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Electronics Design & Consultancy

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[1].

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.

[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.

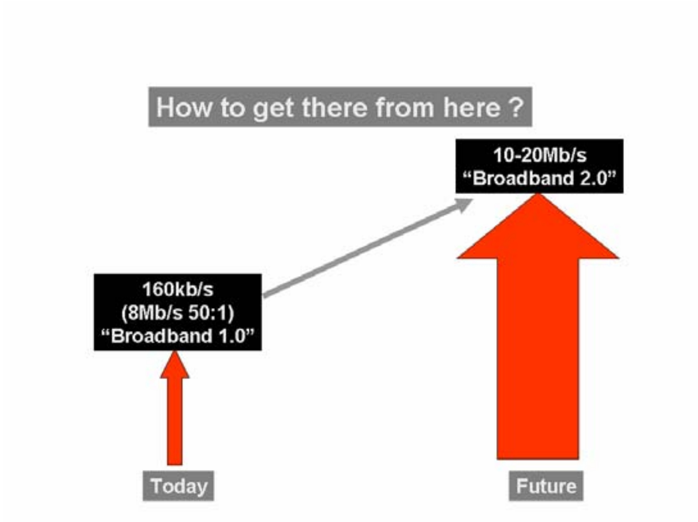

Figure 1 Broadband 2.0

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[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.

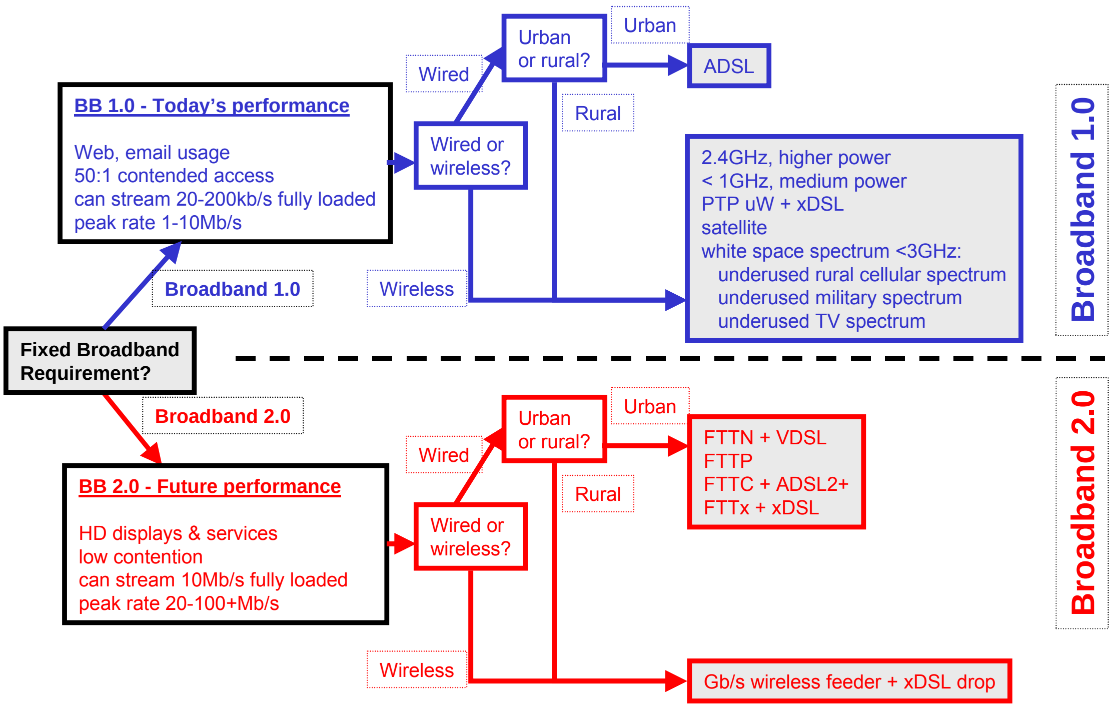

Figure 2 Broadband decision tree

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[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.

Revision History

Version	Date	Description	Author	Approved by
01	14 Nov 06	Release to client	SGM	Steve Methley
02	20 Nov 06	Added footnotes	SGM	Steve Methley

Version 02	Approved by	Steve Methley

Contents

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.

Figure 3 A Last Mile example

[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.

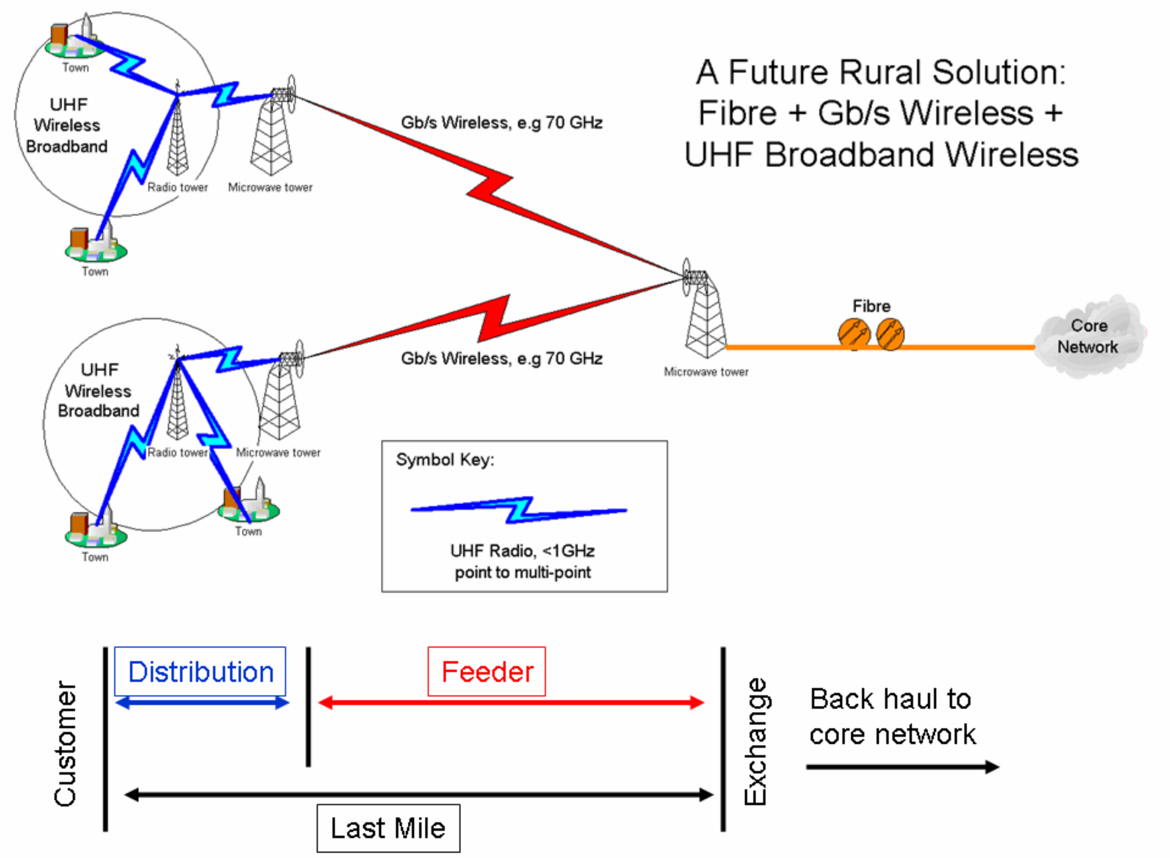


Figure 4 Last mile distribution (UHF), feeder (Gb/s wireless) and back haul (fibre) segments of the network

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.

<u>xDSL</u>

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.

<u>Cable</u>

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.

<u>FTTx</u>

[6] i.e. with respect to transmission direction, the down link having the higher capability

Fibre to the home/office/curb[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[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

[7] the curb means the last distribution point i.e. the street cabinet

[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)

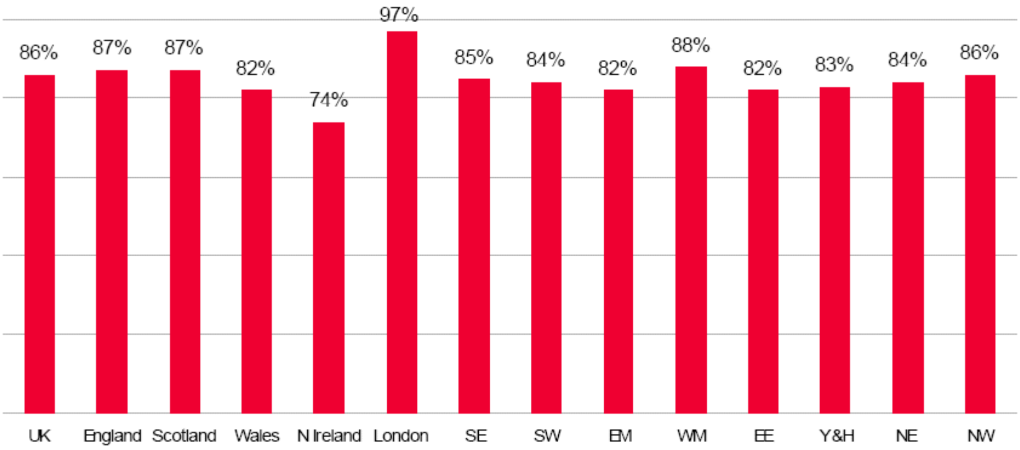
It is considered that UWB is of limited relevance to this project. The applications which are foreseen are primarily very short range, typically eliminating cables within rooms. However the technology is capable of trading bit rate and range so that it may be possible to use UWB in situations more akin 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:

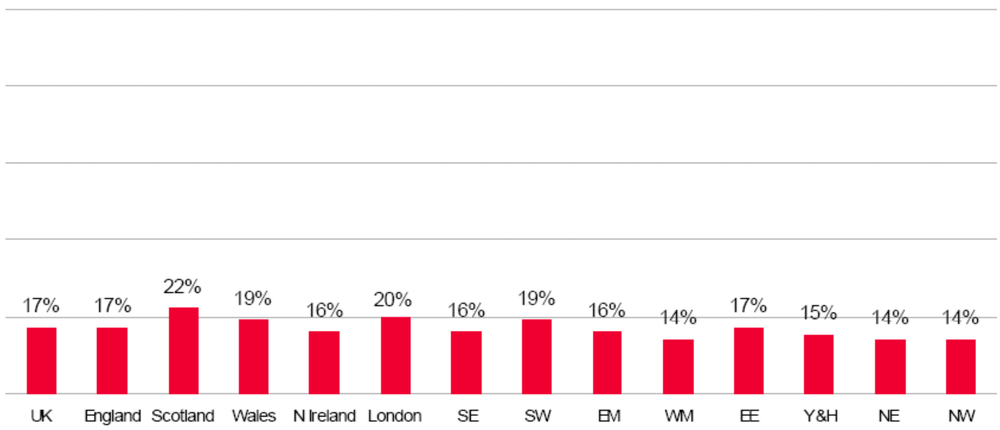
[9] We later make the point that radio can be differentiated from ADSL+WiFi due to nomadic mobility and bandwidth symmetry - these may offer unique selling points, see 1.2.1.



Source: Point Topic, BroadBand User Service, June 2005

Figure 5 Users within 5km of an exchange [Ofcom 2006]

Figure 5 shows the percentage of premises within a 5km implied[10] 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%.



Source: Point Topic, BroadBand User Service, June 2005

Figure 6 Users within 2km of an exchange [Ofcom 2006]

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

[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[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[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[13]. The Commission has

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[11] http://www.ofcom.org.uk/consult/condocs/uso/

[12] http://www.ofcom.org.uk/consult/condocs/telecoms_review1/telecoms_review/

[13] http://europa.eu.int/information_society/policy/ecomm/doc/info_centre/communic_reports/universal_service/com_2006_163_final_en.pdf

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.

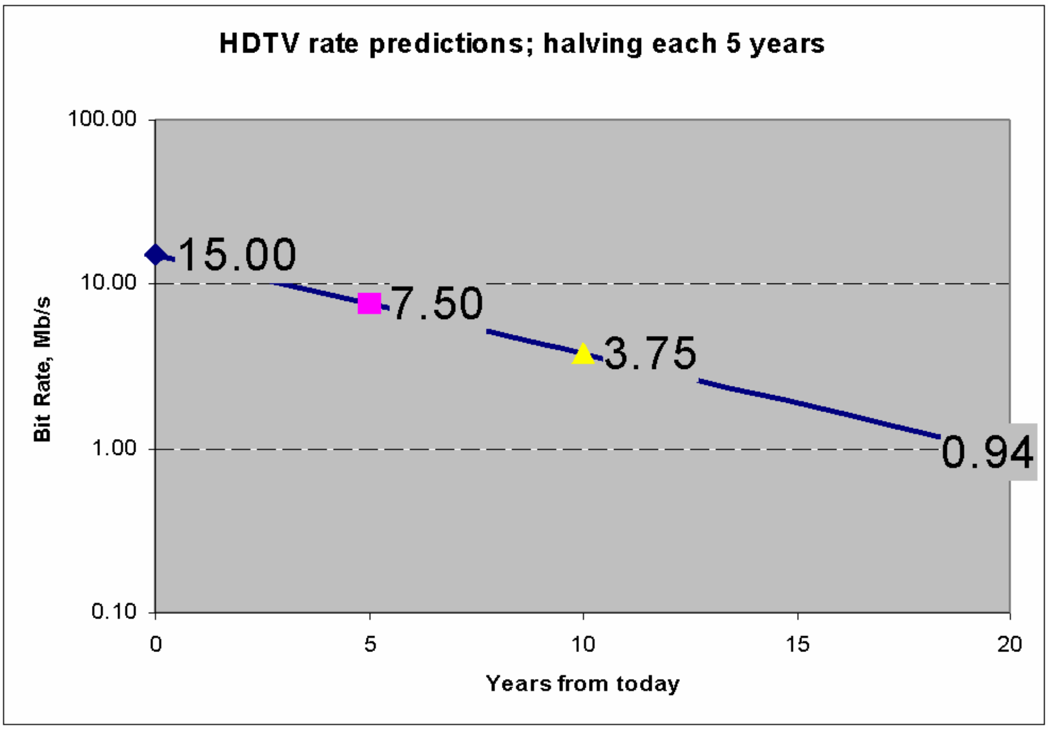

Figure 7 HDTV rate predictions [source: DVB forum]

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.

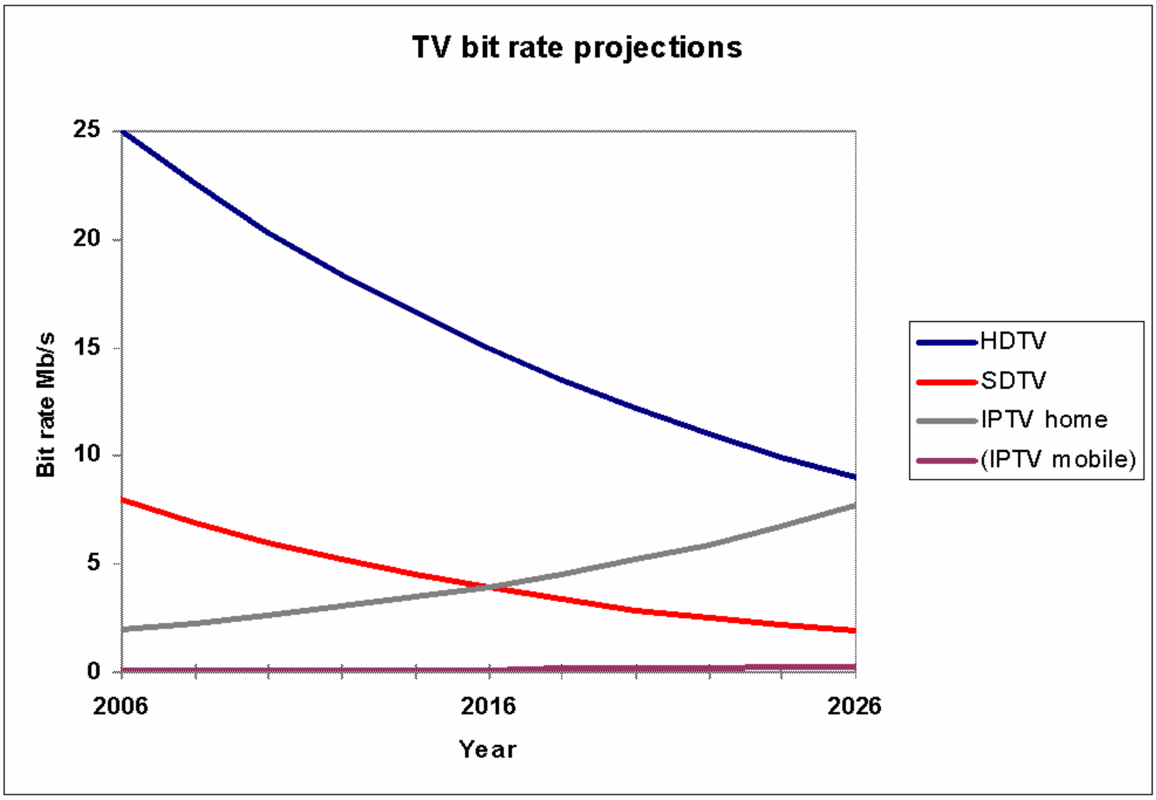

Figure 8 TV rate predictions [after Ghanbari 2006]

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[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.

Figure 9 Today's industrial HDTV encoder targeting 4Mb/s for HDTV

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[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

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[14] Due to CRT driver bandwidth which is designed for interlaced pictures

[15] http://broadcastengineering.com/newsletters/bth/directv_hd_lite_20060925/?r=1

majority[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.

[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

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

Table 1 Collation of UK operator offerings for triple and quad play

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.

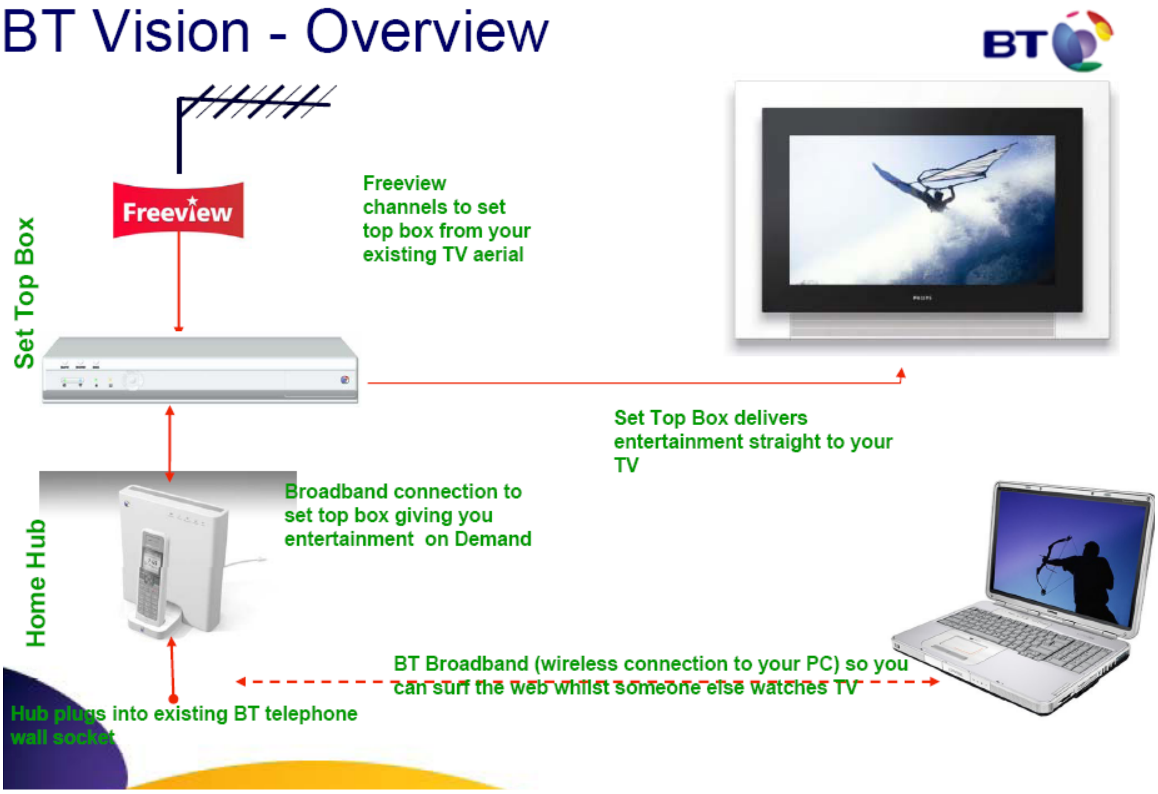

Figure 10 BT Vision

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 Internet[22] 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[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.

<u>Portable usage</u>

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

[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[24], 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[25].

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 contention 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.

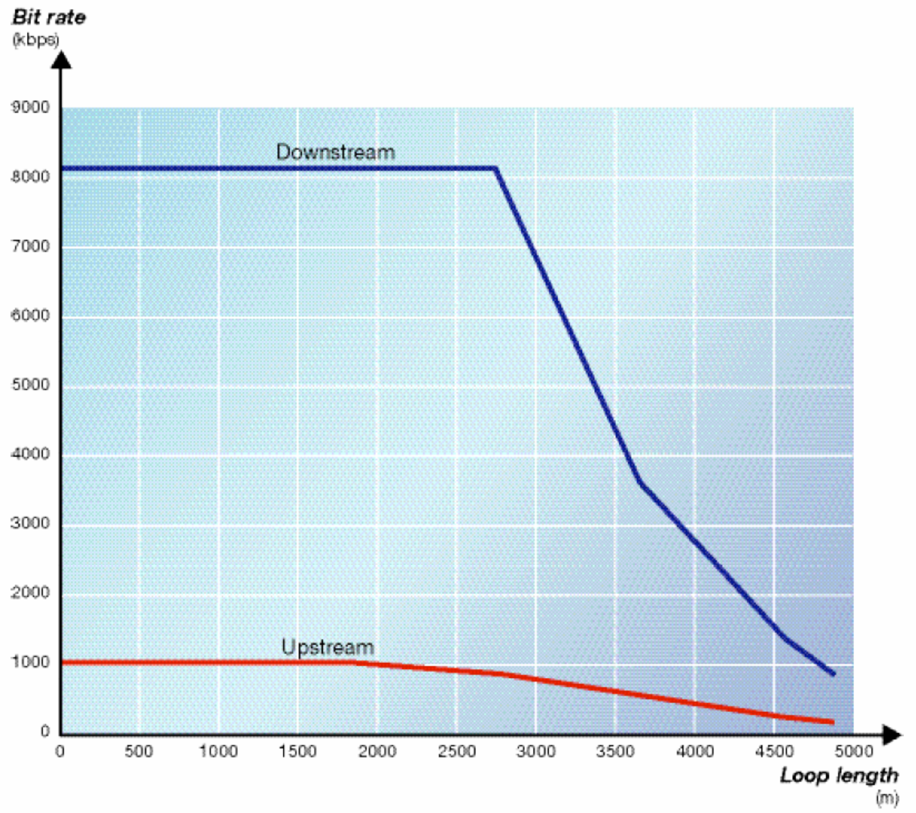

Figure 11 ADSL2 bandwidth versus distance [Ericsson 2006]

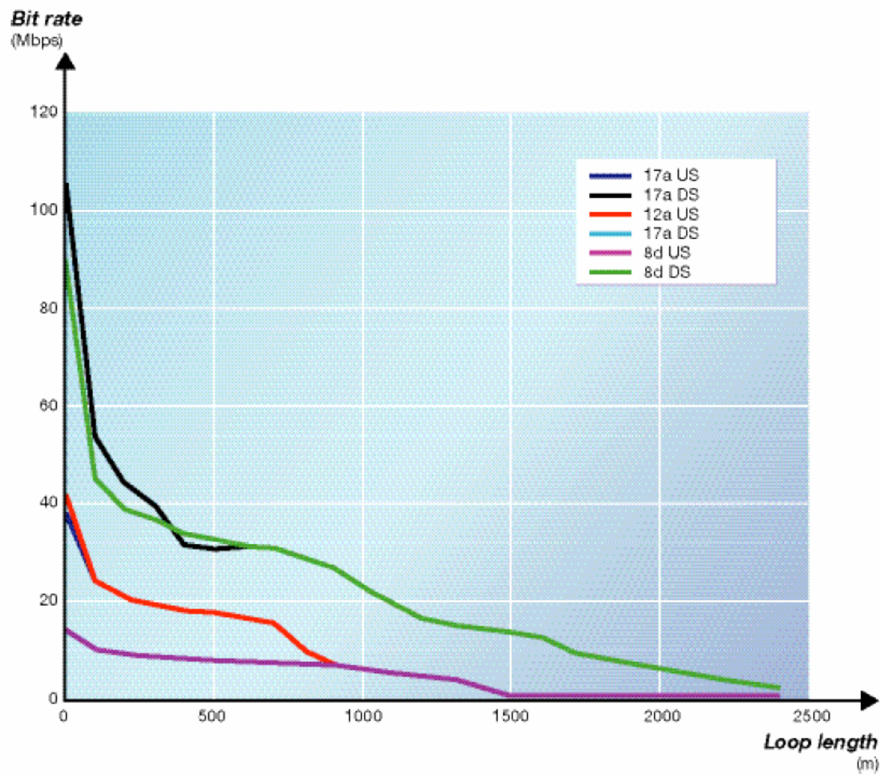

Figure 12 VDSL bandwidth versus distance (for various crosstalk conditions) [Ericsson 2006]

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.

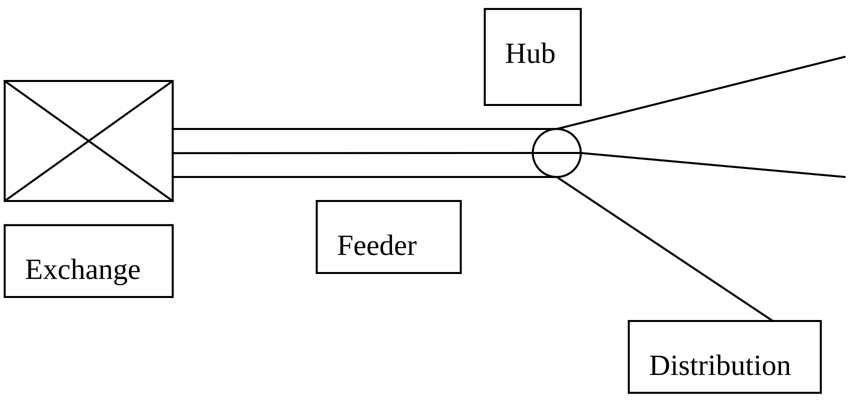

Figure 13 Rural community cabling growth

The copper last mile is divided into a bundle of lines as a feeder the and individual lines as 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.

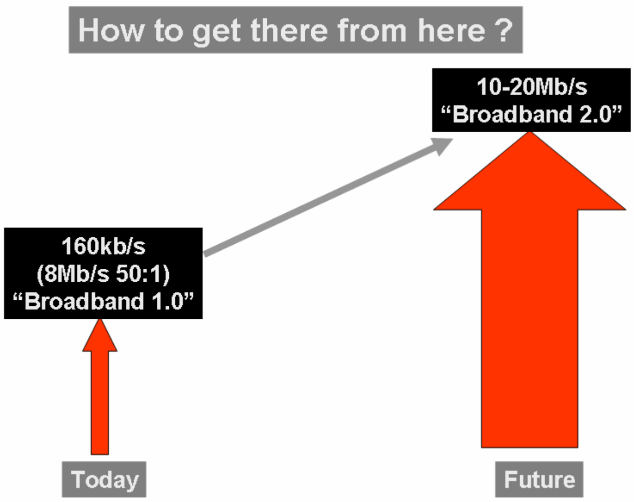

Figure 14 Broadband 2.0 (repeated figure)

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.

1.2 Cost Drivers

This section considers the cost drivers for wireless based solutions to the last mile problem.

1.2.1 Generic cases where economic benefits may arise

Economic Value can be covered from a demand curve perspective, by equating it to consumer surplus, as shown in Figure 15, Figure 16 and Figure 17:

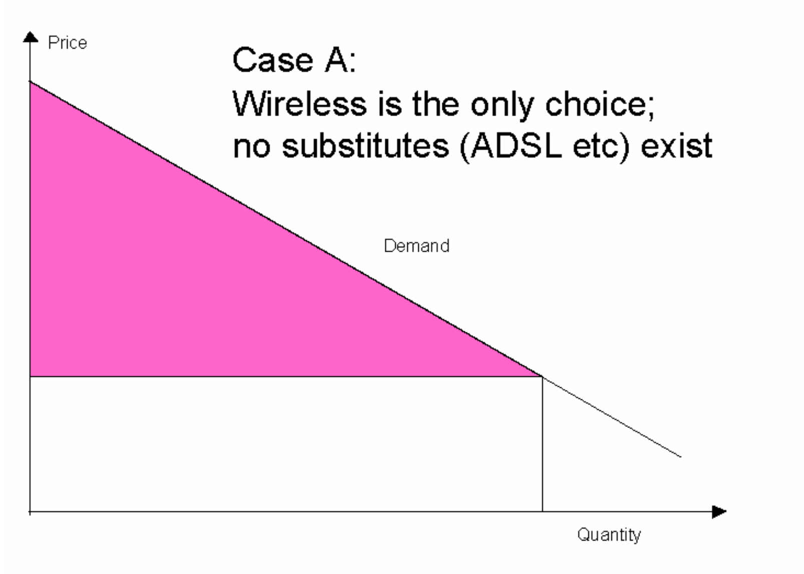

Figure 15 Economic values using demand curves (case A)

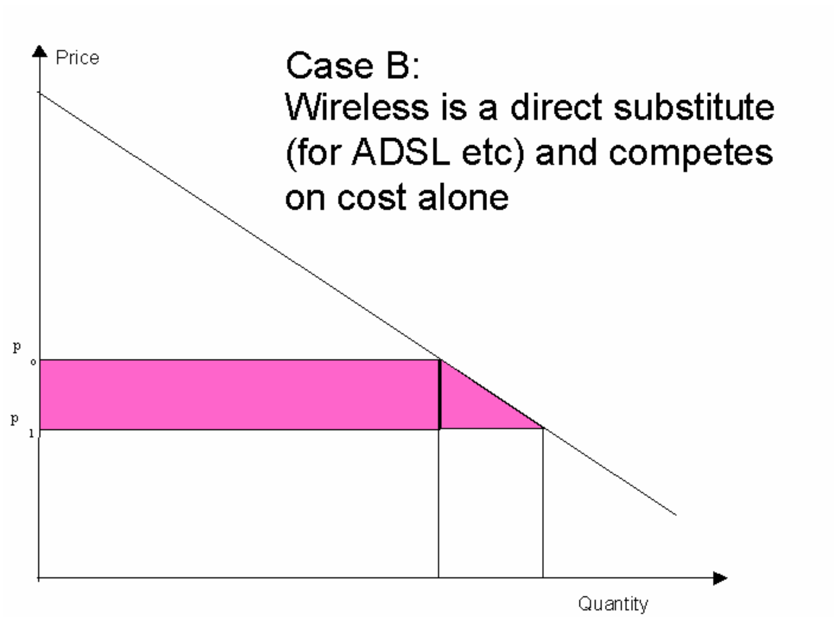

Figure 16 Economic values using demand curves (case B)

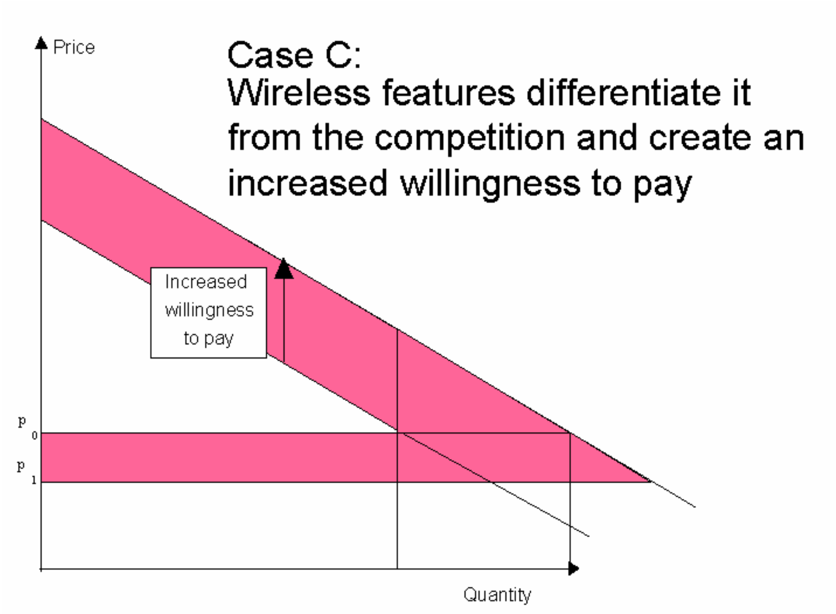

Figure 17 Economic values using demand curves (case C)

Figure 15, Figure 16 and Figure 17 contain 3 general cases where consumer surplus may be identified:

> Case A is sometimes assumed for wireless broadband, although not generally in the UK - where the new application is the broadband itself. In other words, ADSL, satellite etc cannot deliver and wireless broadband is the only solution; there is no substitute.
>
> On the other hand, cases B and C assume wireless broadband and competitive solutions are both available.
>
> Case B is where wireless broadband would cost-in below an existing solution e.g. satellite. This is assumed in Ofcom's 2.4GHz higher power report [Generics 2006]
>
> Case C is where wireless broadband offers a service above what the existing method offers and customers will choose to pay more for this; it could offer better speed, symmetry of speed, mobility etc. Case C is often overlooked when discussing wireless broadband.

However, in this report we suggest that case C may be important and should not be dismissed as by earlier reports, e.g.

> "..there is no economic benefit to be gained by supplying W[ireless] B[roadband] A[ccess] in areas where DSL or cable broadband are available" [Generics 2006, section 7.1.2].

It is the prediction that future wireless may compete on more than simply cost which makes case C so important. Evidence for the applicability of this may be found via the potential service differentiators for wireless identified in Ofcom's Telecoms Review, which states[26] that

> "Consumers value the freedom, flexibility and uncluttered nature of tetherless delivery".

It also raises the attractiveness of

> "..services that can be used 'on the pause' or by access from any available fixed line ('mobility')".

Note that in the present report we refer to such tetherless working under a further sub category of 'portable' rather than simply 'mobile'. Examples of users who have demonstrated a preference for tetherlessness were given in section 1.1.5.4.

The same review also highlights a move from 'asymmetry to symmetry': The old client-server structure is giving way to an architecture where intelligence is at the edges of the network - i.e. the end of the last mile. Peer to peer file serving and home video content generation are making symmetric services more important. Edge based network intelligence also allows for a simpler network in terms of the easy separability of the layers of the communication stack[27] - which may thus be provided by separate parties. This will be positive for competition and innovation.

In summary, future wireless systems may compete via some or all of the following:

- cost (Case B)
- mobility - 'untetheredness' (Case C)
- bandwidth symmetry (Case C)

1.2.2 Truck roll versus self-install, indoor versus outdoor installation

Truck rolls[28] for any work on equipment at the customer premises cost $300 on average each time [FCC-Microsoft 2004]. This includes install and de-install, and can soon break a service's cost model either before or after the service is launched (e.g. Ionica's unexpected de-installation costs whilst operating). The best broadband wireless solution would minimise or eliminate truck rolls, so self install is attractive (e.g. UK Broadband). Omni-directionals are also attractive, following the same reasoning.

But self install may affect range due to the lower height, the effect of penetration loss if indoors, and any net directionality loss. An example of an outdoor self install system is Locust World.

While Locust World is an outdoor system, it is very much promoted as a DIY, self-install system, claiming a low skill level requirement[29]. Nonetheless it is still not really an easy self install prospect for the mass market, as seen in Figure 18 which shows a real installation in progress. See section 2.2.4.1 for more information on Locust World and other community networks.

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[26] http://www.ofcom.org.uk/consult/condocs/telecoms_review1/telecoms_review/annexj/

[27] i.e. separability of the whole OSI 7 layer model's layers from physical layer to application layer

[28] i.e. despatching a service vehicle to a customer premises

[29] low skill relative to satellite dish installation, perhaps

Figure 18 Locust World mesh box installation in Bolivia

1.2.2.1 Indoor versus outdoor

Indoors, measurements have found[30] that directional antennas cannot guarantee a realisable advantage, although this may be frequency specific. The reason is that the direction of strongest signal varies so greatly within a room, due to reflections and diffraction effects from numerous apertures, such as windows. However, if a directional antenna can be sited in the ‘correct’ window, some advantage may be had. However, this relies on a particular customer behaviour and acceptance, which cannot be guaranteed.

Intelligent antennas might be used to steer a peak or a null at a receiver in real time[31], but the technique of MIMO is more attractive as it will aggregate more of the available energy from the incident multipath signal, see Figure 19. MIMO processing is becoming quite commonplace on WiFi equipment and is planned for newer versions of WiMAX and 3G.

[30] at 3.5GHz by Plextek and LCC, when measuring a live network

[31] e.g. Plextek’s hardware demonstrator in “The Development of Smart Antenna Technology”, SES-2004-4a, www.ofcom.org.uk.

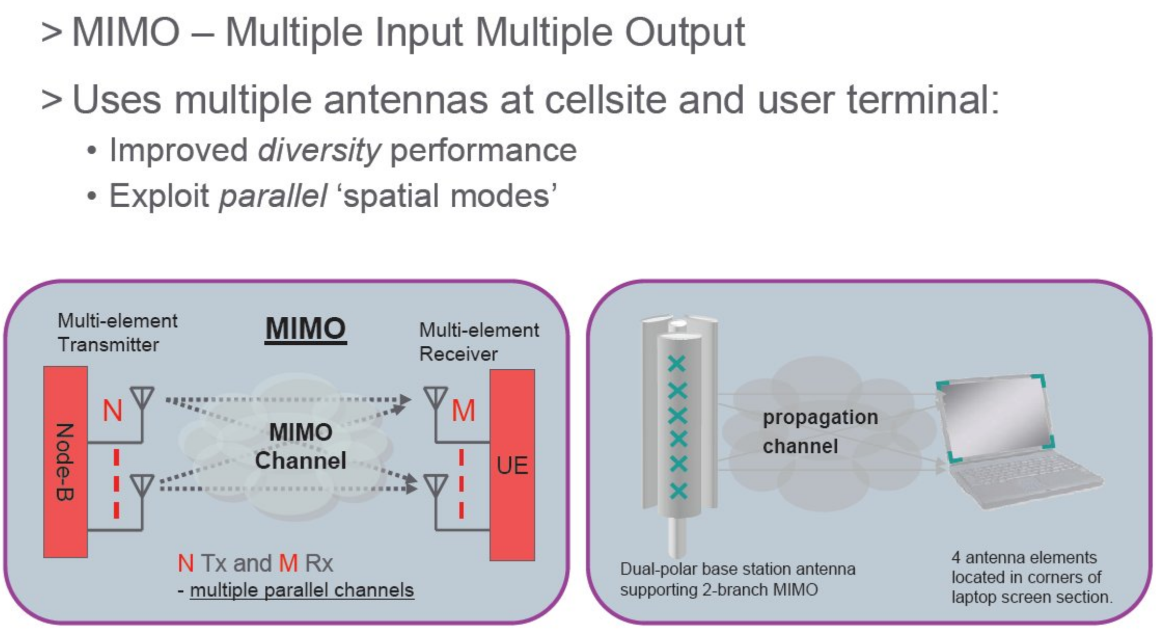


Figure 19 MIMO operation [Nortel]

MIMO is often used to describe a family of multiple antenna systems, which also include SIMO and MISO: SIMO implies multiple antennas at the receiver only, whilst MISO implies multiple antennas at the transmitter only[32]. MIMO solutions are not beam or null steering; they rely on multiple, independent paths between transmitter and receiver, such as would be found in a multipath environment. The MIMO advantage comes from both diversity and parallelism. Whilst one problem with MIMO is unwanted correlation via the possible cross coupling of paths, it nonetheless remains a powerful technique. MISO systems are of more practical use when the receiver cannot physically support multiple antennas at sufficient spacing, such as on handsets.

