the percentage of premises in the UK within 2km and 5km of an exchange, as follows:

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\(^9\) We later make the point that radio can be differentiated from ADSL+WiFi due to nomadic mobility and bandwidth symmetry - these may offer unique selling points, see 1.2.1.
Figure 5 shows the percentage of premises within a 5km implied local loop length range of a BT exchange. Overall, 86% of premises across the UK were within this range. This was higher in London at 97%. Across the UK, 14% of premises were outside the 5km range. In Northern Ireland, this figure was as high as 26%.

Figure 6 shows the percentage of premises within a 2km ‘implied’ local loop length range of a BT exchange. At 2km, the modelling suggests that across the UK, each nation and region had consistently fewer than 19% of premises within this distance of an exchange, with the notable exception of Scotland (22%). This in turn suggests that the fewer people will be able to receive higher-speed services via DSL across the nations and regions – including dense urban areas such as

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10 ADSL line lengths are typically longer than map-measured distances, since the cables must travel in ducts. It is the line length which determines grade of service, with longer lengths leading to a poorer service.
London. However, future technology advances may increase the availability of higher speed DSL services at greater distances from the exchange, although a critical distance will still exist. This will be discussed in section 3.

**Hence for a given version of ADSL and a particular Internet speed, there is a length of copper cable from the exchange beyond which an alternative delivery method is required, and radio is a candidate.**

### 1.1.3 Universal Service Obligation

Many of the copper lines were installed when BT was the sole provider of telecommunications. Despite new competition BT still has a Universal Service Obligation\(^\text{11}\) (USO) which Ofcom last reviewed in 2005.

> “Universal Service ensures that basic fixed line services are available at an affordable price to all citizen-customers across the UK. The scope of the USO is defined by the EC Universal Services Directive (‘USD’). The Secretary of State for Trade and Industry specifies the services which must be provided throughout the UK in the Universal Service Order (the Order). The Order has been implemented by Ofcom through specific conditions on BT and Kingston Communications (in the Hull area) and general conditions on all providers. USO services include the following: special tariff schemes for low income customers; a connection to the fixed network, which includes functional Internet access; reasonable geographic access to public call boxes; and a range of services for customers with disabilities including the text relay service. Concerning Internet access, the obligation on BT and Kingston to provide a connection upon reasonable request encompasses the provision of a narrow band connection capable of ‘functional Internet access’ (FIA). Guidelines on FIA were issued in 2003 which said that users should be able to expect connection speeds of at least 28.8kbit/s. It also set out measures that universal service providers should take in response to complaints about data speeds. The Guidelines have been beneficial and no significant changes are proposed at this time. In particular, it is considered that the benchmark minimum speed should remain at 28.8kbit/s for the time being”.

The USO review is focussed on the next two to five years and was carried out alongside the Strategic Review of Telecoms\(^\text{12}\) (‘Telecoms Review’) which looked at longer term Universal Service issues. The Telecoms Review’s conclusions on USO were set out by Ofcom in September 2005. The Telecoms Review emphasised the importance of USO as a ‘safety net’ for vulnerable consumers but noted that the mechanisms for funding, for example a Universal Service fund and provision of universal service may need to change if and when the provision of USO becomes an unfair burden. It may also be appropriate to alter the overall scope of USO. Though Ofcom does not believe that there is a case for proposing that universal services be extended to include broadband at this point, the Telecoms Review of 2004 considered how the scope of USO might evolve over time.

In March 2006 the European Commission completed a review of USO by concluding that the scope should not be extended at this stage to include broadband services\(^\text{13}\). The Commission has

\(^{11}\) [http://www.ofcom.org.uk/consult/condocs/uso/](http://www.ofcom.org.uk/consult/condocs/uso/)

\(^{12}\) [http://www.ofcom.org.uk/consult/condocs/telecoms_review1/telecoms_review/](http://www.ofcom.org.uk/consult/condocs/telecoms_review1/telecoms_review/)

announced however that it intends to launch a further wide-ranging review of USO in 2007.

