

Frequency Band Review for Fixed Wireless Service

Final Report Prepared for Ofcom

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1 INTRODUCTION

This report presents the findings of a study commissioned by Ofcom into the potential future demand for spectrum in frequency bands currently used by point to point fixed links. This demand could continue to come from fixed links themselves or from other applications, such as satellite links or short range devices. The study involved the development of a number of scenarios for downstream service evolution and assessing the implications for spectrum demand under each one. An attempt was also made to quantify the capacity of certain frequency bands where future demand for fixed links and other services was considered likely to be particularly high.

The primary objective of the study was to develop a set of spectrum demand scenarios to assist Ofcom in developing its strategy for managing the fixed service frequency bands over the next decade. Part of the process of developing the spectrum demand scenarios involved the generation of a set of scenarios illustrating potential market and technology developments in downstream services that rely to a greater or lesser extent on fixed wireless spectrum. These include services such as mobile and broadcasting, which use fixed wireless links for backhaul and distribution, and satellite services which can compete with fixed services for access to specific frequency bands. Account was also taken of the likely needs of other more specialised fixed link users, such as local authorities, utility companies and the public safety community.

The spectrum demand scenarios presented in chapter 6 are not intended to provide precise forecasts of the amount of spectrum required for fixed links in particular bands, but rather to provide an indication of how spectrum demand for fixed links and other services that could use the same spectrum might vary under different sets of assumptions. The demand scenarios are intended to help Ofcom in developing administrative and pricing policies for fixed links and satellite services, for example with regard to permissible link lengths in different frequency bands or the co-ordination criteria applied to shared bands. The following bands were included within the remit of the study. The main focus of the review was on the Ofcom managed bands; other bands listed are those that have been either auctioned as blocks on a technology neutral basis to individual licensees or operate on a licence exempt basis.

Table 1.1: UK Frequency Bands for Terrestrial Fixed Services

Band	Frequencies (MHz)	Band Status
1.4 GHz	1350.5-1374.5/ 1492.5-1517 (2x24 MHz)	Ofcom Managed
4 GHz	3689-3875/ 4009-4195 (2x186 MHz)	Ofcom Managed
5.8 GHz	5725-5875 MHz	Ofcom Managed— Light Licensed
Lower 6 GHz	5930.375-6419.615 (2x237.2 MHz)	Ofcom Managed
Upper 6 GHz	6430-6760/ 6780-7100 (2x330 MHz)	Ofcom Managed
7.5 GHz	7428-7652/ 7673-7897 (2x224 MHz)	Ofcom Managed
10 GHz	10125-10225 / 10475-10575 (2x100 MHz)	Auctioned
13 GHz	12751-12975/13017-13241 (2x224 MHz)	Ofcom Managed
15 GHz	14501-14613/ 15229-15341 (2x112 MHz)	Ofcom Managed
18 GHz	17700-19700 (2x956 MHz)	Ofcom Managed
23 GHz	22000-23600 (2x588 MHz)	Ofcom Managed
26 GHz	24500-26500 (2x896 MHz)	Ofcom Managed
28 GHz	27828.5-28444.5 / 28836.5-29452.5 5 (2x616 MHz)	Auctioned
32 GHz	31815-33383 (1568 MHz total)	Auctioned
38 GHz	37000-39500 (2x1120 MHz)	Ofcom Managed
40 GHz	40500-42500 (2000 MHz total)	Auctioned
52 GHz	51400-52600 (2x504 MHz)	Ofcom Managed
55 GHz	55780-57000 (2x504 MHz)	Ofcom Managed
60 GHz	57100-63900 (6800 MHz total)	Licence Exempt
65 GHz	64000-66000 (2000 MHz total)	Ofcom Managed— Light Licensed
70 GHz	71125-75875 (4750 MHz total)	Ofcom Managed— Light Licensed
80 GHz	81125-85875 (4750 MHz total)	Ofcom Managed— Light Licensed

The current status of these frequency bands is described briefly in the following chapter.