Beam steering is used on transmitters in 'enhanced' WiMAX, see section 3.2.2 where it offers a 9dB (typ.) power budget advantage. This beam steering advantage is essential to achieving indoor coverage, see Figure 20, from Navini. This beam steering enhancement is an optional part of the IEEE802.16 standard. However, it is quite widely accepted that, for mobile WiMAX, beam steering could be all but essential, for example cf. Figure 20 and Esseling et al [2002].

Beam steering is not normally applied to fully mobile systems since the position of the customer must be known continuously by the system. MIMO is more appropriate for the mobile case.

[32] MIMO/MISO/SIMO thus describes the channel input/output, not the transceiver structure.

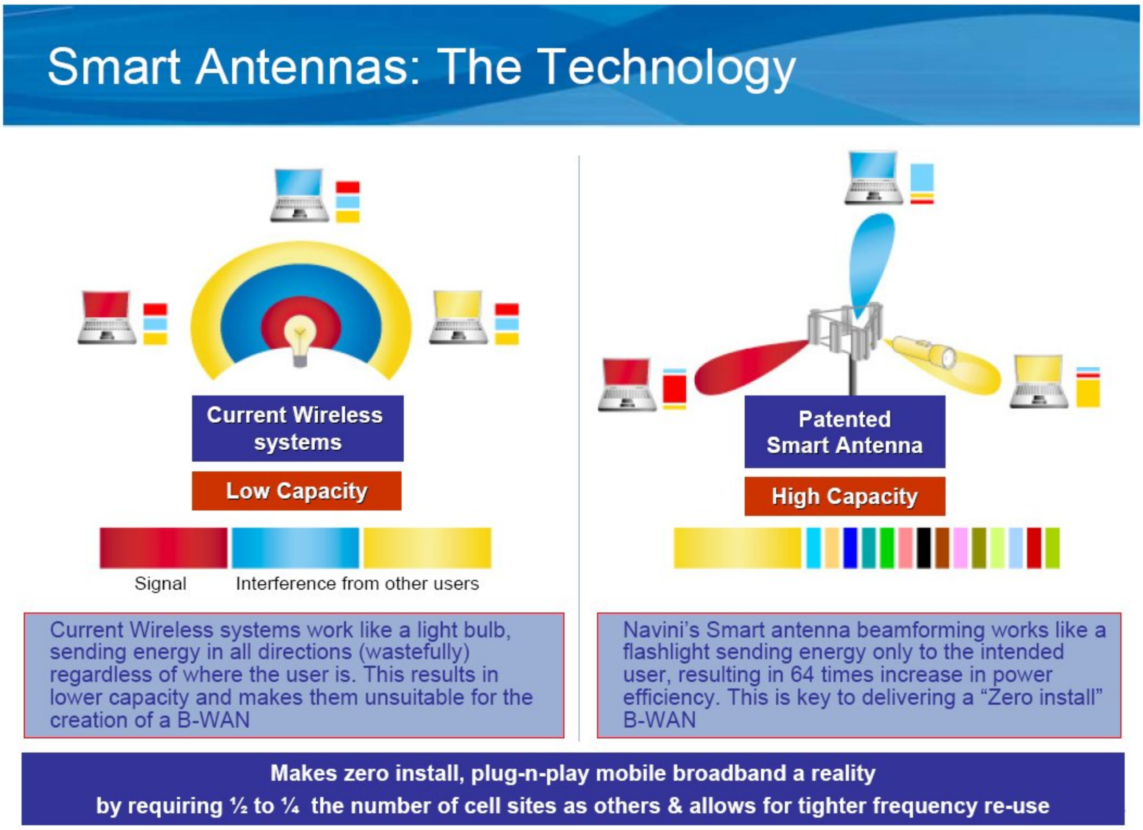


Figure 20 Beam steering is <u>essential</u> for economic WiMAX indoor/mobile operation [www.navini.com]

Arraycomm also produce steerable antennas intended for the same application, Figure 21, as well as MIMO family systems for many of the major wireless standards.

Figure 21 Arraycomm i-Burst antenna system deployment [www.arraycomm.com]

1.2.3 Service distance

Section 1.1.2 showed that 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. If this distance is plotted on a map it forms a jagged boundary of varying geographic distance from the telephone exchange due to the copper cables running through a series of ducts which are routed along available streets etc. Radio coverage from a single transmitter is not a perfectly circular coverage area either and consists of a different jagged boundary, this time due to shadowing etc.

Whatever their detailed shapes actually are, these two contours will always exist - and an area of opportunity for radio delivery lies between these two contours, see Figure 22. This particular opportunity follows the demand curve of case B in Figure 16, where the competition is no longer ADSL because of the service distance limitation. Competition will instead come from e.g. satellite at a higher price point.

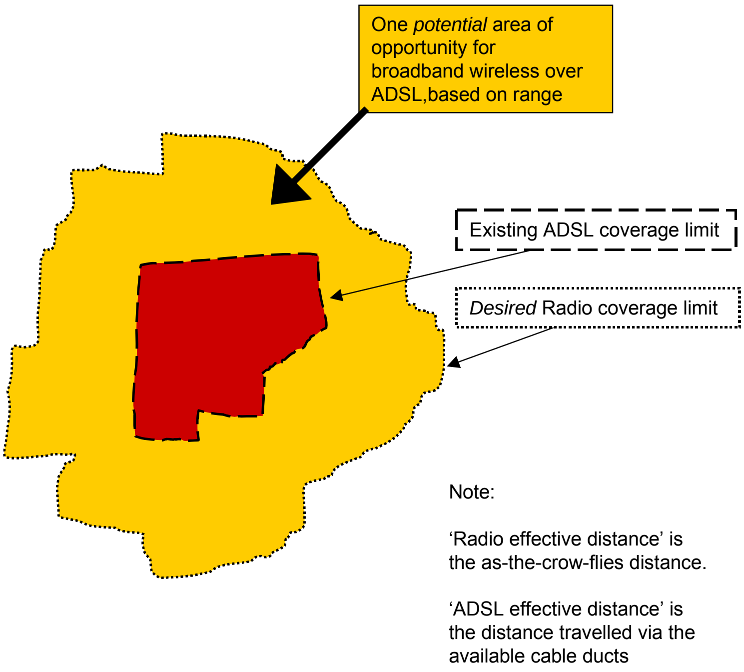


Figure 22 Radio versus ADSL coverage contours

In practice there could be problems if the radio coverage is too patchy within its nominal coverage area. Ionica found this to be an issue as their advertising attracted significant numbers of possible customers for whom they were unable to provide service from their radio access network sites.

1.2.4 Service contention

A copper pair from an exchange to a subscriber is a non-contended link. However, when describing a service some level of contention is generally quoted. Here, we look more closely at contention (introduced in section 1.1.6) and describe why it is a cost driver. Contention arises from sharing to combat the lack of capacity in the back haul from the exchange to the core network, see Figure 23 and, in more detail, Figure 24. When DSL operators take the BT Wholesale service they must accept the contention offered; when operators unbundle from an existing BT exchange the back haul opportunities are limited by the location and often involve expensive leased circuits, which are thus a major cost driver for Internet service. This means that the service speeds which users receive, particular at peak times, fall well short of the maximum capability of the xDSL technology.

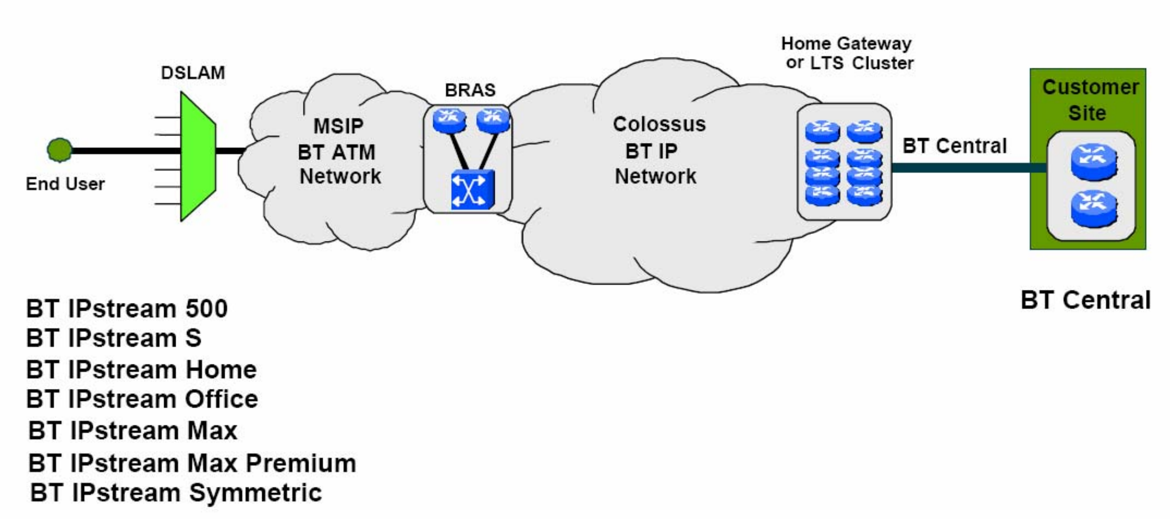
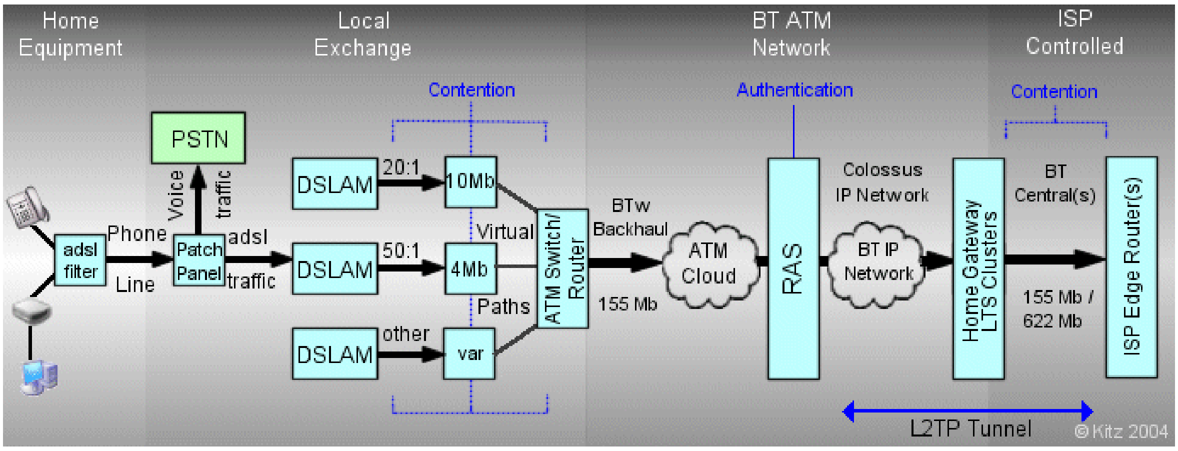


Figure 23 BT's own diagram of the IPStream architecture [source: BT SIN 386]

Figure 23 and Figure 24 show that the ADSL phone line itself is uncontended, plus there is some contention under the ISP's control, on the BT central lines which link the ISP to BT's core network. However it is the contention shown in the middle of Figure 24, on the virtual paths from the DSLAM outputs, which is the main subject of this section.

A simple example is as follows[33]: With a typical contention ratio of 50:1 for a home user, if a peak rate of 1Mb/s would be possible when uncontended, only 20kb/s can be available when fully contended. Of course, for the low duty, bursty, non-real-time services of web browsing and email, users may never notice the effects of contention. On the other hand, if a majority of users attempt to stream video to their homes, some will inevitably be disappointed, either through loss of connection or bandwidth throttling. Interestingly it seems that very few consumers understand that contention even exists, let alone what it means for their service level [Ofcom 2006].



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33 This example is deliberately simplified. In fact, peak rates are determined by the ADSL line card at the exchange, whilst the contention is determined by the capacity of the subsequent virtual paths, e.g. how many 4Mb/s paths are supplied in a 50:1 case. Nonetheless we have related peak and loaded rates via contention in this report, as this is the effect seen by the user. A corollary of this is that on moving from, say, a 1M/s service to an 8Mb/s service implies a consummate increase in virtual path capacity, if contention is to remain the same. This complexity in interpretation may be one reason why BT have moved away from specifying contention ratios.

Figure 24 The origins of xDSL contention in IPStream - in the back haul [source: www.kitz.co.uk]

BT Wholesale themselves are moving away from specifying contention as a ratio for their IPStream Max service. Rather, they are now specifying a 'headline' rate, along with a maximum and minimum synchronisation rate for that speed. The user rate will be less than this synchronisation rate, due to ATM overheads. Examples are shown in Table 2, for actual user download rates (upload speeds are much lower).

Line Rate	User speed
288kbit/s line rate	50-250kbit/s download speed
Above 288kbit/s up to 576kbit/s line rate	0-500kbit/s download speed
Above 576kbit/s up to 1152kbit/s line rate	100-1000kbit/s download speed
Above 1152kbit/s up to 2272kbit/s line rate	200-2000kbit/s download speed
Above 2272kbit/s up to 8128kbit/s line rate	400-7150kbit/s download speed

Table 2 IPStream Max speed thresholds [source: BT Wholesale]

Contention ratio is absent from Table 2, but these figures relate to business lines, which were at 20:1 contention. Home lines may have minimum speeds of half the above (previously 50:1 contention). Taking the example of the highest line rate, the user speed may be 7.15Mb/s at best and 400kb/s at worst. This is a ratio of 18:1, so the effect of contention remains. What BT Wholesale have done however is make it clearer that rates can dip due to contention and have made it clear what minimum rate might actually be delivered..

Whichever method is chosen to specify contention, be that minimum rate or best rate plus ratio, the fact remains that unless contention is improved, it will be a complete show-stopper for IPTV mass deployment. In fact the BT Wholesale guidelines for the IPStream Max product make such implications quite explicit:

> *"... the End Users require occasional fast but 'bursty' access to private network facilities and / or the Internet (via the Customer). The products are not suitable for End Users who require continuous bit-rate, full bandwidth services".* [source: SIN 386 section 4.1[34]]

In other words, the present ADSL service was never intended to support IPTV or any other broadband streaming services. The guidelines quoted above are provided to ISPs, but not to DSL end customers. As noted in section 1.1.5.2, BT Vision relies on special provision at the ADSL level in order to support streaming services. This is a re-division of the ADSL resource for those customers who are willing to pay a premium. It cannot presently be given to all users, but may be more widely available over 21CN. Presumably, at the moment, those not using BT Vision must be using whatever is left over in the DSL resource pool after the premium customers have taken their larger slice.

Indeed, in the future, fibre + xDSL may be the only viable terrestrial solution which may scale and be made available to all, with the possibility of some fibre replacement by Gb/s wireless on point-to-point last mile feeder links. This is discussed further when our fresh approaches are evaluated in chapter 3.

With respect to wireless broadband, this problem actually opens up further opportunities for radio as a means of bypassing wired back haul through the siting of base stations near high speed points

[34] BT IPStream Service Specification, download from http://www.sinet.bt.com

of presence and exploiting greater reach effectively for back haul rather than access area (see section 2.3.3). Furthermore, if contention can be eliminated by adding more back haul to an ADSL system, then the equivalent for increasing the available average user bit rate in a radio system is to have more spectrum/less interference. Radio coverage and capacity is covered in detail via a worked example in section 3.2.2, since increased spectrum or reduced interference (via smaller cells) are both strong cost drivers.

1.2.5 Operating frequency band

The performance of a wireless link is well known to be affected by various propagation effects. This impacts range, BER and can also indirectly affect latency[35]. Performance varies greatly with the frequency chosen for transmission and, given that not all frequencies are available, this leads to quite complex compromise designs being made for a wireless link. These compromises are arrived at via a consideration of the bounds imposed by the key service requirements, already outlined in section 1.1.4. Such propagation considerations led naturally to the emergence of the 'sweet spot', as shown in Figure 25.

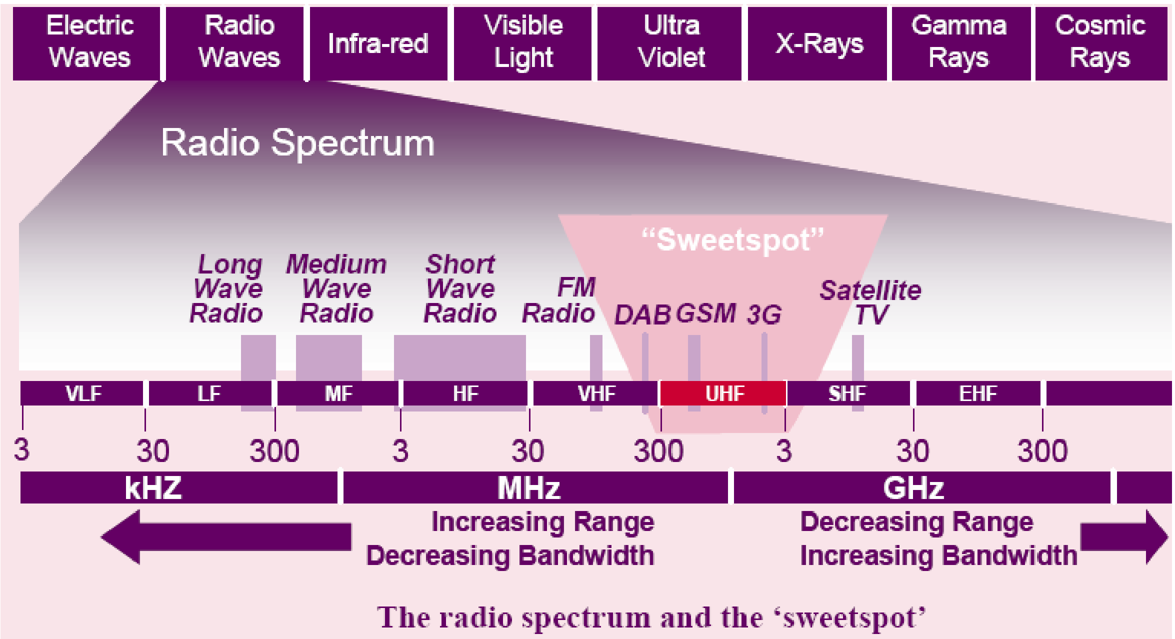

Figure 25 The sweet spot in the RF spectrum [Ofcom]

Interestingly, the 2.4 GHz and the UHF bands are at opposite ends of the sweet spot and should be expected to offer different coverage/capacity behaviour. Comparing range extension by change of power to that by change of frequency, we can relate range for a given power at 2.4GHz to range at 700MHz for same power, by a simple scaling factor[36]. This factor is really a rule of thumb of typically 2 or 3. Nonetheless this gives a great advantage to UHF equipment, in terms of reduced base station numbers and hence cost. Furthermore an additional benefit of TV band equipment is

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[35] by forcing re-transmission or re-routing

[36] This is widely accepted in industry, see for example MaxStream Application note comparing range improvement to be expected at 900MHz vs. that at 2.4GHz. http://www.maxstream.net/support/knowledgebase/article.php?kb=64

that each base station itself costs less, notwithstanding the economies of scale as presently enjoyed by WiFi. So a lower cost of BS due to operating frequency combined with fewer BS due to range means a double advantage for the TV band business case. The downside is the amount of bandwidth available, which is physically more limited. This point is revisited in section 3.

The following simple comparison illustrates the basis for the current interest in using TV spectrum for wireless broadband.

To get a rough visualisation of predicted 700MHz and 2.4GHz relative coverage, a rural area (Saffron Walden, Essex) was briefly investigated, generated using ‘Radio Mobile’[37], with 90m SRTM data. All things being equal[38], the range improvement is about a factor of 2 or more, so fewer base stations would be required for a system at 700MHz, which helps the business case. This factor of 2 agrees well with the industry rule of thumb.

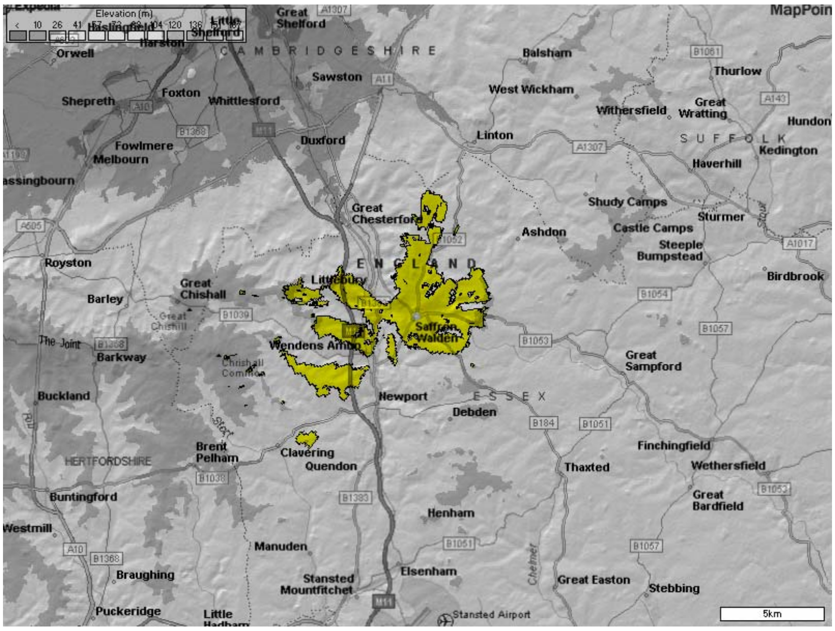

Figure 26 Predicted coverage at 2400-2450MHz - simple rural example

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[37] http://www.cplus.org/rmw/english1.html. Radio mobile is intended for amateur use, but is used widely by US WISPs. It was also used by Intel in their FCC NPRM responses. It can make use of high precision terrain mapping data, obtained from Shuttle terrain mapping missions.

[38] Of course, all things will not be equal, e.g. antenna gains. This is only a simplistic exercise.

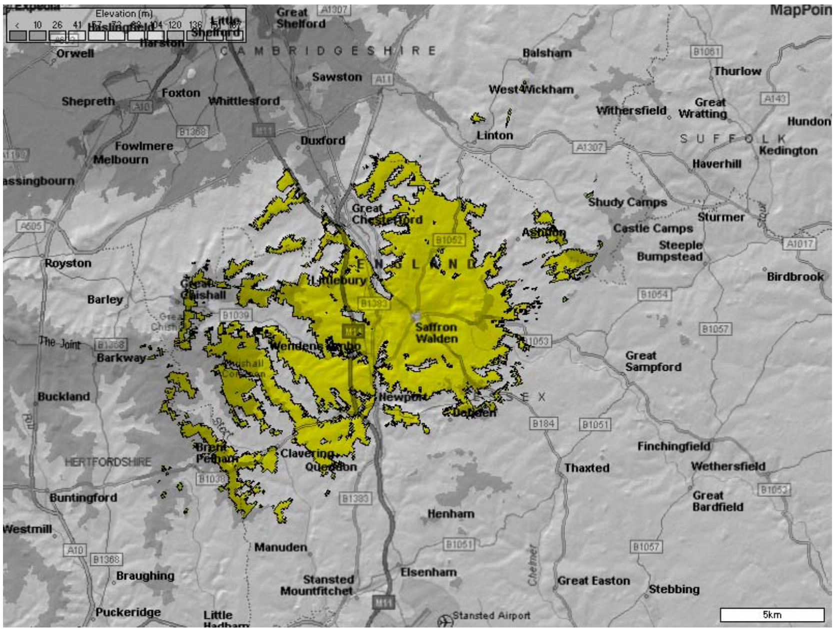

Figure 27 Predicted coverage at 700-900MHz - same simple rural example

Operation at microwave frequencies is also possible and helps in the specific cases where point-to-point range increases are required. Ofcom is consulting on the award of spectrum at 10 GHz, 28 GHz, 32 GHz and 40 GHz; two key elements of the proposed spectrum packaging and licensees' rights and obligations for the spectrum to be auctioned are as follows:

- Twelve licences will be offered. Most will have nation-wide coverage - one in the 10 GHz band, two in 28 GHz, and six in 32 GHz. In addition, three in 28 GHz will have varying degrees of geographical coverage.
- The licences will be technology and application neutral.

Ofcom commissioned work to assess the potential demand for the four bands 10 GHz, 28 GHz, 32 GHz and 40 GHz. This identified a number of potential applications, which fall broadly into three categories:

• mobile and fixed network operators who might use spectrum to back haul their own networks, primarily with the aim of reducing costs. The interest here is in paired spectrum.

• FWA network operators who might deploy broadband access networks in addition to providing back haul, both for themselves and for other network operators. The interest here is primarily in paired spectrum.

• Broadcasters who might use spectrum in the 10GHz band for video links and wireless cameras. The interest here is in unpaired spectrum.

For completeness, it is noted that 60GHz systems are weather limited to 1.5km range [RAL 2006]. ADSL can already provide that reach, but interest in high microwave systems remains, as they are a viable last mile feeder solution contender, since they provide much higher capacity than standard microwave back haul: High microwave systems at 60-80GHz can deliver Gb/s rates and are often termed 'Gb/s wireless'; they compete with fibre.

1.2.5.1 Building penetration vs. frequency characteristics

One of the cost drivers already identified was avoiding truck rolls by choosing to operate user equipment indoors. All of the following need to be considered when characterising the potential for indoor operation:

- height loss
- building loss
- relative antenna loss

1.2.5.1.1 Height and building loss

Building penetration loss is due to the attenuation imposed by walls and floors. Usually there is also an effect due to shielding when the receiving antenna's height is decreased below that of an outdoor antenna. The shielding might be buildings in the urban case or foliage or geographical features in the rural case.

A plethora of measurements exist on this general topic, but they are often hard to compare and rationalise, since they have used different parameters. Usually, penetration loss is measured in isolation in one type of experiment, or height loss is measured inseparably from an unknown associated building loss in the other type of experiment. Fortunately, combining building and penetration loss measurement is quite convenient, as this combined figure is what is required by the link budget planning process (see the worked example in section 3.2.2).

One paper, relevant to the purposes of this report [Bot et al], looks at the penetration of DTV signals into buildings at 762MHz. Of particular interest is that the authors used a 7MHz OFDM signal, rather than the typical spot frequency measurement: Fine grain frequency dependant attenuation can affect the OFDM signal markedly, a factor not usually accounted for in measurements[39]. The authors found evidence to show that antenna diversity would be very useful in OFDM systems, to combat the 25dB deep notches they found in the spatial dimension. Their main findings were:

- Less than 15dB penetration loss was found in 90% of buildings (Holland[40])
- Less than 22dB combined building/height loss was found in 90% of buildings (relative to 10m)

The combined difference was as high as 30dB in some cases.

In terms of the frequency dependent aspect of building loss, evidence shows that this loss is surprisingly flat over about 1 to 6GHz. Rudd [2003] considered 1.3, 2.4 and 5.8GHz and found penetration losses of 9, 11 and 13 dB. ETSI DVB-H guidelines for penetration loss at VHF/UHF, were also fairly consistent with those listed above; both typically 11dB. ETSI DVB-H also considers height loss in rural, semi-urban and urban areas and finds an average of 13, 18, and 24dB for 1.5m versus 10m. Thus urban areas are prone to deeper shielding, as expected due to the density of tall buildings. Although average losses seem fairly consistent, the spread and variability of measured, real-world building/height loss is of some concern, since assumptions made here strongly affect the link budget (see example in section 3.2.2) and hence system economic viability.

Returning to our cost driver preference for zero-install (1.2.2), what this means for indoor operation at 700MHz versus 2.4GHz is that, with penetration loss relatively flat, the better range of 700MHz remains attractive. However, moving indoors has two more effects, as discussed next.

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[39] OFDM is designed to cope with frequency dependant attenuation, but its wider bandwidth also makes it possible to see more attenuation variation.

[40] Buildings in Holland might be representative of Europe and perhaps the US, but not necessarily the rest of the world.

1.2.5.1.2 Relative antenna loss

The two aspects to this are:

- Indoor/outdoor

    For example an outdoor antenna might be a Yagi with e.g. a gain of 12dB, whereas an indoor antenna is potentially an omni-directional which can have 0dB or lower gain. The question of indoor antenna performance was covered in section 1.2.2, where it was shown that real, practical experience of deployed systems is that indoor directional antennas have offered little advantage. This has been due to the multipath in the indoor environment - suggesting that spatially diverse receive antennas might be a better option, which could help the power budget.

- Practical antenna versus frequency issues

    It might be thought that continuing to lower the operating frequency will always improve the range, however it is generally accepted that VHF is not better than UHF due to the lower indoor antenna gain available at VHF, which is due to practical limitations concerned with the increased wavelength. Where this is true UHF systems will continue have lower node density.

Hence, when moving down to 700MHz from 2.4 GHz, the net result is that the power budget needed for indoor operation will increase markedly over the outdoor case, principally due to height/building loss and the relative loss of antenna gain (both of which arise directly from the multipath, non-LoS situation dictated by indoor operation). It would seem prudent to add a factor of up to 30dB [Bot et al], section 1.2.5.1.1, for indoor reception compared to outdoor reception, possibly less if spatially diverse receive antenna systems are in use. The 30dB estimate is to over height loss, building loss and directionality loss, when moving from 2.4GHz outdoor to 700MHz indoor operation.

1.2.5.2 Mesh and multihop systems

Recently, the idea of multihopping to consolidate or extend a cell has been adopted by IEEE802,16j, see

Figure 28.

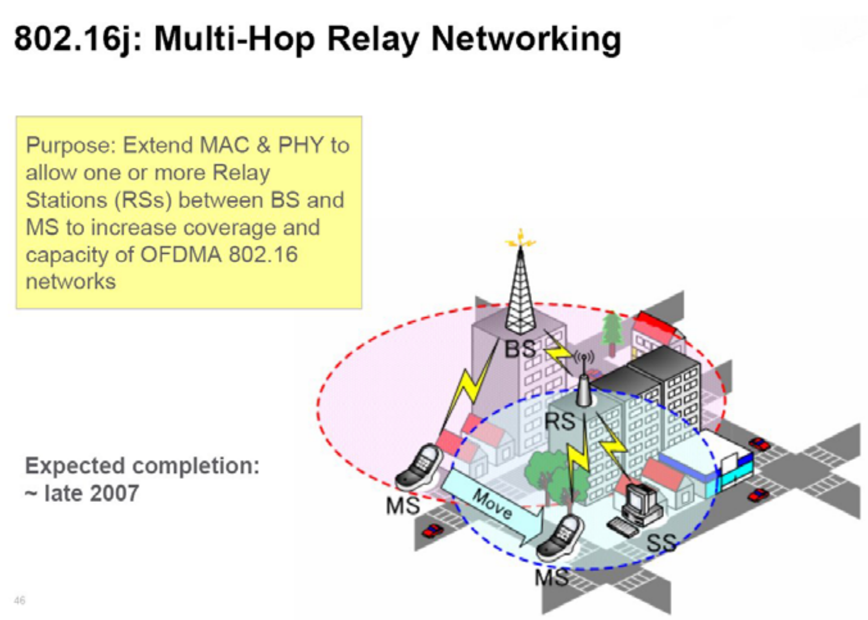

Figure 28 802.16j multihop relaying (a subset of mesh) [Nortel]

This is very much along the lines described in our previous Mobile Mesh report [Methley et al 2005] and proposals intended for HiperAccess [Esseling et al 2002]. Importantly, multihopping can bring many ‘mesh’ benefits, but limits the downsides caused by too many hops or the need for complex routing algorithms [Methley et al 2005].

There are two key points:

- Typically, coverage in urban is improved (power for power) more than for rural.
- The larger attenuation and foliage absorption at frequencies above the sweet spot are actually of help to a mesh/multihop deployment, as it isolates the individual hops paths. This is quite the opposite to a mobile/PMP deployment, see Figure 29, where such ‘clutter’ is a problem.

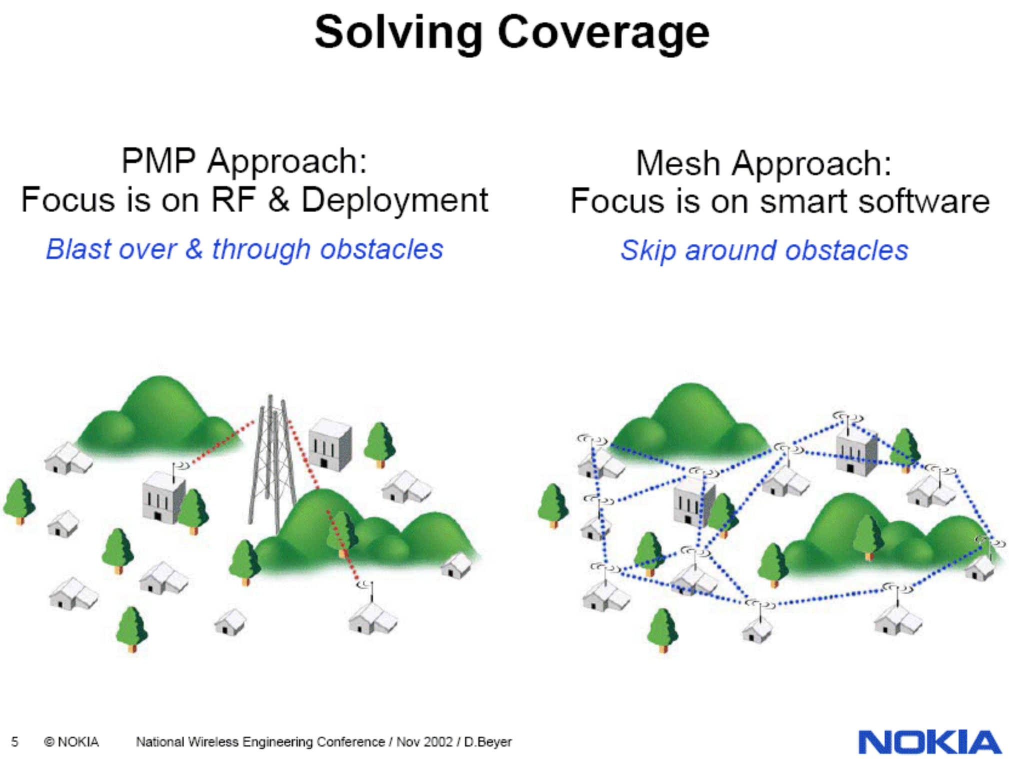

Figure 29 PMP vs. mesh coverage behaviour [Nokia]

Mesh coverage behaviour as shown is the basis for the fresh approach of ‘mesh at higher frequencies’, section 2.3.1, where higher means above the sweet spot. Such less precious spectrum may be more easily available.

1.2.5.3 Benefits of 700MHz rural vs. 2.4GHz higher power rural

The ranges used in the High Power report [Generics 2006], are shown in Table 3 so that comparisons with both 2.4GHz higher power and 700MHz may be made[41]:

100mW	1.75km
1W	3.50km
10W	7.25km
80W	16.50km

Table 3 Range (cell radius) vs. power in 2.4GHz band [Generics 2006]

Note that consumer surplus versus range, Table 4, as calculated for the High Power report agrees with the points made in this report about using radio for cases beyond the useful reach of DSL (section 1.2.3, Figure 22): As rural BS range is extended beyond 1.75km, benefits begin to increase as DSL begins to struggle for range, tailing off as range grows beyond a figure, 7.5km, where most consumers are within range of wireless (but not DSL).

[41] Quasi open terrain parameters were used in Okumura modelling to yield these single figures which have then been applied globally, irrespective of actual terrain type. This assumption thus ignores differences in open terrain which is up to 5dB better and in suburban terrain which is up to 15dB worse.

Cell radius	Frequency	Scenario	Residential consumer surplus[43] GBP, million	Business consumer surplus GBP, million	Total consumer surplus GBP, million
1.75	2.4	Current regulations	18	148	166
3.50	2.4	1W EIRP	35	319	354
3.50	5.8	Current regulations	40	386	426
4.25	5.8	4W EIRP	47	464	511
7.25	2.4	10W EIRP	54	556	609
7.25	5.8	25W EIRP	59	605	664
16.50	2.4	80W EIRP	65	640	705
16.50	3.5	125W EIRP	66	647	713
16.50	5.8	200W EIRP	67	647	714

Table 4 Consumer surplus vs. cell radius [Generics 2006 (Table 25)]

This seemingly obvious point is made since the corollary is that moving to a lower transmission frequency can also reap similar Economic Value benefits, with the added attraction that existing WiFi services will not need to be disrupted by a move to high power in the WiFi band. Working in the TV bands, especially for rural applications, looks attractive from a range point of view and will be examined more in section 3.

Using 1W at 700MHz would allow a similar consumer surplus to be generated as by using 10W at 2.4GHz[42]. In fact the surplus could be higher if costs due to interference are lower, as might well be the case outside the 2.4GHz band (standard power WiFi users would not suffer interference).

1.2.6 Back haul and the last mile feeder gap

Providing a suitable wireless broadband access scheme is of little use if the aggregated traffic back haul requirements have not been addressed as part of the solution. Suitable access solutions may have both a last mile distribution and a last mile feeder component, based on different technologies.

Firstly, back haul is discussed generally and then the refinement of the last mile feeder aspect is added.

1.2.6.1 Back haul overview

The Internet is a high speed network which can be connected to at PoPs (Points of Presence). Telecommunications operators use leased line or microwave to connect from suitable PoPs to their switches. This is known as back haul; blocking and/or delay is possible through the under provisioning of circuits against traffic peaks. These lines are carrying traffic between the Internet and all the customers hosted on the exchange (switch).

The situation being considered is that of the connection of a terminal to the Internet for high speed applications. Figure 30 compares the different architectures involved in providing this service.

[42] Assuming range increase is proportional to the root of a power increase

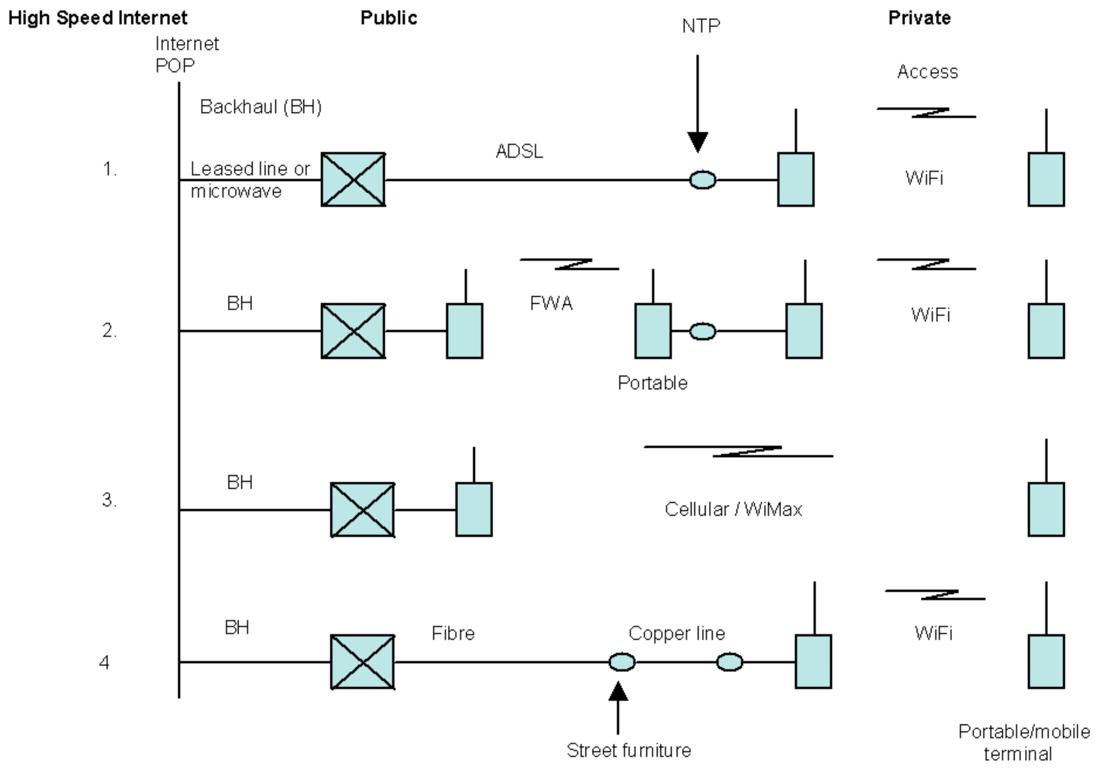

Figure 30 Present Internet access architectures

In case 1 ADSL over copper is used between the switch and a Network Termination Point (NTP). (The NTP is a useful fixed point at which to specify and monitor performance levels which is harder to define with some radio solutions). To the left of the NTP this is a public network run by the operator, to the right is a private network which may just be a fixed terminal or a wired router and a WiFi link to a wireless enabled terminal. Every individual customer has a separate ADSL line from the exchange to their premises

Although the architecture is the same, a public WiFi hotspot moves the public/private distinction further towards the right in the diagram, with the NTP divorced from the user.