The question of course is that if ubiquitous broadband becomes available, will those on USO be effectively below a new digital divide, since they are connected to the Internet below the cut off speed for future applications?

1.1.4 Quality of service - future needs

Over the next 10-20 years, the service requirement will become increasingly difficult to deliver as the mix of services becomes biased towards real time services like video and VoIP. Quality of service is usually practically specified within a service level agreement. This traditionally includes at least the following, which are discussed below:

- Bandwidth
- Latency
- Packet loss
- Availability

Security must be added to this list to bring it up-to-date, especially for a wireless system. Security is a concern for wireless systems in a way that it is not for wired systems, purely because of the public accessibility of the transmission medium. It is well known that the original security system of the popular 802.11 WLAN was subsequently proven insufficient, although steps have been taken to improve this. Additionally, recent years have seen that the security requirement itself is increasing in importance when considering such issues as Denial of Service (DoS) attacks, which are potentially more easily launched on radio. This has a direct affect on consideration of QoS. However the provision of better security is at the expense of bandwidth and time, which are already under pressure. Beyond noting the above, security is not within the scope of this report.

1.1.4.1 Bandwidth

The bandwidth required will be determined by the applications: The evolution towards more video transmission will increase the bandwidth required. But over the future 10-20 years, technology advances will be made. There are at least two points of view on what the future requirements will be:

Firstly, the DVB Forum has tracked the efficiency improvements in video compression technology over time [McCann 2006]. It was noted that the bit rate required halves approximately every 5 years. Thus in 20 years’ time, the required bit rate may be only 1/16th of that required now. This means that today’s 15Mb/s HDTV coding may evolve to require only 1Mb/s in future, as drawn in Figure 7. At the same time, local storage will be increasing in size, such that many hundreds of gigabytes of solid state storage will be available, lessening the need for transmission bandwidth.
Secondly, an alternative and perhaps more easily believable view is that, even as codecs improve, the quality demanded of TV will be pulled higher by the customer. The net result is shown in Figure 8.
Compared to Figure 7, Figure 8 shows the improvement in HDTV coding is less over time, due to demanded quality improvements; it is interesting to note that LCD display technology can show a higher quality picture than CRT based displays, even of the same resolution\textsuperscript{14}. IPTV to the home is shown to increase in bit rate required due to quality (including resolution) improvements – its increase is assumed to be tempered by transmission technology capability, whereas no such constraint has been applied to the SD and HDTV curves. The curve for mobile TV is also shown for comparison – this is much smaller due to the lower resolution and quality of the small screens on mobile devices. The focus of the report is not mobile TV.

An example of an industrial HDTV encoder comes from Thomson GrassValley: GrassValley’s ViBE MPEG-4 encoder is currently implemented in a DSP-based architecture, but on moving to single chip it could enable dual-pass encoding with low latency at bit rates down to 4Mb/s for HD. This approach is intended to enable broadcasters to deliver HDTV in the same bandwidth as today’s SDTV services. It suggests a quick evolution to lower HDTV bit rates. However we note that the US provider DirecTV (satellite) has been sued by a user since it increased the compression on its HDTV services in order to lower the bit rate and bandwidth. The user complained of lowered quality, in his perception, apparently leading to the coining of the unflattering term ‘HDTV Lite’ according to some reports\textsuperscript{15}.

On the wider subject of ‘how much bandwidth is enough’, Ofcom’s Spectrum Framework Review raised 100Mb/s as a ‘personal’ intra-home or intra-office rate. Another data point is that 802.11n’s home networking task force thinks 150Mb/s raw (about 100Mb/s to the user) should be enough; once again this is a personal rate, specifically within the home.

Combining this with the line of reasoning developed above, this section suggests that future bandwidth requirements in the local loop will most likely be less than 100Mb/s. Potentially a figure of the order of 10Mb/s delivered effectively uncontended could be sufficient for the

\textsuperscript{14} Due to CRT driver bandwidth which is designed for interlaced pictures

\textsuperscript{15} http://broadcastengineering.com/newsletters/bth/directv_hd_lite_20060925/?r=1
majority.\textsuperscript{16}

We note that an uncontended 10Mb/s service is far different from today’s ADSL broadband. The difference is so great that we will refer to this enhanced level of broadband service as “Broadband 2.0”.