2 CURRENT STATUS OF FIXED LINK BANDS

2.1 Introduction

“Fixed links” in the context of this study are point to point radio links used to convey voice or data traffic between two specified geographic locations. Such links provide an alternative to other transmission media such as copper cables or fibre and are used for a variety of applications, including:

- Backhaul provision for mobile network base stations
- Distributing TV signals from studios to broadcast transmitter sites
- Providing direct voice or data connections to end users (leased lines)
- Connecting nodes within private or corporate communication networks.

Fixed links require a line of sight path and typically employ highly directional antennas mounted on towers, rooftops or other tall structures. The directional beams ensure that the radiated energy is concentrated along the desired path (i.e. towards the other end of the link) and minimise the risk of interference to other links operating on the same frequency.

To minimise further the interference risk, fixed link generally require co-ordination with one another to ensure sufficient geographic, angular and frequency separation between them. Since the transmission paths are line of sight, fixed links can operate in higher frequency bands than non-line of sight services like mobile or broadcasting. Most bands are currently shared, i.e. many different licensees are accommodated with link co-ordination carried out by the licensing authority (Ofcom), but recently some bands have been auctioned on an exclusive basis to individual licensees who will then carry out their own co-ordination.

Fixed link spectrum can be broadly split into six categories, based on the path length and data transmission capacity that can be realised by an individual link, namely:

- Below 3 GHz
- 3 – 10 GHz
- 10 – 20 GHz
- 20 – 30 GHz
- 30 – 50 GHz
- Above 50 GHz

Spectrum below 3 GHz is limited to a single relatively narrow frequency band and link bandwidths are constrained below 10 Mbps, but transmission can cover long distances (many tens of km) and it is possible to operate over obstructed paths. Similarly long distances can be covered in the 3 – 10 GHz range but much higher data bandwidths are realisable (up to 100s of Mbps per link). Hop lengths get

progressively shorter as the frequency increases, so that bands in the range 10 – 20 GHz are typically used for shorter rural or suburban links with medium hop lengths (10 – 20 km) and frequencies above 20 GHz for short urban or suburban links of typically 10 km or less. Similarly high bandwidths can also be supported in these bands. Above 50 GHz attainable hop lengths are restricted to a few km but very high bandwidths of 1 Gbps or more are realisable, reflecting the significantly higher amount of spectrum available.

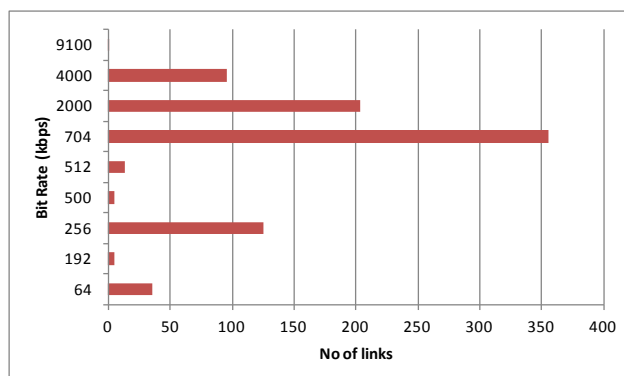
The following sections describe in more detail the various fixed link frequency bands that are currently available.

Note: In the following sections, users classified as “fixed networks” are identified as such based on their core business and include fixed network operators such as BT and C&W. Many of the links licensed to such operators may be used to provide capacity to third parties, such as mobile networks, local authorities or utilities; however, we have been unable to obtain a breakdown of such use.