In Case 2, the ADSL link is replaced by FWA. The private user sees an NTP as in Case 1 and the options for fixed or WiFi access are unaltered. However the NTP is potentially portable and the FWA can be point to point (exactly the same as ADSL) or point to multipoint.

Case 3 is cellular radio (or WiMAX) which can provide a fully mobile system or be used to deliver directly from a switch to a wireless enabled terminal, as shown, or for FWA (as case 2)

Case 4 is a cable company such as NTL or Telewest. There is considerable variation in what these companies have rolled out but commonly there is a fibre from the switch to a street furniture cabinet. The fibre is shared but individual subscribers have short copper lines to their premises. The NTP provides telecommunications and cable TV services.

With local loop unbundling, alternative operators to BT must install their equipment at the BT exchange which physically fixes one end of their back haul circuits although they may be connecting to a different PoP. Access solutions using radio can use alternative sites either to optimise the served area or to reduce the back haul costs, the ideal being a site at a PoP.

Meshes seamlessly combine access and back haul in their normal operation, hence it is necessary to compare a mesh broadband system against both the access and back haul aspects of a competing system.

1.2.6.2 The last mile feeder gap

A last mile access method needs to be able to ensure connection to the back haul - and in some cases multiple technologies must be involved. In these cases it is useful to define a feeder part which is integral to the whole solution, see the example of Gb/s wireless as a feeder in Figure 31.

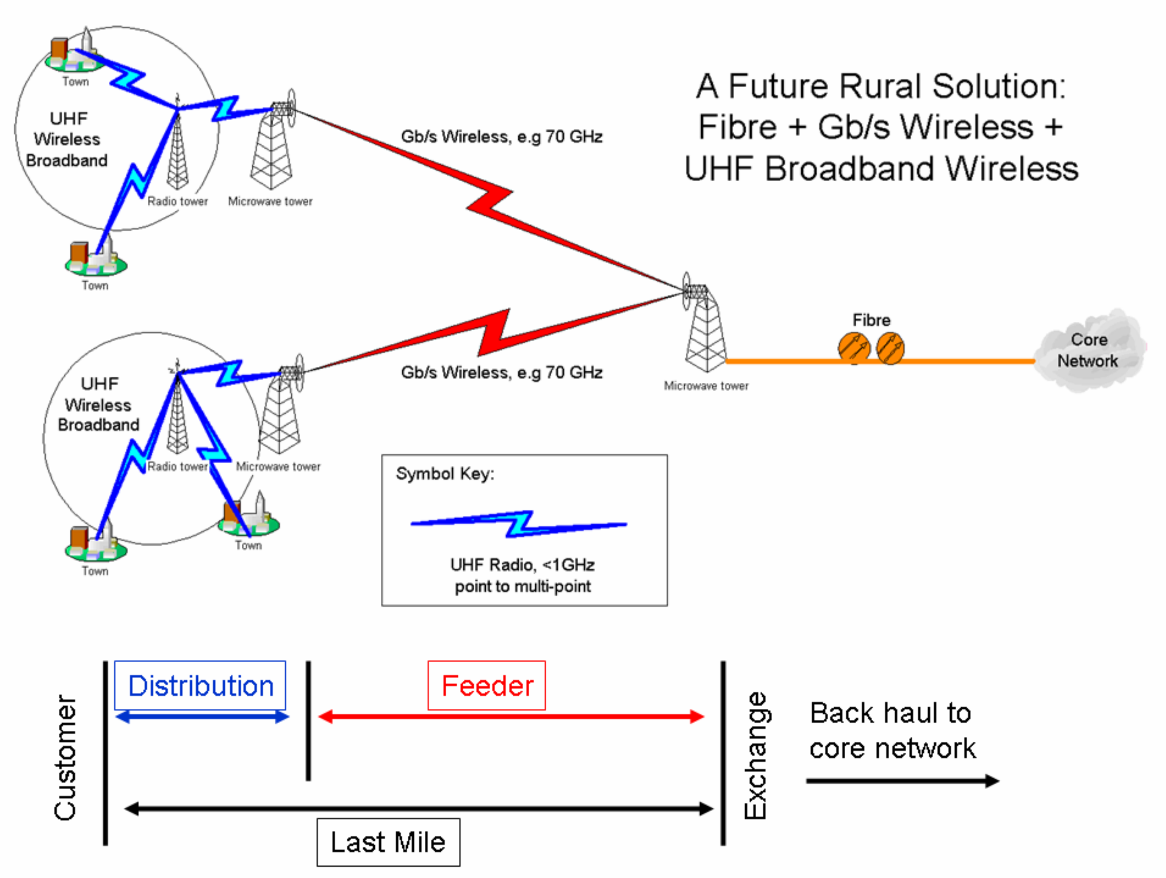

Figure 31 Last mile distribution (UHF), feeder (Gb/s wireless) and back haul (fibre) segments of the network (repeated figure)

In those cases where the reach of the last mile solution is insufficient to reach the back haul, we may say there is a feeder gap. VDSL as last mile distribution is often subject to this, due to its short reach. In the VDSL case it is often necessary to extend fibre further into the local loop to fill the gap. The cost of doing this is a component of the VDSL total deployment cost

Wireless schemes with limited range require a feeder too - and like the VDSL case, this can require a high bandwidth feeder, often beyond the 155Mb/s of the fastest 10/28/38GHz microwave links. The aggregated bandwidth could require Gb/s connection - so fibre or Gb/s wireless are required.

Gb/s wireless is of great interest firstly since its CapEx is much lower than pulling fibre into the local loop. Secondly, fibre in the local loop presently appears to be deterred by regulation in the UK, where local loop unbundling requirements appear to curtail innovation by incumbents. See section 2.3.3 for an example of filling the feeder gap with Gb/s wireless.

1.2.7 Cost drivers summary

Self install, with omni-directional antennas is very attractive from a CapEx and OpEx point of view, but clearly introduces a power budget problem. Power budget appears to be a major problem for mobile WiMAX; beam steering is said to be essential for WiMAX indoor/mobile operation.

Wireless last mile gives a degree of flexibility when choosing back haul, as it enables a choice of concentration site other than the exchange. Radio's opportunity is both the range beyond DSL and the unique advantages of tetherlessness and symmetry, if direct competition with ADSL is desired. Back haul provision is an inseparable part of the equation and includes contention issues.

For rural scenarios, 700MHz may be a better choice than High Power 2.4GHz due to economics (less interference[43]). But 700MHz does have limited bandwidth and capacity, as will be shown in section 3.

Meshes could flex the coverage equation by allowing higher frequency, short multi hops.

[43] A major cost identified for moving to allow 2.4GHz high power is that to those business users who remain at 'normal power'. If, instead of 2.4GHz high power, 700MHz was used, then this interference cost would not occur - yet similar benefits would accrue due to increased radio range.

1.3 Last Mile Summary – requirements and cost drivers

We have coined the term “Broadband 2.0” for the future needs we have identified, a very much higher requirement than the “Broadband 1.0” which is available now. How to achieve Broadband 2.0 is quite a challenge, as indicated by Figure 32.

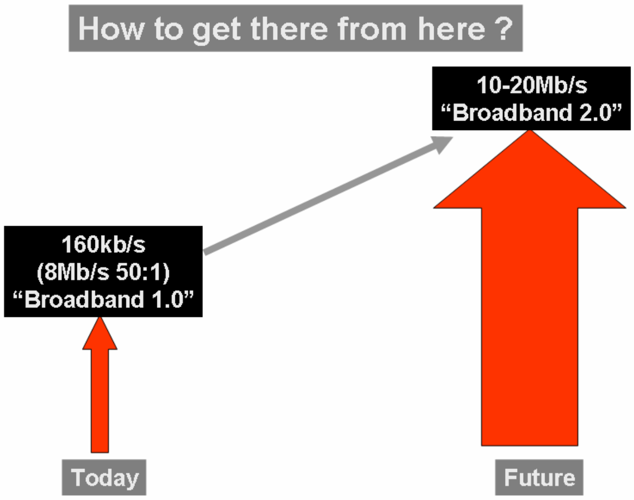

Figure 32 Broadband 2.0 (repeated figure)

We are also looking for future systems to have lower cost potential in terms of CapEx and OpEx, such as self install systems at lower frequencies (UHF). Here, the concept of a last mile feeder, within the last mile, is useful: Where the access technology itself cannot directly reach the exchange/central office; the last mile feeder technology provides the link between the primary connection point (or equivalent) and the central office. By splitting the last mile this way, different technologies can play to their strengths in a combined solution.

2 Benchmarking, Emerging Standards and Fresh Approaches

2.1 Benchmarking Outside the UK

Naturally, solutions for different foreign national problems may not be applicable to the UK. Examples are operating bands, site selection, deployment and legacy networks. Nonetheless we see benchmarking as a powerful technique for picking up pieces of the overall solution. It may be the case that borrowing a common solution from one country may yield something which is seen as an important innovative solution when translated to a related problem in a second country.

Access to non-UK information has been via operators and equipment providers, from wireless standards development bodies and from the authors' direct, hands-on experience of site selection and network optimisation in many countries.

Although it is not intended to draw conclusions within the benchmarking chapter itself, attention is drawn to particular issues of interest at the end of each country's section.

2.1.1 USA

2.1.1.1 General Access Issues

The United States has long had the most developed and widespread last mile access for telephony. The provision of broadband services in the residential market is now also extensive and provided primarily by ADSL and Cable TV Hybrid Fibre-Coax technology.

The United States Government Accountability Office May 2006 Report "*Broadband Deployment Is Extensive throughout the United States, but It Is Difficult to Assess the Extent of Deployment Gaps in Rural Areas*" [US GOA 2006] reported data collected by Knowledge Networks/SRI indicating that in 2005 66% of US households had one or more computers and 58% of households had a computer connected to the Internet, see Figure 33.

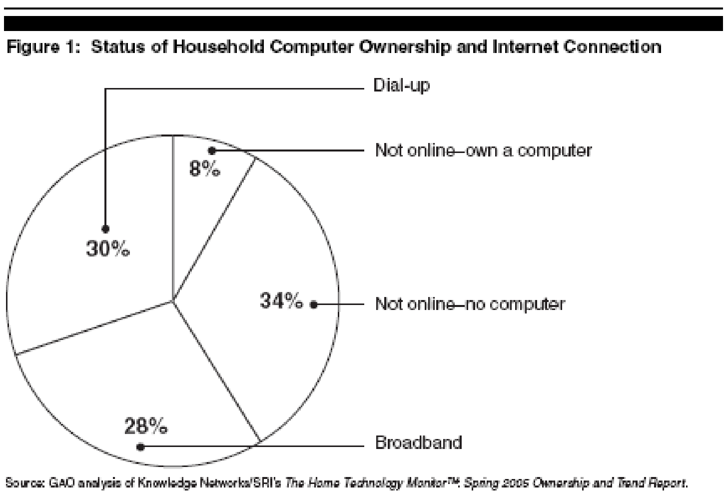

Figure 33: Household Computer Owners [US GOA 2006]

Approximately one-half of those connections were broadband connections.

Broadband Access has been growing rapidly in the United States. The FCC reported in July 2005[44] that from 1999 to the end of 2004 the number of Broadband circuits provided had increased from under 3 million in 1999 to just under 40 million by the end of 2004

2.1.1.2 Technologies used to Provide Access

The same July 2005 FCC report also details the technologies being used to provide this access and the number of connections by type over the period, see Table 5, Figure 34.

High-Speed Lines [1]
(Over 200 kbps in at Least One Direction)

Types of Technology [2]	1999	2000		2001		2002		2003		2004		Percent Change	
	Dec	Jun	Dec	Jun	Dec	Jun	Dec	Jun	Dec	Jun	Dec	Dec 2003 - Jun 2004	Jun 2004 - Dec 2004
ADSL	369,792	951,583	1,977,101	2,693,834	3,947,808	5,101,493	6,471,716	7,675,114	9,509,442	11,398,199	13,817,280	20 %	21 %
Other Wireline	609,909	758,594	1,021,291	1,088,066	1,078,597	1,186,680	1,216,208	1,215,713	1,305,070	1,407,121	1,468,566	8	4
Coaxial Cable	1,411,977	2,284,491	3,582,874	5,184,141	7,059,598	9,172,895	11,369,087	13,684,225	16,446,322	18,592,636	21,357,400	13	15
Fiber or Powerline	312,204	307,151	376,203	455,593	494,199	520,884	548,471	575,613	602,197	638,812	697,779	6	9
Satellite or Wireless	50,404	65,615	112,405	194,707	212,610	220,588	276,067	309,006	367,118	421,690	549,621	15	30
Total Lines	2,754,286	4,367,434	7,069,874	9,616,341	12,792,812	16,202,540	19,881,549	23,459,671	28,230,149	32,458,458	37,890,646	15 %	17 %

See notes following Chart 8.

Table 5 Broadband Access Growth FCC July 2005

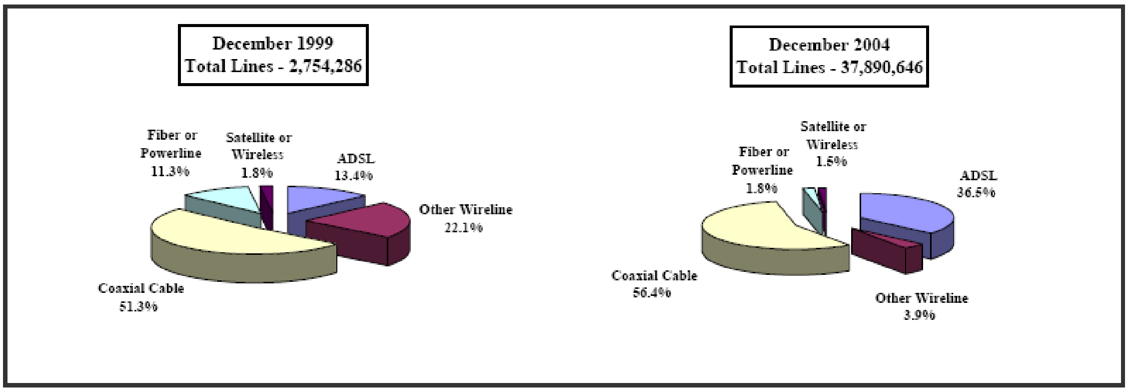

Figure 34: Change in Media Type over Time FCC July 2005

Cable TV services have extensive coverage in the United States and were quick to offer two-way access services over their networks. Throughout the early period most broadband connections were provided over Cable TV networks. The use of ADSL technology to provide broadband services using the local telephone network has developed more quickly and by 2004 was in a position to challenge Cable TV coaxial cable media as the main access technology.

[44] High-Speed Services for Internet Access: Status as of December 31, 2004: Industry Analysis and Technology Division Wireline Competition Bureau July 2005 FCC

Alternatives to Cable and ADSL in use in the United States include Fibre to the Home (FTTH) and broadband service distributed by satellite (VSAT). In the FCC report, Fixed Terrestrial Broadband Access was grouped together with satellite broadband. We believe the majority of the connections reported in this category are satellite connections. The use of power lines to provide broadband communications has also been much discussed in the US. In the FCC report power line communications has been grouped together with fibre. We believe the majority of these connections are implemented using fibre. The GAO report quoting the US trade association, The FTTH Council, reported as of September 2005 that 2.7 million homes were passed by fibre and over 300,000 homes were connected to fibre in 652 communities in 46 states. FTTH deployment was reported as concentrated in urban and suburban communities, or in newly developed communities (known as “greenfields”). Growth in this sector has been relatively slow by comparison with Cable and ADSL, although subsequent to the report publication, Verizon have made concerted efforts in FTTH/FTTP, see 2.1.1.5.

2.1.1.3 Differences between rural and urban USA

US GOA [2006] also reported data collected by Knowledge Networks/SRI indicating that in Spring 2005 the penetration of broadband services in Rural areas lagged that provision in Urban and Suburban areas.

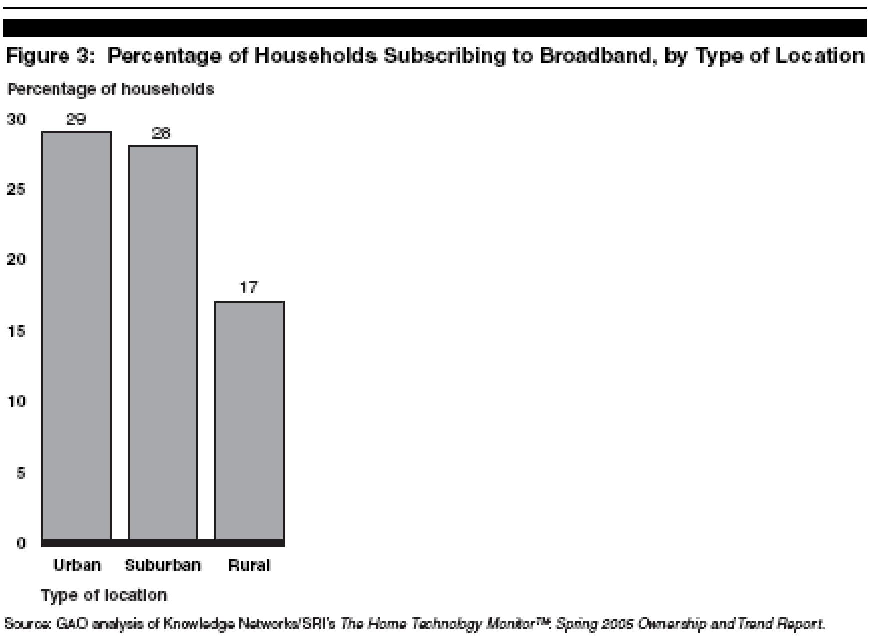

Figure 35: Broadband Access by Area Type from GAO Report

Another widely quoted survey, PEW Internet[45] reports on the differences in Broadband access between rural and urban/suburban America. These results which report adults rather than

[45] PEW Internet and American Life Project: Rural Broadband Use February 2006

households show that there has been less availability of broadband in rural areas than in urban or suburban areas but that this gap is closing.

By the end of 2005, PEW Internet reports that 24% of rural Americans had high-speed Internet connections at home compared with 39% of adult Americans living in Urban or Suburban communities. By contrast in 2003, 9% of rural Americans had broadband at home, less than half the rate (22%) in urban and suburban areas.

	Rural internet users	Urban & Suburban internet users
Digital subscriber line (DSL)	46%	47%
Cable modem	44	45
Wireless or satellite	6	5
T-1 or fiber optic	1	2
Other	2	1
Source: Pew Internet Project combined Sept-December 2005 surveys of 5,262 adult Americans, 3,508 of whom were internet users.		

Table 6 PEW Internet Survey Access Type

Table 6, from the PEW/Internet report, indicates that ADSL is now matching or has overtaken Cable as the dominant delivery mechanism and that other broadband access methods have a very small share both in Rural and Suburban areas. In fact there is no real discernible difference in access technology type between rural urban/suburban areas. Compared to the survey reported in the GAO report this survey reports a bigger percentage of subscribers using satellite or wireless connections.

2.1.1.4 Wireless Access over the last mile

Both licensed and unlicensed spectrum has been available in the US for last mile wireless access during the last six years which has seen a rapid growth in broadband residential access in the US. LCC reports work on commercial or trial wireless projects throughout this period involving applications in the US LMDS band (28GHz), the US MMDS band (2.5GHz) as well as the unlicensed bands at 2.4 and 5.8GHz. Systems have ranged from point to multipoint systems using largely outdoor antennas to fixed and nomadic systems using indoor terminals. Wireless technologies have included systems based around OFDM and the cable DOCSIS standard, proprietary OFDMA techniques, CDMA and TD-CDMA techniques and systems based on WiMAX (OFDM and OFDMA). Considerable expertise exists in the US in the development of wireless access technology and a major industry exists based around the provision of cellular wireless telecommunication.

To date none of these systems have yet found widespread commercial take-up on the scale of ADSL and Cable in the USA for broadband access.

By contrast the number of areas that can access WiFi service, known as “hot spots,” may exceed 40,000 in the US. WiFi hot spots include such diverse entities as airports, colleges, retail establishments, and even entire towns. Increasingly, municipalities are planning or deploying larger area or city-wide hot spots; some municipalities considering or deploying a WiFi network include Atlanta, Philadelphia, San Francisco, and Tempe, Arizona. To date these systems are used primarily by people away from their normal location rather than to provide residential broadband access. The GAO report notes that some WiFi stakeholders identified a few problems with the service. Because WiFi hot spots operate in unlicensed spectrum, interference can be a problem. Several stakeholders reported in the GAO report mentioned congestion or limited distance capability in WiFi as a potential limitation of the service.

2.1.1.5 Issues of interest

2.1.1.5.1 TV bands

We note that whilst a number of WiMAX profiles exist - there is none at 700MHz (TV band) - yet. The US has already held TV band auctions and the present owners, after trading, say they are in a good position to roll out wireless broadband in many municipal areas[46]. The next TV band auction is expected to be in 2009, for the remaining spectrum released by DSO. Not all TV band digital dividend spectrum was auctioned - some was given to essential services.

2.1.1.5.2 AWS bands - advanced wireless services.

Before the next TV band auction will be an AWS auction: The paired bands 1710-1755, 2110-2155MHz were up for auction very soon at the time of writing. This is 2x 45MHz, which are oddly 400MHz apart - this means up and down link propagation may be quite different, not usually desirable in an FDD system. Spectrum is expected to be auctioned in 5MHz or 10MHz blocks. It remains to be seen what the winners of advanced wireless service spectrum will choose to do with it. A following AWS-2 auction is also under consideration to extend AWS into further nearby frequencies[47].

2.1.1.5.3 Fibre to the Premises (FTTP)

FTTP is yet another FTTx scheme, this time with the fibre roll out going all the way to the consumer's place of work, or home (The various FTTx schemes are explained in section 3.2.5).

"By deploying fiber (*sic*) to homes and businesses in [its] territory, Verizon is reinventing its wireline business"[48]. This is a move which seems to be based on sound strategy, since Verizon and similar carriers have only limited options in the face of the march of cable and virtual network operators, who are moving in on Verizon's phone business by offering converged services, e.g. triple-play.. These options are:

1. Sell off the fixed business and concentrate on mobile
2. Accept convergence is coming and choose a partner
3. Accept convergence is coming and horizontally integrate to support a service mix.

Expanding to own a fibre service is clearly an example of option 3.

With respect to pricing and service plans, Verizon have announced the following:

> *With FiOS, Verizon offers superior broadband speeds at very competitive prices along with Verizon's existing wireline and wireless, local and*

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[46] Aloha Partners own the licences for 100% of the top 4 wireless market areas in US, and 85% of the top 10.

[47] http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=66, see 'AWS band plan' (pdf)

[48] Verizon Fibre Optic Services (FiOS) fact sheet, http://www22.verizon.com/about/community/fl/technology/fios_fact.html

long-distance telephony services – and, eventually, new video services.

Pricing for FiOS:

- *5 Mbps/2 Mbps for $34.95 a month as part of a calling package, or $39.95 a month stand-alone*
- *15 Mbps/2 Mbps for $44.95 a month as part of a calling package, or $49.95 a month stand-alone*
- *30 Mbps/5 Mbps at $199.95*

"New video services" relates to FiOS TV, which promises free on-demand programming plus pay-per-view services. An HDTV service is also planned.

In terms of quality of service, whilst neither bit rates nor uninterrupted service are guaranteed for the Internet connections at the moment, Verizon's plan seems to be to reserve bandwidth separately for customers of FiOS TV, by using a separate wavelength, see Figure 36[49].

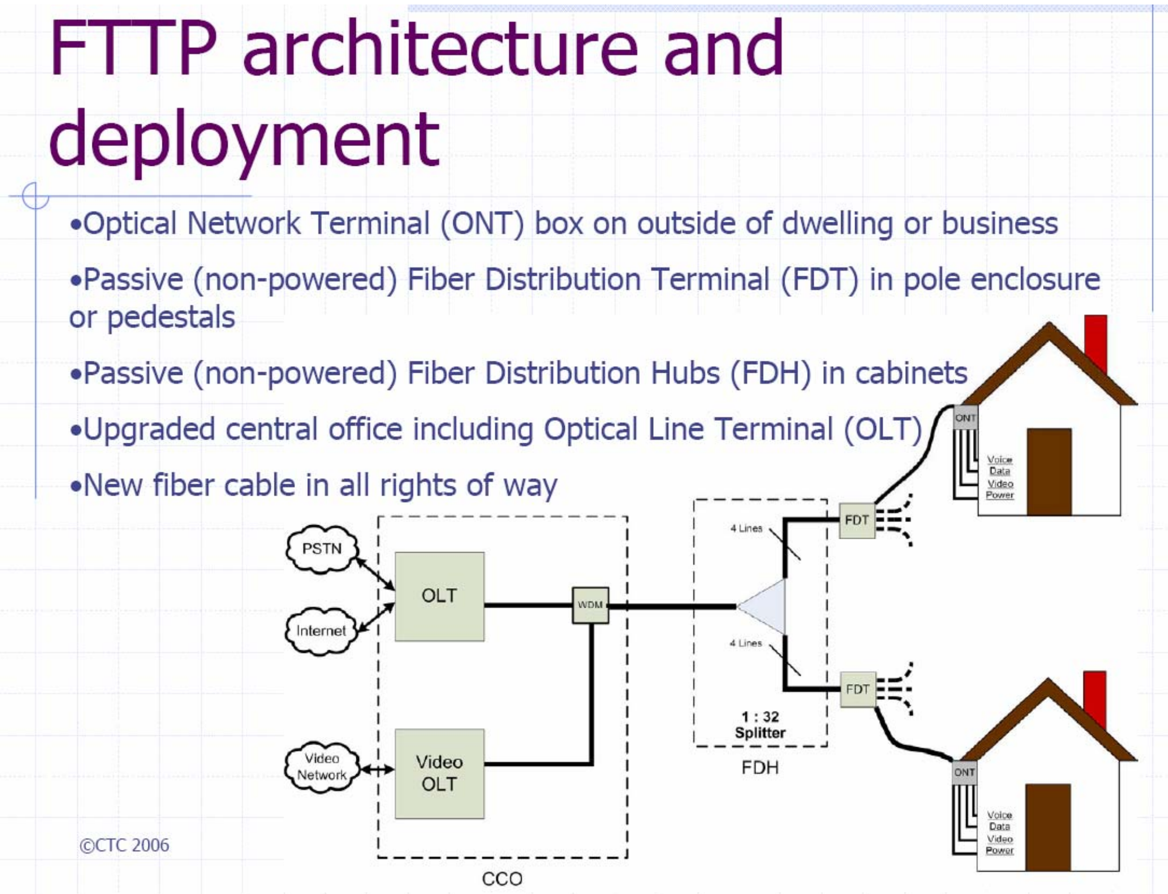

Figure 36 Verizon's FTTP architecture, according to CTC

Video and data/voice are split by wavelength division multiplexing (WDM), giving each have their own optical line terminations (OLTs). Verizon presentations have indicated that the 1550nm fibre window will be used to carry downstream TV, in both SD and HDTV modes. These will use RF channelisation for multiplexing onto the optical carrier (so in that sense, IPTV is a little of a mis-nomer as it is not a one-size-fits-all, single stream). Separating data and video is a sensible

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[49] from CTC, www.ctcInternet.com

strategy, since each have different constraints, although the penalty is any future opportunity cost of reduced flexibility. Verizon's plant itself is scalable to 1Gb/s per customer and the distribution fibre is both buried and aerially deployed, with aerial fibre being cheaper to install.

The problem with such a strategy is clearly the CapEx, of which a given proportion must be up-front, before any revenue flow. On the other hand, failing to compete in this market is likely to lead to marginalisation of Verizon's business. Verizon plans to spend $20billion by 2010 in reaching 16 million customers; this includes spending $3billion to reach New York's 3.1 million customers[50]. The US has approximately 120 million households: Initially therefore, Verizon is naturally cherry-picking those 10-15% which are easy to reach and are most likely to consume the services offered.

A second example of new entrants into the US FTTx space is AT&T Lightspeed who have an FTTN approach for new-builds, which consists of fibre to the node (street cabinet), followed by a last mile of VDSL. CapEx may be lower (buried cable costs are sunk in a new-build irrespective of whether fibre or copper is installed), but future bandwidth scalability will be limited. Lightspeed does not separate the TV from the data, as does Verizon, but carries it all within the single IP stream.

Both FTTx deployments in the US are purely commercial ventures, unlike Korea and Japan, see 2.1.3.

Fibre technology is included as a 'fresh approach' in section 3.2.5 and the economic aspects are further considered in section 4.

2.1.2 Australia

2.1.2.1 General Access Issues

The penetration of broadband access in Australia had reached 27% of the 5.7 million active Internet subscribers in Australia as at the end of September 2004.

The following breakdown of the market was reported[51]:

- 5.7 million homes have Internet access
- 2.0 million homes with choice of Telstra HFC (Cable), Optus HFC (Cable) and ADSL
- 0.7 million homes with choice of ADSL and one Cable system
- 3.3 million homes with ADSL as the fixed broadband option
- 1.6 million homes in rural and remote areas that are too far from Telstra exchanges to be served by ADSL

2.1.2.2 Technologies used to Provide Access

In response to the growth in broadband demand, a large number of broadband service providers have entered the market. Out of 690 Internet Service Providers (ISP), there are over 200 fixed broadband ISPs and 50 broadband wireless ISPs (WISP). The fixed broadband ISPs fall into three groups:

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[50] source: NY Times, 14 August 2006.

[51] *ibid.*

- Incumbents:

  Telstra BigPond provides DSL and HFC Cable services on its own networks

  OptusNet has it own HFC Cable network but to provide DSL services, it has to lease capacity on Telstra copper (local loop) network and install DSL equipment on Telstra exchanges, i.e. being a facilities-based provider

- Facilities-based DSL ISPs who install their own DSL equipment

- DSL resellers of Telstra DSL service for simple resale

As of 31 December 2004, the ACCC estimated that there are 1.55 million connections in total, including 1.13 million DSL and 0.4 million HFC Cable connections. This corresponds to a penetration of 27% of a base of 5.7 million business and households with Internet access[52].

According to the ACCC data, DSL has the largest market share of 73%, followed by HFC Cable with 26% and satellite 1%. DSL shows growth of 26% for the 12 months ending December 2004, HFC Cable slower growth of just 11% and satellite with no growth.

The ACCC data is shown in Figure 37.

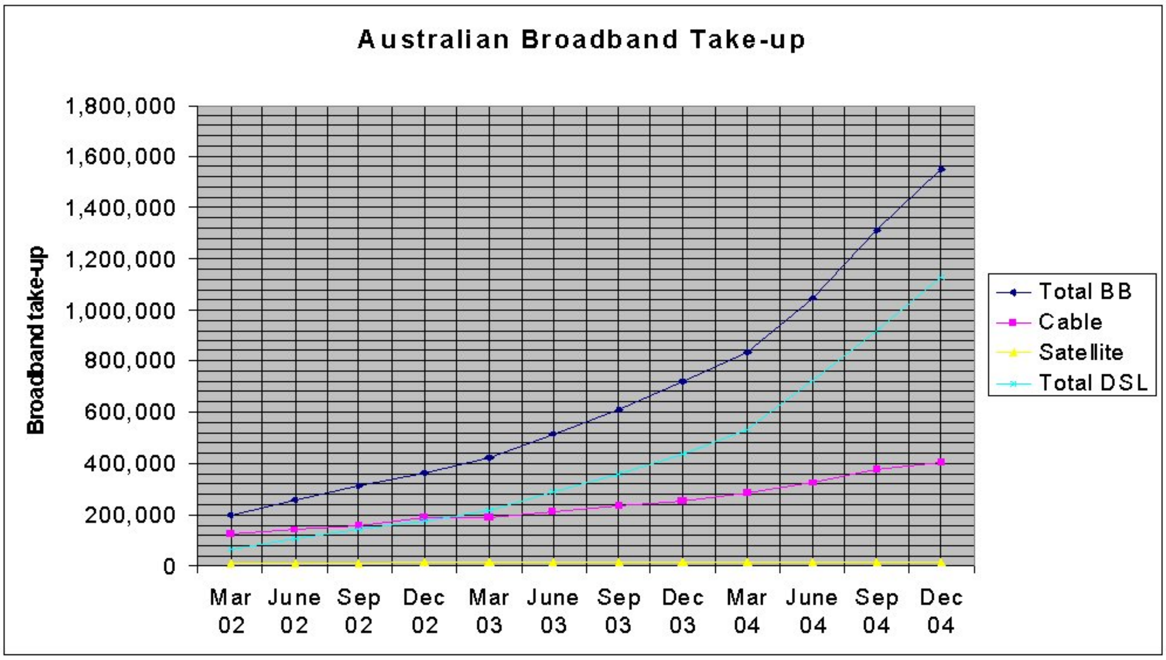

Figure 37 ACCC data on broadband take-up

2.1.2.3 Wireless Access

The broadband wireless sector has also shown significant growth in the last 12 months with vigorous push by a number of service providers including Unwired, Personal Broadband Australia, BigAir, Pacific Wireless and Access Providers. However the number of subscribers receiving broadband services by wireless is still small. The number of broadband wireless subscribers was estimated by IDC at just over 25,000 in 2004 but is expected to grow substantially over the next

52 *ABS Business Use of Information Technology 8153.0, September 2003.*

few years[53].

Analysts IDC estimates that there will be 3.4 million broadband connections in Australia by 2008 and 287,000 broadband wireless connections, or 8.5% of all broadband connections by 2008 [54]. Ovum makes a similar forecast with 3.1 million connections by 2007 and 298,000 broadband wireless connections, or 9.6% of the total broadband market by 2008[55].

The IDC data is shown in Figure 38.

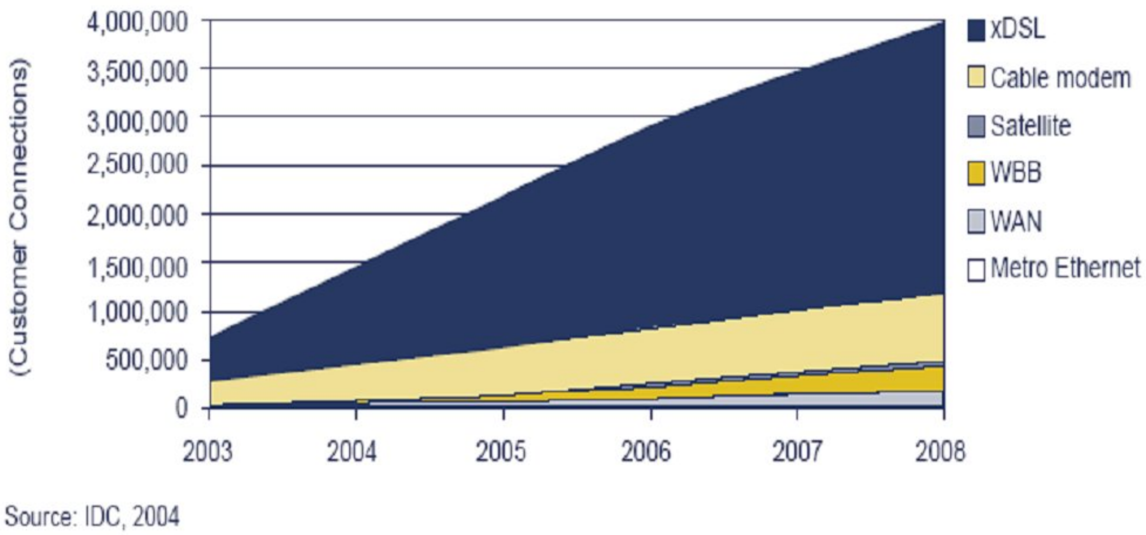

Figure 38 Broadband customer connections outlook [IDC]

Notable Wireless last mile operators in Australia include:

- Access Providers (Melbourne);
- Neighborhood Cable (Mildura, Victoria);
- BroadbandNet (Perth, Geraldton, Kargoorlie);
- Broadband Wireless (various cities in Tasmania); and
- Unwired Australia (in Sydney, currently).
- Personal Broadband Australia BA (Sydney, Melbourne, Brisbane, the Gold Coast and Canberra);

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[53] *Department of Communications, Information Technology and the Arts, "Government Use of Wireless Broadband", 2004*

[54] *Access Providers Ltd Prospectus, 8 October 2004, p. 22.*

[55] *Andrew Colley, ZDNet Australia, "Wireless to eat 10 per cent of broadband pie by 2007", 14 September 2004.*

2.1.2.4 Issues of interest

Unwired Australia promotes itself as being very successful in rolling out its WiMAX solution. The solution comes from Navini networks and includes WiMAX antenna enhancements, specifically a steerable beam, which is an option over and above base WiMAX. Navini's own data claims that beam steering is essential for the 802.16e business case. Beam steering was discussed in section 1.2.2.1 and Navini's method was shown in Figure 20. Beam steering is not normally applied to fully mobile systems (MIMO is more appropriate), so Unwired Australia may be expecting only portability from its customer base.

Australia's ADSL competition offers very different bandwidths to the UK; either provider capability or customer expectations are much lower: 1Mb/s appears to be the top ADSL rate under discussion, with most rates expressed in units of kb/s. The low speed of ADSL competition may be another reason why wireless broadband is seeing some success in Australia, along with the use of WiMAX beam steering enhancement. Concerns must be that:

- ADSL competitiveness could quickly increase
- beam steering must increase CAPEX and decrease delivery efficiency to some degree

2.1.3 Korea and Japan

2.1.3.1 Korea

Korea will have fast broadband of 20Mb/s to most homes this year and is pushing towards faster. They see fibre as the way to get a future-proof 100Mb/s to the home and the government has committed the country to being an IT test bed[56]: Equipment providers are encouraged to install their latest, fastest equipment in Korea. These are not trials, but actual customer roll-outs.

The need for bandwidth is real: Koreans in their 20's are the driver - a full 90% of them belong to 'CyWorld' which is an on-line, community-based, social networking application. The application has already moved to Japan as well and is to be launched in China the US later in 2006. Social networking sites are already popular in the US/UK, e.g. MySpace, albeit without the large virtual reality content of CyWorld. If the owners of CyWorld (SK Telecom) manage the cultural transitions from East to West correctly, then there appears to be every reason to expect it to succeed in a major way. CyWorld is available on fixed and mobile platforms, as shown in Figure 39.

[56] The DTI mission report seminar "Exploiting the broadband opportunity" provides an excellent overview

Exhibit 4.3 Cyworld can be accessed from fixed and mobile devices

Figure 39 CyWorld - access from many platforms [DTI]

Another example is OhmyNews; is a community driven news site, where users feed stories into the online newspaper. This includes multimedia data.

2.1.3.2 Issues of interest

This investment in last mile broadband is government sponsored.

Even if wireless schemes were used for the last drop, a high speed access system would still need fibre for back haul to cope with the aggregated rates, so a move to more fibre in the network is inevitable.

CyWorld and OhmyNews are more examples of the increase in user generated content, pushing for a more symmetrical broadband connection.

The take up of IPTV is being stunted not by technology, but by business model issues, much as this report predicted in section 1.1.5.3.1, when discussing distribution rights.

2.1.3.3 Japan

Japan expect 30 million FTTH broadband users by 2010. This very ambitious target has been set for many of the same reasons as Korea. Prices are currently only $25-$58 per month for a

100Mb/s fibre connection, depending on location. Table 7 shows that such prices compare favourably with contemporary ADSL offerings. Two versions of FTTx are listed; the first is standard FTTH, whilst the second is 'fibre to the apartment block', followed by Ethernet for distribution internal to the building, most likely using copper Gigabit Ethernet. Note the back haul link is a high data rate by today's standards; 60Gb/s in this example[57]. Over time, even this must be expected to prove insufficient; some of the reasons are explained next with respect to Japan's measured Internet traffic attributes.