Furthermore, it seems equally reasonable to additionally assume that a minimum value of useful bandwidth, higher than today, will also be required. Presently, for many services, the effect of low bit rates is that the activity simply takes a little longer e.g. downloading e-mails, opening web pages. However at some future time there will be minimum speeds which will be required for an important service to function well. Likely examples of this are real or nearly real time television programmes, gaming, video telephony, etc. Once the requirement includes the availability of a minimum bit rate, then more of the existing copper ADSL circuits (i.e. those at greater distances from the exchange) will cease to be adequate and an alternative means of last mile provision will be needed for more cases. Indeed, recent ADSL speed advances have all been restricted to ever shortening distances, so the technology may be reaching a practical plateau for all but those customers very close to the exchange.

1.1.4.2 Latency, packet loss and availability

Because of the increasingly real-time nature of the service mix, the QoS focus will move to latency and latency variation.

Latency is a system parameter which is effectively fixed at design time by the chosen architecture; latency cannot be reduced in service, in the same way that bandwidth can simply be increased, e.g. via more links and/or more spectrum. The next version of 3G, LTE, is undergoing a major redesign in order to reduce latency to the 20msec level, since the present 3G architecture simply cannot achieve this. Naturally, the end to end latency consists of much more than that within whatever access network is used. Hence a holistic approach is demanded. Interestingly, IEEE 802.16’s QoS comes at the expense of it never expecting to have to share the channel: Controlling latency, when the radio medium to be accessed is shared, is a major issue. Latency is also compromised when multi-hop systems are considered, like a chain of radio back haul nodes or a mesh.

Packet loss typically means a short term dropout, but it can have an amplified effect if the transport protocol reacts ‘badly’ to loss (e.g. TCP’s congestion control back-off is confused by high radio BER, for which it was never designed).

Availability is coverage related in a radio system, which is revisited when mesh approaches are discussed, see section 2.3.1. It is worth noting that, in a ADSL system, availability is complicated by the presence of contention in the back haul. This is of key importance and is explained shortly, in section 1.1.6.

1.1.5 Platform and service convergence

Convergence is occurring simultaneously in two areas. These are fixed-portable-mobile convergence and service convergence.

\textsuperscript{16} Here we mean a true 10Mb/s to the user, not ‘up to 10Mb/s’ as presently advertised by ADSL, but rarely delivered due to distance and contention limitations.
1.1.5.1 Fixed-portable-mobile convergence

There is convergence between the two traditionally different types of terminal usage: fixed and fully mobile\(^{17}\). Basic WiFi (and DECT for home applications in the telephony case) allows cordless usage in which the terminal can be used anywhere within a single radio coverage area. But the connection is dropped when moving outside this area and, as the radio standard can only cope with low levels of rapid fading, communication is maintained only up to walking speed. Combined cordless and cellular terminals are regularly proposed: A converged service should appear to be fully mobile overall but when in a home building the service is actually delivered by the cordless system to reduce the cost of service, enhance in-building coverage, and benefit from not needing to support the terminals moving at high speed.

Alternatively a level of portability is offered by systems such as UK Broadband\(^{18}\). The equipment (presently from IPWireless) provides a broadband wireless service based on the 3rd Generation standard TD-CDMA developed by the global 3GPP. But the fully mobile features, such as handover, are disabled, partly because the licence prohibits offering a mobile service\(^{19}\). Customer units have directional antennas, although this may change to omni-directionals (see section 1.2.2), and are used in a point to multipoint manner. Ideally, a unit is mounted on a window ledge and oriented to face the base station. Users then connect fixed or portable terminals to this unit. Within the coverage area of UK Broadband the units are portable in that they can be taken to any other location and re-oriented towards a base station.

It should be noted that it is primarily only real time services that are concerned with maintaining uninterrupted connectivity. Interruptions in connectivity are far less of a problem if the primary services are e-mails and downloads.