2.2 Spectrum below 3 GHz

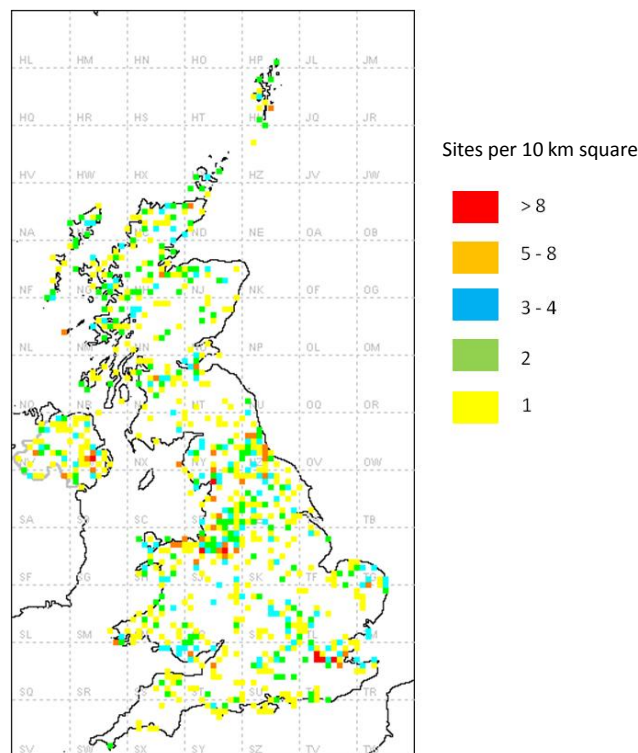
In the UK there is currently only one open band available below 3 GHz for civil point to point fixed links, namely the 1.4 GHz band. This comprises the paired sub-bands 1350.5-1374.5 MHz and 1492.5-1517 MHz, i.e. a total of 2x24 MHz. The maximum channel bandwidth is 3.5 MHz, which can support up to 9 Mbps with the highest modulation scheme (32QAM), although very few links exceed 4 Mbps in practice. According to Ofcom recent licensing data, there are currently just over 800 links in this band (see figure below).

Figure 2.1: Distribution of link bit rates in the 1.4 GHz band



Links in the 1.4 GHz band are widely distributed around the UK, as illustrated in the following map:

Figure 2.2: Approximate distribution of transmitter sites in the 1.4 GHz band

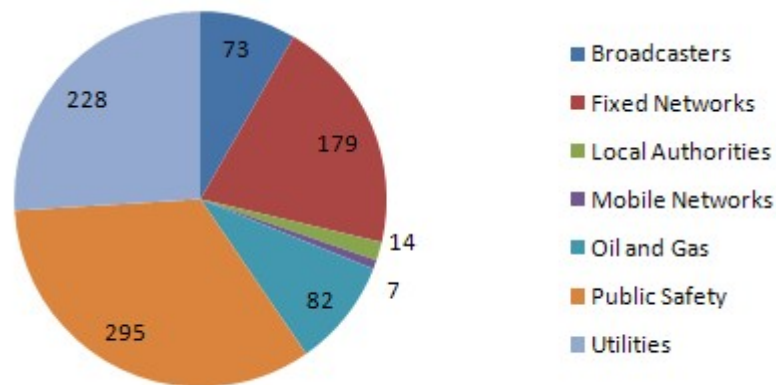


While some of the higher link concentrations are near major population centres there are also a significant number serving rural areas and providing connections to offshore installations. The heaviest users of this band are the utilities and public safety community

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there are also a number of legacy fixed network links and a growing number of DAB transmitter feeder links. All of these applications have in common a relatively narrow bandwidth requirement (typically 2 Mbps or less) and often involve connections to sites where space is limited (e.g. electricity substations) or shared transmitter masts in rural areas. 1.4 GHz is particularly attractive in such situations because compact antennas can be deployed whilst still achieving relatively long hop lengths.