Brand	Service	Technology	Speed	Price	Place
Yahoo! BB ADSL	8M	ADSL	8 Mbps Down, 1 Mbps Up	$26 (£15.03)	Household
	12M		12 Mbps Down, 1 Mbps Up	$30 (£17.34)	
	26M		26 Mbps Down, 1 Mbps Up	$33 (£19.10)	
	50M		50 Mbps Down, 3 Mbps Up	$34 (£19.65)	
	50M Revo		50.5 Mbps Down, 12.5 Mbps Up	$36 (£20.80)	
Yahoo! BB Hikari	Hikari Home	Fiber to the Home	100 Mbps (Up/Down) Access line 1 Gbps Backbone 60 Gbps	$58 (£33.53)	Individual house
	Hikari Mansion	Fiber to the apartment block then Ethernet	100 Mbps Down 50 Mbps Up Access line 1 Gbps Backbone 60 Gbps	$25 (£14.45)	Apartment within an apartment block

Exhibit 3.4 Japan: Yahoo! BB's Product Portfolio (a Softbank company)

Table 7 FTTH and ADSL prices in Japan [DTI]

Japan has also been studying its Internet usage patterns [Fukuda et al 2005] and found that usage is

- increasing; total consumer broadband traffic is estimated at 250Gb/s
- tends to be symmetrical
- has a lowering peak to mean ratio (more 'constant' traffic, like streaming video)

The study of Internet Exchange (IX) traffic studied seven major ISPs and found that residential consumer traffic differs from business traffic in terms of its statistics. Moreover, the residential traffic dominates the total, so that residential traffic statistics also dominate total traffic statistics. These statistics include:

- about 70% of residential traffic is constant, all the time
- peer to peer traffic between consumers is equal to the traffic routed up to the IXs

Both the above are key findings: The first means that our expectation of the benefits of statistical multiplexing when designing the core network especially, must change; there will be less advantage and hence a higher core bandwidth required. The second is more evidence that locally generated content is on the rise, which pushes for symmetry of access speeds. Interestingly the authors of the study do not try to speculate on what is driving the peer to peer, symmetrical traffic.

[57] The contention ratio or user minimum bandwidth is not available; this may not be a practical issue until subscriber numbers ramp up.

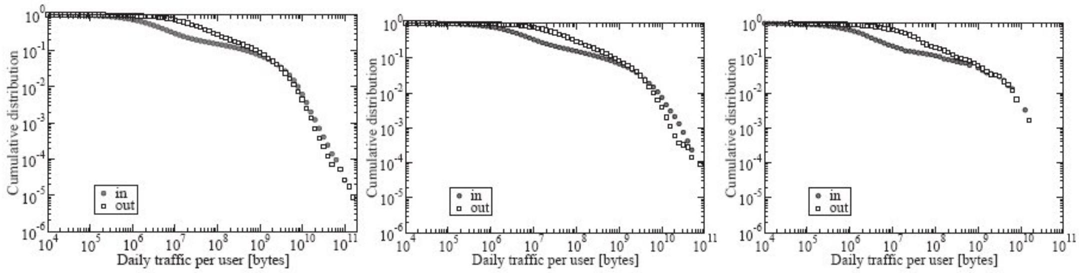

Figure 13: Cumulative distribution of daily traffic per user: all prefectures (left), a metropolitan prefecture (middle) and a rural prefecture (right)

Figure 40 Cumulative distributions of in/out traffic [Fukuda at al 2005]

Figure 40 shows more analysis of the symmetry effect - it is the heavy users of the Internet who have the most leaning towards symmetrical use. Lower users are biased towards downloading by a factor of ten. This may be preference or it may be the limitations of the asymmetry of ADSL links. Heavy users would also be expected to be early adopters of future technology and thus may indicate the future trend.

2.1.3.4 Issues of interest

Fibre is clearly the most future-proof way to go, whether the last drop is wireless or not; the increased requirement for core bandwidth has been realised in Japan and Korea, based both on extrapolated measurements and a strongly held 'vision' from the governments.

In the mid to long-term, Japan is reportedly expecting WiMAX deployment to cover small cells of 2-3km and deliver e.g. up to 75Mb/s with 802.16e using spectrum in the 2-6GHz range. Present trials are WiBro[58] at 2.3GHz, delivering 1Mb/s with good QoS, suitable for real time traffic.

2.1.4 South Africa

In South Africa radio has been used for several years for WLL. Sentech[59] has addressed several types of application each using a different wireless technology.

Sentech's 'MyWireless' service is a portable, always-on wireless broadband Internet connection. The aim is to enable an Internet connection to be established anywhere within the declared coverage area with a small self-installed wireless modem. IPWireless[60] have been selected as the equipment supplier. The equipment is to the 3G UMTS TDD standard. This is a fully mobile standard but is used for the fixed and portable market only. Coverage areas are limited but sufficient such that some users may use their connection from multiple locations e.g. workplace and home. Coverage is less extensive than the main fixed operator, Telkom's fixed line service, but may be available in some places where there is no ADSL service provided by Telkom.

On this basis the service is of a form between full cellular radio and WiFi (with hotspots). It allows for portability rather than mobility, although as the technology is to a 3GPP standard, the CPE may work even if it is moving rapidly. Some forms of Fixed Wireless Access (FWA) require the CPE to

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[58] WiBro is Korean WiMAX in essence and has been harmonised into 802.16.

[59] www.sentech.co.za, a South African broadband provider

[60] the same as used by UK Broadband, previously used as an example in this report

be specially sited often with outdoor antennas which are directional and mounted in elevated positions. In such cases professional installation is generally used. The MyWireless proposition is attractive in that the customer sites the CPE equipment and can use it in multiple locations. The price paid for this by the operator is that higher signal strengths are needed. This requires careful judgement on the number of cells needed to create a service which meets customer expectations without going to a number which cannot be economically justified. In addition adequate allowance must be made for problems in acquiring preferred sites for base stations, difficult radio propagation paths, variable in-building penetration, etc.

The range of solutions is:

Full cellular	- mobile access across wide area
MyWireless	- portable access within limited coverage area
FWA	- fixed access within limited coverage area
Telkom DSL	- fixed access across wide area
WiFi	- portable access at hot spots only

In all cases the areas covered differ but within a covered area there is differentiation through connection speeds and pricing. All solutions are improving but the Telkom fixed line solution can always be expected to have a speed advantage.

Iburst is being rolled out in South Africa; it would seem to offer similar features to but uses a different technology as its basis.

The equipment is 3G UMTS TDD equipment from IPWireless. Its strengths are that the equipment is modern and ‘state of the art’, the standard has a clear development plan-giving greater performance in future, alternative vendors of this technology exist, and its take-up by the industry is growing. The IPWireless technology has 48MHz of spectrum available at 2.5GHz. 3x10MHz being used in current planning (and 3 x 15MHz in 2007).

Other technology used for last mile access includes:

- VectaStar, which is a point to multipoint radio system from Cambridge Broadband. It is being used at 3.6GHz as dedicated FWA for high-end business services (Biznet) and as the back haul for the MyWireless base stations. One VectaStar system can support six IPWireless base stations or a mix of FWA and IPWireless base stations. As an FWA system, VectaStar provides multiples of 64kB/s.
- BreezeACCESS XL equipment from Alvarion is used for FWA point to multipoint in the 3.6GHz band. It is cheaper and has lower capacity than VectaStar and is used as an FWA delivery method in some projects. A 28MHz allocation is used for point to multipoint at 3.6GHz and a further 28MHz has been requested.
- Microwave point to point can also be used by Sentech. As traffic levels grow, point to point links will become cost effective and replace VectaStar which can then be moved to new areas. Spectrum for point to point links is requested as needed, and assigned at 7GHz. In addition, point to point can be used to serve FWA customers directly and gives greater range than a point to multipoint solution.

2.1.4.1 Issues of interest

The markets addressed by Sentech include some that are well matched to their technology solution but in general they seem to be treating it as a ‘me too’ service to Telkom and as such they are under pressure to control costs and ensure a high coverage standard across their coverage areas. It is only where portability and lack of alternatives are strengths that they are able to compete on factors other than price.

2.1.5 France

On 7th July 2006 ART, the French Regulatory Authority for Telecommunications, published its selection of WLL operators in Metropolitan France's 22 regions and some overseas areas. This award was based on a call for bids in the 3.4 – 3.6GHz band.

The applications were examined according to three criteria

- the contribution of broadband services to territorial development
- the project's ability to encourage broadband competition
- the bidder's financial offers

The selected candidates have committed to large deployments, which will become obligations in the authorisations. The obligations will involve deployments, starting in June 2008, in a total of more than 3,500 sites. The deployment commitments target, in particular, zones not covered by DSL, referred to as broadband 'white spots.'

Moreover, some selected candidates intend to resell frequencies, where they do not use them, and to provide wholesale frequency access offers on their network. Some selected candidates have no retail plans and may only provide wholesale offers.

There will be three authorised WLL operators in every area of France. It is believed by the regulator that this will help stimulate broadband access competition, not only in rural areas, but also in densely populated areas by competing with existing fixed networks.

In addition, wholesale WLL infrastructure offers will attract third party service providers

France's Postal and Electronic Communications code provides for flexible procedures allowing the evolution of frequency allocation. They allow the transfer of frequency authorisations in a secondary market, under the allocation process for frequencies in the 3.4-3.6 GHz band. Under a frequency transfer mechanism, authorisation holders can transfer use of their frequencies to third parties but not their authorisations, because the regulator holds the frequency owners responsible for obligations in their authorisations.

ART is currently working to identify other available frequencies in the 3.4-3.8 GHz band that could be used to issue authorisations in the future.

In addition the 5470-5725 MHz frequency band was opened early in 2006 and this unlicensed band can also be used to provide broadband access services by these operators.

2.1.5.1 Issues of interest

ADSL broadband 'white spots' are to receive wireless broadband from the operators under specific contractual obligations imposed by the French regulator.

France Telecom and others are rolling out some fibre in Paris: France Telecom also launched a very high speed FTTH pilot programme for customers in Hauts-de-Seine in January 2006.

2.1.6 Germany

The number of applications for BWA spectrum received between 21 December 2005 and 28 February 2006, by the German regulator (RegTP), showed that the demand for spectrum in the

3400–3600 MHz range significantly exceeds availability.

It was therefore felt necessary to hold ‘award proceedings’ before assigning spectrum.

The planned rulings prescribing award proceedings, selecting an auction as the award mechanism and setting forth the determinations and rules for conducting the auction have been published in the Federal Network Agency’s Official Gazette (issue 13/2006 dated 6 July 2006). The deadline for submitting comments on the key elements of the rulings is 4 August 2006.

Deutsche Telekom had planned to spend up to 3 billion Euro on a fibre-to-the-curb (FTTC) project that was set to deliver up to 50Mb/s of broadband access to homes in 50 German cities by the end of 2007. However Deutsche Telekom has stalled its FTTN+VDSL roll-out plans, based on regulatory uncertainty over unbundling fibre plant.

2.1.7 Recent industry viewpoints

Recent industry viewpoints were gathered from the Broadband World Forum Europe which was organised by the International Engineering Consortium, from 9th -12th October 2006 in Paris. With several thousand attendees it provided a useful snapshot of current industry views. The belief that speeds will continue to increase in the networks including the last mile is widely held. Services such as IP HD SERVICES will drive requirements and, on the equipment side, technologies are available which can provide the necessary speeds. Examples of statements from workshops and papers are as follows.

Breaking Access Bottlenecks – Workshop 9th October 2006 (Chairman: Dirk Van Den Berghen, Alcatel)

‘’Nowadays, service providers around the world worry about the way they can bring their advanced data, voice, and video services to the full extent of their existing or potential customer base. At the same time, they are gradually moving away from the best-effort "Internet access-only" offering toward communication and entertainment service offerings, mostly pushed by the competitive environment.

Transforming the access network to suit the very demanding needs of triple-play offerings is not an easy task, and this can be confirmed by service providers who are willing to testify on their consolidated plans for implementation.

What are the key parameters to be successful in the altering broadband market?

- Provide all end users with an optimal bandwidth offering by mixing different network flavours and topologies in the most cost-effective way.
- Take away all technical hurdles for end users to subscribe to services by remotely mastering their digital homes.
- Migrate legacy services to a wide array of new (triple-play) services while securing the cash cow (i.e., voice) via a cost-effective network evolution toward IMS, WiMAX, and VoIP.
- Make sure that the best-in-market operational processes and operations support systems (OSSs) are in place to optimize per subscriber costs.

Providing all end users with an optimal bandwidth offering in the most cost-effective way creates a typical requirement such as bringing fibre to the most economical point. To deliver full-service offerings, including IPTV, service providers are bringing fibre closer to the end user and change their access technology being used, from ADSL to ADSL2plus, very-high-data-rate digital subscriber line (VDSL/VDSL2) or passive optical network (GPON) technologies''

Trend of Broadband Access Network –Daniel Tang (Huawei)

''As the broadband network rapidly becoming prevalent, the competition in this market gets much fiercer. To outdo the competitors, operators are trying to provide more services over the broadband network to attract more customers, increasing the profitability of the network and cultivate customer loyalty. The convergence of broadband and narrowband networks is a trend in the industry. And how to provide a unified multi-service broadband access platform is a matter for discussion. ''

Triple Play Deployment Challenges – Eric Reid (Agilent)

''Development and deployment of triple play services (Voice, Video and Data) is driving significant change throughout the core, edge and broadband access network. As networks evolve towards a Triple Play infrastructure there are now more complex challenges arising from the convergence of triple play services. Service providers, Network Equipment manufacturers and cable providers therefore need effective tools to ensure the performance and reliability of today's next generation networks.''

2.1.8 Benchmarking summary

It can be seen that there are several differing approaches to WLL provision in other countries. Lessons will be sought from this in the discussion of chapter 3, taking due regard of the differences in existing broadband availability, geographic/population distribution and the principles behind the regulatory regimes.

Two major trends were noted:

- Korea and Japan's future fibre vision is being fuelled by government intervention as is France's coverage of ADSL 'white spots'.
- South Africa's wireless broadband operators are seeing most success when they compete based on mobility and not just cost, which agrees with Ofcom's survey finding of growing market pull for tetherlessness.
- Forbearance on unbundling fibre by the FCC has encouraged innovation in the US [FCC 2004b]. The EU has thus far taken a contrary view.

2.2 Emerging Standards

2.2.1 Telecoms based: HSDPA etc

HSDPA is a technology for improving the down link performance of W-CDMA networks and is intended to enable mobile broadband multimedia services. Specific improvements include[61]:

- higher data transfer speeds

[61] Source: taken from the GSM Association web site

- improved spectral efficiency
- greater system capacity for GSM operators

Initial services are aimed at users with laptops using an HSDPA PC card. The first HSDPA compatible handsets are also now being launched. Ovum estimates that the number of connections will reach 635,000 in Western Europe by the end of 2006 and will grow to 50 million by the end of the decade.

Regular surveys from the Global mobile Suppliers Association (GSA) confirm that 100 HSDPA networks, an increase of 100% in six months, are in deployment or commercially launched in 49 countries. As of end-May 2006, there were 30 commercial HSDPA networks in operation in 23 countries. The GSA forecasts that the number of commercial HSDPA networks will more than double to 63 by end 2006, with all W-CDMA network operators expected to activate the HSDPA upgrade. HSDPA services are now commercially available in Austria, Bahrain, Bulgaria, Croatia, Czech Republic, Estonia, Finland, France, Germany, Hungary, Isle of Man, Israel, Italy, Kuwait, Madeira, The Netherlands, The Philippines, Portugal, South Africa, South Korea, Switzerland, United Arab Emirates, and the USA[62].

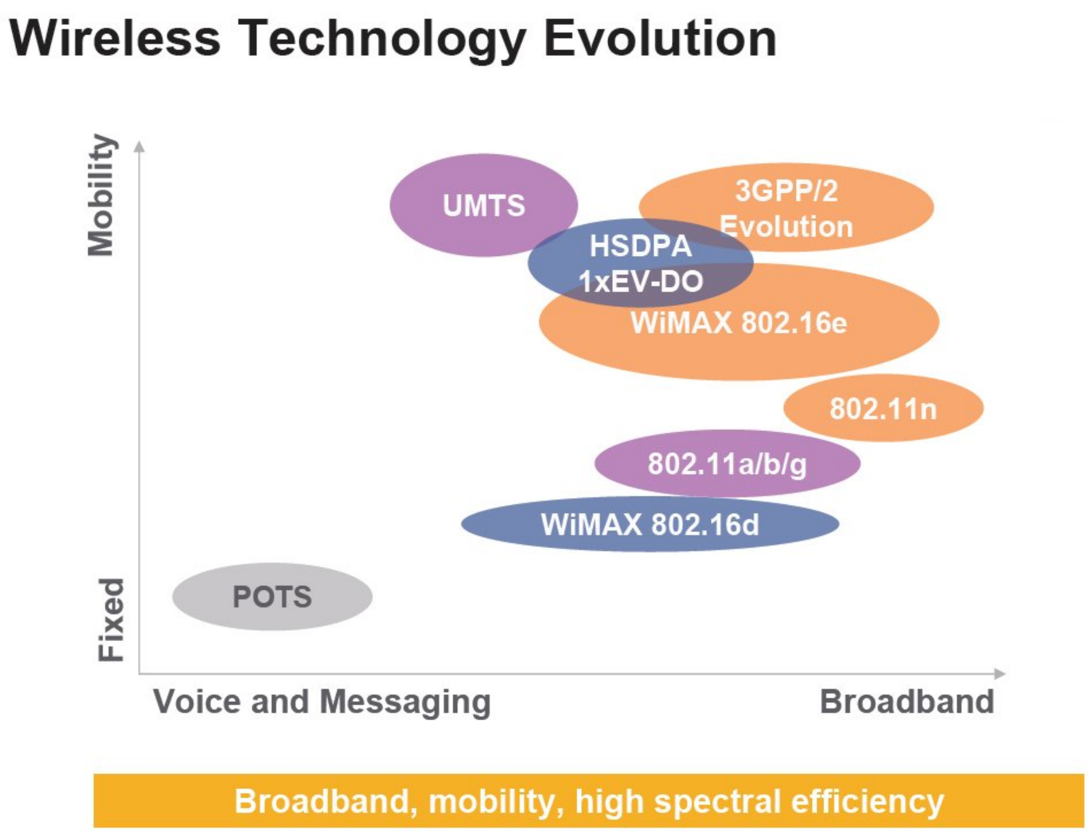

Figure 41 WiMAX - HSPDA-etc comparison [Nortel]

Figure 41 shows where HSDPA fits in terms of its mobility-bandwidth offering. WiMAX, discussed next, is also shown to be similarly placed for the mobile 802.16e version.

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[62] source: www.gsacom.com

2.2.1.1 Future potential

HSDPA already has an infrastructure in place (3G); it needs ‘only’ a software update. The HSDPA emphasis on mobility has perhaps led to the latency issues for VOIP and multimedia, hence the plans for LTE (3G Long Term Evolution, also known as ‘Super 3G)’. This is intended to better enable multimedia delivery, by improving capacity to potentially 100Mb/s and reducing latency to potentially 20ms. Both factors are well beyond present 3G capability and would challenge WiMAX’s capabilities. LTE deployment is likely to be 5-7 years away and will need additional spectrum allocation.

2.2.2 Datacomms and broadcast based: WiMAX etc

WiMAX is the promotional body for systems following the IEEE802.16 standard. The standard itself has quite a long history and started quite differently to its present form; this was as an LMDS or MMDS[63] system evolution, later a back haul solution. One thing to carry over from WiMAX’s inception is its high QoS ability - but this is due to the ‘impoliteness’ of its protocol by modern standards; 802.16 was only ever intended for operation in licensed spectrum.

Presently there is 802.16d for fixed outdoor/indoor operation and 802.16e has followed for nomadic/mobile operation. Surprisingly, perhaps, the two 802.16 versions must be operated independently. The later systems are OFDM based so, unlike their predecessors, are suitable for non-LoS applications.

Notable enhancements under discussion within 802.16 include beam forming for extra gain at the base station for indoor/nomadic/mobile systems. An example is the beam forming advantage of +9dB (refer back to Figure 20), used by Navini Networks in their Unwired Australia deployment. Despite it being an enhancement, Navini make a point of saying it is essential for a successful mobile deployment. As pointed out later in 2.1.1.5, Navini’s success may rely on its beam forming technology, but it may also rely on the lack of competition from Australian ADSL.

The jury is in fact still out on the realistic prospects of WiMAX. Most agree that WiMAX has been ‘over-hyped’ in terms of what it could do. Presently it seems most likely to be deployed in 2.5/3.5GHz licensed bands first, but the prospect of use in the TV bands (see 2.1.1.5) may speed the creation of a 700MHz WiMAX profile by the WiMAX Forum. Some regulatory change may be required to use the ‘mobile’ versions of WiMAX in what are presently ‘fixed’ bands.

2.2.2.1 Future potential

WiMAX presently has no installed infrastructure - it could be built as a green field, or as an overlay on e.g. an existing cellular network. Greenfield is likely to be much higher cost. The WiMAX emphasis is speed and QoS (in the down link). It is more spectrally efficient than 3G due to OFDM and MIMO.

WiMAX is being ratified as an alternative RAT (radio access technology) by 3GPP - so that a process will be standardised for seamless handover between WiMAX, 3G and other RATs like WiFi.

[63] historical multimedia distribution systems - for packet TV distribution by MPEG2

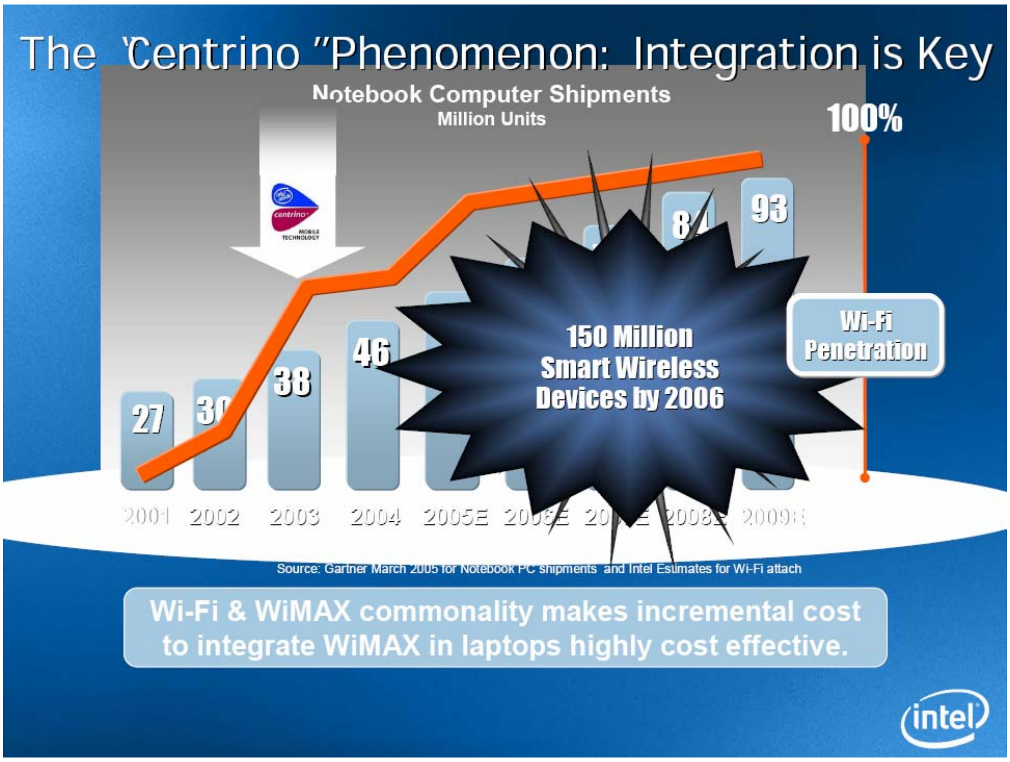

Figure 42 The Centrino Phenomenon [Intel 2006]

WiMAX's big play may be that, like WiFi, it becomes very widely deployed - 'free-to-user' on laptops and it thus exerts significant market pull. Intel describe their WiFi success as the "Centrino Phenomenon", Figure 42, and would clearly like to repeat it with a 'WiMAX Phenomenon', see Figure 43, from the developer's guide on Intel's web site.

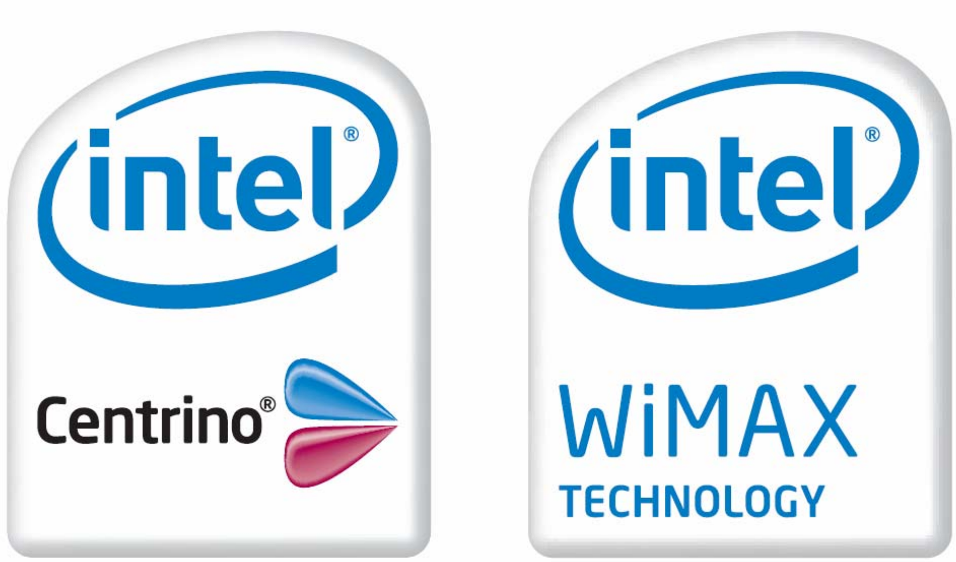

Figure 43 Intel WiMAX joins Centrino brand [Intel web site]

In recent months, Intel have relaxed their WiMAX-only stance and now promote an integrated seamless solution of WiMAX + WiFi +3G, for an anywhere-connected solution[64].

In a similar vein, Motorola is uniquely placed to promote WiMAX, if they build it into their handsets (Motorola is number 2 in handset sales). Motorola have the whole WiMAX chain in-house, from base station to handset.

2.2.3 Broadcast based: DVB-H, satellite etc

DVB-H (digital video broadcasting to handsets) could reduce the demand for Internet access bandwidth, via substitution, by providing an alternative delivery method for TV centric services at lower resolutions such as the popular QVGA (320x240 pixels). It does seem likely that SD and HD TV will not be delivered by DVB-H, however.

Satellite TV could, and does, deliver standard and high definition TV: If satellite were to become the major delivery method for TV, pressure on Internet access bandwidth could reduce. One factor in deciding this will be the availability of content, see ‘content is king’, section 1.1.5.3. Another factor is whether customer pull will be for a broadcast service or for personal on-demand programming. It seems reasonable to expect a mix, thus both mechanisms must be provided.

2.2.3.1 Future potential

DVB-H is a competitor for service delivery - will users prefer to watch mobile TV on a small screen or quality TV at a fixed location? Two distinct user groups are likely, which splits the available market for either solution, although the options are not mutually exclusive.

Satellite is a relatively mature competitor, but mainly for broadcast, not for the on-demand aspect.

2.2.4 De facto standards

de facto standards are those which are unlikely to been through a formal approval process, but which exist nonetheless due to uptake by the popular market. They may draw on both standards and proprietary methods.

2.2.4.1 Community Networking

Locust World Mesh Networks[65] claim the following:

> ‘‘Mesh networking provides an innovative method to build complex data networks very easily. Using the intelligence of each component, meshing helps them to join into a self-organising structure. Mesh Networking is particularly suited to wireless networks, where the connections can't be predicted in the same way as a wired network, catering for mobile nodes, instant growth and unpredictable variations in reception and coverage.
>
> The Locust World Mesh uses a public networking standard AODV, to build the mesh. AODV, Ad hoc, on demand, Distance Vector, published by NIST, is recognised as a leading standard for wireless mesh networking. The Locust World mesh router is available as a software package and as a hardware device, and it is widely used to deliver

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[64] Steve Greenwood, Intel. Personal communication.

[65] www.locustworld.com

wireless broadband networking in challenging terrain.''

Locust World equipment seems to have been used primarily for shared ADSL services in community networks. Remote communities can use the mesh to share a single expensive Internet link, like a satellite or leased line, among enough users to make the service affordable. A T1 or satellite connection is often out of reach of individual small businesses and personal users, but if there is enough local interest then their purchasing power can tip the balance and help to provide excellent value within the local community. Such Locust World based systems are appearing because traditional cost and service inhibitors are controlled by a 'community'. This is a good example of achieving new spectrum utilisation by recognising that certain deployments have very different 'business cases' than is typical. Spectrum efficiency and other engineering measures of mesh networks are of relatively little importance to these cases: The potential capacity of the radio network is so much greater than the ADSL limit at the gateway Access Points that it is not an issue for network design.

On the Locust World web site there are examples of ADSL such as SpeednetScotland in Troon which uses radio as an alternative ADSL provider.

Locust world is a very simple subset of the coalition peering concept, see section 2.3.6.

2.2.4.2 Municipal wireless networking

BT has plans to cover 12 UK cities with WiFi, Milton Keynes has its own plans for WiMAX, notably since the phones lines in Milton Keynes are aluminium based and do not have the DSL reach available on copper. Two more examples are as follows:

2.2.4.2.1 The Cloud

Founded in 2003, The Cloud is a leading WiFi network operator, providing access to a wireless local area network covering over 7,000 hotspot locations throughout the UK, Germany and Sweden. Through The Cloud's carrier-grade wholesale network, Service Providers can offer fully branded services to their customers.

The Cloud WiFi network includes high profile locations such as airports, train stations, hotels, roadside and now large area urban hotzone deployments. A growing number of operators are taking advantage of WiFi to offer access services. As a wholesale network operator, The Cloud provides a shared infrastructure capable of supporting multiple branded services simultaneously, without the brands incurring capital costs.

2.2.4.2.2 MVNOs

Mobile Virtual Network Operators have developed by using the infrastructure of mobile cellular network operators. The leading example is Virgin Mobile which is hosted by T-Mobile such that the 'vertical' brand and MVNO compete for customers but use the same access infrastructure. Differentiation is achieved through self provided systems such as Customer Care (i.e. call centres etc). In the WiFi market, The Cloud is primarily set up as a carrier's carrier with no strong self owned brand.

Mixtures of self build and virtual operation are also possible. For example, 3 has built a 3G mobile network but offers a service which includes, for coverage, 2G virtual network operation initially on O_2 but now on Orange.

Future WLL is likely to be provided through a mixture of self built and virtual network provision.

2.2.4.3 Future potential

Community networks appear to be a niche solution to a problem which may disappear if mainstream services ever arrive in the served locations. Overall, it is an early adopter solution, with quite a technical understanding required for operation and maintenance.

Municipal wireless networks appear to be addressing a large demand. It seems likely that the services will cover data well, but perhaps not voice (which must be digital, e.g. VoIP) since they are WiFi based which in its current form often does not perform all that well with VoIP.

2.3 UK Fresh Approaches - Introduction

This section covers six fresh approaches to the broadband last mile future requirements, i.e. the Broadband 2.0 requirements developed earlier in this report. The main technical challenge of Broadband 2.0 is to develop the ability to provide an effectively contention-free 10Mb/s steam for real time services to large home displays, which is a far higher performance that presently exists. The services could be HDTV, gaming or any similarly demanding new application to come over the next 10-20 years. The six approaches are

- Mesh or multi-hopping systems
- Use of UHF spectrum, e.g. TV bands
- Gb/s wireless hybrids
- Licensing mixes to foster both innovation and reliability
- Ubiquitous broadband
- Joined-up broadband

The later two approaches are alternative potential means of providing ubiquity of access. They are both ‘value added’ items for the report, in the sense that wireless broadband could enable this type of service provision, but which our baseline of ADSL+WiFi would find much harder to provide, although it would be possible.

This section is an introduction; evaluation of the approaches with respect to future broadband will be presented in section 3.2.

2.3.1 Mesh or multi-hopping at higher frequencies

Higher frequencies can be used to avoid the congested sweet spot (refer back to Figure 25) - the shorter range resulting must be handled by having many mesh nodes (users or infrastructure) to ensure coverage and increase availability (refer back to Figure 29). Nodes might be small enough to fall within the *de minimus* ruling, meaning they are exempt from planning regulations. Multiple hops will be used, but constrained to a small number to avoid latency issues. Mesh was studied extensively in our earlier Ofcom report [Methley 2005]; a paper resulting from that work, containing many of the key points, is included at Appendix H.

In summary, based on previous work, the fresh approach to be considered in this report will include the following attributes:

- multihop not mesh (multihop is tree and branch; this avoids many mesh routing issues but also eliminates route diversity)
- low hop count (avoids latency issues)
- *de minimus* form factor (avoids planning regulations)
- user nodes as last drop only (to completely control availability, roll out density)
- a mix of licensed/unlicensed devices (to jointly maximise reliability and innovation)

Section 3.2.4 evaluates mesh for wireless broadband.

2.3.2 Use of TV bands - cleared and/or white space

There are two distinct approaches:

- Cleared spectrum (section 2.3.2.1) relates to the frequencies which will be cleared by Digital Switch Over under the UK's Digital Dividend Review - this is to be a reallocation plus a reassignment (or exemption) of spectrum resource.
- White space spectrum (section 2.3.2.2) relates to that which is suitable for shared use by a secondary unlicensed service operating within the primary TV band, at frequencies where that band is deemed quiet in that location, at that time, by some means.

These are very different approaches.

Responses to Ofcom's SFR [2005] by Microsoft [2005] and to FCC's NPRM (Notice of Proposed Rule Making - a 'consultation' document) [FCC 2004] by Intel [FCC-Intel 2004a], Microsoft [FCC-Microsoft 2004] and some from the TV industry [FCC-MSTV 2004] constitute a rich summary of the technical and political points. But Ofcom's SFR and FCC's NPRM are quite different:

- Ofcom's SFR document is mainly concerned with the digital dividend with respect to TV bands, i.e. those channels which will be cleared. Ofcom make no comment on likely use, but Microsoft strongly advocate that 3 channels should be made unlicensed, citing one use as wireless Internet service provision, due to the better propagation of UHF over the 2.4GHz band. On the other hand, Ofcom's SFR document practically dismisses unlicensed, shared use of TV bands – on the grounds that, unlike the US, there is little white space to be had in the UK. Microsoft's SFR response disagrees and promotes white space TV sharing as a nearer term aim than digital dividend use.
- FCC's document is in fact two 'dockets' considered together; the use of TV bands by unlicensed sharing, plus a separate consideration of making unlicensed spectrum available under 1GHz. However, in the US, some upper UHF TV channels have already been auctioned. These have since been traded, with the result that some companies now have a group of licenses to cover a proportion US cities; their intent would appear to be wireless Internet provision[66]. Hence the responses of Microsoft and Intel both concentrate on unlicensed access to TV white space and discuss the methods of doing so. The TV industry takes a predictably conservative view of the prospect of any changes to their licensed status which may be on the horizon. The FCC NPRM document itself is primarily concerned with the white space option, methods of spectrum sensing and classification of unlicensed devices, so that different rule groups might apply.

Sections 2.3.2.1 and 2.3.2.2 examine the details of the two approaches.

2.3.2.1 Cleared TV bands (Digital Dividend)

On moving to digital TV in the UK, 14 fewer channels will be needed, Figure 44. The switch over will be phased; it is due for completion not until 2012. Small (remote) areas will be switched over from 2007, to test the program.

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[66] see 2.1.1.5 for more detail

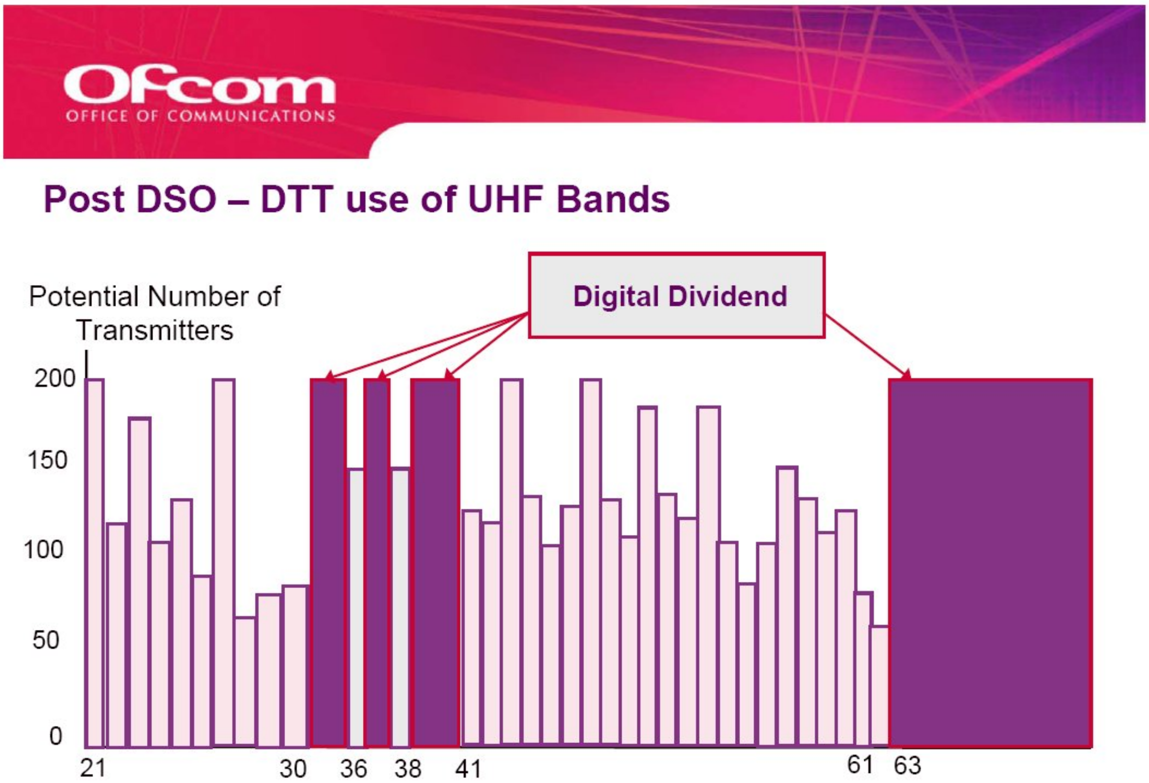

Figure 44 Digital Dividend Channels [Ofcom]

Figure 44 is not quite to scale: there are 14 channels to be cleared; these total 112MHz spectrum, since they are 8MHz channels.

Ofcom's interest in the Microsoft response to the SFR is high as it is relevant to the digital dividend review. Microsoft had made a similar but much more detailed response to an FCC NPRM concerning both unlicensed operation in the TV bands and in any 'new' spectrum below 1GHz; these issues are now being considered jointly by the FCC because of the high degree of commonality of the arguments. Microsoft's NPRM response summary includes the following:

> *"....... Microsoft believes that one critical avenue to a future of ubiquitous broadband is the availability of unlicensed spectrum below 1 GHz. The superior propagation characteristics of such lower band spectrum can make the critical difference between success and failure for those seeking to provide wireless broadband services. ......"*

Microsoft Research's Wireless and Networks group has made keynote presentations [Bahl 2004] containing some of the supporting material for the NPRM response, e.g. the general range issue for Wireless Broadband. In the UK, Microsoft see Digital Switch Over (DSO) as a specific opportunity to give broadband wireless what it says it needs for economic success - more node-to-node range. This would be by moving from the present 2.4GHz solutions to <1GHz solutions. Microsoft calculations (details unpublished) suggest this would:

- eliminate 33% of base stations
- reduce CAPEX by 50%.

This could finally make the business case for rural broadband, say Microsoft.

Microsoft's NPRM response includes range estimates for 5 different installation types (indoor/rooftop/hot spot WISP; indoor/rooftop mesh) at 3 frequencies; low VHF, high VHF and UHF. This is shown in Table 8, where distance are given in km.