In the US, landline subscribership is falling; customers are dropping second lines in favour of wireless [TIA 2006]. This trend appears to also be beginning in the UK, where many urban customers want no landline at all and simply take mobile/wireless.

1.1.5.2 Service convergence

Increasingly, at the level of service convergence, operators are offering more and more previously disparate services, bringing together fixed, mobile and broadcasting. For example at the time of writing, NTL was already offering fixed telecoms, Internet access and broadcast TV but combined with Virgin Mobile under the Virgin brand to include mobile. Other companies including BT, O2 and The Carphone Warehouse are all offering converged services. Initially there are savings through common billing of services but over time it will be possible to alter the conventional alignments of service type and delivery method. This will be when the common delivery platform of IP is available.

Example: Bundled Services

Increasingly operators are embarking on so called triple and quadruple play strategies. i.e. in the latter, customers can have fixed and mobile phone calls, digital TV and broadband Internet access from one provider and one bill.

Some examples are shown in Table 1.

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\(^{17}\) in-call handover, rapidly moving terminals, roaming etc

\(^{18}\) http://www.ukbroadband.co.uk

\(^{19}\) a reduction of restrictions is expected in 2007, see section 2.3.4.6
Initially these bundled services are being built up by acquiring each part through merger and acquisition but over time such operations would benefit from simplification and cost savings through greater convergence of the means of delivery particularly in the last mile.

The move to a single platform (IP) is the enabler for complete service convergence, e.g. IPTV, which will be rich in integrated, value-added services rather than just ‘vanilla’ TV (see section 1.1.5.3). In the US, installed numbers of IP delivery platforms are predicted to overtake traditional platforms by 2008 [TIA 2006]. However this has different implications for incumbents and new entrants, due to the presence or absence of legacy infrastructure.

Early solutions such as BT Vision show the topology whereby over the air and line connections to broadcast and Internet enable alternative delivery methods for content. BT Vision is in beta form now and is expected to be in the mass market by early 2007.

The platform over which BT Vision, Figure 10, is delivering its IPTV service is a novel hybrid access solution. The free package of channels is delivered via Freeview, while the on-demand video service is streamed to the household via a special quality DSL link at 1.5Mb/s using MPEG-4 compression. The Philips set-top box that BT Vision uses is capable of receiving signals from both the rooftop aerial and the DSL connection. It is also a PVR with hard disc storage.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Virgin/NTL</th>
<th>Sky/Easynet</th>
<th>Orange</th>
<th>BT</th>
<th>Carphone Warehouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Base</td>
<td>9.5M</td>
<td>8.1M</td>
<td>17M</td>
<td>16M</td>
<td>n/a</td>
</tr>
<tr>
<td>Fixed line calls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Broadband</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (free with fixed)</td>
</tr>
<tr>
<td>Digital TV</td>
<td>Yes</td>
<td>Yes</td>
<td>Not yet</td>
<td>Autumn 2006</td>
<td>No</td>
</tr>
<tr>
<td>Mobile</td>
<td>Yes</td>
<td>Few</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bundled</td>
<td>2007</td>
<td>Planned</td>
<td>2007</td>
<td>Autumn 2006</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 1 Collation of UK operator offerings for triple and quad play
It is important to realize that, because BT is planning to use a 1.5Mb/s data rate for video delivery using the H.264 codec (MPEG-4), this is not to be over regular ADSL; contention\(^{20}\) and QoS issues would preclude this. In fact, BT Wholesale has recently promised “Advanced Services” on ADSL, which would allow a customer to choose improved QoS (such as reserved bandwidth and good latency) for the first time. This is expected to attract a price premium. Such a re-division of available DSL capacity cannot scale to all customers, all the time - clearly BT expect either a limited take up of the service, or an evolution of the access network under their 21CN plans, or both.

Finally, 1.5Mb/s is sufficient for only one single TV channel to any household at any one time. The resolution will be SD and the quality remains to be seen when the service is delivered to the public, but 1.5Mb/s is quite a low rate, especially for viewing on a large home display and the danger is that it may be perceived as sub-broadcast quality.