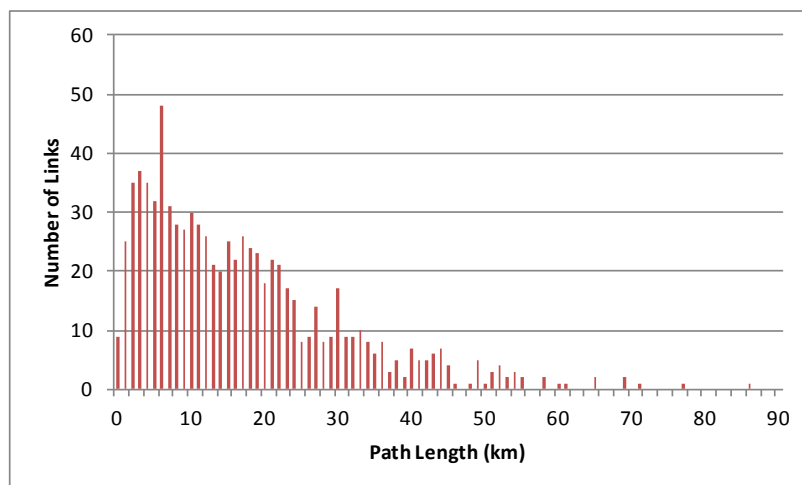
Figure 2.3: Distribution of user types in the 1.4 GHz band



The 1.4 GHz band enables compact Yagi antennas to be deployed as an alternative to large dish structures and this can result in considerable cost savings both from the antenna itself and the much lower weight and wind loading, which means that lighter mast structures can be employed. However, the lower antenna gain limits the hop length that can be achieved, hence many links in this band are shorter than the low frequency would imply. The lower directivity of compact antennas also means there is less angular discrimination between links resulting in a greater probability of interference and more limited frequency re-use. The number of shorter links is also due to the lack of other higher frequency bands to cater for very low data rates (i.e. below 64 kbps).

The distribution of hop lengths in the 1.4 GHz band is illustrated below.

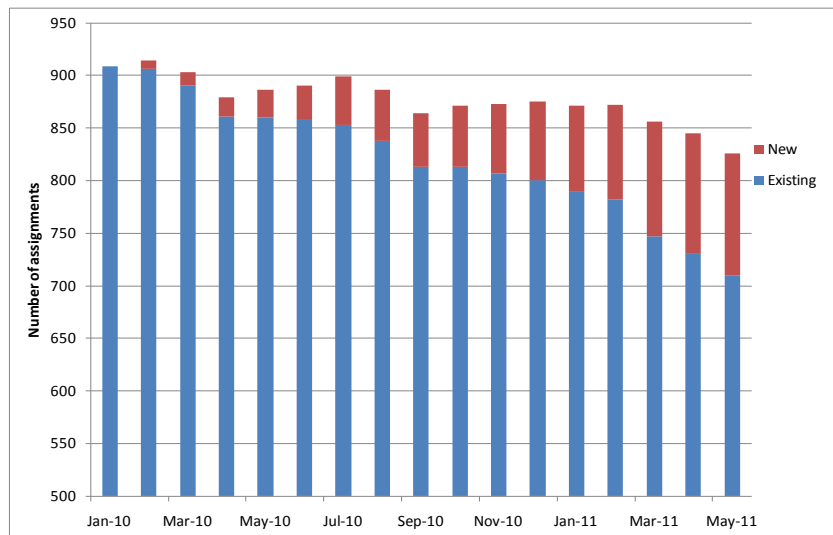
Figure 2.4: Distribution of hop lengths in the 1.4 GHz band



Over the last year there has been a slight downward trend in the total number of links assigned in the 1.4 GHz band, as illustrated below. Existing links are those at the start of the period and new links are those assigned after the start of the period. It is interesting to note that whilst there has been a decline of approximately 20% in the number of existing links, this has been partially offset by the licensing of over 100 new links, indicating continuing interest in the band. In the future continuing

growth can be anticipated from broadcasters (to support DAB rollout) and utilities (to support rollout of “smart grid” networks) in particular.

Figure 2.5: Licensing trend in 1.4 GHz band



2.3 Spectrum in the 3 to 10 GHz range

There are three main frequency bands in this frequency range, namely 4 GHz, 6 GHz and 7.5 GHz. 6 GHz is further split into two distinct bands, referred to as the lower and upper 6 GHz bands.