	Rooftop WISP	Hotspot WISP	Zero-Install WISP	Rooftop Mesh	Indoor House-to-House Mesh
Low VHF	7.2 – 31.4	3.0 – 8.8	1.7 – 5.7	4.8 – 20.7	0.08 – 0.62
High VHF	3.9 – 20.7	1.6 – 5.3	0.9 – 3.4	2.7 – 13.2	0.06 – 0.39
UHF	1.7 – 12.4	0.9 – 3.3	0.6 – 2.3	1.3 – 7.7	0.05 – 0.35

Rooftop WISP: the WISP installs tower mounted base stations to cover the service area. The tower antennas are 30 m above ground level. The subscriber units are roof mounted, nominally 10 m above ground level. Both the tower and subscriber stations have omni-directional coverage antennas with 6-dBi gain and 1 W transmit power (6 dBW EIRP).

Hot Spot WISP: the WISP installs a roof mounted base station nominally 10 m above ground level. The base station antennas have omni-directional coverage antennas with 6-dBi gain and 1 W transmit power (6 dBW EIRP). Subscriber units are PCMCIA cards with attached short (5" long), normal mode helix antennas and 100 mW transmit power. The base station controls the subscriber units' channel selections insuring that they only operate on vacant TV channels.

Zero-Install WISP: the WISP installs roof mounted base stations nominally 10 m above ground level. The base station antennas have omni-directional coverage antennas with 6-dBi gain and 1 W transmit power (6 dBW EIRP). Subscriber units are PCMCIA cards or PCI cards with attached short (5" long), normal mode helix antennas and 100 mW transmit power. The base stations control the subscriber units' channel selections insuring that they only operate on vacant TV channels.

Rooftop Mesh: these are peer-to-peer mesh networks with subscriber units that are professionally installed and roof mounted, nominally 10 m above ground level. They have omni-directional coverage antennas with 6-dBi gain and 1 W transmit power (6 dBW EIRP).

Indoor House-to-House Mesh: these are ad hoc peer-to-peer mesh networks. Subscriber units are PCMCIA cards or PCI cards with attached short (5" long), normal mode helix antennas and 100 mW transmit power. These units transmit if they receive a control signal from a TV station or FM broadcast station identifying vacant channels within their service areas. Alternatively, they could use GPS or other location sensing methods, or cognitive radio techniques, to identify vacant channels.

Table 8 Microsoft's coverage range summary as submitted to FCC (units = km) [FCC - Microsoft]

Microsoft's choice of scenarios is interesting and indicates that they agree with the need to consider self install very seriously, plus they also clearly expect/wish for a proportion of traffic to be peer to peer, never necessarily using the core Internet.

The ranges available are better than at 2.4GHz, but in their NPRM response Microsoft do not consider the effect of interference, and hence capacity, which goes hand in hand with this. In their SFR response there is only a single comment which says 3 channels would be needed to allow for interference and cell reuse. Implicit in this comment is that Microsoft expect a single, shared TV channel (6MHz in US, 8MHz in UK) to offer a useful service. To illustrate this they provide a table, based on 802.16 (6MHz channel). Best rates are 2.5Mb/s for BPSK and 22.5Mb/s for the most complex modulation, 64QAM. This table is reproduced in Table 9.

			Guard Factor			
Modulation	Code Rate	Receiver Sensitivity	1/32	1/16	1/8	1/4
BPSK	1/2	-88 dBm	2.5 Mbps	2.4 Mbps	2.3 Mbps	2.1 Mbps
QPSK	1/2	-85 dBm	5.0 Mbps	4.9 Mbps	4.6 Mbps	4.1 Mbps
	3/4	-83 dBm	7.5 Mbps	7.3 Mbps	6.9 Mbps	6.2 Mbps
16-QAM	1/2	-78 dBm	10.0 Mbps	9.7 Mbps	9.2 Mbps	8.3 Mbps
	3/4	-76 dBm	15.0 Mbps	14.6 Mbps	13.8 Mbps	12.4 Mbps
64-QAM	2/3	-72 dBm	20.0 Mbps	19.4 Mbps	18.3 Mbps	16.5 Mbps
	3/4	-70 dBm	22.5 Mbps	21.9 Mbps	20.6 Mbps	18.6 Mbps

Table 9 Reported 802.16a 6MHz channel data rate possibilities [FCC - Microsoft]

But no relationship is made by Microsoft between these range and bit rate tables[67]. This situation is very common when describing WiMAX-like schemes, where maximum ranges and maximum bit rates are often discussed together even though in reality, they are not simultaneously achievable. More 802.16 WiMAX information is presented in sections 3.2.1 and 3.2.2 where we introduce a power budget spreadsheet for WiMAX applications operating at different frequencies. Section 3 discusses this further, especially the pivotal assumptions used in determining WiMAX power budgets and hence useful range.

The content of Intel's response is most appropriate for white space, section 2.3.2.2, although they do support the Microsoft comments.

As further context, Ofcom's commissioned research into higher power at 2.4 and 5.x GHz has concluded that there is considerable economic value to be gained [Generics 2006]. If the range improvement by moving to the DSO frequencies is similar to that gained by higher power, then an economic value of similar magnitude could be created (c.f. 1.2.5.3). Of course this assumes other things are equal, notably the bandwidth available and the costs of any interference. Whilst both working at higher power and working at UHF will both bring benefits via the required increase in range, there are differences in the costs incurred (notably interference), so the *net* benefits are different. This will be expanded upon in section 4.

In summary, if only three TV channels are to be made available[68] then, at first sight, this appears to be insufficient to service a last mile application, except perhaps in areas of low demand density, such as rural. This point is discussed in section 3.

2.3.2.2 White space in TV bands (unlicensed band sharing)

The FCC's and hence Microsoft's and Intel's interest is not just in DSO 'digital dividend' spectrum, but also in general geographically un-utilised TV spectrum, i.e. TV band sharing[69]. This is to be an unlicensed approach and the FCC do specifically cite this as being expected to help WISPs (Wireless Internet Service Providers) by extending their range. Intel have strongly voiced their support for this.

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[67] the receiver sensitivities listed suggest useful range at only the lowest bit rates

[68] 3x 8MHz = 24MHz

[69] TV bands are primarily not shared at present, with limited exceptions e.g. medical telemetry (but new applications will use the WMTS bands), remote controls and some land mobile use in certain areas

The FCC consultation document suggests 3 ways in which the avoidance of harmful interference to authorised users may be achieved:

1. Existing TV/radio stations to transmit channel availability information directly to the unlicensed device - a control signal approach
2. The unlicensed device to determine its geographical location via e.g. GPS and then look-up channel availability from a reference table - by a professional installer (GPS indoors is a known issue)
3. The unlicensed device to directly sense spectrum occupancy and hence available 'white space' (i.e. a smart or cognitive radio approach). This is known to be quite futuristic.

The FCC has invited comment on these three options.

The FCC further divides the interference issues with respect to power:

- low power (at 100mW) personal/portable devices (e.g. laptop) - control signal approach proposed
- high power (up to 1W, similar to LPTV levels) fixed/access devices (e.g. WISP) - professional installer approach proposed

Intel's response to the NPRM was produced at the same time as Microsoft's. Furthermore, Intel have followed up with further 'reply comments' [FCC- Intel 200x b] to oppose some of the points made by TV incumbents (who are clearly in opposition to the NPRM). This issue is high on Intel's agenda and they are ceaselessly pursuing the FCC on this matter.

Intel contend that:

- There is and will continue to be 'white space' in the TV bands. (But we note that US TV coverage is less dense than UK). Intel found at least 36MHz of unused spectrum practically everywhere in the US.
- Permitting personal/portable devices to share the TV band would neither be harmful to TV reception, nor to TV translators/cable head-ends, nor to wireless microphones.
- Intel support the FCC avoidance measures of control signal, sensing and professional installation.
- The change over period to digital TV may require some fluidity in the band allocations; this would not impact shared devices, nor would the introduction of shared devices hinder DSO.
- Intel suggest that the incumbent TV operators are as much winners as new shared band users.

Modelling by the 'Radio Mobile' program using Shuttle Radar Topography Mission (SRTM) data is a common step for WISP operators. It has also been used by the Intel response, the TV industry and for Figure 26 and Figure 27 in this report.

Intel show the existence of white space in the LA area in Figure 45. The normal coverage range as defined (B contour) is approximately the 100km contour shown by the labelled fine white circle. The modelled coverage is the yellow plot by Radio Mobile. It is the area within the 100km contour, but which is <u>not</u> shaded yellow which is predicted to be uncovered and therefore potential white space. Intel do not comment on the total available user density in this white space; in fact this particular example is an area in the foothills of the San Bernardino mountains, which is not prime real estate. Intel have suggested that the FCC move away from the B contour definition of TV station coverage to one based on terrain modelling, such as Radio Mobile, which is a Longley-Rice model using terrain data from the Space Shuttle missions. Clearly Intel hope this will show more of the expected white space.

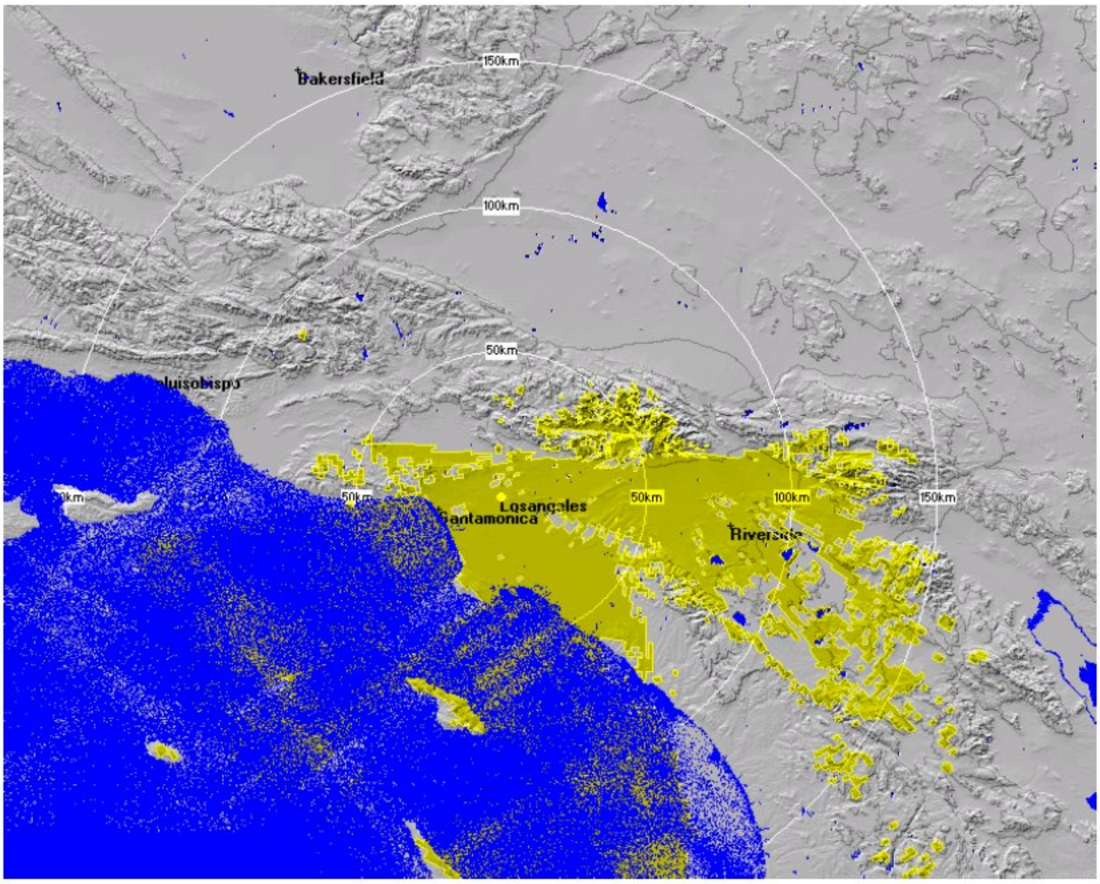

Figure A10. Channel 30 Longley-Rice Predictions

Note: This figure illustrates the existence of "white space" within the primary coverage area.

Figure 45 Intel 'Radio Mobile' plots of LA area, showing white space [FCC - Intel]

The Microsoft response was in agreement with the Intel response with respect to white space.

The Maximum Service TV (MSTV), National Association of Broadcasters joint response had a marked tone of objection to it, but very little analytical detail. They were concerned about the 'all-or-nothing' (hard failure) aspect of DTV - where enough interference will suddenly cause complete picture loss. If this happens to early adopters of DTV, will the mass market ever develop, was their point. As stated above, Intel refuted this completely.

Towards the end of writing this report, the FCC produced a time scale and plan to approve LE devices in TV bands by 2009. Also the MSTV consortium produced a much more technically based document illustrating the interference issues, and pointing out that IEEE802.22 was an already existing forum for standardising TV band shared access.

Section 3.2.3 evaluates cleared TV bands for wireless broadband, including the latest FCC and MSTV publications.

2.3.3 Hybrid fibre-wireless and Gb/s wireless

These items are discussed together because they both introduce fibre into the argument.

2.3.3.1 Hybrid Fibre Wireless

Hybrid Fibre Wireless is like HFC[70], as used by cable operators, but using radio rather than coax as the last drop. The attraction is the good back haul - and the facility to geographically place radio on suitable back haul, whereas ADSL is forced to use the existing geographic position of the exchange. One example could be WiMAX in a green field approach.

GPONs[71] are being pushed by the fibre industry to deal with the expected increase in back haul requirements for integrated multimedia services, i.e. gigabit rates are predicted to be needed. This will mean new line equipment and maybe new fibre. If a new fibre is needed anyway, then why not choose the best site for BS coverage at the same time, rather than a existing site which may have been picked on install convenience alone?

This is a deceptively simple, powerful approach, but one which includes fibre; so bandwidth upgrades need never be an issue, relative to radio. It is only one step from fibre to the home (FTTH, section 1.1.1), which itself, if broadband access requirements are expected to push up to 100Mb/s, is probably the only way to deliver this with the requisite latency, jitter, etc.

FTTP+VDSL is what is installed also in Japan/Korea - FTTC+Gb/s wireless+mesh/UHF is similar concept, as far as bandwidth-distance arguments go.

The likely issue with hybrid fibre wireless is that the fibre portion is likely to have far higher capability that the wireless portion.

2.3.3.2 Gb/s wireless

Gb/s wireless is a full-speed fibre replacement technology applicable to solving the last mile feeder gap problem (section 1.2.6). There has been a lot of interest in Gb/s radio links, which operate typically at 60GHz, or at 70/80GHz. They are intended as fibre replacements, or microwave back haul upgrades - where microwave back haul means the current 10/28/38GHz offerings around 155Mb/s max bit rate. Gb/s fibre offers at least 1Gb/s and has been shown up to 2.5Gb/s SONET speeds as well as GigE (Gigabit Ethernet).

For the interests of this report Gb/s wireless is a key last mile feeder technology for the following reasons.

1. Gb/s wireless can cost less than pulling new fibre for the same bit rate, due primarily to the absence of trenching costs (see section 4.4), which can be very high in urban areas.
2. Assuming that the need for increased back haul speeds to service broadband access is accepted, then fibre is the technically obvious way of providing it. However, fibre to the home is not presently attractive in Europe, it seems, due to the prevailing regulatory regime[72], although fibre does come to the exchange or sometimes the neighbourhood - so the b/w gap is in the last mile feeder. Gb/s fibre can fill this.

A Gb/s wireless example is GigaBeam, where a duplex link costs $40k, plus $1-3k installation,

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[70] Hybrid fibre coax, used by the cable TV industry

[71] Gigabit passive optical networks

[72] unbundling requirements may be deterring innovation by incumbents; one expectation is that since the US has forbearance [FCC 2004b] on unbundling requirements, the UK may follow.

plus annual roof rights of say $3k. The five 9's[73] distance is up to 2 miles, shorter than low frequency (and bit rate) microwave. Four 9's is double this. GigaBeam is 70/80GHz, which has lower loss than 60GHz and lower rain effects. It suffers no fog effect, unlike FSO.

Lastmile Communications Ltd is a company looking at high speed communications to lamp posts and the like via 60GHz technology from Qinetiq, and onwards to the consumer via WiFi, but with large local storage of information. The focus is the node hardware and software, not the 60GHz links. The original idea was for roadside to vehicle communications, using content stored locally at the roadside (up to 4GB) by the 'media caching node'; this reduces the need for real time back haul. This has developed into communications for anyone, not only vehicles.

For this report, the use of 60GHz is of interest, as is the idea that big local storage will reduce real-time bandwidth demands.

Section 3.2.5 evaluates fibre-wireless and Gb/s wireless for the future last mile.

2.3.4 Mix of Licensed, Licence Exempt and Segregated Bands

Ofcom wish to move from a command and control approach to one which is technology and application neutral[74]. This is equivalent to letting the market decide, hence ideally to reach the point of maximum utility. Of course, this is the aim for when the market is in future equilibrium, but there must be a transition period, which could be long or short, and smooth or volatile. This report concentrates on the future, rather than the transition.

Technology and licensing must be in step, regardless of whether licenses are technology neutral, if schemes are to succeed. For example, polite protocols for a band must be technically realisable and standardised in some way.

2.3.4.1 LE - licence exempt

Ofcom has a duty to consider licence exemption first. While a licence may not be required, there will be some constraints on band usage, such as maximum transmit powers etc. However, users are expected to suffer any interference caused to them (although they are not supposed to act in a way as to cause interference). The interference may be from any source in the band, without known characteristics. It is probable that polite protocols ('band etiquette' in the US) will be required.

2.3.4.2 Segregated Bands - LE restricted to specific applications

Ofcom had defined Licence exempt Application specific bands (LEA bands) as Licence Exempt bands restricted to specific applications. We would comment that 'application' may not be the best form of restriction, it maybe better to segregate on power or 'industry' (e.g. the RFID industry, who have lobbied for their own unlicensed band). Hence we will use the term 'segregated LE bands'.

This is a move towards limiting interference, in that while any technology may be employed, at least the application will be known. Hence the example from the 2.4 GHz ISM band, of microwave ovens interfering with e.g. Bluetooth or WiFi, will not be possible. However, 802.11 plus 802.16 would be allowable under an LEA designated for broadband access applications, but they wouldn't work together. Polite protocols would need to be mandated and 802.16 would have to change markedly. The problem is that 802.16's good QoS depends on its impoliteness.

Over-provisioning is the traditional way to introduce QoS potential into a shared medium service

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[73] five 9's = 99.999%, four 9's = 99.99%, etc

[74] SFR

(like shared Ethernet). This approach could also be used in segregated LE spectrum to increase the effectiveness of 'best effort' services, although it flies in the face of technical spectrum efficiency.

2.3.4.3 L - licensed

Licensed spectrum is very attractive to operators in terms of interference guarantees, which lead to QoS guarantees, but it comes at a cost - which has recently been very variable and unpredictable from the auction process. With this type of licensing comes inflexibility, but this is gradually being replaced by non-exclusive licensees, plus codes of practice, which are intended to substitute interference guarantees.

2.3.4.4 LE codes of practice - blurring L/LE boundaries

Traditionally, operators have had licences which give them exclusive usage of blocks of frequencies over defined geographic areas, including nation-wide. This means that the quality of service that can be offered to their customers is completely under their own control such that 'carrier-grade' quality of service can be offered. The only complications to this arise from international co-channel interference which is controlled through agreements on possible levels and deployment limitations, notified local interference (often for defence use) and interference from adjacent out of band channels which is predictable and may be controllable through agreement. Any other interference should not be present and the regulator should have the source removed.

LE spectrum cannot provide the same level of certainty that it will be available. However much of this spectrum is only made available for low power usage so that the potential for interference is low. In addition if someone wishes to use LE spectrum indoors, then the building will give a degree of screening from neighbouring users, although this can be highly variable.

A further licensing variant has occurred with the DECT/GSM 1800 guard band in the UK[75]. Ofcom held an auction in April 2006 for multiple licenses in this band for simultaneous use with the winners agreeing a method of working together. There were to be between 7 and 12 licenses depending on the value of the cumulative bids. The outcome[76] is summarised in Table 10.

UK - DECT Guard Band winners

Mix of large and small firms

Orange has GSM band adjacent to this allocation

Some of these have specific plans for new services

All have to work together to allocate channels and avoid interference

A NEW MODEL FOR SPECTRUM SHARING

1 British Telecommunications PLC £275,112
2 Cable & Wireless UK (England) £51,002
3 COLT Mobile Telecommunications Ltd £1,513,218
4 Cyberpress Ltd £151,999
5 FMS Solutions Ltd £113,000
6 Mapesbury Communications Ltd £76,660
7 O2 (UK) Ltd £209,888
8 Opal Telecom Ltd £155,555
9 PLDT (UK) Ltd £88,889
10 Shyam Telecom UK Ltd £101,011
11 Spring Mobil AB £50,110
12 Teleware PLC £1,001,880

Orange Personal Communications Ltd £50,000 Zynetix Ltd £50,000 were not awarded licences because they were outbid

Table 10 UK DECT guard band winners

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75 i.e. 1781.7-1785 MHz paired with 1876.7-1880 MHz

76 http://www.ofcom.org.uk/radiocomms/spectrumawards/completedawards/award_1781/

Although there are licensees (L), the concurrent assignment of spectrum means that there are similarities with LE assignment in that exclusive access to the spectrum cannot be guaranteed. To handle this problem Ofcom require the operators to establish a Code of Practice as a means of ensuring some degree of 'fairness' of access.

Ofcom's award document [Ofcom 2005] consulted on the proposed grant in 2005 – 06 of wireless telegraphy licences to use this spectrum and the associated auction process. In particular licensees are under an obligation to collaborate. Other aspects are included in the awards text extract in Appendix E.

Ahead of the auction, some potential bidders started to draft a code of practice by which all licence holders will operate in order to ensure efficient and co-operative use of the Spectrum through a body known as Mobile200[77].

Various flow charts were produced to consider how possible or actual contention could be identified and resolved. It was noted that similar procedures had already been voluntarily adopted by operators of WiFi hotspots in the 2.4GHz band.

In general it was considered

- best to adopt detailed joint planning etc as a last resort only
- to not allow first mover advantage to dominate but neither to hold spectrum back for all operators
- that there could be a *de minimus* power level for non-notifiable use
- that higher power use might be possible in certain locations

It was also recognised that although the licences were technology neutral it was simpler to solve co-ordination issues for one technology standard and a practical code should only address the systems actually being deployed.

Following the auction, Mobile 200 has continued to meet to develop the code. The large variation in the bids made for the spectrum indicates that there are very different business plans for the operators. The mixture of the well financed operators who have ambitious plans with the small operations creates difficulties in that there are very different views on the level of effort and costs involved in setting up the Code of Practice and its subsequent running costs. It is not yet certain that something which is acceptable to the plans of all these diverse operators is achievable.

It is proposed that next year there will be an auction for the L-Band spectrum from 1452-1479.5 MHz and Ofcom is again proposing that there be an industry code of practice on engineering co-ordination even though in this case the licences are NOT for concurrent use of spectrum. Hence the code is only concerned with interference between adjacent blocks within the band. Ofcom's view of the requirement is:

> 'Ofcom would expect that at least the following principles should be considered in the code
>
> - Efficient frequency use of the spectrum
> - Possible conditions on limiting transmission powers to that just necessary to effectively provide service
> - Selection of sites in a manner that will minimise the probability of mutual interference
> - Identifying the type of information that needs to be communicated between licensees

[77] www.mobile200.org.

and the arrangements for its exchange

Ofcom would retain the power to impose an engineering co-ordination procedure if necessary but in general would not have a role in resolving individual engineering co-ordination disputes'

The move to operator determined codes of practice has clear merits but there are concerns that it may be harder to close down transmissions which breach the codes as sometimes these will be outside the powers of Ofcom.

2.3.4.5 Commercial LE usage

Can an operator use LE spectrum for a commercial service? This may require some new thinking for operators who have a deep culture of using licensed spectrum.

It depends on the type of service and whether instantaneous availability must be guaranteed or not. If there is to be considerable real time traffic or high priority traffic then licensed spectrum (or very underused LE spectrum) is necessary. However if set-up delays can be tolerated then LE might be suitable.

For a commercial service it is possible to specify the peak and mean capacities required (with geographic variations also factored in). Certainty of availability would require dedicated licensed spectrum but knowledge of the likely loading of LE bands might make a mixed L + LE or LE only commercial service a reasonable proposition.

For example, referring back to Figure 30 on page 49, licensed spectrum could be used up to access point (NTE), but LE could be used beyond, at the customer end. The potential advantage is achieving both reliability/availability in the 'back haul' and enabling innovation in the last mile.

2.3.4.6 Liberalisation of Mobile

Spectrum Trading and Liberalisation have been introduced into several bands by Ofcom. The extension of trading and liberalisation to bands designated for mobile services is planned by 2007. These cover:

- The removal of restrictions from licences that presently prevent the use of spectrum for the provision of mobile services, including 3G services and mobile services other than 3G
- The potential extension of spectrum trading and liberalisation to the bands currently licensed for 2G and 3G mobile services.

For example the licence of UK Broadband Ltd is a Public Fixed Wireless Access Operator Licence and mobile use was specifically excluded from their spectrum award.

Section 3.2.7 evaluates licence approaches for wireless broadband.

2.3.5 Personalised ubiquitous broadband - a nationally tetherless last mile

Here the assumption is that one could design a single system with the necessary communications layers to allow 'portability' for anyone to move around the wireless local loop, nationally. An example is the laptop worker going to a friends house to work 'on-the-pause'. However consumer 'pull' for a tetherless last mile with a national scope will be dependent upon the availability of both:

- suitable terminal devices (handsets, laptops, home gateways etc)

- suitable applications making use of those devices

This is a fresh approach which builds above the approaches already described. It is given in order that the market may be informed of the full package enabled by wireless broadband and is a potential market differentiator. It is driven by consumers' desire/need for tetherless access, as summarised in Ofcom's market report [Ofcom 2006]. The basic concept is similar to, but considerably beyond, the ADSL+WiFi tetherlessness available today; a single nationally tetherless last mile would allow portability between home locations, with a seamless service presently unavailable from ADSL+WiFi.

The use of personalised mobile communication devices is expected to continue its trend to grow. For example, smartphone and PDA-phone sales continue to show large growth; 330%[78] over the last 3 years in some geographical areas. Worldwide there is steady growth of around 55%[79].

However, anecdotal evidence (there is little real market analysis[80]) suggests that there is evidence of a decline in sales and development of mobile *applications*, even though *handset* sales still seem buoyant. This is examined further in section 3.2.8.

But, before this, we next consider another, more holistic approach, which may be more readily applicable.

2.3.6 Joined-up broadband - Coalition Peering Domains

For ubiquitous connectivity, there is another factor, arguably representing a more practical vision than the single system approach of section 2.3.5. In the real world wireless last mile, truly ubiquitous access may only be achievable, in practical situations, if the last mile can seamlessly support *multiple* last-mile technologies. This would allow harnessing of the existing deployed base of technologies to quickly build the tetherless last mile. This could include the many flavours of the IEEE 802.11 family, the 802.16 family and, in the next few years, possibly IEEE 802.20, as well as existing wired and wireless technologies such as Bluetooth, ADSL, etc.

Once again, this is a fresh approach which builds on the approaches already described. It is given in order that the market may be informed of the full package enabled by wireless broadband. This example is not a differentiator for broadband access, but it does show that wireless broadband can participate in a flexible approach, especially to achieve coverage in difficult areas, which is one of Ofcom's wider objectives.

To allow the edge-system to form last mile networks easily, dynamically and economically, there needs to be some way of exploiting and harnessing the installed base of technology. This is especially true for mobile/roaming last-mile users (truly mobile applications that are used whilst mobile) rather than those simply wishing to exploit a tetherless last mile to dispense with wires but not wishing to be mobile (e.g. domestic bandwidth sharing of a single ADSL line). Furthermore, we are already seeing the use of multiple subscriber connections being aggregated on an ad hoc basis by the end-users themselves for bandwidth sharing by aggregating the use of multiple DSL lines from different subscribers[81]. (Of course, some providers offer reverse multiplexing capability

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[78] http://news.zdnet.co.uk/hardware/mobile/0,39020360,39115515,00.htm

[79] http://www.allaboutsymbian.com/news/item/4116_Latest_worldwide_smartphone_fi.php

[80] http://mobileopportunity.blogspot.com/2006/06/why-are-mobile-application-sales.html

[81] CUWiN - http://www.cuwireless.net/ , FON - http://en.fon.com/

to individual users to allow aggregation or bonding of multiple DSL lines at the *same* location, such as the service offered by AAISP[82], but this is a different function and is not discussed in this report.)

Current business models for the service provision of Internet connectivity focus on individual users or parties. In the local-area, the use of wireless technologies promotes easy interconnectivity and resource sharing between local users, leading to the appearance of community networks — ad hoc networks residing at the edge of, but still connected to, the Internet. These networks may be multi-hop at the edge and typically use localised naming and addressing with network address translation (NAT) functions and application proxies to give global connectivity. Currently, such activities are seen as both disruptive and difficult to sustain, breaking traditional network-service business models and causing a discontinuity of the network architecture. However, there is new architectural entity, the coalition domain that allows structure and control to be added to such ad hoc edge networks. By examining a number of tensions that arise between parties with the adoption of such an approach, it can be that it is feasible to include such network usage within the existing network architecture. This brings new opportunities for an operator.

There are numerous advantages to offering such connectivity sharing:

- There is increased overall upstream (back haul) and downstream capacity, albeit it is shared between more users.
- For data applications (email, WWW, file-transfer and file-sharing, interactive applications such as ICQ & IM), the users see the well-known statistical multiplexing gain without having to pay for improved service.
- Potentially, a single ISP offering such sharing for their customers with support at the ISP could gain advantage by encouraging neighbours all to buy a service from that single ISP.
- Where users can use multiple ISPs, they gain increased robustness through diversity in case of ISP failures.
- Multiple technologies can be incorporated.

However, there are numerous challenges, which will be discussed in section 3.2.9, for example as follows:

- To enable a truly transparent and ubiquitous joined up capability requires some existing network-level functions to be greatly enhanced and/or modified. The functions that would need to be re-examined in order to enable this capability include addressing, routing, discovery and management protocols. Additionally, there may need to be some changes to transport and application protocols in order to fully exploit the available connectivity.
- Currently, the authors are not aware of any standards-based work that is looking to address this issue – using the mix of deployed heterogeneous access technologies to form a tetherless last mile dynamically. However, there are numerous experimental deployments in community area networks, based on ad hoc solutions. There would appear to be a possible commercial provider of a functionally similar service on the horizon in the UK, based on IP but using proprietary technology extensions (ShardedBand [83]), and our consortium does have a member undertaking research into future architectures to enable such network operation in a seamless manner based on standard IP protocols.

[82] http://aaisp.net.uk/multiline.html

[83] http://www.sharedband.com/

2.3.7 Summary of fresh approaches, motivations and issues

The fresh approaches and their motivations are summarised in Table 11:

Fresh Approach	Motivation
Mesh networking at higher frequencies	Urban coverage despite clutter via the use of multi-hopping in less precious spectrum, which also achieves small cells with potentially high capacity
Use of cleared or vacated TV bands (Digital Dividend)	Range improvements at frequencies under 1GHz to reduce system CapEx
Use of white space in TV bands (unlicensed band sharing)	Range improvements at frequencies under 1GHz to reduce system CapEx
Fibre and Gb/s radio hybrid schemes	Providing sufficient back haul and/or last mile feeder to cope with the demand from the future service mix, including removing the contention bottleneck. This is needed by all broadband last mile solutions.
Personalised ubiquitous broadband - a nationally tetherless last mile	Satisfying the demand for tetherless-ness from users via a single national solution
Joined-up broadband - Coalition Peering Domains	Improving broadband quality and reducing outage by diversifying across multiple access paths and technologies, including wireless

Table 11 Fresh approaches and motivations

The next chapter evaluates these approaches against the future last mile requirements.

3 Technology Evaluation

3.1 'Where We Are' versus 'Where We Want to Be'

Figure 46 reminds us once again of the future requirements for broadband over the last mile

- Where we are now is Broadband 1.0, the present day service, typified by ADSL, which is unsuited to mass deployment of future home-based, large-display services, like HDTV-on-demand, gaming etc
- Where we want to be is Broadband 2.0 which provides for the future requirements of at least 10Mb/s, effectively uncontended[84], streaming over the last mile – far in excess of what can be done now

How to get there from here is examined in this section, from the point of view of technology.

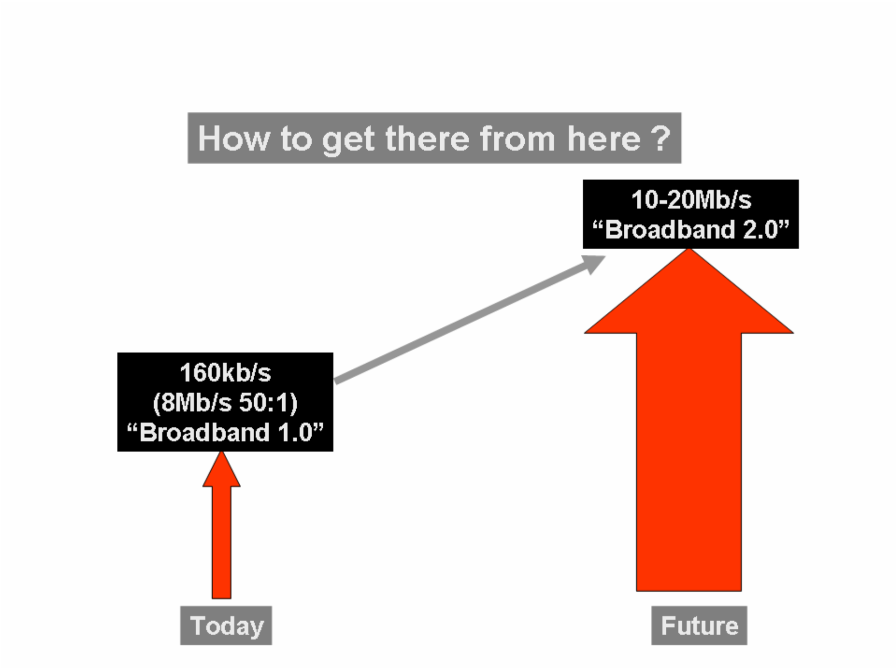

Figure 46 Broadband 2.0 (repeated figure)

3.2 UK Fresh approaches - detailed inspection

This section begins with the basics of planning for wireless coverage, capacity and quality of service. This is key to understanding how wireless might or might not be able to address the requirements of Broadband 2.0. In fact, consideration of the basics of wireless coverage leads to a very definite conclusion regarding the limitations of wireless; we show wireless is insufficient for the last drop of the future last mile – but does have a place in the last mile feeder and in rural areas where even Broadband 1.0 is better than no broadband at all. Wireless also has a continuing place

[84] '10Mb/s effectively uncontended' could be supplied as 100Mb/s at 10:1 contention, for example

in home networking, although home networking is beyond the scope of this study.

Following this the various fresh approaches to the problem are discussed in a logical order

- UHF/ TV bands - cleared
- Mesh and multihop
- Gb/s wireless and fibre
- UHF/TV bands – white space
- Licence mix
- Ubiquitous broadband
- Joined-up broadband

3.2.1 Overview - coverage and capacity planning

Network operators have to plan wireless services based on an effective balance between the provision of cost effective coverage, adequate capacity for traffic and service quality as required by subscribers, see Figure 47. Major wireless carriers, today principally providing mobile services such as WCDMA and GSM, devote considerable resources to the planning and optimisation of the wireless access part of their network In the UK a GSM wireless operator may have upwards of 10,000 radio base stations operational.

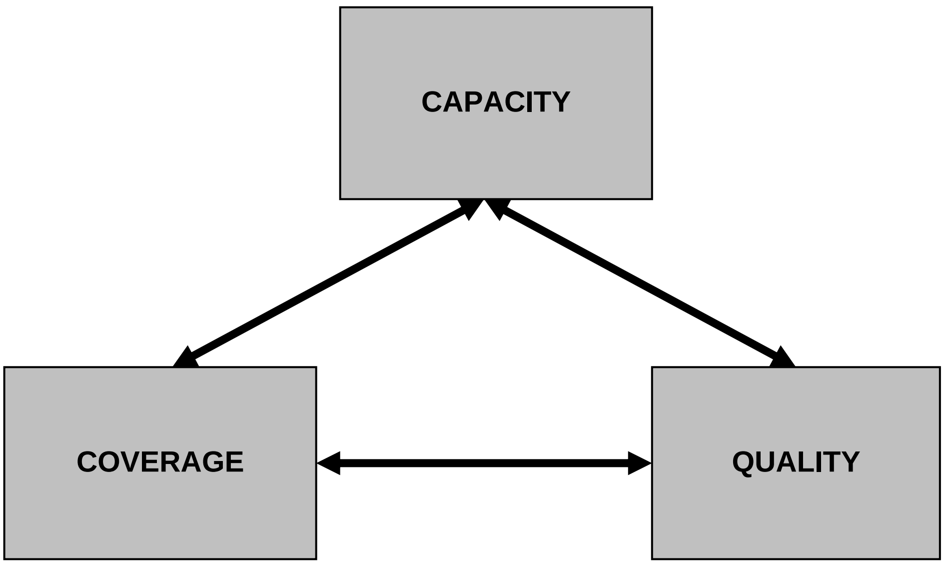

Figure 47 Finding a balance: coverage, capacity and quality of service

The geographic distribution of traffic is far from uniform, with much less dense traffic ($Mb/s.km^{-2}$) in rural areas than in urban centres or hotspots such as airports. The network planner can adapt the infrastructure to this demand to a certain extent by deploying bigger cells in rural areas and smaller cells in urban areas, even using microcells and similar techniques. Some GSM operators have the advantage of being able to use both 900MHz and 1800MHz spectrum in high traffic areas and 900MHz only in more rural areas, bigger cells being possible at 900MHz. However most mobile wireless systems are coverage limited in rural areas and capacity limited in urban areas. What this means is that in rural areas equipment and spectrum is not fully utilised since sites must be added simply to improve coverage. On the other hand in high traffic areas spectrum and equipment is fully utilised and additional sites are added to relieve congestion.

3.2.1.1 Challenges facing Fixed Wireless Operators

Fixed Wireless operators providing a broadband service in competition with ADSL face a number of challenges, particularly if they are building a "green-field" network from scratch.

Where customer radio terminals are located outdoor at height then the networks can be operated as capacity limited networks[85] with a relatively small number of transmission sites. However most networks that have targeted primarily residential and small business customers have opted to exploit the benefits of "self-install" with user terminals being integrated indoor units. Examples of operational networks of this type include UK Broadband and Unwired Australia. Coverage in this situation is much more limited because of reduced user equipment antenna performance compared to external antennas and the additional attenuation introduced by the fabric of the buildings in which they are operated, see section 1.2.5.1.

Users wishing to sign up for service to these type of networks must first provide their postal code - and the network planners must have a very high degree of confidence that the user will get service at that location, before service is offered.

This degree of confidence is not easy to obtain, particularly at the higher frequencies such as 3500MHz being used. Network operators can address this by developing radio propagation simulations using very accurate terrain, building and vegetation data, sometimes with sub 1metre accuracy, and by taking extensive field measurements as well as utilising performance data from subscribers already connected to the service.

To further complicate the planner's task, it seems to be a facet of human nature that our expectations of telecommunication facilities are highest indoors; we may tolerate a poor cell phone signal outside, but expect home/office communications to be very much higher quality. Of course if the fixed indoor service if provided wirelessly, then the challenge is a larger one.

Moreover, the position of the users antenna in the indoor application is always going to be defined by the position of the user's computer. This may well not be ideal from an RF communications point of view.

3.2.1.2 Outline Planning Process

In order to make decisions about when and whether to deploy more networks, generic radio planning models are used to support business plans. Typically these models may include:

- A concept of desired coverage area often subdivided by land use (urban, suburban, etc)
- A concept of forecast subscriber numbers and market segmentation often again distributed by land use type
- Data service parameters and VOIP parameters
- Spectrum availability and any constraints

[85] When engineered correctly by the operator, capacity limited networks ensure the most attractive balance of costs and revenue. In other words the capacity under-provision is small relative to the demand and the number of base stations is then as small as practical.