### 1.1.5.3 Specific considerations for IPTV

#### 1.1.5.3.1 TV - content

The well-accepted headline is that interactivity will be key - it will not be plain, vanilla TV in future. Personalisation may well be linked to targeted advertising; buddy lists and other Internet chat-like aspects should be expected.

Microsoft says, above all, that telcos must not lose sight of the fact that the killer app for TV is TV:

\(^{20}\) contention is explained in section 1.1.6
“It’s about great, interactive TV experiences”21. This agrees with many analyses which essentially say ‘content is king’. The rights to distribute content may be what separates service provider winners from losers, much like it does with multichannel TV now. The studios and other content owners are not likely to begin to give it away just because broadband is here. Interestingly, Sony is in a unique situation of being well integrated at the content level via Sony Pictures as well as at the hardware level via both Sony Semiconductor (e.g. DVB chips) and the Sony PSP games platform.

### 1.1.5.3.2 TV - delivery

Internet TV delivery is not the simple, one-way, broadcast which one might assume, for several reasons:

As TV viewing migrates to the Internet, techniques such as multicasting may be used. The BBC has been trialling this technology by feeding its live television to the computers of volunteers. Multicasting shares the burden of bandwidth with an Internet provider to maintain live feeds during periods of heavy demand. If such techniques prove useful the need for high speed up links from these relaying stations may not be best met by the unbalanced speeds of ADSL.

A new technology, called Location Free TV, allows users to watch their own TV - live from anywhere in the world. A box is connected to their existing TV, satellite or DVD set-up and transmitted and controlled over broadband links and the Internet by a distant PC, laptop or PSP. Examples are:

- Sling Media, www.slingmedia.com and
- PSP location free, www.sony.co.uk/locationfree

Such technology requires a high speed connection from the home towards the Internet22 rather than the comparatively low speed provided by much ADSL.

This is another argument for symmetry of local loop bandwidth provision.

### 1.1.5.4 Fixed-mobile customer base

Increasingly customers are acquiring more of their communication and entertainment services from a single supplier. This section considers this trend and assesses how it impacts on the means of providing last mile communications.

Section 1.1.5.2 showed that most providers are offering or planning to offer triple or quadruple play services. This can either involve disparate delivery methods simply bundled for billing, management and customer service reasons or, increasingly, it involves utilising common transport for several types of service.

Although the focus of our report is not mobile communications, the distinction between which traffic is carried by the mobile network and which by the fixed network is blurred. For example many users frequently use a mobile terminal even when an alternative fixed device is present.

It should be noted that

- in the UK there are about 20 million fixed telephony subscriptions versus 60 million mobile phones.
- 10% of homes have only a mobile phone and not a fixed line phone.

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21 Christine Heckart, general manager of marketing for Microsoft TV, keynote, Globalcomm 2006

22 i.e. high uplink capacity
a recent survey by Olswang\textsuperscript{23} suggests that 20 per cent of people aged 13 to 55 have moved their computers into the living room as the primary source of entertainment

Hence the traditional means of delivering each service is often being replaced by an alternative means and this trend affects the traffic mix for fixed /mobile and triple-play operators.

With present fixed/mobile convergence, the user of a suitable mobile phone may enjoy cheaper calls in the home by automatically switching to become a cordless phone subscriber for the call instead. Another possible attraction may be a single voice mail for both the fixed and mobile phone, but on this basis only one phone user can enjoy the integration for inbound calling - the same aspect of any bundled package is similarly constrained. However, when telephony services (fixed and mobile) are all provided by VoIP then greater levels of sharing become possible, since this is an integrative platform.

The trend to not having a fixed line has occurred through

- falling costs of mobile
- regard for phone as a personal device
- absence of good fixed/mobile offering
- more nomadic lifestyle users
- users with frequent changes of address

It should be stressed that the phone in these cases is often acting as a substitute for a conventional fixed line cordless phone and hence is taking traffic which otherwise would be on the fixed access network.