2.3.1 4 GHz

The 4 GHz band was historically allocated exclusively to BT but part of the band has more recently been licensed for point to multipoint wireless systems and most of the former BT links have been decommissioned as trunk telephony traffic migrated to fibre, leaving only 40 links in total across the UK. There are also currently 147 permanent satellite earth stations (space to earth) operating in the band. Most of these are in the southern half of the UK, apart from a sizeable cluster in North East Scotland (believed to be serving the offshore industry) and one in central Scotland.

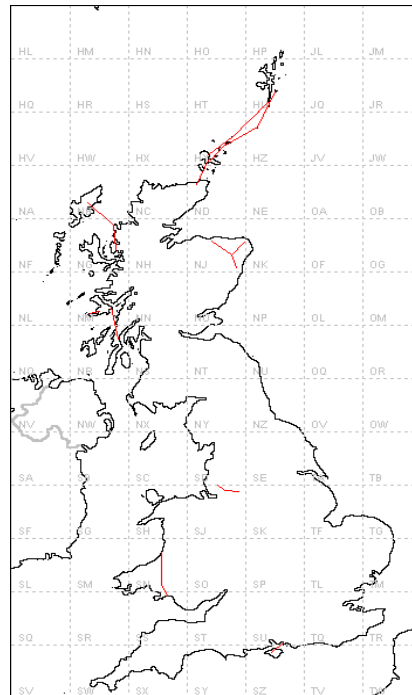
The only significant geographic deployment of 4 GHz links currently is in mid / South Wales (8 links) and the Northern Islands of Scotland (11 links). Future deployment of links in this band will be subject to co-ordination with receiving satellite earth stations which may constrain use in certain areas. There are also plans to introduce recognised spectrum access (RSA) for receive only earth stations (ROES) operating in the band.

Another concern raised by users is the very large antennas and waveguide feeders that are required at this frequency range, which results in significantly higher costs

than in higher frequency bands (even compared to 6 or 7.5 GHz bands). There is also an additional premium on licence fees compared to the higher bands¹.

The distribution of the currently deployed links in the 4 GHz band is illustrated below:

Figure 2.6: Geographic location of fixed links in the 4 GHz band

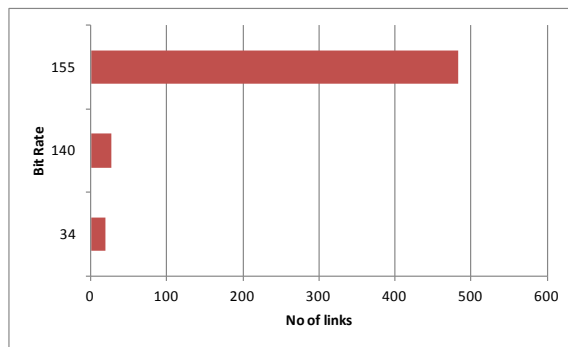


2.3.2 The 6 GHz bands

Both the lower and upper 6 GHz bands were historically allocated exclusively to BT, but are now open to all licensees. The lower band comprises 5930.375-6419.615 MHz (2 x 237.2 MHz in total) and the upper band comprises 6430-7100 MHz (2 x 330 MHz). Both bands are predominantly used by high capacity (STM-1) links—there are currently 476 links in the two 6 GHz bands carrying a total data capacity of 71.2 Gbps, an average of 149.6 Mbps per link.