- Expected radio propagation characteristics
- Expected equipment performance, link budget, capacity
- Site portfolio, deployment costs
- Forecast revenue, CapEx and OpEx and the cost of subscriber acquisition
- Some kind of sensitivity analysis

3.2.2 A step-by-step coverage and capacity planning example

In this section, we wish to explore the potential impact on service ranges and capacity by operating last mile wireless systems at different frequency allocations, such as the TV bands. This is most usefully shown by example and we have done this based on generalised expected equipment performance parameters for a WiMAX SOFDMA system plus reported propagation characteristics in different frequency bands.

Equipment performance in terms of coverage range has been traditionally expressed in a link budget giving the maximum allowable path loss for down link and up link transmissions. One possible generic link budget for WiMAX is presented in Table 12. The system relies on appreciable BTS beam forming gain (an optional part of the standard) in order to achieve a suitable maximum allowable path loss of around 152dB between the transmit terminal and the receive terminal. This data is used for illustration only and is not meant to represent any specific implementation. It is approximate since it assumes that only propagation parameters will depend on frequency. These parameters, such building losses and link margins, may then be included later for several different frequencies.

This is of course specified for the lowest capacity transmission format QPSK with coding rate 1/2 (SNR ~4dB).

Receiver	**BTS**	**MS**
Rx input sensitivity	-95 dBm	-89 dBm
Interference Degradation Margin	2.0 dB	2.0 dB
Cables and Connector Losses	3.0 dB	0.0 dB
Rx Antenna Gain	18.0 dB	3.0 dB
Diversity Gain	5.0 dB	0.0 dB
Receiver Beam forming Gain	9.0 dB	0.0 dB
Isotropic power for 50% cell edge coverage	-122 dBm	-90 dBm
Transmitter	**MS**	**BTS**
Tx output peak power available for traffic	0.5 W	20.0 W
	27 dBm	43 dBm
combiner loss	0.0 dB	1.0 dB
Cables and Connector Losses	0.0 dB	3.0 dB
TX Antenna Gain	3.0 dB	18.0 dB
Transmit Beam forming Gain	0.0 dB	9.0 dB
Peak EIRP	30 dBm	66 dBm
	1.0 W	3990.5 W
Maximum Allowable Path Loss		
Isotropic path loss for 50% cell edge coverage	152.0 dB	156.0 dB
Zero Building Penetration Loss	0.0 dB	0.0 dB

Zero Additional Margin	0.0 dB	0.0 dB
Isotropic Path Loss 50% Cell Edge balanced Link	152.0 dB	152.0 dB

Table 12 A WiMAX link budget example (with margins set to zero)

Given a maximum allowable path loss of 152dB, the likely cell radius can be estimated under different conditions. When the user equipment is close to the ground with generally non-line of sight conditions then a normal first approach would be to use an empirical model derived from measurements. Note that propagation loss, building loss and link margins will be added later.

3.2.2.1 Empirical Propagation Models

Empirical models developed for mobile applications such as COST231 Hata are well known. Erceg's model is cited by IEEE 802.16 and is also derived in part from mobile measurements at 1900MHz in the USA.

In the UK, Plextek and LCC carried out a series of twenty propagation trials at 3500MHz in densely populated suburban and urban areas of London, the West Midlands and the North West in 2004, using a number of existing cellular rooftop sites that could be feasibly used for wireless broadband applications. The results were reported in Walden and Rowsell [2005]. A curve fit model derived from the aggregate of all the data is presented below.

Model Definition	
	PL = A + 10 γ.log10 (d/d0) for d > d0,
where	A = 80.6 (at a d0 of 73m)
and	γ=4.3
and	d0 =73m

Table 13 Rowsell and Walden Model

In this type of deployment scenario we would expect an outdoor range with 50% area availability of around 3.5km

We found this was comparable to results obtained using Erceg's 'B' Model, Table 14, with 25-30m transmitter heights, being largely representative of the heights we used.

Model Definition			
	PL = A + 10 γ.log10 (d/d0) for d > d0,		
where	A = 20 log10(4 π d0 / λ)		
and	γ=(a – b hb + c / hb)	Hb from 10m to 80m	a,b,c are terrain parameters
and	d0 =100m		
with a frequency correction term			
	PLf = 6 log (f / 2000)		
and a mobile height correction term			
	Δ PLh = - 10.8 log (h / 2);	Categories A and B	
	Δ PLh = - 20 log (h / 2);	Categories C	

Table 14 Erceg Model

These ranges are very dependent on the environment. The COST 231 Hata Urban model is often used with a range of environmental correction factors to adjust to different environments. The

COST231 Urban model predicts a smaller range than we measured on our test sites, Table 15. In order to align them a correction factor of about 11dB is required, which was not unexpected based on previous experience of fitting model predictions to real-world measurements.

Model Parameters			
1	frequency	Frequency	MHz
2	d	distance	metres
6	Mobile height	Hm	
7	Base Height	Hb	
	Cm	0 or 3	

Model Definition	
	Lb = 46.3 + 33.9log f - 13.82log(hBase) - a(hMobile)+(44.9- 6.55log(hBase)log(d) +Cm
where	
	a(hMobile) = (1.1× log f- 0.7)hMobile- (1.56 × log f- 0.8) (mobile antenna height factor)
	Cm =
	0 dB for medium sized city and suburban centres with medium tree density
	3 dB for metropolitan centres

Table 15 COST231 Hata Model

3.2.2.2 Effect of Frequency - propagation loss

COST 231 Hata has been widely used as a model at different frequencies so it is instructive to vary the frequency term and see what changes in range are suggested by the model. Table 16, Table 17, Table 18 show predicted ranges of 3.5km, 4.8km and 16.0km at 3.5GHz, 2.5GHz and 700MHz respectively. Cm in these cases is the actual correction factor needed to tie model to measurements, as already described.

Model Example					
Parameter Input					
f	3500	MHz	Range	3.49	km
PL	152	dB	a(hMobile)	1.67	dB
Hm	2	m			
Hb	30				
Cm	-11.5				

Table 16 Range at 3500MHz = 3.49 km

Model Example					
Parameter Input					
f	2500	MHz	Range	4.80	km
PL	152	dB	a(hMobile)	1.57	dB
Hm	2	m			
Hb	30				
Cm	-11.5				

Table 17 Range at 2500MHz = 4.80 km

Model Example					
Parameter Input					
f	700	MHz	Range	15.97	km
PL	152	dB	a(hMobile)	1.22	dB
Hm	2	m			
Hb	30				
Cm	-11.5				

Table 18 Range at 700MHz = 15.97 km

It should be noted that there are other frequency dependent effects in reality: Achievable antenna gains will likely be reduced with decreasing frequency, receiver noise figures will fall and hence receiver sensitivities will rise. It may also be expected that building penetration losses will fall somewhat, although this loss is fairly flat over the frequencies discussed.

3.2.2.3 Effect of frequency - building losses and fade margin

In practice the network operator will choose to operate with reduced cell sizes[86] to improve the service to fixed or tetherless subscribers, particularly indoors, because of signal variability due to

- shadowing (area availability) and
- building penetration losses

Building penetration losses have been measured at different frequencies, for example Rudd [2003]. Typically a prudent operator may allow a building loss of between 12 and 20dB for residential property in the UK at 3.5GHz, somewhat less at lower frequencies. These figures are for a 30m outdoor BS and an indoor, handheld MS on a ground floor.

Taking these effects into account the following link budgets and hence "ball park" cell ranges are suggested for operation at 3.5GHz and 700MHz in Table 19 and Table 20.

[86] relative to those calculated so far

WiMAX Fixed Indoor Service 10MHz b/w **3500** MHz

	Dense Urban		Urban		Suburban		Rural			
Receiver	**BTS**	**MS**	**BTS**	**MS**	**BTS**	**MS**	**BTS**	**MS**		Refer
Rx input sensitivity	-95 dBm	-89 dBm	-95 dBm	-89 dBm	-95 dBm	-89 dBm	-95 dBm	-89 dBm	A	
Interference Degradation Margin	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB	B	
Cables and Connector Losses	3.0 dB	0.0 dB	3.0 dB	0.0 dB	3.0 dB	0.0 dB	3.0 dB	0.0 dB	C	
Rx Antenna Gain	18.0 dB	3.0 dB	18.0 dB	3.0 dB	18.0 dB	3.0 dB	18.0 dB	3.0 dB	D	
Diversity Gain	5.0 dB	0.0 dB	5.0 dB	0.0 dB	5.0 dB	0.0 dB	5.0 dB	0.0 dB	E	
Receiver Beamforming Gain	9.0 dB	0.0 dB	9.0 dB	0.0 dB	9.0 dB	0.0 dB	9.0 dB	0.0 dB	F	
Isotropic power for 50% cell edge coverage	-122 dBm	-90 dBm	-122 dBm	-90 dBm	-122 dBm	-90 dBm	-122 dBm	-90 dBm	G	G=A +B +C -D -E -F
Transmitter	**MS**	**BTS**	**MS**	**BTS**	**MS**	**BTS**	**MS**	**BTS**		
Tx output peak power available for traffic	0.5 W	20.0 W	0.5 W	20.0 W	0.5 W	20.0 W	0.5 W	20.0 W		
	27 dBm	43 dBm	27 dBm	43 dBm	27 dBm	43 dBm	27 dBm	43 dBm	J	
combiner loss	0.0 dB	1.0 dB	0.0 dB	1.0 dB	0.0 dB	1.0 dB	0.0 dB	1.0 dB	K	
Cables and Connector Losses	0.0 dB	3.0 dB	0.0 dB	3.0 dB	0.0 dB	3.0 dB	0.0 dB	3.0 dB	L	
TX Antenna Gain	3.0 dB	18.0 dB	3.0 dB	18.0 dB	3.0 dB	18.0 dB	3.0 dB	18.0 dB	M	
Transmit Beamforming Gain	0.0 dB	9.0 dB	0.0 dB	9.0 dB	0.0 dB	9.0 dB	0.0 dB	9.0 dB	N	
Peak EIRP	30 dBm	66 dBm	30 dBm	66 dBm	30 dBm	66 dBm	30 dBm	66 dBm	O	O= J-K-L+M+N
	1.0 W	3990.5 W	1.0 W	3990.5 W	1.0 W	3990.5 W	1.0 W	3990.5 W		
Maximum Allowable Path Loss										
Isotropic path loss for 50% cell edge covergae	152.0 dB	156.0 dB	152.0 dB	156.0 dB	152.0 dB	156.0 dB	152.0 dB	156.0 dB	P	
Building Penetration Loss	18.0 dB	18.0 dB	14.0 dB	14.0 dB	12.0 dB	12.0 dB	10.0 dB	10.0 dB	R	
Additional Margin	0.0 dB	0.0 dB	0.0 dB	0.0 dB	0.0 dB	0.0 dB	0.0 dB	0.0 dB	S	
Isotropic Path Loss 50% Cell Edge balanced Link	134.0 dB	134.0 dB	138.0 dB	138.0 dB	140.0 dB	140.0 dB	142.0 dB	142.0 dB	T	
Area Reliability Calculation										
Path Loss exponent with distance	3.5		3.5		3.5		3.5			
Standard Deviation of Log Normal Fading	8		8		8		8			
Margin for Log Normal Shadowing(Outdoor)	5.9 dB		5.9 dB		5.9 dB		5.9 dB			Input Margin required
CN (linear)	3.8905		3.8905		3.8905		3.8905			
sd(0)	1.8421		1.8421		1.8421		1.8421			
X0	0.5215		0.5215		0.5215		0.5215			
Y0	0.7443		0.7443		0.7443		0.7443			
At Cell Edge	23.0%		23.0%		23.0%		23.0%			
Area Correction	13.9%		13.9%		13.9%		13.9%			
Outage Across the Entire Cell Across Entire Cell	9.2%		9.2%		9.2%		9.2%			
Area Probability of Coverage	**90.8%**		**90.8%**		**90.8%**		**90.8%**			
Isotropic PL at this Area Probability	128.1 dB		132.1 dB		134.1 dB		136.1 dB			
Cell Radius Calculation										
Path Loss	128.1 dB		132.1 dB		134.1 dB		136.1 dB			
UE Height agl (Hm)	2		2		2		2			
Base Station agl (Hb)	35		25		20		25			
Environmental correction factor (Cm)	-6		-11		-16		-22			
UE Height Correction Factor (ahm)	1.67		1.67		1.67		1.67			
Cell Radius Predicted	**0.54 km**		**0.86 km**		**1.23 km**		**2.26 km**			

Table 19 WiMAX fixed indoor service, 10MHz channel at 3.5GHz

WiMAX Fixed Indoor Service 10MHz b/w **700** MHz

	Dense Urban		Urban		Suburban		Rural			
Receiver	**BTS**	**MS**	**BTS**	**MS**	**BTS**	**MS**	**BTS**	**MS**		Refer
Rx input sensitivity	-95 dBm	-89 dBm	-95 dBm	-89 dBm	-95 dBm	-89 dBm	-95 dBm	-89 dBm	A	
Interference Degradation Margin	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB	2.0 dB	B	
Cables and Connector Losses	1.0 dB	0.0 dB	3.0 dB	0.0 dB	3.0 dB	0.0 dB	3.0 dB	0.0 dB	C	
Rx Antenna Gain	18.0 dB	0.0 dB	18.0 dB	0.0 dB	18.0 dB	0.0 dB	18.0 dB	0.0 dB	D	
Diversity Gain	5.0 dB	0.0 dB	5.0 dB	0.0 dB	5.0 dB	0.0 dB	5.0 dB	0.0 dB	E	
Receiver Beamforming Gain	9.0 dB	0.0 dB	9.0 dB	0.0 dB	9.0 dB	0.0 dB	9.0 dB	0.0 dB	F	
Isotropic power for 50% cell edge coverage	-124 dBm	-87 dBm	-122 dBm	-87 dBm	-122 dBm	-87 dBm	-122 dBm	-87 dBm	G	G=A +B +C -D -E -F
Transmitter	**MS**	**BTS**	**MS**	**BTS**	**MS**	**BTS**	**MS**	**BTS**		
Tx output peak power available for traffic	0.5 W	20.0 W	0.5 W	20.0 W	0.5 W	20.0 W	0.5 W	20.0 W		
	27 dBm	43 dBm	27 dBm	43 dBm	27 dBm	43 dBm	27 dBm	43 dBm	J	
combiner loss	0.0 dB	1.0 dB	0.0 dB	1.0 dB	0.0 dB	1.0 dB	0.0 dB	1.0 dB	K	
Cables and Connector Losses	0.0 dB	1.0 dB	0.0 dB	3.0 dB	0.0 dB	3.0 dB	0.0 dB	3.0 dB	L	
TX Antenna Gain	0.0 dB	18.0 dB	0.0 dB	18.0 dB	0.0 dB	18.0 dB	0.0 dB	18.0 dB	M	
Transmit Beamforming Gain	0.0 dB	9.0 dB	0.0 dB	9.0 dB	0.0 dB	9.0 dB	0.0 dB	9.0 dB	N	
Peak EIRP	27 dBm	68 dBm	27 dBm	66 dBm	27 dBm	66 dBm	27 dBm	66 dBm	O	O= J-K-L+M+N
	0.5 W	6324.6 W	0.5 W	3990.5 W	0.5 W	3990.5 W	0.5 W	3990.5 W		
Maximum Allowable Path Loss										
Isotropic path loss for 50% cell edge covergae	151.0 dB	155.0 dB	149.0 dB	153.0 dB	149.0 dB	153.0 dB	149.0 dB	153.0 dB	P	
Building Penetration Loss	14.0 dB	14.0 dB	10.0 dB	10.0 dB	8.0 dB	8.0 dB	6.0 dB	6.0 dB	R	
Additional Margin	0.0 dB	0.0 dB	0.0 dB	0.0 dB	0.0 dB	0.0 dB	0.0 dB	0.0 dB	S	
Isotropic Path Loss 50% Cell Edge balanced Link	137.0 dB	137.0 dB	139.0 dB	139.0 dB	141.0 dB	141.0 dB	143.0 dB	143.0 dB	T	
Area Reliability Calculation										
Path Loss exponent with distance	3.5		3.5		3.5		3.5			
Standard Deviation of Log Normal Fading	8		8		8		8			
Margin for Log Normal Shadowing(Outdoor)	5.9 dB		5.9 dB		5.9 dB		5.9 dB			Input Margin required
CN (linear)	3.8905		3.8905		3.8905		3.8905			
sd(0)	1.8421		1.8421		1.8421		1.8421			
X0	0.5215		0.5215		0.5215		0.5215			
Y0	0.7443		0.7443		0.7443		0.7443			
At Cell Edge	23.0%		23.0%		23.0%		23.0%			
Area Correction	13.9%		13.9%		13.9%		13.9%			
Outage Across the Entire Cell Across Entire Cell	9.2%		9.2%		9.2%		9.2%			
Area Probability of Coverage	**90.8%**		**90.8%**		**90.8%**		**90.8%**			
Isotropic PL at this Area Probability	131.1 dB		133.1 dB		135.1 dB		137.1 dB			
Cell Radius Calculation										
Path Loss	131.1 dB		133.1 dB		135.1 dB		137.1 dB			
UE Height agl (Hm)	2		2		2		2			
Base Station agl (Hb)	35		25		20		25			
Environmental correction factor (Cm)	-6		-11		-16		-22			
UE Height Correction Factor (ahm)	1.22		1.22		1.22		1.22			
Cell Radius Predicted	**3.06 km**		**4.09 km**		**5.72 km**		**10.76 km**			

Table 20 WiMAX fixed indoor service, 10MHz channel at 700MHz

Clearly an allocation at 700MHz could give an operator much more scope for service provision in rural areas. However the amount of spectrum at lower frequencies will be more limited, so coverage has to be considered alongside capacity.

3.2.2.4 Capacity Issues

Many systems, including our WiMAX example, can adapt the modulation type and coding to provide different data throughputs depending upon the quality of the underlying radio path. Close to the base site higher order modulation schemes and coding schemes for higher throughput can be used, see Figure 48.

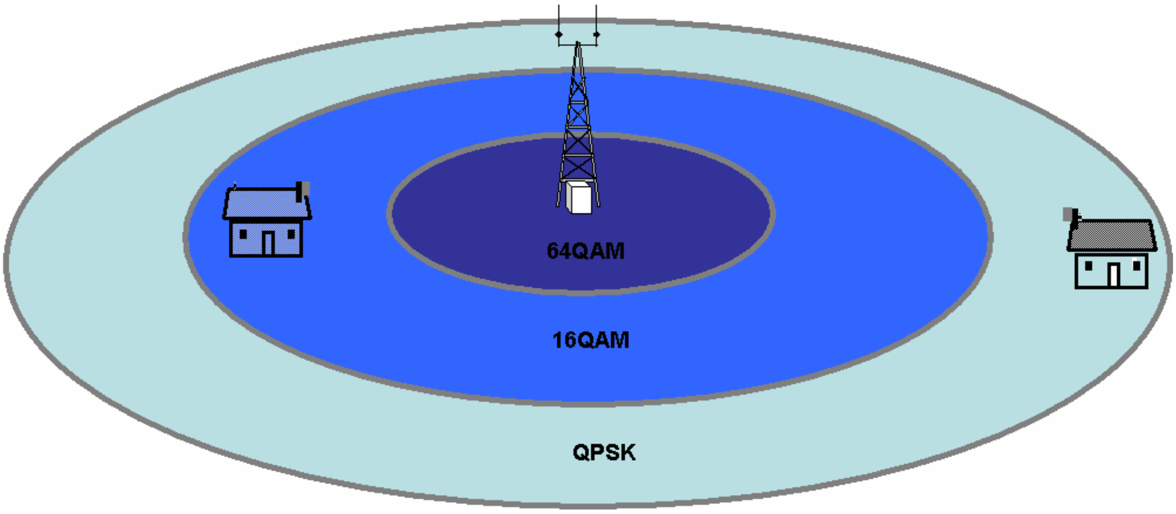

Figure 48 Modulation format versus location in cell

Typically however the majority of the cell area is served by the lower formats because of the cell geometry. Continuing with a WIMAX example, a simple estimate of down link capacity at Layer 3 for a cell is shown in Table 21 and Table 22 which uses two 5MHz FDD channels per sector.

WiMAX Down link Usable Channel Capacity at Layer 3		
QPSK-1/2	2.02	Mb/s
QPSK-3/4	4.05	Mb/s
16QAM-1/2	5.40	Mb/s
16QAM-3/4	8.10	Mb/s
64QAM-2/3	11.03	Mb/s
64QAM-3/4	12.16	Mb/s

Table 21 Channel capacity versus modulation and coding type

# of channels / site	6	
QPSK % Area	60%	
16QAM % Area	29%	
64QAM % Area	11%	
Single Channel Throughput	4.0	Mb/s
Mean Sector Throughput	8.0	Mb/s
Mean Site Throughput	23.9	Mb/s

Table 22 Capacity calculation example (illustrative only)

Given the cell ranges identified in Table 19 and Table 20, then the example system can cope with a range of traffic densities from around 31Mb/s.km^{-2} in dense urban environments at 3.5GHz to around 0.08 Mb/s.km^{-2} in rural areas using 700MHz. This is a very strong coverage-capacity trade-off.

3.2.2.5 Spectrum Estimates

Given the estimate for downlink throughput presented in Table 22, and continuing to use the capacities and cell ranges suggested in the preceding sections, it can be envisaged how a wireless system could be planned to offer today's Broadband 1.0 service: Such a simple calculation is shown in Table 23.

Traffic Model	Broadband 1.0			
Macrocells				
Code	Name	Parameter	Parameter	Parameter
GEOGRAPHY				
	Environment Type	Urban	Suburban	Rural
	Frequency (MHz)	3500	3500	700
	Direction	Downlink	Downlink	Downlink
	Cell Geometry (m)	860	1230	2260
	Cell Area (m2)	2323823	4753532	16048079
MARKET				
	Service Application Type	Mix	Mix	Mix
	Area Per Household	250	650	7000
	Penetration Rate	10%	10%	10%
	Subscribing Households per cell	930	731	229
TRAFFIC AND SERVICES				
		Todays Broadband	Todays Broadband	Todays Broadband
	Downlink Peak Rate (kbit/s)	2000	2000	2000
	Uplink Peak Rate (kbit/s)	256	256	256
	Average Downlink(kbit/s)	40	40	40
	Average Uplink (kbit/s)	5.12	5.12	5.12
	Cell Traffic Downlink (Mbit/s)	37	29	9
	Cell Traffic Uplink (Mbit/s)	5	4	1
SYSTEM CAPACITY				
	Downlink Mean effective throughput in 10MHz	23.9	23.9	23.9
	Frequency |Re-Use Factor (or PUSC factor)	3	3	3
	Effectoive Bit/Hz	0.80	0.80	0.80
SPECTRUM REQUIREMENTS				
D1	Spectrum Required (MHz)	46.7	36.7	11.5

Table 23 Deriving nominal spectrum requirements for Broadband 1.0

The long term mean throughput on the downlink is estimated as 40kbit/s (50:1 contention of a peak 2Mbit/s service). With the assumptions already made for household density in urban, rural and suburban the hypothetical system of Table 23 is capable of serving reasonable numbers of households per cell with approximately 40MHz of spectrum.

Whilst this is an oversimplified scenario, the point is to next replace the 40kbit/s average downlink with that of the 10Mbit/s postulated for Broadband 2.0, Table 24. Here it is seen that many GHz of spectrum would be required. Of course, this spectrum would be unobtainable at the carrier frequencies used.

Traffic Model	Broadband 2.0			
Macrocells				
Code	Name	Parameter	Parameter	Parameter
GEOGRAPHY				
	Environment Type	Urban	Suburban	Rural
	Frequency (MHz)	3500	3500	700
	Direction	Downlink	Downlink	Downlink
	Cell Geometry (m)	860	1230	2260
	Cell Area (m2)	2323823	4753532	16048079
MARKET				
	Service Application Type	Mix	Mix	Mix
	Area Per Household	250	650	7000
	Penetration Rate	10%	10%	10%
	Subscribing Households per cell	930	731	229
TRAFFIC AND SERVICES				
		Future	Future	Future
	Downlink Peak Rate (kbit/s)	100,000	100,000	100,000
	Uplink Peak Rate (kbit/s)	100,000	100,000	100,000
	Average Downlink(kbit/s)	10,000	10,000	10,000
	Average Uplink (kbit/s)	10,000	10,000	10,000
	Cell Traffic Downlink (Mbit/s)	9,295	7,313	2,293
	Cell Traffic Uplink (Mbit/s)	9295	7313	2293
SYSTEM CAPACITY				
	Downlink Mean effective throughput in 10MHz	23.9	23.9	23.9
	Frequency |Re-Use Factor (or PUSC factor)	3	3	3
	Effectoive Bit/Hz	0.80	0.80	0.80
SPECTRUM REQUIREMENTS				
D1	Spectrum Required (MHz)	11667.7	9179.7	2877.7

Table 24 Deriving nominal spectrum requirements for Broadband 2.0

The basic coverage-capacity limitations illustrated above are key inputs to the following sections.

3.2.3 Use of TV bands – cleared, or any UHF bands < 1GHz

We know from section 2 that:

- UHF < 1GHz has a propagation advantage over 2.4GHz
- Limited spectrum would be available from DSO or other re-allocations
- The trade-off between coverage and capacity is strong

Range is a problem for Wireless Internet Service Providers (WISPs) at 2.4GHz; this is what drives the need to work at lower frequencies, particularly under 1GHz, e.g. in the TV bands. The example in section 3.2.2 showed that range can be better in a 700MHz WiMAX system than at 3.5GHz, but also went on to show that user capacity is necessarily going to be limited, via the expected cell capacity limit. One likely conclusion is that whilst a move to 700MHz in rural areas might provide an equivalent service to today's contended ADSL service, it is unlikely to scale beyond that. The limit is spectrum; smaller cells would help - but then the economics fail, as before, via increased total base station cost. In other words, big cell + big bit rate = big spectrum. The related problem, even with more spectrum, is the concentration of signals at a base station if each user has a dedicated point to point link, although mesh can help here.

The ranges in the example are in the 3-10 km range; this is higher than reported by e.g. Siemens [Ball et al 2006] - and this is likely to be because the Siemens numbers do not allow for any beam steering gain, which is a future WiMAX option included in the example. Ball et al [2006] states clearly that cell back haul may have to use fibre and that WiMAX success appears to depend on its 'optional' features being implemented. This agrees with Navini/Unwired Australia. Both Siemens/Navini conclusions are for non-real time traffic too; thus it must get worse with real time video etc.

Although the example was WiMAX, it may be generalised to any wireless scheme. The approach taken by 802.22, whose remit of providing Wireless Regional Area Networks (WRANs) is quite similar to the last mile problem. Figure 49 shows how 802.22 was dimensioned at the start of the standards process, by considering the potential of the spectrum available at UHF. UHF was chosen for its coverage characteristics.

WRAN System Capacity and Coverage

RF channel bandwidth:	6	MHz	(also 7 MHz and 8 MHz TV channel bandwidths in various parts of the world)
Average spectrum efficiency:	**3**	bit/(s*Hz)	(corresponds to 64 QAM, 3/4 FEC code rate) (adaptive modulation will allow higher efficiency for close-in terminals with higher levels of modulation (e.g., 256 QAM, 7/8 FEC code rate) while lower efficiency, more robust modulation will be used for hard-to-reach terminals in fringe areas (e.g., QPSK, 1/2 FEC code rate))
Channel capacity:	18	Mbit/s	For average spectrum efficiency. Range could be 3 to 30 Mbit/s.
System capacity per subscriber (forward):	**1.5**	Mbit/s	(T1 equivalent capacity is expected to be a reasonable forward data rate for rural and remote broadband access service, similar to current ADSL and cable broadband access services offered in urban and suburban areas)
System capacity per subscriber (return):	384	kbit/s	(allows good quality videoconferencing)
Forward/Return ratio:	3.9		(slightly better than current ADSL and cable broadband access services)
Over-subscription ratio:	**50**		(also called 'contention ratio', to take into account the statistical behavior of broadband access, between typical ratios used by ADSL (40) and cable modem (80))
Number of subscribers per forward channel: **(FDD operation is initially assumed) (TDD would reduce capacity to 80% per TV channel based on the above Forward/Return ratio)**	600		(could vary between 500 and 1000 subscribers depending on the acceptable level of network loading. Higher numbers will lead to more channel contention, resulting in increased latency and reduced throughput for the subscribers.)
Assuming 1.5 Mbit/s forward and 384 kbit/s return in a 6 MHz channel with 3 bit/(s*Hz) and 50:1 over-subscription, each TV channel can provide service to up to 600 subscribers. The area that the Wireless Regional Area network (WRAN) operator needs to cover should include enough subscribers to make it economically viable early in the process when the take-up rate is low. This will define the potential subscriber base and the population density for a sustainable business case.			
Minimum number of subscribers:	**90**	subs.	to ensure the viability of the system early enough in the process
Assumed early take-up rate:	**5%**		conservative figure for the early days of the network, allows for growth in the service
Potential number of subscribers:	1800	subs.	three 6 MHz channels would ultimately be needed for the service to all potential subscribers in the forward direction (and one 6 MHz channel in the return direction)
Assumed number of persons per household:	**2.5**	persons	typical from population census
Total number of persons per coverage area:	4500	persons	
WRAN base station EIRP:	98.3	Watts	resulting from a limit of 4 Watt EIRP for the CPE transmit power
Radius of coverage for WRAN system:	30.7	km	
Minimum population density covered:	1.5	person/km^2	

Figure 49 802.22 WRAN system dimensioning approach

802.22 assumes 6MHz US TV channels. At a respectable spectral efficiency of 3 bits/s/Hz, a channel capacity of 18Mb/s is available. The problem is that 802.22 wanted to provide an ADSL-like data rate to 600 subscribers per coverage area. This is simply not possible within the spectrum available – unless contention is introduced, precisely as for ADSL. Thus, with a contention of 50:1, 600 users may be served a peak rate of 1.5Mb/s[87]. 802.22 refers to contention as 'over-subscription'. There is nothing wrong with such an approach if it is intended to apply to today's bursty email and web access - but it cannot cope with the streaming needs of Broadband 2.0.

Note further, that whilst ADSL contention may be eliminated by adding back haul, a wireless system suffers contention via limited air interface resource, so either more spectrum or more base

[87] 1.5Mb/s divided by 50 and multiplied by 600 = 18Mb/s

stations are required. Solving this is quite a different prospect to simply[88] adding more back haul.

We may consider this further via Figure 50, which shows the effect of removing 50:1 contention from

1. ADSL via back haul
2. Wireless (802.22 example) via more spectrum or more base stations

Even worse, if we wish to both remove contention and increase user bandwidth in order to approach the level of Broadband 2.0, we immediately need huge, quite unrealisable amounts of spectrum at UHF.

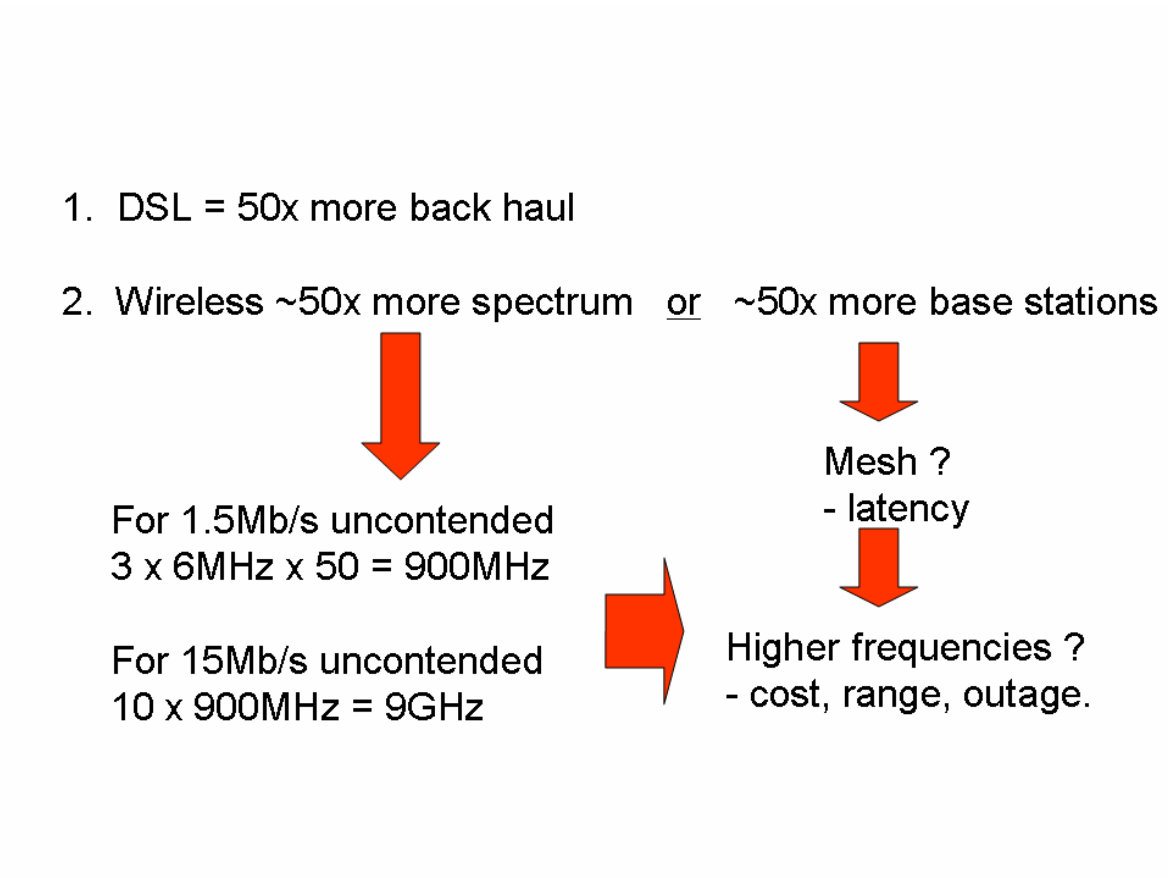

Figure 50 Eliminating 50:1 contention - ADSL versus 802.22 wireless examples

Potential solutions to the problem include mesh, discussed next, but this comes with its own issues, as will be shown. Working at higher frequencies is also possible, since more bandwidth is available this way. The problem here is cost – microwave and Gb/s wireless are suitable when shared as a last mile feeder (see e.g. 3.2.5), but are unfeasibly expensive on a per user basis, plus range and outage are issues. A sister Ofcom project (High Frequency Licence exempt Bands) is reaching similar conclusions. The reader is referred to this report for much more detail, when it becomes available.

Naturally, if bandwidth is the problem, then optical frequencies suggest themselves[89]: We have

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[88] Of course, this means *relatively* simply by adding back haul, when compared to finding more spectrum or base station sites, which is a higher level of difficulty

[89] It may be helpful to think of optical transmission as having carrier frequencies around 200THz

already noted issues with free space optics, but fibre looks attractive and is examined later in 3.2.5.

The sharing of live TV bands is discussed later (3.2.5.3). This may be a good solution to achieve a little more spectrum in rural areas – but this would still fall short of the spectrum needed for Broadband 2.0.

3.2.4 Mesh or multi-hopping at higher frequencies

We know from section 2 and Methley et al [2005] that:

- Mesh suits systems with small, high capacity cells (but mesh does cause a high capacity effect)
- Mesh can suit less precious spectrum above the sweet spot
- Each mesh hop increases latency and the sharing of the spectral resource

The larger attenuation and foliage absorption at frequencies above the sweet spot are actually of help to a mesh/multihop deployment, as it isolates the individual hops paths. This is quite the opposite to a mobile/PMP deployment - refer back to Figure 29, page 47 - where such 'clutter' is a problem.

However, in short, for all the considerable flexibility mesh has to offer, it is still subject to the over-arching capacity and coverage limitations for wireless, as already described: Following the same example (Figure 50), mesh would make building 50x more base stations easier in some ways, but they would still have to be built – and the result may still fall short of Broadband 2.0, due to bandwidth sharing and latency increasing per hop. In fact, more than 50x more base stations may be needed, since moving to very small cells from very large cells changes the local topography and propagation greatly. Siting 50x more base stations would also be a considerable practical problem. Finally, we note that a mesh system would have to be fed via a suitable last mile feeder of fibre or Gb/s wireless.

Therefore, in summary, we do not say that mesh may not solve the problem - but that it may not solve the problem economically and in a future-proof manner. We make this last comment with particular regard to our investigation of FTTx systems, which appear shortly, in section 3.2.5.

Nonetheless, a multi-hop radio used as a last mile with Gb/s wireless or even WiMAX as a last mile feeder does appear to be a worthy solution for some rural broadband – in those cases where even Broadband 1.0 is better than no broadband at all or a lesser satellite based solution.

3.2.5 Hybrid fibre-wireless, Gb/s wireless and FTTx+xDSL

We know from section 2 that:

- Fibre can solve the last mile feeder problem, leaving another technology free to solve the distribution and last drop
- Fibre alone can also be an end-to-end last mile solution
- Gb/s wireless is a full speed fibre replacement technology, and potentially lower total cost

3.2.5.1 Hybrid-fibre wireless

This scheme relies on having enough bandwidth for a wireless last drop of Broadband 2.0. It is rejected for all the capacity and coverage limitations of wireless already stated, e.g. Figure 50, and the resultant economic implications.

3.2.5.2 FTTx+xDSL

Our considerations of wireless so far have led to the conclusion that whilst wireless might just conceivably remain a technical solution to the issues of delivering broadband 2.0, it seems unlikely to be an economical solution, due to the requirement of either far too much spectrum or far too many base stations to be practical or financially viable.

We have noted that fibre appears to have few practical, technical limitations for the requirements of Broadband 2.0: It is now appropriate to examine FTTx a little more deeply. The main problem of course is the CapEx needed to install a fibre solution. This issue has resulted directly in the emergence of the hybrid schemes which continue to use existing cooper lines as far as possible. These scheme are collectively described as FTTx + xDSL, where fibre is invariably the last mile feeder, reaching out from the exchange to the short copper drops to the customer premises. Figure 51, from Alcatel, shows the various divisions of fibre and copper amongst the various FTTx + xDSL combinations, all the way from wholly copper (commonly ADSL) to wholly fibre (FTTH or FTTP[90]).

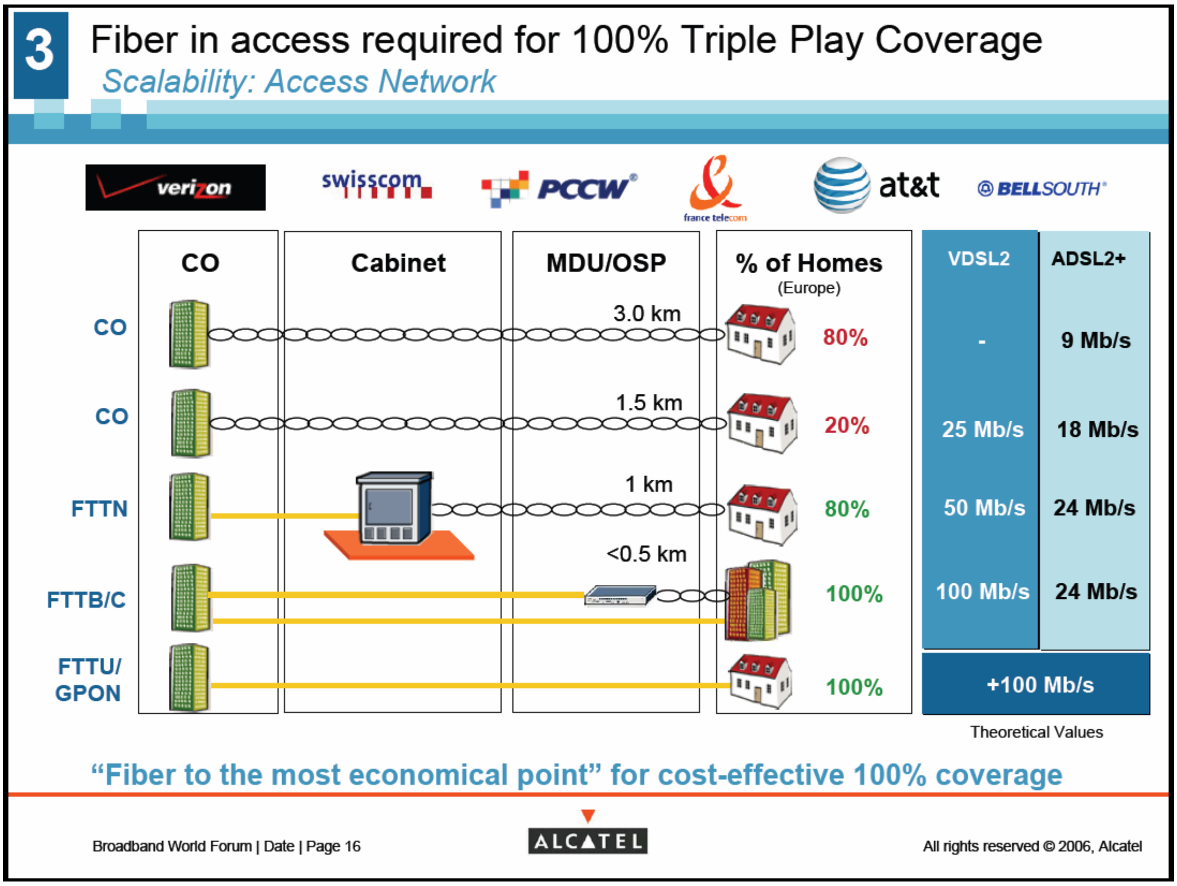

Figure 51 Fibre to the x, where x is the most economical point [Alcatel 2006]

The five cases shown in Figure 51 are as follows

1. CO, 3.0km of copper. This means that users within 3km of an exchange could receive 9Mb/s via ADSL2+, and this could be appropriate for about 80% of European homes. 20% of homes would be unable to receive this level of service.