If triple play is seen as an attractive service then those without fixed lines may become dissatisfied. Their difficulty will arise because mobile is be concentrating on services to the handheld device and so fails to address any larger screen portable market. In other words, these users can only access radio based solutions and these are not being targeted at large screen HD services. Although the wireless distribution system within the home may be fast enough, fixed wireless access (FWA) systems covering more of the last mile are unlikely to support the performance levels that are needed for Broadband 2.0. However it is possible that FWA solutions may find favour with some people who value their service not being as rigidly locked to location as a fixed line. However, their service levels will as a consequence only support smaller screen TV and slower Internet rates.

This may complicate the decision of whether wired broadband to the home or to the kerb is most appropriate - it may be that in some circumstances where the current population is averse to installing a fixed line e.g. small blocks of flats, then wired broadband to the kerb plus a wireless hotspot is a better option than wired broadband to each property with individual cordless distribution.

Portable usage

A characteristic of radio delivery is that it allows some degree of portable use and as such portable sits between mobile and fixed communications. This area is already seeing competition between full mobile offerings and hot spot provision and it is unclear how this will divide up over the next few years. As pointed out above, it is possible that FWA solutions may find favour with some people who value their service not being as rigidly locked to location as a fixed line.

If the last mile is serving fixed subscribers only then different locations can use different technologies or frequency bands. Indeed there is some merit in using different bands in urban and

\textsuperscript{23} The Olswang Convergence Consumer Survey 2006, www.olswang.com
rural areas to get the most appropriate coverage from each base station. Where there is some advantage in a homogeneous approach is in equipment volumes which can help costs and allows users to retain equipment if they move their home location. However if the last mile is intended to address portable usage as well, then the systems deployed benefit from being a homogeneous technology.

1.1.6 Base line evaluation - ADSL plus WiFi

Our given baseline of ADSL+WiFi is as exactly as used today by very many home consumers. Nonetheless, whether this is in fact a true broadband service is open to some debate, as follows:

The providers of ADSL service quote a maximum bit rate, but this effectively falls for the user when there is contention for capacity. Additionally, beyond 2-3km from the exchange the maximum rates can never be attained by anyone, due to the effects of line attenuation and hence worsening SNR. This means that only users near the exchange may enjoy the maximum rate - but only when utilisation is low. It is interesting to note that, to date, the service providers have generally not suffered complaints even from users distant from exchanges, because the underlying service speed has increased rapidly over time and the expectations of users has remained quite low. Unfortunately, however, this is not a sustainable state of affairs.

By way of example, if a peak rate of 2Mb/s is available via ADSL, then with 50:1 contention, the fully loaded case is only 40kb/s. Whilst many applications remain using ‘bursty’ data streams, there is a statistical multiplexing effect which means that most users are satisfied most of the time. However, with our observation that the future service composition will include a larger component of streaming and isochronous services, this statistical multiplexing gain will diminish and greater provision per user (i.e. lower contention) will be required. Hence ADSL+WiFi could be a broadband service to some of the people, some of the time, but not to all of the people, all of the time. Simply put, it is unlikely to satisfy the future broadband service requirements.

It is interesting to consider that the 10Mb/s, zero contention service to the user proposed in section 1.1.4.1 could be delivered as 100Mb/s at 10:1 contention in the future - these are not exact equivalents, but to expect contention to disappear entirely is unlikely as there will still be some bursty traffic component in the service mix, for which a contended service remains appropriate. 100Mb/s at 10:1 could allow a high peak rate for bursty traffic to pass quickly, but also enable constant real time traffic for all users, up to 10Mb/s.

Future speed improvements in ADSL also look quite unlikely, given the distances required (>2km, cf. Figure 6) and the copper bandwidth available. VDSL could help line speed over limited distances, but does not address contentention aspects (indeed it would enable increased competition for the contended resources). ADSL2 and VDSL2 bandwidth distance trade-offs are shown in Figure 11 and Figure 12.