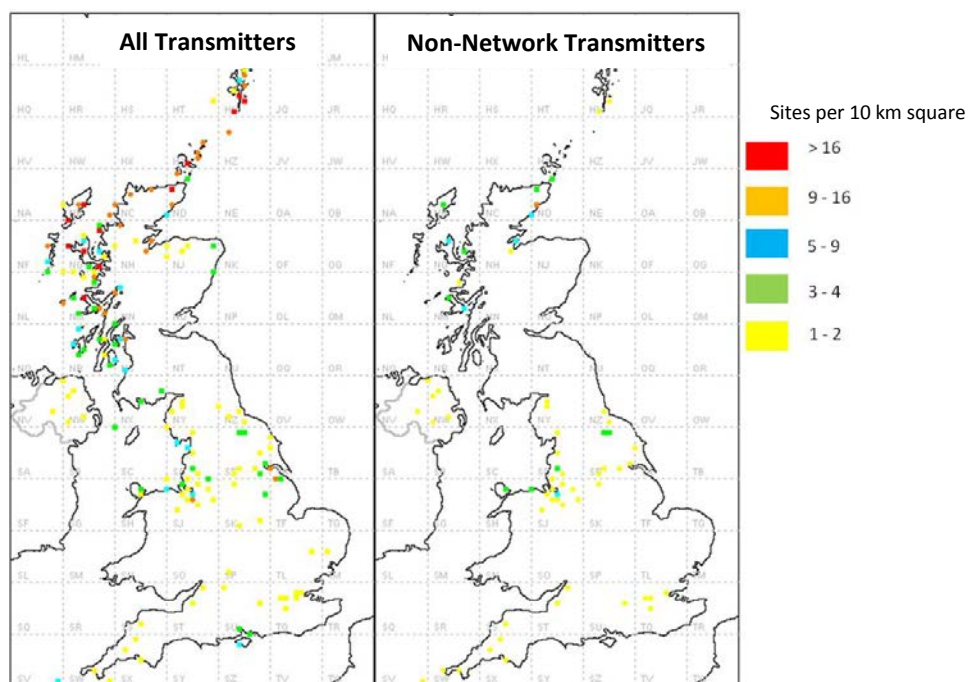
¹ The current band multiplier at 4 GHz is 1 and at 6 and 7.5 GHz is 0.74.

Figure 2.7: Distribution of link transmitter bandwidths in the 6 GHz bands



The geographic distribution of links within the band is skewed towards the north and west of the UK, with few links in the South East, as illustrated below. Note that some of the links are over-sea paths connecting offshore islands or oil / gas platforms to the mainland. The maps show the density of links per 10 km national grid square, for all the links and for links not licensed to public network operators.

Figure 2.8: Approximate distribution of transmitter sites in the 6 GHz bands



The paucity of links in the southern part of the UK reflects the migration of most of BT's legacy trunk microwave links to fibre in recent years.

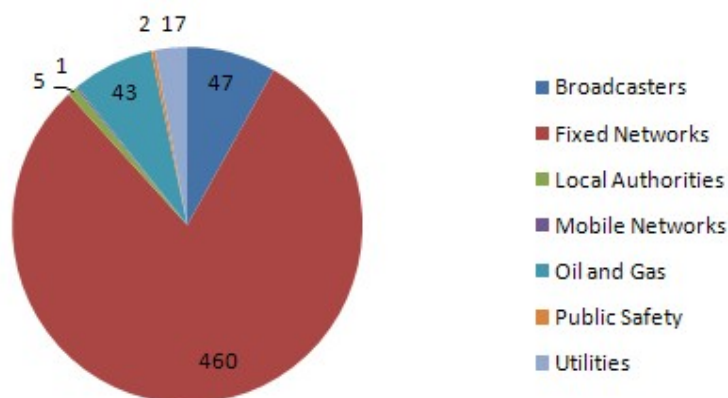
80% of the links in the 6 GHz bands are assigned to fixed network operators. This is to be expected given the band's legacy as an exclusive BT managed band. We believe some of these links may be used to provide services to other sectors such as the offshore and broadcast community but have been unable to obtain such information from the network operators.

The 6 GHz bands are also used by Arqiva to support digital TV transmitter feeds at locations where 7.5 GHz is not available, as antenna sizes and deployment costs in

the two bands are comparable. There has been no significant take-up to date by mobile network operators (although it is possible that some of the fixed network links are deployed in support of mobile networks).