[90] Fibre to the home, or premises, respectively – largely equivalent schemes

2. CO, 1.5km of copper. This means that those users within 1.5km of an exchange could receive 25Mb/s by VDSL2 or 18Mb/s by ADSL2+, but this would be appropriate for only about 20% of European homes. 80% of homes would be unable to receive this level of service.
3. FTTN, 1km copper. This means that users within 1km of an installed FTTN node could receive 50Mb/s by VDSL2 or 24Mb/s by ADSL2+, and this would be appropriate for about 80% of European homes. 20% of homes would be unable to receive this level of service.
4. FTTB/C, <0.5km copper. This means that urban users well within 500m of an installed FTTB/C node at the building or curb-side could receive 100Mb/s by VDSL2 or 24Mb/s by ADSL2+, and this could be appropriate for all European urban business premises or apartment blocks.
5. FTTU/GPON, no copper. This means that all users are fed by fibre all the way and can receive 100Mb/s or more. FTTU would be a dedicated fibre to the user, whilst a GPON system would use splitters (e.g. 32 way) to create a Gigabit Passive Optical Network, in order to save some immediate head-end costs (e.g. the source transmitter and receiver are shared across many users), at the expense of future upgradeability.

For Figure 51, Alcatel have assumed that triple play drives bandwidth and hence the march of fibre into access network. In common with this report, Alcatel believe future bandwidth demand will be well in excess of today's requirement; they say they assume 25Mb/s or more per home by 2010. As well as bandwidth, fibre also helps QoS, whether point-to-point or PON is used; since each system has been specifically designed for QoS. In contrast to the provider's notable installation effort, the user sees a self install system, which will keep OpEx down. Some fibre financials are given in section 4.4 which show that the CapEx - revenue hurdle is recently being overcome.

To address the tetherless requirement, all cases could terminate at a WiFi home network, perhaps 802.11n which will be capable of distributing high definition, real time services around the home.

Interestingly, however, Verizon (introduced in section 2.1.1.5) have reduced home wiring costs by using MoCA, Figure 52. MoCA (Multimedia over Cable Alliance) uses coax to distribute signals around the home and interfaces to the FiOS WDM/FDM approach directly: However, this choice by Verizon is an especially convenient case, since they already use a cable TV like system over their fibre – Verizon's choice of MoCA should not necessarily be taken to mean that other fibre providers should follow suit – it will be a less convenient match to a provider using a single IP steam to multiplex triple play.

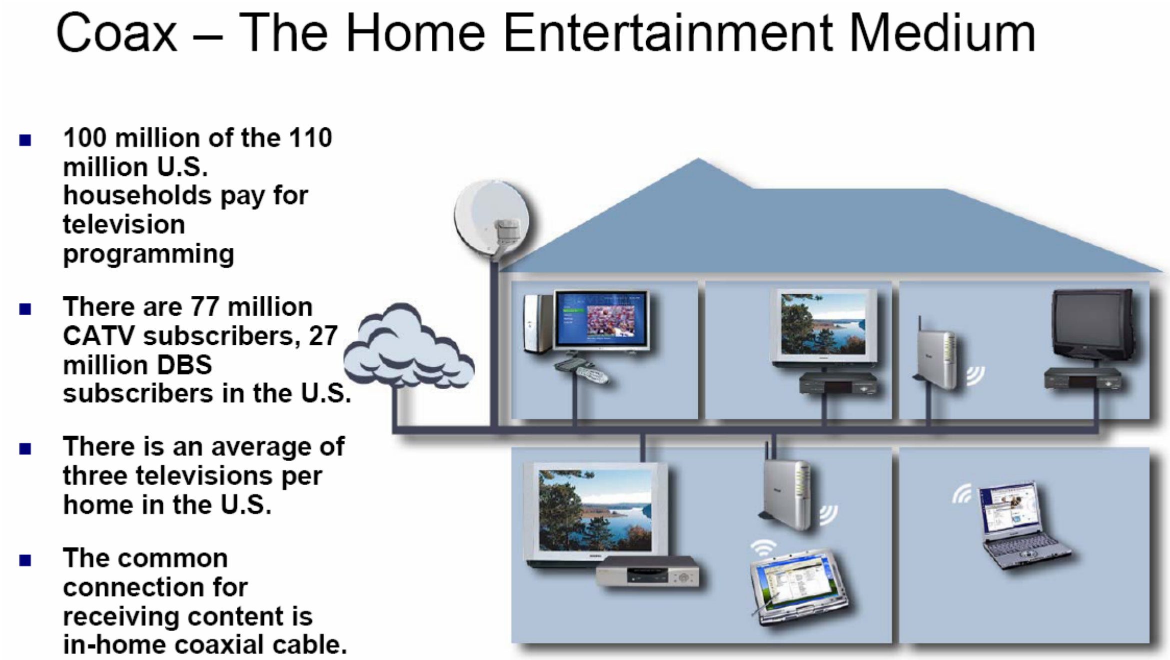

Figure 52 MoCA - broadband home net - using installed US base of coax [mocalliance.org]

3.2.5.3 Gb/s wireless

For all the schemes in Figure 51, Gb/s wireless could be used to replace the fibre portion. This could be very important for those instances where laying fibre is too expensive. Typically the cost of laying fibre is highest in the densest urban areas, so some urban deployments of xDSL could be fed by Gb/s wireless. Rural areas, especially where it is desired to reach a remote but densely populated town, could also use Gb/s wireless, although in some cases traditional microwave or WiMAX could be adequate.

3.2.6 Use of TV bands - white space

We know from section 2 that:

- Good propagation in the TV bands is attractive for the WISP business case
- There commonly exists some white space in TV bands
- In the UK, TV coverage is much more concentrated than in the US, hence the amount of white space may be relatively less
- Various techniques exist to identify white space
- There is a large disagreement about the interference level which may be caused to the incumbent TV services if the white space is used

The FCC have recently released a public notice on TV shared band devices (Appendix G), with the timetable shown in Table 25 for ultimately releasing devices to the US market.

Projected Date	Milestone

October 2006	Commission adopts a First Report and Order and Further Notice of Proposed Rule Making
March 2007	FCC Laboratory reports the results of measurements of the interference rejection capabilities of DTV receivers
July 2007	FCC Laboratory reports the results of tests evaluating potential interference from unlicensed devices to TV and other radio services
October 2007	Commission adopts a Second Report and Order specifying final technical requirements for unlicensed devices that operate in the TV bands
December 2007	FCC Laboratory begins accepting applications for certification of unlicensed devices operating in the TV bands; certification will be granted at such time as the application has been reviewed and found to comply with the rules; certification will permit manufacture and shipment of products to distribution points
February 2009	Products will be available for sale at retail

Table 25 FCC public notice on TV shared band devices

This has resulted in a recent MSTV publication showing the result of interference experiments, which found

- OOB (out of band) interference can be a problem within 78 feet
- 1st adjacent channel interference may always be a problem at any distance – and must be avoided
- Co-channel interference can affect up to 75 sq.miles
- Applying Polite Protocols is difficult due to the low signal level and broad width of the band. The receiver positions are also not known.

In order to assess this, the following approach is taken: For this report, let it be assumed that the technical problems may be answered and devices may be released to the market: How useful would this be for Broadband 2.0? The answer is that even if all the TV band spectrum was somehow available for use, it would still not be enough, based once again on the arguments summarised within Figure 50. Of course in reality the spectrum available would be much less than this, especially in the UK where TV coverage is extensive relative to the US. There would also be less TV ‘white space’ in transition period before full digital switchover in 2012.

Nonetheless, once again, if rural users could be given Broadband 1.0, where presently they have no broadband, then white space working could be beneficial to the UK. This is the same conclusion as was reached for cleared TV spectrum or indeed any available UHF spectrum in section 3.2.3.

3.2.7 Mix of Licensed, Licence Exempt and Segregated Bands

We know from section 2 that:

- Innovation is encouraged by licence exemption (e.g. WiFi)
- Licensed spectrum is the only way to guarantee reliability by guaranteeing interference levels
- Polite protocols and Codes of Practice may achieve some of the aims of licensed spectrum

Further, the considerations of this section are made subsequent to having shown that a wireless last mile is unlikely to serve Broadband 2.0, but that some users, e.g. rural, could usefully be given Broadband 1.0, where presently they have none. Also, Gb/s wireless could be used as a feeder fibre replacement to serve Broadband 2.0 deployments via ongoing local xDSL or fibre.

Within the UK, there has been, in recent times, a general blurring of licence types, including a shift of responsibility for interference resolution. A future fruitful approach might be to combine licensed and unlicensed spectrum within the last mile application, arranged so as to jointly optimise the system availability (licensed spectrum) with the potential for innovation (licence exempt). This brings up many issues, including the following:

> Technology neutrality may be a worthwhile policy goal for a regulator – however, interference depends on technology, so it must receive due consideration at a defined point in the process. Regulators may choose to recommend Polite Protocols[91] or Codes of Practice. Alternatively, the licence holders themselves may decide that it is simplest for them all to operate the same technology via their own Code of Practice, as happened with the shared DECT guard bands.
>
> Quality of Service and Polite Protocols are in fact directly competing aims in shared bands, with the prime example being 802.16 which achieves enviable QoS at the complete expense of band etiquette. Over-provisioning bandwidth was typically used to give QoS in packet based fixed links - the equivalent is ensuring lightly loaded spectrum in wireless unlicensed links. This could be achieved by tight interference control, by over-provisioning spectrum itself or by smarter wireless systems, amongst others. The first two are very difficult under light regulation and market forces.

Considering the Ofcom policy of using market forces for spectrum management; this favours a licensed approach with minimal restrictions on how the spectrum is used and for what application. However it is difficult to see there being a strong enough business case being made for a suitable band for a wireless last mile to successfully compete against other likely bidders for such spectrum.

Another alternative is for last mile providers to use licence exempt spectrum. However there are limitations. The lack of control over other users of the band makes it difficult to control latency. The licence exempt solution works best where the band is lightly loaded and so rural last mile may be possible. It is important to note that licence exempt is unlicensed but not unregulated and through setting technical restrictions on use, the regulator can make it easier or harder for a last mile business model.

Ofcom have defined a possible licence exempt application specific type of band. We are not convinced that such an application restriction will generally be sufficient and would suggest that more limits (segregation) might be necessary. Technology freedom is difficult to allow, although in practice it is restricted by technical parameter limits applied to the band. Codes of Practice are an approach Ofcom is proposing but there are problems with these particularly where

- operators are very different in scale,
- there are legal issues over exchanging business information,
- there is an excessive overhead in handling minority technologies or standards

Finally, we note that for the very specific case of WiMAX, its use would have to be in licensed spectrum as it is unsuited to sharing.

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[91] It is not presently clear whether these could be enforced

3.2.8 Personalised ubiquitous broadband - nationally tetherless last mile

Although mobile broadband is not this report's focus, it is relevant to any ubiquitous access discussion, hence its inclusion in this and the following section only. This section also contains an overview of 802.11 technologies, which this report expects to continue to serve home networking into the future.

We know from section 2.3.5 that:

- There is a growing need for a high-bandwidth (broadband) tetherless last mile.
- Wireless broadband is not likely to satisfy fixed, last mile solutions, but could be quite adequate for mobile broadband (due e.g. to the smaller screen sizes)
- There could also be evidence of a slow down in the mobile applications.
- There are numerous mobile/portable/fixed wireless access technologies already available and others on the horizon.

Taking the third point: why are people not buying applications? One potential answer is that newer handsets are assuming the availability of higher capacity wireless, pushing ever closer to the 1Mb/s mark[92]. So, greater connection capacities are required to truly enable the mobile applications market, and a tetherless broadband last mile seems attractive.

The fourth point is the problem of multiple legacy wireless devices, all of which would wish to access a national wireless last mile. This is discussed next; firstly we review the legacy schemes, all of which are very well developed solutions in their fields.

3.2.8.1 Existing technologies for broadband access

With the high penetration of 802.11 technologies (from laptops, to smartphones and PDA-phones to hand-held games consoles), the 802.11 technologies are likely to remain available for a long time. Bluetooth is also widely available. A summary comparison is given in Table 26.

	802.11a	802.11b	802.11g	Bluetooth
Data Rate (Mbps)	54	11	54	721Kbps 56Kbps
Operating Frequency (GHz)	5	2.4	2.4	2.4
Typical power output (mw)	40-800	100	100	100
Compatibility	Not compatible with 802.11b or 802.11g	Not compatible with 802.11a or 802.11g	Compatible with 802.11b	Not compatible with 802.11a/b/g.
Typical Range	150feet	150feet	150feet	30feet
Interference risk	Low	High	High	High
Price	Expensive	Cheap	Moderate	Moderate
Hot-spot access	Poor	Good	Good	Poor

Table 26 IEEE 802.11 and Bluetooth Comparison Summary
(source http://networking.anandsoft.com/wireless-lan-comparison.html)

Bluetooth appears above for the sake of completeness, and may be used to provide access for some

[92] http://www.palm.com/us/products/smartphones/treo700w/

less capable devices, but clearly it is not really a broadband access technology. There are many services, including commercial services, being set-up using 802.11 technologies (e.g. hot-spot services such as BTOpenzone[93]). However, availability is poor, currently, as the services have concentrated on areas with high user densities (e.g. airports etc). Reception is usually adequate within the hot-spot, providing a useable service for data applications (if not for real-time applications such as voice and video). IEEE 802.11e was ratified by the IEEE in December 2005 and offers QoS enhancements to the existing 802.11 family. This may help improve capability and resource sharing at hot-spots, but it is too early to tell how much impact 802.11e will have. Additionally, many 802.11 client-side deployments (e.g. laptops) are unlikely to be 802.11e capable and may not even be upgradeable to 802.11e.

3.2.8.2 Emerging technologies for wireless broadband access

The development of the IEEE 802.11 family continues and 802.11n[94] is on the horizon for Q1/2008 standardisation (pre-standard 802.11n products are available now but are unlikely to be upgradeable). This will work in the 2.4GHz (as 802.11b/g) or 5GHz (802.11a) frequency range, have a service range similar to 802.11a/b/g (~50m), but currently is planned to offer a maximum data rate of 600Mb/s, though many observers believe that the typical data rates are likely to be around 200Mb/s. However, much still needs to be agreed on the 802.11n standard.

This requirement for greater data rates is also being used to push forward standards activity with other IEEE standards. Whilst 802.11 standards work in LE frequencies, IEEE are also considering technologies that could be use in the licensed spectrum, namely 802.16a/e and 802.20. Both the 802.16e[95] (mobile WiMAX), as well as on 802.20[96] (Mobile Broadband Wireless Access – MBWA – restarted 15 September 2006 after a 4 month suspension) will provide mobile/roaming capability, whilst 802.11a is aimed at static wireless links, suitable for wireless back haul and fixed wireless mesh networks. A summary comparison of IEEE 802.16e and IEEE 802.20 is given in Table 27. The comparison with 3G is provided for information.

802.16e	802.20	3G
IP 802.16a mobility (more than 1Mbps)	IP roaming & handoff (more than 1Mbps)	Circuit-switched cell data (less than 1Mbps)
Extensions to MAC and PHY from 802.16a	New MAC and PHY with IP and adaptive antennas	W-CDMA & CDMA-2000
Backward compatible with 802.16a	Optimized for full mobility	Evolving GSM or IS-41
Between 2-6 GHz	Licensed Bands below 3.5GHz	Licensed Bands below 2.7GHz
Packet Architecture	Packet Architecture	Circuit Architecture
Low latency	Low latency	High latency

Table 27 Mobile Data Architecture Features - A summary comparison (source http://www.dailywireless.org/ [97], based original data from a report by Flarion Technologies)

[93] http://www.btopenzone.com/

[94] http://grouper.ieee.org/groups/802/11/Reports/tgn_update.htm & http://www.broadcom.com/docs/WLAN/802_11n-WP100-R.pdf

[95] http://www.ieee802.org/16/tge/

[96] http://grouper.ieee.org/groups/802/20/

[97] http://www.dailywireless.org/modules.php?name=News&file=article&sid=3332

3.2.8.3 IP level networking and upper layers

We assume that the broadband access is predominately IP-based. There are many issues with respect to the use of IP for such networking. A key issue is addressing and routing. With such a scenario – roaming users and mobile applications in a broadband access cloud that provide ubiquitous access – addressing, routing and management in the IP domain becomes a problem. More details are given in section 3.2.9.

3.2.8.4 Security

With all the 802.11 technologies, security remains an issue. The original security mechanism for 802.11 (WEP – Wired Equivalent Privacy), was known to be weak and has now been superseded, many users remain unconvinced on the 802.11 security mechanisms and often employ additional mechanisms above the 802.11 'layer'.

Security mechanisms for 802.16 and 802.20 are also not finalised.

IP security and IP mobility do not interwork easily with the use of common IP functions such as NAT (Network Address Translation). Whilst solutions to all of these problems do exist, there is very little commercial deployment of mobile IP.

There are other security threats, such as Denial of Service (DoS) attacks, which are hard to counter but extremely easy to launch in IP-based networks. This poses an increasing challenge to wired IP networks and has a higher impact still in wireless IP usage due to the broadcast/shared-medium nature of the underlying transmission system.

3.2.8.5 Conclusion - Personalised ubiquitous broadband

The number of wireless technologies present and in development is both a solution and a problem. Each have merits as a well developed solution in the right circumstances, but there is little natural commonality between them.

In other words, the widespread existence of several legacy wireless communications schemes makes integration into a single seamless last mile very difficult, plus the danger is that good features of each scheme could be lost in a levelling and integration process . It would seem to be a far better approach to have a system methodology which accepts that all schemes have different values - and to integrate them dynamically. It is then a small step to also include wired access technologies into the mix. This makes for a much more capable and powerful solution, discussed next.

3.2.9 Joined-up broadband - Coalition Peering Domains

We know from section 2.3.6 that:

- A possible picture of the future is one where broadband access across many different technologies is orchestrated to allow ubiquitous connectivity.
- Ad hoc architectures for enabling community area networks, based on IEEE 802.11 family technologies are already being used to harness multiple DSL/cable broadband access lines.
- A joined-up broadband vision from the outset will result in as many technologies as possible being able to access a ubiquitous last mile.

3.2.9.1 Multi-network, multi-device connectivity

The nature of inter-network and inter-device connectivity is evolving. Not only are data rates increasing significantly, but so is the ease with which users may inter-connect multiple machines or devices. By doing this, they are able to utilise more efficiently and flexibly both their local resources and their access to the wide-area. Such flexibility has increased user expectations and fuelled the emergence of new and diverse types of high-bandwidth multimedia applications and services, including video and audio streaming, Internet telephony and multimedia conferencing.

However, there still remains some disparity between the relatively high data rates that may be achieved within the local-area and the relatively lower data rates available within the wide-area. This is particularly accentuated within the mobile arena, putting a limit on the types of applications and services that users are able to access.

Most portable devices now provide users with the choice of multiple types of wireless network connectivity including 3G, IEEE 802.11b/g and Bluetooth. However, these devices do not yet exploit fully all the connectivity that may be available to them.

For example, a group of devices that support both 802.11b and 3G could use any untapped 802.11b connectivity between them as a *backplane* for forwarding wide-area traffic through all the 3G links (Figure 53 and Figure 54). By doing this, they would benefit from the statistical multiplexing gain of, effectively, aggregating their wide-area connectivity.

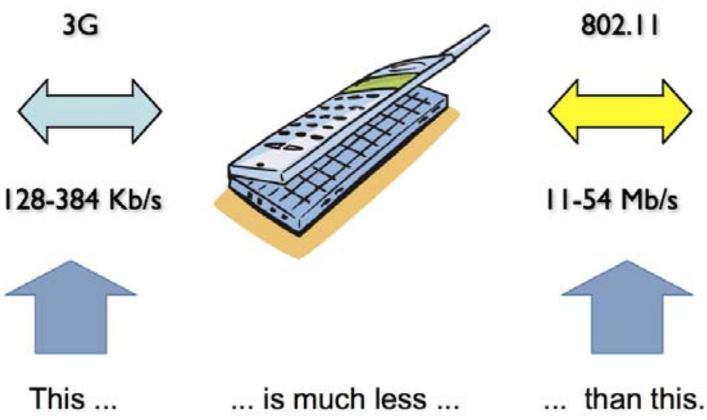

Figure 53 A modern smartphone

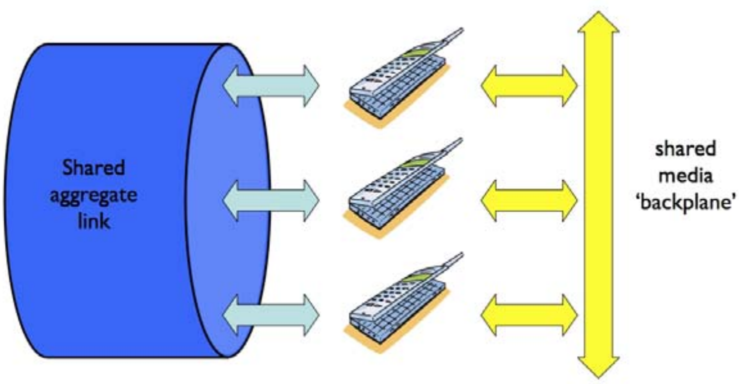

Figure 54 A bandwidth aggregation scenario

Of course, to implement this scenario we need network functions:

1. To discover other devices and their capabilities.
2. To coordinate the formation of the coalition (nodes joining and leaving).
3. To arrange for packet ‘spraying’ on the egress/upstream direction.
4. To arrange for packet spraying on the ingress/downstream direction.

These functions impact on routing and addressing for IP. Additionally, what we have here is effectively a multi-homed[98] edge network. Multi-homing is not well-supported in IP currently. Additionally, for supporting the distribution of packets across the multiple paths in the downstream direction, we need the upstream network service(s) to be aware of the existence of the coalition to the point that there is knowledge of all the downstream links that connect to the same coalition peering domain (CPD) and that the packets being sent to the CPD can be distributed across all the links to gain maximum benefit. The specific benefit of the scenario shown above is that by aggregating the lower-speed links, the end users may be able to gain a broadband service (albeit shared amongst them) where such a service does not actually exist, i.e. it is a virtual service.

Of course this model can be generalised: any ingress/egress links could be used (ADSL, cable, GSM, etc.) and any local area connectivity could also be exploited (wired Ethernet, Bluetooth, etc.)

Additionally, careful analysis would be required of the user incentives and desire to have this kind of sharing within specific business models. For example, commuters on a train all subscribing to company X’s 3G service and to the CPD service that company X offers may choose to enable the CPD function when they are using their service in order to peer with any other subscribers of company X’s 3G service and all gain from it.

The situation just described is a generalisation; two specific instances of that generalisation are described below - both can be considered work in progress, one academic research and one commercial.

3.2.9.2 Coalition Peering Domains

Note that much of what is presented in this section is taken from ongoing work [99] [100] [101] [102].

Figure 55 and Figure 56 illustrate a number of collaborative efforts or local peering agreements between pairs of community members. These peerings may be either as simple as links interconnecting different pairs of community members, or more complicated associations controlled through policy defined locally by the community members. As the numbers of such local peering agreements begin to increase and to intersect between community members, we refer

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[98] multi-homed devices have more than one IP address.

[99] R. Atkinson, M. Lad, S. Bhatti, S. Hailes, “A Proposal for Coalition Networking in Dynamic Operational Environments”, Proc. MILCOM2006 – 25th Military Communications Conference, Washington DC, USA 23-25 October 2006.

[100] M. Lad, S. Bhatti, S. Hailes, P. Kirstein, “Coalition-Based Peering for Flexible Connectivity”, Proc. PIMRC2006 - The 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications , Finlandia Hall, Helsinki, Finland . 11-14 September 2006.

[101] D. Quercia, M. Lad, S. Hailes, L. Capra, S. Bhatti, “STRUDEL: Supporting Trust in the Dynamic Establishment of peering coalitions”, Proc. SAC2006 - The 21st Annual ACM Symposium on Applied Computing , Bourgogne University, Dijon, France . 23-27 April 2006.

[102] M. Lad, S. N. Bhatti, S. Hailes, P. Kirstein, “Enabling Coalition-Based Community Networking”, Proc. LCS2005 - London Communications Symposium 2005 08-09 September 2005.

to the creation of a *coalition* within the community and the formation of a Coalition Peering Domain (CPD).

Each Coalition Member (CM) may represent an individual with either a single node, or a local network. Coalition members who have wide-area connectivity (or more generically, connectivity outside the CPD) form together the edge of the CPD and act as Coalition-Edge Forwarders (CEFs); they are the CPD ingress--egress points, allocating some proportion of their external connectivity for this purpose. In the simplest case they may forward outgoing packets on their CPD-egress link. However, in a more interesting case they may forward some of these outgoing packets by `spraying' (distributing) them, across the CPD edge, via their CPD-internal interfaces to other member CEFs within range, who then forward the packets outside the CPD. Thus outgoing traffic is distributed across multiple CEFs, so enabling a higher upstream data rate by aggregating multiple CM egress links. This type of wide-area connectivity aggregation is an example of collaboration between individuals for mutual benefit. This approach is useful when the local capacity between a number of CMs is greater than or equal to their individual egress capacity to a common remote entity.

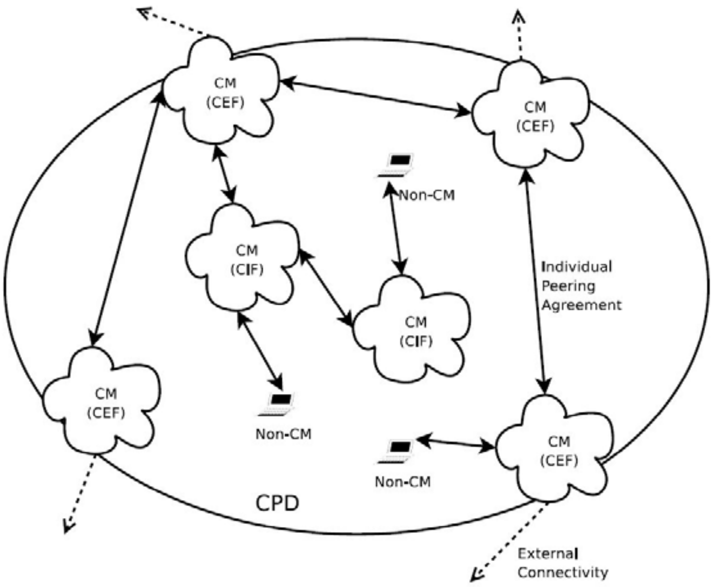

Figure 55 Coalition Peering Domain - nodes and networks

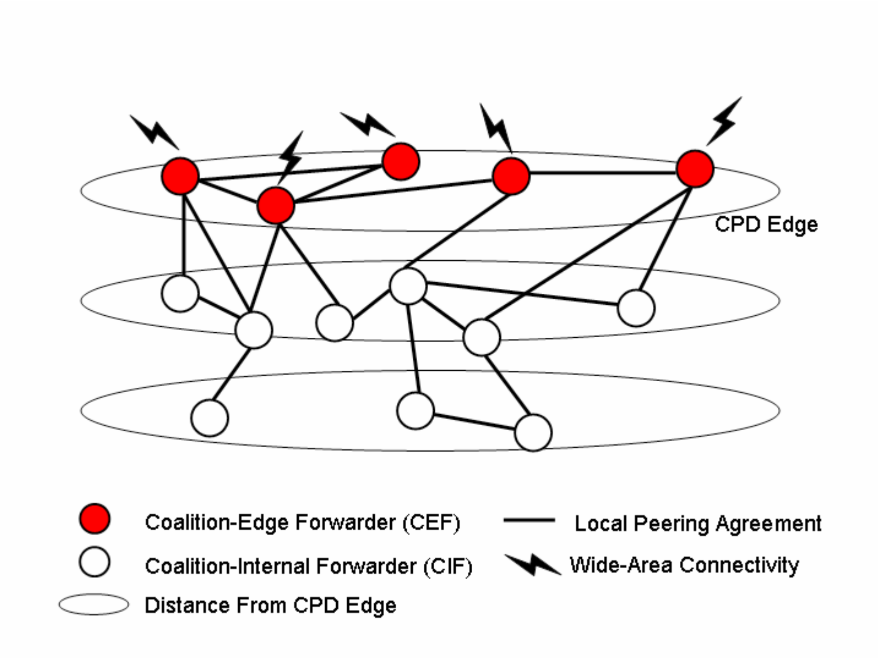

Figure 56 Coalition Peering Domain – abstract view

Coalition members who do not have connectivity outside the CPD, or who choose not to make available their wide-area capability to other CMs, act as Coalition-Internal Forwarders (CIFs). The forwarding of CPD-internal traffic (the traffic traversing between CMs) may be performed using modified forms of standard inter-domain or ad hoc routing protocols. In the example of collaboration for the purpose of wide-area connectivity aggregation, CIFs forward CPD-outbound traffic by directing it towards their `nearest' CEF for CPD egress. This traffic can be sprayed across the CPD edge by the receiving CEF as described above, thus, CIFs may also benefit. Of course, CIFs may also use mechanisms for load balancing and take responsibility for spraying directly to multiple CEFs, depending on the physical connectivity of the CPD.

Existing routing mechanisms are not adequate for enabling the CPD:

- BGP-based routing would be too heavyweight and too complex for most people (who are not experts in BGP) to manage.
- Existing ad-hoc routing protocols would need to be modified to cope with dynamic addressing requirements.
- Security models and trust relationships have to be examined for suitability in such a dynamic scenario.

Although the CPD architecture provides a means to enable easier collaboration between individuals, while maintaining local control, it is still disruptive to the existing architecture and service provision models. There are a number of challenges that must be overcome.

CMs need a mechanism to communicate with each other once they have formed local peering agreements. This implies that some form of addressing scheme should be employed within a CPD. However, addressing is a centralised function that would, in this context, need to be applied to a distributed system. This is a non-trivial task and needs careful consideration.

Although the use of Network Address Translation (NAT) devices may provide an obvious solution for community-area networks, they pose a number of problems that may limit the overall usefulness of the CPD. There is an increased chance that the arbitrary use of private addressing may lead to clashes between potentially peering CMs. They limit the operation of some types of applications as well as the abilities to apply security at the IP layer, and ultimately introduce unnecessary complexity in configuration and maintenance.

If we assume that all CEFs have a globally reachable address (allocated to them by their wide-area connectivity provider), then CEFs may communicate with each other by using these global addresses but routing them locally via the local peering agreement links. This can be enabled through the operation of an existing (or modified form of) routing protocol between the CEFs across the CPD edge. If we assume also that CEFs have additionally a block of addresses that they may sub-allocate (e.g. an IPv6 /64 block allocation), then CEFs may sub-allocate portions of this address space to any CIFs with which they peer. Routing of traffic to CIFs can thus take place through the address allocation hierarchy. This would also behave well with reverse path or CPD-ingress traffic because receiving CEFs can forward it to the allocating CEF for onward CPD-internal routing. Even though traffic destined for a specific remote destination may be sprayed across the CPD edge, the reverse path still relies on standard routing. This means that individual CEFs may be burdened with a greater volume of return path CPD-ingress traffic. However, the asymmetry of most wide-area connectivity technologies may be sufficient to offset this inequality. Alternatively, the burden for reverse spraying may be placed on either the remote party, or a provider-controlled device located beyond the CPD edge. Such multi-path routing would however, have implications for higher layer protocols that rely on the underlying routing infrastructure. Traffic may arrive at its destination with some delay or in an unordered fashion. If not addressed, this would cause major problems for delay-intolerant applications, such as video etc.

3.2.9.3 SharedBand

Note that much of the description here is taken from the SharedBand WWW site [103] [104] [105].

SharedBand takes an ‘overlay’ approach to creating shared connectivity. It works by creating a Community LAN between all of the Internet connections at a location. Sharedband then routes packets over the Community LAN in order to traverse the multiple IP connections, hence pooling the total capacity available to the community. For example four 2Mb DSL connections could be pooled to provide a shared 8Mb Internet pipe.

Sharedband treats the Internet, Community and Local network connections as 'just another IP pipe'. Consequently, it is agnostic about the technologies used. Provided IP packets can be sent and received over the medium, it may be Sharedband enabled.

Sharedband is low overhead software that can run on a wide variety of end user equipment including PCs, DSL modems, set top boxes and wireless routers. These include various Cisco/Linksys, Netgear and Asus wireless routers and ADSL modems.

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[103] SharedBand Technical White Paper - http://www.sharedband.com/Sharedband-Technical-Whitepaper.pdf

[104] http://www.sharedband.com/Sharedband-Broadband-Networking.pdf

[105] http://www.sharedband.com/About/how-sharedband-works.html

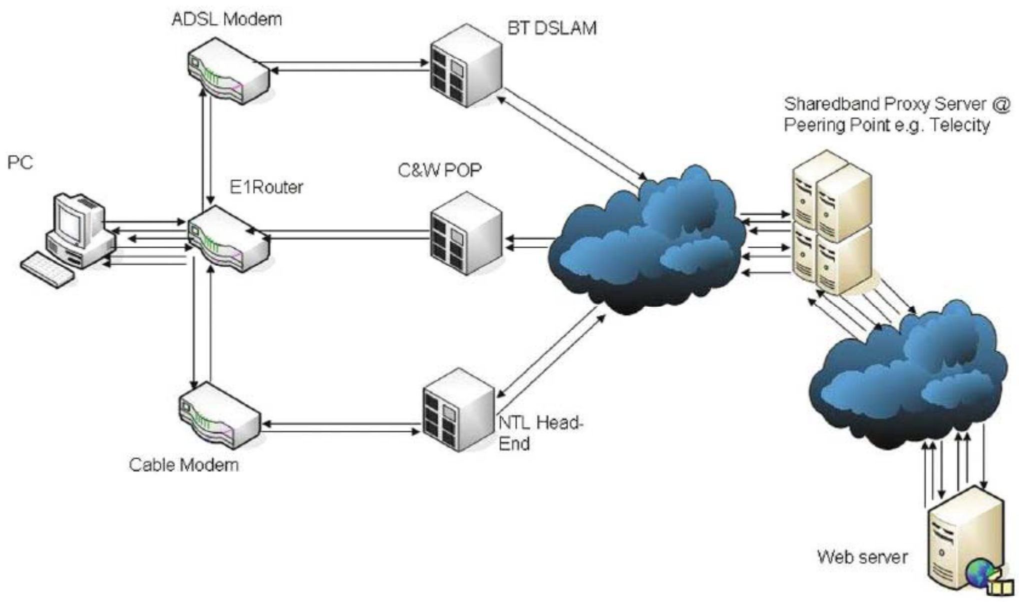

Figure 57 SharedBand deployment example
(source http://www.sharedband.com/About/how-sharedband-works.html)

In Figure 57, note that:

- The host marked ‘PC’ could, of course, be an entire site network.
- There could be multiple site network attached to the systems, one at each of the units marked ‘ADSL modem’, ‘E1 Router’ and ‘Cable Modem’.
- Each of the separate links going (ADSL, E1, Cable) could be interchanged with any other type of access link, including a wireless link.

Another model for shared-band is to use wireless access as shown in Figure 58.

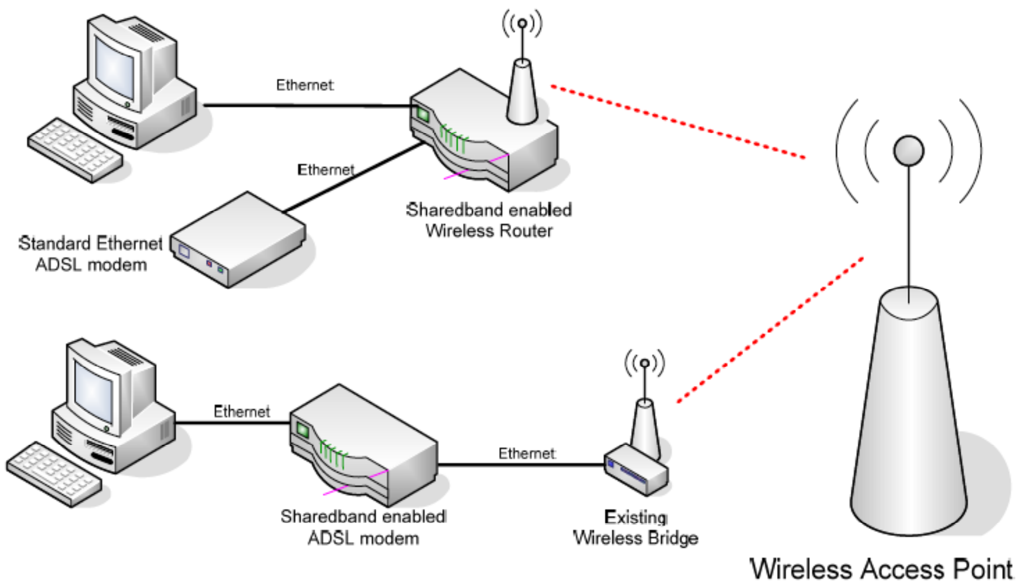

Figure 58 SharedBand using wireless access
(source http://www.sharedband.com/Sharedband-Technical-Whitepaper.pdf)

For the operation of Sharedband:

- Proprietary software is required for the wireless access points and/or access routers/devices at each site.
- The ISP must support access to the SharedBand Proxy Server Peering Point (see Figure 57).

The Proxy server can be located anywhere on the Internet, provided it is able to route IP packets to/from the Sharedband DSL links (or other links) and Internet services such as CNN. In order to minimise latency and improve performance it is recommended the Proxy server is located at the DSL provider's POP or hosting centre. For deployments where multiple DSL providers are used the Proxy server should be installed in a neutral hosting facility such as Telehouse which has fast connectivity to the main DSL providers. The proxy receives packets from multiple Sharedband routers and forward packets to the intended destination such as a web server. Returning packets are then forward to the originating PC via the Sharedband appliances and possibly the community LAN (depending whether the receiving Sharedband node is directly connected to the PC).

Once a second each Sharedband router sends a multicast heartbeat & announcement onto the Community LAN which contains details on its Internet connection, status and other useful information. Sharedband routers listen out for these heartbeats and build up a picture as to what Sharedband resources are available on the Community LAN. This allows a routing table to be constructed of all possible routes to the Proxy server and packets are sent on a weighted round-robin basis. In addition each Sharedband router sends heartbeats via Unicast to the proxy server (via its own DSL line or if that is not available another Sharedband router) so it can also build up an accurate picture as to what resources are available in a community. If a Sharedband proxy or router does not see any heartbeats from a node for 5 seconds it presumes that the node is no longer available and removes it from its routing table.

When the proxy server receives a heartbeat from a Sharedband router it responds with a short announcement to notify it that the proxy is alive.