ADSL2 bit rates fall sharply beyond about 2.5-3km from the exchange, whereas VDSL2 bit rate immediately begins to fall sharply over the first 0-100 metres from the exchange. Both distances apply to line length as installed in available ducts, which are typically longer than map measured distances between points.

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24 BT Wholesale provided only two ADSL contention ratios; either 50:1 and 20:1, with the lower (better) rate priced higher for its expected business use. See 1.2.4 for the origins of contention.

25 Whether all the people will require full access at the same time is debatable, but it could happen. Whether a very small level of contention remains appropriate, given there will be a service mix including non real-time services, is for an operator to decide, and price accordingly.
Figure 11 ADSL2 bandwidth versus distance [Ericsson 2006]
Thus the most likely upgrade path would include a method to reduce contention, although today’s price of an uncontended link (usually called a leased line) is far in excess of what a home user could afford. Contention is covered further in section 1.2.4.

It is the ADSL rather than the WiFi which presently throttles Internet access for home WiFi users. However, it is worth noting that WiFi is also a contended system, but this time via the sharing of unlicensed spectrum: In the WiFi case, contention is against other WiFi uses in the home - or even neighbours if they are using the same spectrum - even though neither of these other user groups may in fact be using their WiFi for Internet access.

### 1.1.7 Rural community growth

Telephony in villages has largely been provided by copper line often at quite long distances from the exchange. The cost of adding new lines varies depending on how much digging or cable pulling is required. Over time as communities have grown, satellite exchanges have been introduced and these help reduce the cable distance from the exchange so that higher speeds can be supported when ADSL technology is introduced.

The level of telecoms traffic which is now sought in villages is rising quite rapidly, because

- building developments within villages are increasing the density and number of units through such policies as ‘brown field’ sites. Often large gardens within the village boundary are being redeveloped as many small housing units. Previous farm buildings are becoming industrial units
- home working is becoming more common and workers (both home workers and others remotely keeping in touch with their offices) are expecting to have the same access to data as they enjoy in a conventional office
- Internet usage is particularly attractive in remote locations for activities which avoid travel, e.g. shopping, access to libraries for school work

Existing cabling in a village will support ADSL but the distance from the exchange can mean that the speeds are too slow, see Figure 13.

![Diagram of Rural Community Cabling Growth](image)
distribution, as introduced in principle in Figure 4, page 11. The means to achieving higher speeds to end users may be to replace the lines between the exchange and a hub point by fibre, traditional microwave or Gb/s wireless. The best solution depends very much on what already exists and how easy it would be to install new lines.

1.1.8 Future requirements summary – “Broadband 2.0”

Our baseline for comparison is ADSL + WiFi.

We believe that the last mile requirement will increasingly be one in which there is a convergence of the services and platforms providing communications and entertainment to the home. We note that HD displays and services are set to play an increasing role in this future. On this basis we have developed a future requirement of

- 10Mb/s, without an effective contention limitation
- low latency and loss (high QoS)
- appropriate back haul
- improved uplink capacity
- tetherless
- ubiquitous

This list was developed from considerations which included bandwidth needs based on continued technology progress, especially with respect to TV codec development, and that the focus would move to quality of service.

This service level is so much higher than that presently available, that we will refer to it as Broadband 2.0, see Figure 14. Clearly the step-up involved represents a large technical challenge.

We have noted that there is always a critical range beyond which ADSL rates will have fallen too
far to support the desired applications (whose minimum speed requirement will increase over time) - radio is a candidate for filling these gaps.

We also noted that the USO as it stands at 28kb/s may in fact not define the new digital divide: Any bandwidth/latency offering below the cut-off for new, future services would be effectively no useful connection at all. Hence a new service driven requirement (probably based on some large screen display service, e.g. HDTV) could set the effective future digital divide for subscribers.

Finally we observe that ADSL is unlikely to satisfy the future broadband service requirements. Future speed improvements in ADSL also look quite unlikely, given the distances required (>2km, cf. Figure 6) and the bandwidth available on the old copper lines. Reduction of the contention ratio is an essential avenue to pursue for improved xDSL, although this presently comes at a high cost.