Both the lower and upper 6 GHz bands are shared with satellite uplinks and coordination is therefore required. Most of the permanent earth stations in the 6 GHz band are in the southern half of the UK, apart from a sizeable cluster in North East Scotland (believed to be serving the offshore industry) and one in central Scotland. Most of these operate in the frequency bands 5925-6425 MHz band, but a few uplinks extend up to 7075 MHz.

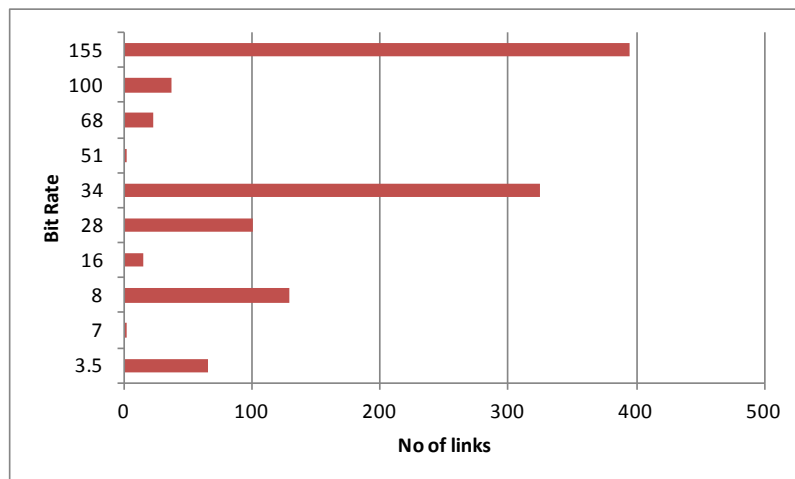
Figure 2.9: Distribution of user types in the 6 GHz bands



2.3.3 7.5 GHz

The 7.5 GHz band was the first microwave fixed link to be made available for private users in the 1970s and at that time mainly served the needs of broadcasters and the fuel, power and water industries. Since the launch of the cellular mobile networks in the 1980s and 1990s the band has become increasingly popular for longer mobile backhaul links. Early use was predominantly by analogue links for TV distribution and low / medium capacity digital links (up to 8 Mbps). Analogue links have now been completely superseded by digital technology. Although there has been a trend towards higher bit rates (STM-1) there remains a mix of bit rates as illustrated in the chart below.

Figure 2.10: Distribution of link bit rates in the 7.5 GHz bands



Unlike the 6 GHz band, there is a greater concentration of links in this band near major population centres such as North West and South East England, as illustrated below:

Figure 2.11: Approximate geographic distribution of transmitter sites in the 7.5 GHz band