When a Sharedband router receives a packet as the default gateway it encapsulates the packet in Sharedband's own UDP based protocol wrapper. UDP has been selected to ensure Sharedband will work correctly with Stateful Packet Inspection (SPI) firewalls which are present on many of today's DSL modems. The encapsulation adds a maximum of 16 bytes overhead to each packet. Because packets are being slightly enlarged, Sharedband will look for TCP SYN flags and automatically adjust the MSS value to ensure no packet fragmentation problems occur. Sharedband can map dedicated IP addresses to specific hosts attached to a Sharedband router, or perform Port Address Translation (PAT) where multiple users are sharing a single IP address. When the proxy server receives a Sharedband encapsulated packet, it undoes the encapsulation, re-writes the source IP address and port number to either a dedicated or shared IP address / port and sends the packet to its intended destination. The reverse occurs for returning packets.

At the time of writing (Sep 2006), the SharedBand WWW site did not list any ISPs as offering its service.

3.2.9.4 Summary and challenges for the joined-up broadband vision

The SharedBand approach has advantages that the service is potentially available readily and existing applications could work over the system.

However:

- It is an approach based on the use of overlays proxies and localised addressing mechanisms, and may not be transparent to all applications.
- It is based on a subscription to a commercial service.

- The SharedBand Proxy Server Peering Point presents a potential:
    - Performance bottleneck for users.
    - A single point of failure for the service as a whole.
    - A potentially easy target for a Denial of Service (DoS) attack.
- There are currently no providers of the service.

The CPD has the advantage that is potentially more generic, is deployable by end users directly and will not be a commercial offering.

However, for realising the Coalition Peering Domain (CPD) vision, there are a number of challenges to the current IP-based network architecture:

- IP does not easily support multi-homing. To support multiple ingress/egress links for an edge network, support for multi-homing is essential. Without it, the possible gains of route diversity (load sharing, resilience, bandwidth aggregation across multiple links) are extremely difficult to realise.
- Support for dynamic IP address management across multiple domains, hybrid IP routing (ad-hoc and fixed routing interworking) and multi-path forwarding across the CPD member nodes and networks.
- Signalling and resource discovery protocols to allow such functions as CPD join, leave and update, as well as management functions.
- Support localised (across the CPD) and wide area roaming in a coherent manner.

There are no obvious solutions currently available for these. Whilst it seems possible to build the required functionality, it is some years away from a commercially deployable capability. However, a possible standards-based solution has been proposed by one of our consortium [99]. The proposal takes an example within the military network context, though the architecture is general enough to be applied as described above. However, this proposal describes a system that has yet to be built and tested.

In overall conclusion, achieving ubiquitous access for many devices in many places is probably better served by the joined-up broadband vision (specifically coalition peering domains), rather than attempting to create a single last mile wireless system. The solution, whilst not ready now, is appropriate to the 10-20 year timeframe of this report.

3.3 Key questions and answers for Ofcom

This section gives very short answers to the key questions – more details are available in the immediately preceding sections. The predicted future broadband requirement notably includes a 10Mb/s streaming component; we have termed this Broadband 2.0 as it so far exceeds the present streaming capability typified by ADSL of 200kb/s[106], which we have termed Broadband 1.0.

Crucially, over the 10-20 year timeframe of this report, we predict that fibre will reach further into the local loop, thus providing the majority with Broadband 2.0 by FTTx + xDSL.

Rural areas however may welcome Broadband 1.0 by wireless, if otherwise they have no broadband at all, or an expensive satellite service. The other area where wireless may play a role is via Gb/s wireless as a fibre replacement, plus its importance within the home will continue.

3.3.1 Are TV band approaches suitable?

Only if no more than the present contended ADSL services are required (Broadband 1.0). Calculations aimed at providing Broadband 2.0 indicate that either there is insufficient physical spectrum available, or an unfeasibly high base station density would be required.

This conclusion may be generalised to both cleared and white space TV bands approaches and indeed to any approach at UHF below about 1GHz.

3.3.2 Are mesh approaches suitable?

Mesh approaches suffer from the same basic limitations for wireless as for TV/UHF approaches, with the added complication of shared bandwidth and increased latency. The main advantage of a mesh is helping availability of coverage in difficult scenarios, not throughput enhancement. They could aid Broadband 1.0 deployment.

Working at higher frequencies would allow more bandwidth, for example 5GHz of spectrum is available at 60GHz, but the prices make such a service uneconomic[107]. This point on cost may be extrapolated to non-mesh 60GHz systems.

3.3.3 What about the emerging standards?

Key emerging wireless standards are WiMAX version e[108] and HSDPA. WiMAX plusses are that it is multimedia biased and will receive a big push from Intel based laptops. On the downside it has no polite protocols, so needs dedicated spectrum, and there presently exists no infrastructure. HSDPA plusses are that infrastructure exists, although software upgrades are necessary. On the downside it has latency and hence multimedia issues.

The real issue however is that these systems were designed to provide *mobile* broadband, whose requirements are nowhere near those required for home broadband. One key reason is the difference in viewing screen sizes. It is therefore unfair to expect WiMAX version e or HSDPA to compete in the Broadband 2.0 last mile space.

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[106] 10Mb/s ADSL provided at 50:1 contention may only stream 200kb/s when fully loaded. This will not support IPTV.

[107] For more detail, see the Ofcom report 'Higher Frequency Licence Exempt Bands', to be published.

[108] Version e (mobile) is expected to dominate over the older version d (fixed)

3.3.4 How will back haul cope?

The aggregation of Broadband 2.0 customer lines will certainly require bandwidth upgrades. Some of this might be provided by Gb/s wireless as a fibre replacement technology.

3.3.5 How to achieve truly personal broadband?

Coalition peering domains are preferred to a nationally tetherless single system, since they are more integrative and flexible with respect to incorporating as yet unknown future devices.

3.3.6 Does last mile need a dedicated band?

No, since dedicated bands don't stop the 802.11/802.16 interference problem, yet both could be grouped as last mile applications. Polite protocols are preferred, perhaps in conjunction with Codes of Practice.

Unlike mobile, where there are great advantages in using the same technology/system approach everywhere, last mile access is serving fixed subscribers. Different locations could use different technologies or frequency bands. Indeed there is some merit in using different bands in urban and rural areas to get the most appropriate coverage from each base station.

3.3.7 What about licensing?

The technical restrictions placed on licence exempt bands are extremely important. We suggest that the regulations are drafted such that only systems with some sharing etiquette or polite protocols are allowed otherwise the bands will only be suitable if

- lightly loaded or
- long delays/ high latency can be tolerated (i.e. best effort is enough).

Although it was not an initial aim of this work, it has been quite impossible not to recognise the importance of fibre to the future of broadband. We note that forbearance on fibre unbundling rules has been introduced in the US [FCC 2004b] and this has led to large-scale, commercially-driven innovation. This is not presently the case in the EU.

3.3.8 How much spectrum?

Wireless seems capable of emulating what contended ADSL can do now, i.e. Broadband 1.0. The issue is that ADSL could be enhanced by eliminating the 50:1 contention via improved back haul. The problem for radio is that this 50 times capacity increase would require 50 times more cells or 50 times more spectrum.

This is the cornerstone of the argument which says that the requirements of Broadband 2.0 are for far more spectrum than is presently available at non-line-of-sight frequencies - by an order of magnitude or more. Moving to higher, line-of-sight carrier frequencies is precluded on grounds of cost.

For rural areas, wireless would support Broadband 1.0 only. Our worked example showed that about 40MHz of spectrum is suitable for Broadband 1.0. This is very much along the lines of what is supplied today by, for example, UK Broadband.

Although outside this report's scope, given that home wireless usage is likely to increase and the traffic is likely to move over to mainly streaming, it would seem appropriate to reconsider the likely amount of licence exempt spectrum required, given that some estimations performed recently have considered only non-real time traffic.

3.4 Preferred solutions summary – urban and rural scenarios

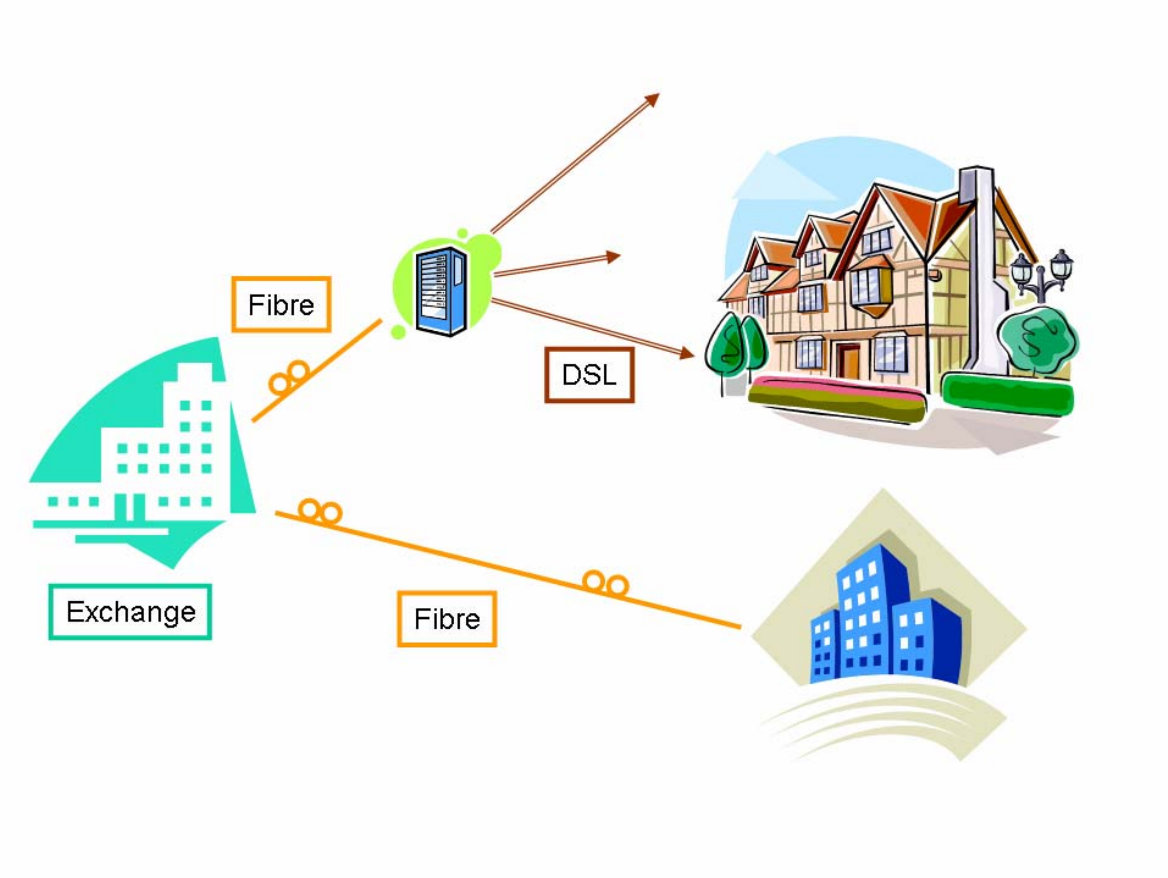

Figure 59 Future urban Broadband 2.0 scenarios: FTTP and FTTx + xDSL

Figure 59 shows that fibre will need to extend into the local loop. Where legacy copper exists this may be used as a distribution network, following the fibre feeder. In other words, this is FTTx+xDSL. Where no legacy copper exists, or the maximum future-proof bandwidth is required, fibre all the way to the premises is appropriate. In other words, this is FTTH/FTTP.

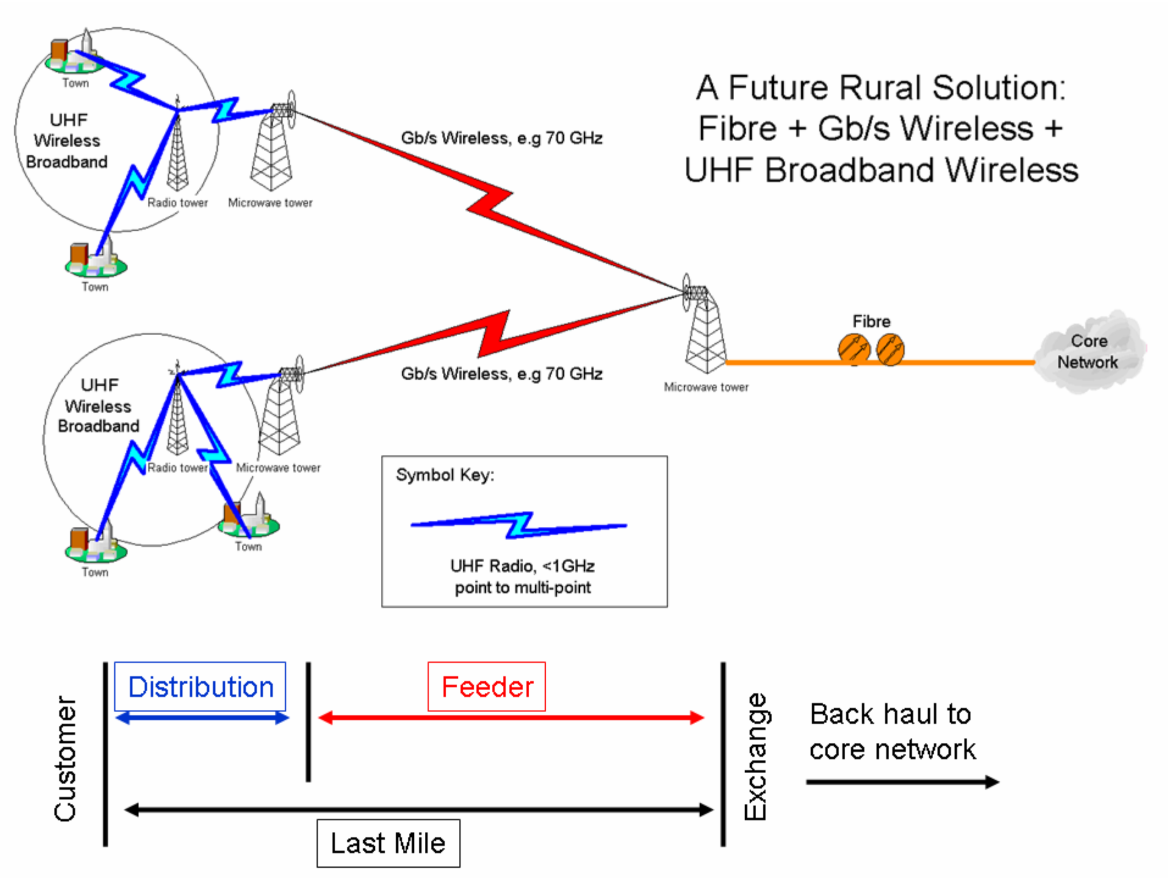

Figure 60 Future rural Broadband 1.0 scenario: Gb/s wireless + UHF wireless (repeated figure)

Figure 60 shows clearly the role which Gb/s wireless can play in filling the gap between any new high speed access technology and the existing reach of installed fibre. In the rural case, we know (e.g. 3.2.2) that the penalty for large cells of several km is that access capacity will be low, given the limited bandwidth. Hence, Gb/s feeder may be overkill and WiMAX or leased microwave at 10/28/38GHz could be used for rural last mile feeder.

In the urban case, the cells will be small enough to ensure better bandwidth, so aggregation towards Gb/s rate in the last mile feeder is more likely, c.f. section 1.1.7.

3.4.1 A technology decision tree for wireless broadband

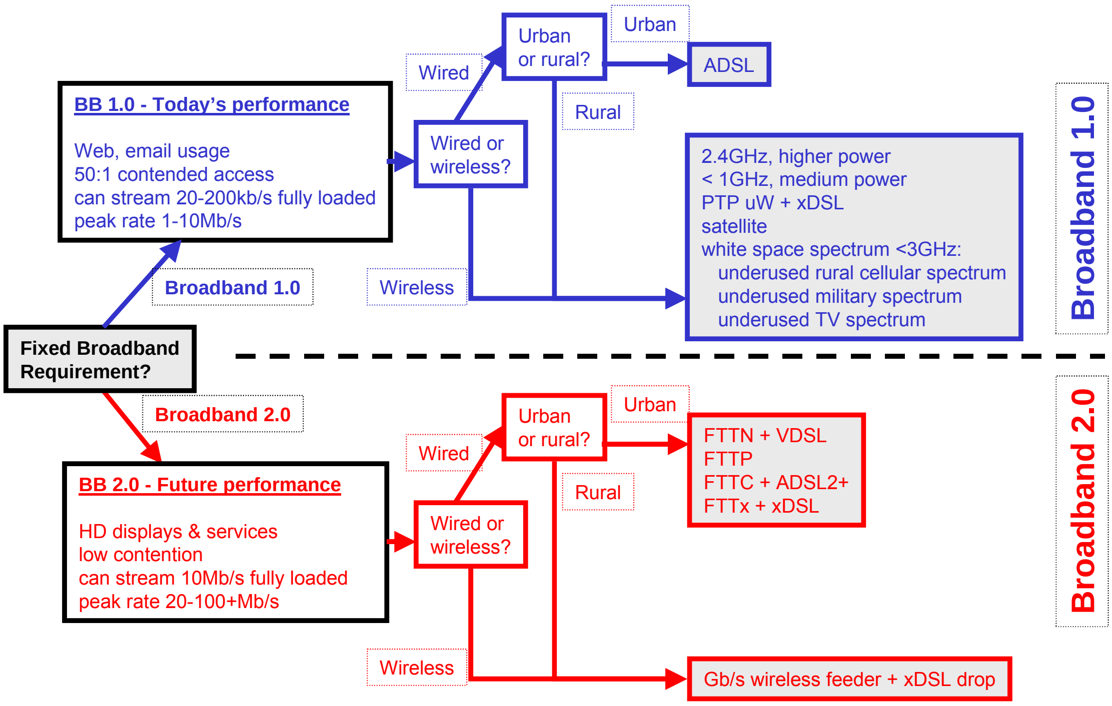

Figure 61 Technology decision tree for broadband (repeated figure)

Figure 61 shows that if only Broadband 1.0 capability is required, then many solutions, including wireless can be considered. However, if a Broadband 2.0 capability is needed, then fibre or Gb/s wireless as a fibre replacement must be included in the solution.

4 Net UK Benefits and Business Cases

4.1 Net UK benefits from a social welfare perspective

We use the economic value approach [Webb 1998].

It is widely accepted that the key to providing future economic rural wireless connectivity is to reduce the number of base stations below that presently required[109]. This is equivalent to using some method to increase transmitted range.

Whatever method is chosen to increase range, benefits will accrue similarly for the same achieved range and will be independent of method, *ceteris paribus*. For example, either of the two following methods can increase range and hence benefits:

- Higher transmitter power
- Suitable choice of transmit frequency

If both methods resulted in a range of, say, 10km, then each solution could facilitate the same benefits, *ceteris paribus*. Economic value could then be calculated by also considering the costs of each method.

4.1.1 Assumptions

We note that the High Power report [Generics 2006] has already shown that increasing range to 7.5km will result in the greatest increase in consumer surplus[110]. The figure of 7.5km is entirely consistent with earlier sections of the Last mile report, which indicated that ranges beyond the reach of ADSL were a target for wireless last mile applications. The last mile report shows that a 7.5km range can also be achieved by working at UHF with a smaller power increase.

Turning to the future, fibre will replace ADSL, since ADSL is incapable of supporting the future multimedia mix. Section 3.2.5 showed that many schemes exist, under the title of FTTx, , where x may represent the home, the curb etc - in general the greatest reach of fibre into the local loop. For example FTTP takes fibre all the way to the premises (home/business) and FTTN takes fibre to the node, or street cabinet, from where VDSL may take the signal onwards over the remaining short distance.

We assume that FTTx will attack the business market first, cherry picking these sites since they pay the highest prices and are closest to the exchange (i.e. they are non-rural). This is a difference between the last mile report and the High Power report: We assume that either ADSL or fibre will serve all the non-rural customers - these customers will not need wireless. Hence the last mile factual[111] expects the business portion of the consumer surplus to be zero and the consumer surplus to be derived entirely from benefits delivered to residential customers in rural areas. The business contribution to consumer surplus was very large (90%) in the High Power factual, so the effect of

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[109] i.e. at 2.4GHz

[110] This result was before any considerations of frequency and power, i.e. it was independent. The assumed range of the base stations leads to the consumer surplus. Therefore any realistic combination of frequency and power, which yields the same cell range, would yield the same consumer surplus, *ceteris paribus*.

[111] factual – the case of the proposed scenario, versus counterfactual – the base scenario

removing it is large.

In the last mile report, improved range is achieved by choosing to work in the UHF band. In fact this represents a dual net benefit contribution, since the interference costs identified in the High Power report for 2.4GHz business users are simply not present in the UHF band approach.

Table 28 shows this in more detail, comparing High Power (HP) and Last Mile (LM) factuals. the counterfactual is the same in each case - the status quo.

	Parameter/attribute	**High Power factual (HP)**	**Last Mile factual (LM)**	**Same/ Different**	**Comment**
1	Access method	2.4GHz, 10W	<1GHz, power TBD	Different	See 2 below
2	Coverage cell radius (Key normalising step for comparison purposes)	7.25km	7.25km	Same	Choose power to achieve the same 7.25km range. Expected 10dB lower, ceteris paribus
3	Spectral resource (Key normalising step for comparison purposes)	3 x 20MHz channels (independent)	3 x 20MHz channels (independent)	Same	Availability of equivalent spectral resource <1GHz is assumed
4	Residential users (Key benefits similarity)	> 4km cannot receive residential quality wired broadband	> 4km cannot receive residential quality wired broadband	Same	Wired broadband may be fibre or ADSL – the roll-out limitations are assumed to be the same in either case
5	Business users (Key benefits difference)	>2km cannot receive business quality wired broadband	All business users receive fibre early, since operators cherry-pick best ARPU's.	Different	HP figures show CS separately for business and residential, so LM factual analysis can • use residential proportion of CS only, and • equate this to representing the rural portion of a deployment, since HP factual states the business and rural sets are largely exclusive *CS = Consumer Surplus*

6	Business/residential vs. Urban/rural sets	Business => Not Rural	Business => Not rural	Same	Key finding from HP study (p129), used in 5 above
7	Major interference victims (Key cost difference)	Business users already in band	None in band	Difference	The assumption is that there would be, and continue to be, no legacy business users in a chosen band <1GHz. Clearly this could be chosen to be true or false in future, depending on the spectral allocations used.
8	Interference suffered by residential users (Key cost similarity)	None	None	Same	As above, since there are no legacy residential users in band either. This assumption has been maintained, although for HP we expect it would fail to be so clearly true into the future as home working (for example) increases and uses wireless resources more intensively (low utilisation was the rationale for the assumption). A second example would be the expected increase in home entertainment.
9	Substitute for those users outside wired broadband range (Key substitute similarity)	Satellite	Satellite	Same	Satellite costs used by HP were queried by Ofcom. They were thought to be (i) high at £500pcm for business and (ii) so different to wired costs that a linear demand curve construction may not be appropriate. The LM study could not find a 4Mb/s

					symmetric up/down satellite solution for the UK. The nearest was 1Mb/s / 256kb/s at £355pcm or more commonly 512/128kb/s at typically £70pcm. Nonetheless, we have kept the same approach for comparison purposes, although we note an overestimate of CS may be expected.
10	CPE (user) antenna	Outdoor, 10dB directional	Outdoor, 10dB directional	Same	Again, kept the same for comparison purposes. Cost drivers identified in the LM work suggest that indoor, non-directional CPEs are more desirable for an economic service (lower OpEx). As a first order estimate, this might be accounted for by increasing the transmitted power in the <1GHz case by the 10dB of lost directionality, plus 15db of penetration loss.

Table 28 High Power vs. Last Mile factuals

4.1.2 Benefits via consumer surplus

The benefits are as in the High Power report [Generics 2006], but for residential users only. From Table 25 of that report (Table 4, page 48 in this report), the residential component of consumer surplus is seen to be £54M.

4.1.3 Interference costs

The major interference cost, to 2.4GHz business users in band, is absent for several related reasons:

- Business users are assumed to be served by fibre

- Businesses are mostly non-rural, so are not in the proposed deployment area
- There are no incumbent business users in the UHF band in any case

4.2 Net Benefit to the UK

The net benefits are £54M, since there are no cost to business users (there are no existing business users in band) and we have maintained the assumption from the High Power report that residential user costs are negligible.

4.2.1 Applicability of the model – an upper bound

We note the comments in the High Power report from the authors and from Ofcom. Many of these still apply, for example

- The deployment of ISP cells into ADSL fringe areas is questionable from a commercial perspective. This will lead to an overestimate of net benefits.
- Satellite costs may have been overestimated, possibly as a result of trying to offer a symmetric service by satellite (for which a low cost service is not intended). This will overestimate net benefits. In other words the analysis is likely to have established an upper bound.

In terms of costs, we have shown that the major cost identified by the High Power approach is absent. There must however be some future possibility of a UHF rural broadband causing costs to others, but without knowing which exact spectrum is to be used, these costs cannot be estimated. However, assuming positive costs are likely to occur, this does make the estimate of net benefits a likely over-estimate.

Also in terms of costs, since some DSO spectrum could be used for such a service, there are the opportunity costs of choosing broadband access for this spectrum rather than, say, mobile TV.

Overall we note that the net benefit as calculated is quite modest and likely to be an over-estimate. However we expect that a bigger social benefit will arise - that of staving off the deepening of the 'digital divide', by ensuring that rural users can access at least an ADSL-like service which will be better and cheaper than satellite, although such service will still fall short of the fibre service ultimately enjoyed by the majority.

4.3 National competitive advantage

Not included in the economic value assessment is the importance to the UK of having Broadband 2.0 provided by fibre, in terms of remaining internationally competitive into the future. We see this as a major driver. It would be a greater national advantage to have Broadband 2.0 sooner rather than later.

4.4 Financial aspects for a provider's business case

This report has identified a fibre based last mile as the most likely future option for the delivery of Broadband 2.0. The technical case had been satisfactory for many years – what has changed recently is the business case, which we outline next.

4.4.1 Fibre revenues and costs

Fibre install costs vary widely depending on the location, for example building underground fibre networks in highly congested urban areas is reported to cost $100 or more per foot of cable installed[112]. By contrast, placing fibre underground in the suburbs costs $7 to $25 a foot. The following 'rules of thumb' costs for installing fibre obtained from a GigaBeam Inc. webinar agree with the above

In a US city with pop. 250-500k people: $100k/mile in suburban areas for fibre
$200k/mile in urban areas for fibre
$250k/mile in the dense urban core for fibre

In NY or SF, it is $1M per mile for fibre

Moving to look at revenues, Verizon reported that, at a per customer revenue of $39 pcm, it expects to recoup the cost of the extent of its fibre deployment by the end of the decade. This is in no small part due the predicted continuance of the cost savings which Verizon have reported, in terms of reduced maintenance.

This result is a departure from earlier analyses of fibre deployment and represents a dramatic change in the perception of installing fibre. It must be noted that a lower ARPU of ~ 20Euro has been estimated by Alcatel, which assumes users receive 25Mb/s with symmetry and services which include HD services and peer to peer file sharing. This may simply be a national difference in willingness to pay, or it may reflect the differences in the US business model, notably that Verizon is competing against the cable companies for triple play.

Whichever is true, the business case for fibre appears to be the most robust it has ever been.

[112] source: Michael Render, president of Render, Vanderslice & Associates, a market research firm

5 Recommendations

5.1 Technology

Over time the basic transport requirement for Internet in terms of speed and latency will rise and these minimum levels will be set by the services that are expected. For example Internet TV for domestic viewing sets a clear performance level requirement rather than the best efforts which dominate today.

This report has identified and accepted FTTx + xDSL is the most likely candidate to supply last mile broadband access over the next 10-20 years. It is widely accepted that streaming content of at least 10Mb/s is likely. This is so far away from what today's broadband can do (typified by ADSL which can stream only 10's of kb/s) that we have termed it Broadband 2.0. Wireless cannot compete with FTTx+xDSL to provide this service.

However FTTx+xDSL will not be a total coverage solution - it may cover about the same proportion as ADSL today - and some last mile feeder links may be Gb/s wireless in place of fibre. Where Broadband 2.0 does not reach, then there is a space for wireless to play – but only to provide today's lesser level of broadband, Broadband 1.0. But our belief is that any realistic business plan from a commercial company will still leave some people for whom an adequate service would not be provided.

This situation was summarised in Figure 61, a technology decision tree for future broadband. Additionally, it should not be forgotten that an increase in back haul capability will be needed to support Broadband 2.0, irrespective of the access method used.

Additionally, it is expected that the present success of IEEE 802.11 for home networking will continue.

It is a national policy matter as to what performance levels should potentially be available to prevent a 'digital divide'. With telecoms there is a USO placed on BT which could be re-visited, or other providers could be tasked with providing service if financed appropriately. Perhaps meeting some of the costs through regional funding schemes, or supporting community initiatives etc would be appropriate.

5.2 Spectrum

5.2.1 Broadband 2.0

Gb/s wireless feeders should be allowed access to many GHz of bandwidth at 60/70/80GHz.

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

5.2.2 Broadband 1.0

In order to facilitate Broadband 1.0 in rural areas, spectrum should be made available at suitable frequencies, for example within the UHF TV bands by re-allocation or geographic sharing; or sharing of geographically underused cellular or military spectrum at UHF.

5.3 Regulatory

5.3.1 Licensed bands

With Ofcom's spectrum management policy preferring market forces to be the major driver, last mile is unlikely to be the favoured application when compared to other below 3GHz based uses. In other words, with respect to DSO spectrum, market forces are unlikely to promote rural broadband access.

5.3.2 Licence exempt bands

Any additional bandwidth and subsequent lack of interference to/from other users would give a better service than the existing licence exempt bands. However as in the case of new licensed spectrum it is hard to justify this as being the best use for this spectrum, on a market forces argument, except perhaps in rural areas.

We would also comment that if new licence exempt bands are to be a part of the solution. (e.g. as regional blocks released through cognitive sharing) then their regulation should be different from current unlicensed bands. Permitting only radio standards with compatible radiation characteristics and polite protocols or etiquettes for co-existence are desirable. We would also suggest that problems with current Codes of Practice are noted and measures are adopted to overcome these.

5.3.3 Fibre

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.

The EU regulatory bodies may wish to consider forbearance[113] on fibre unbundling in order to encourage deployment and empower innovation as in the US. Fibre is essential to providing a Broadband 2.0 capability to the UK.

5.4 Key recommendations summary

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 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

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[113] e.g. c.f. [FCC 2004b]

mainly streaming, it would seem appropriate to reconsider the likely amount of licence exempt spectrum required, given that some estimations performed recently have considered only non-real time 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.

Plextek

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Appendix B Abbreviations and Glossary

21CN	BT's 21st century network plans
3GPP	3rd generation partnership project (3G etc standards association)
ARPU	Average revenue per user
BER	bit error rate
BS	base station
CATV	common antenna TV
CPE	customer premises equipment
DOCSIS	data over cable interface specification
DRM	digital right management
DSL	digital subscriber line
EFM	Ethernet in the first mile
EV	economic value
Gb/s wireless	Radio at 60-80GHz, >1Gb/s throughput, range <1-2 miles
HD, HDTV	High Definition (TV)
HSDPA	High speed down link packet access
IEEE802.11	'WiFi' standards setting body
IEEE802.16	'WiMAX' standards setting body
IX	Internet Exchange
L/LE/LEA	Licensed, Licence Exempt, LE-Application specific
Last mile distribution	see Figure 4, page 10
Last mile feeder	see Figure 4, page 10
MPEG-x	Video coding standards, e.g. MPEG-2, MPEG-4
MS	Microsoft
NPRM	notice of proposed rulemaking (FCC)
PMP	point to multipoint (e.g. cellular)
PoP	Point of Presence (for Internet provider)
PP	polite protocols (for medium access) (aka 'etiquette' in US)
QoS	quality of service
Radio Mobile	Propagation prediction tool using terrain data. (uses ITM - irregular terrain model, Longley-Rice). Can read SRTM terrain data.
SD, SDTV	Standard definition (TV)

Segregated Bands	
SNR	signal to noise ratio
SRTM	Shuttle Radar Topography Mission (terrain data for propagation modelling)
VoIP	voice over IP
WiMAX	An implementers’ forum for 802.16 applications
WISP	wireless Internet service provider

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Appendix E DECT Guard Band - award text extract

‘’Proposed approach to engineering co-ordination

6.29 Licensees will be under a general obligation to co-ordinate on a best endeavours basis and to negotiate in good faith where interference occurs.

6.30 In principle, Ofcom proposes to allow concurrent low power licensees to manage the engineering co-ordination process amongst themselves. There may be a need for licensees to exchange information on the location and characteristics of base stations and to come to local arrangements on sharing spectrum, siting of transmitters, power levels, etc. Exactly what information is exchanged (if any) and how this is managed should be left up to the industry to agree. The arrangement relating to this engineering co-ordination should be formalised by the establishment of an industry Code of Practice.

6.31 Ofcom proposes to require all concurrent low power licensees to agree such a Code of Practice within 6 months after the licences are awarded. The Code should deal with the procedural and technical issues with managing engineering co-ordination. This Code of Practice will need to set out clearly defined principles which will allow the licensees and Ofcom to judge whether an individual licensee is complying with the Code.

6.32 The objective of the Code should be to promote efficient use of the Spectrum Bands so that, as far as possible, systems are deployed in a manner that will allow similar and competing services to be deployed alongside each other (e.g. in neighbouring premises and locations, including on different floors of the same building). In developing the Code, Ofcom would expect that, as a minimum, the following principles should be considered:

a. Efficient frequency use of the Spectrum Bands (e.g. not using more channels than is absolutely necessary to provide an effective service to customers);

b. Possible conditions on limiting transmission powers (below the licensed limit) to that just necessary to effectively provide service;

c. Selection of sites and the siting of equipment within customer premises and elsewhere in a manner that will minimise the probability of mutual interference; and

d. Identifying the type of information that needs to be communicated between licensees and the arrangements for its exchange.

6.33 Mitigation techniques such as automatic power control and dynamic frequency selection may be considered for inclusion in the Code of Practice where they can be implemented on a technology neutral basis.

6.34 Licensees should be aware that the Code, and the activities of the licensees in connection with engineering co-ordination, need to comply with the requirements of competition law and any other relevant legal requirements.

6.35 The proposed licence will also give Ofcom the power to impose an engineering co-ordination procedure if absolutely necessary (e.g. where licensees either fail to agree the Code or where it is clear that the objective sought by the Code is not being achieved either through lack of co-operation or shortcomings in the Code itself).

6.36 As a matter of policy, Ofcom will not have a role in resolving individual engineering co-ordination disputes. Ofcom will only become directly involved where the objectives sought by the Code of Practice are clearly not being secured. Such involvement will be limited to the imposition by Ofcom of a Code of Practice setting out a relevant engineering co-ordination procedure rather than the micro-management of individual co-ordination requests. Where a licensee fails to abide by a Code of Practice that has been imposed by Ofcom, this will be treated like any other breach of licence conditions and therefore it is possible that it could lead to Ofcom revoking the licensee's licence.''

Appendix F Third Party Services

Third party services means things like wireless hotspots in cafes etc. This distinguishes between personal use of Bluetooth, WiFi etc and systems where there is a service provider. 2003 was when public hotspots were permitted: the key step being to allow many devices to access the same hotspot rather than the personal use of a dedicated pair of radios.

With WiMAX and wide area WiFi coverage any congestion of unlicensed bands might be expected to be dominated by these applications rather than contained personal use.

The European Commission adopted a recommendation on 20 March 2003 that calls upon Member States "to facilitate the use" of wireless networks for accessing public services over the Internet. It encourages Member States to allow deployment of WiFi access networks with minimal conditions.

The Commission talks in terms of R-LANs, or Radio Local Area Networks – better known as WiFi or WLANs (as in Wide LANs).

Basically, WiFi offers broadband wireless access to the Internet. Until recently, broadband access has been mostly offered over the copper telephone network (e.g. using ADSL technology) or via cable TV networks with cable modems. WiFi offers a complementary approach, for anyone within range of a so-called "hot spot," provided they have a suitably equipped laptop or other web-enabled device.

Erkki Liikanen, European Commissioner for Enterprise and Information Society said:

> "Today's Recommendation is an important step for the deployment of multi-platform and high-speed Internet connections. The R-LAN technology will give European citizens ready-access to the knowledge-based society when in public places, and away from their home location and will be complementary to other means to access broadband services."

Wireless networks currently operate predominantly in the licence exempt 2.4 GHz band. The new recommendation will encourage all Member States to allow the deployment of public WiFi access networks without sector specific conditions and subject only to general authorisations in line with the new Authorisation Directive.

Appendix G FCC public notice on TV shared band devices

ET Docket No. 04-186

On May 13, 2004, the Commission adopted a *Notice of Proposed Rule Making* ("*Notice*") proposing to allow the operation of unlicensed devices on TV channels that are unused at any given location.[114] This public notice establishes a schedule for resolving outstanding issues in that proceeding so that unlicensed devices designed to operate on unused TV frequencies may be placed on the market with the completion of the DTV transition.

The Notice proposed to require that fixed unlicensed devices incorporate a geo-location method such as GPS or be professionally installed, and that they access a database to identify vacant channels at their location. It proposed to require that portable unlicensed devices operate only when they receive a control signal from a source such as an FM or TV station that identifies the vacant TV channels in that particular area. The Commission also sought comment on the use of spectrum sensing to identify vacant TV channels, but did not propose any specific technical requirements for devices that use spectrum sensing.

Comments were filed both in favour of and in opposition to the proposals in the *Notice.* Broadcasters and other TV spectrum users expressed concern about potential interference from unlicensed devices to the various services that operate in the TV bands. These services include full service TV, low power TV, TV translators, TV boosters, broadcast auxiliary services such as wireless microphones, and the commercial and private land mobile radio services. Manufacturers and users of unlicensed devices largely support the use of spectrum sensing and other measures as a means to prevent interference.

The record before the Commission does not contain sufficient information to adopt final technical rules for operation of unlicensed devices in the TV bands. For example, because the *Notice* did not make any specific proposals regarding spectrum sensing, there is no information in the record as to key criteria that would need to be specified to allow the use of that technique, such as the required levels for sensing, spectrum to be scanned, and durations for the sensing. Accordingly, the Office of Engineering and Technology is developing a First Report and Order and Further Notice of Proposed Rule Making that would make initial decisions and specific technical proposals necessary to adopt complete and final rules, taking into the account the comments received in response to the May 2004 *Notice*.

In addition, a number of parties participating in this proceeding have stressed the importance of conducting field tests to ensure that whatever standards are ultimately adopted will protect other radio services against harmful interference. We encourage interested parties to conduct tests and submit them into the record for this proceeding. In the meantime, the FCC Laboratory plans to conduct its own testing program to quantify the interference rejection capabilities of DTV receivers and to assess potential interference from unlicensed devices operating in the TV bands. The FCC Laboratory also plans to test DTV converter boxes once they become available. Details regarding FCC testing will be announced at a later time.

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[114] *Unlicensed Operation in the TV Broadcast Bands; Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band*, Notice of Proposed Rulemaking, 19 FCC Rcd39. 10018 (2004).

Taking these factors into account, the Commission staff has developed the following schedule of actions in this proceeding.

Projected Date	Milestone
October 2006	Commission adopts a First Report and Order and Further Notice of Proposed Rule Making
March 2007	FCC Laboratory reports the results of measurements of the interference rejection capabilities of DTV receivers
July 2007	FCC Laboratory reports the results of tests evaluating potential interference from unlicensed devices to TV and other radio services
October 2007	Commission adopts a Second Report and Order specifying final technical requirements for unlicensed devices that operate in the TV bands
December 2007	FCC Laboratory begins accepting applications for certification of unlicensed devices operating in the TV bands; certification will be granted at such time as the application has been reviewed and found to comply with the rules; certification will permit manufacture and shipment of products to distribution points
February 2009	Products will be available for sale at retail

This proposed schedule provides sufficient time to develop appropriate technical standards to prevent interference to TV broadcasting and other services, as well as sufficient lead time for industry to design and produce new unlicensed products that would be available for sale to the public at the completion of the DTV transition on February 17, 2009.