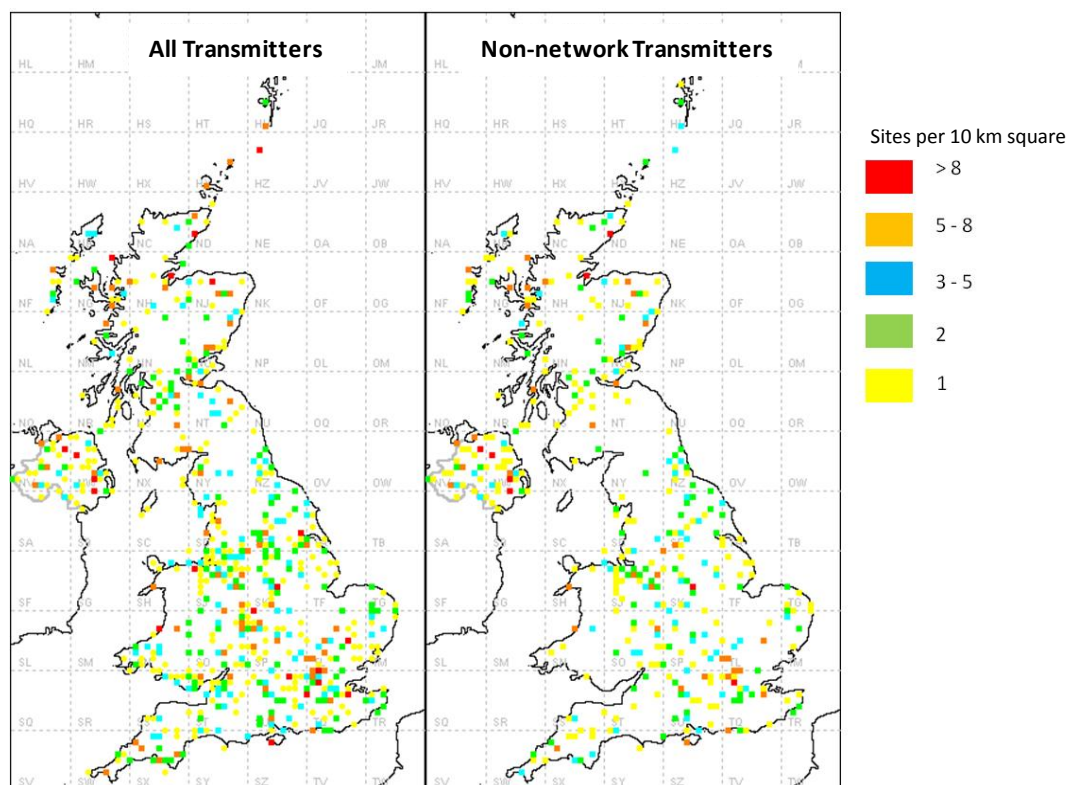
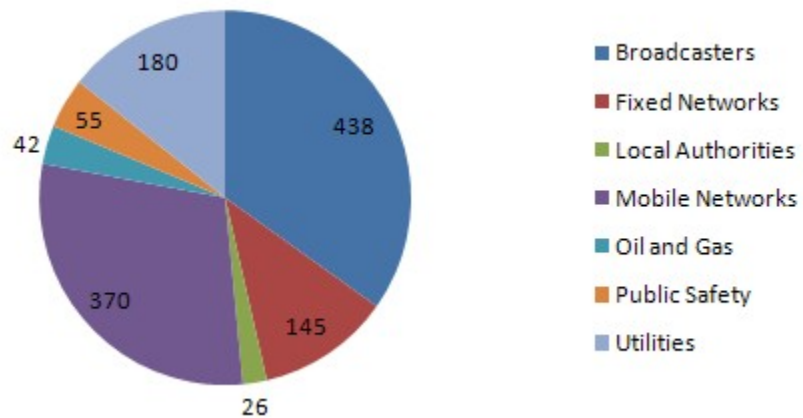


Figure 2.12: Distribution of user types in the 7.5 GHz band



Note that some of the fixed network links in this band may in fact be used to support mobile network backhaul (where mobile networks have outsourced backhaul services to other providers).

2.4 Spectrum in the 10 to 20 GHz range

There are a number of frequency bands in this range, some of which were historically allocated on an exclusive basis either to Cable and Wireless or to BT.

2.4.1 10 GHz

The 10 GHz band was formerly licensed for point to multipoint fixed wireless access services, but demand for these services failed to materialise and the spectrum was subsequently returned and offered for auction in 2008. Two bidders were successful, namely T-Mobile who acquired 2 x 80 MHz and Digiweb who acquired the remaining 2 x 20 MHz. Digiweb is a well established provider of broadband fixed wireless access in Ireland and is currently offering its Metro FWA service in Northern Ireland using this spectrum. At the time of acquiring the spectrum the company stated that it intended to rollout the Metro service across other parts of the UK over the next five years but at the time of writing coverage is limited to the Belfast area.

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It should be noted that the lower part of this band is used by the MoD at various training locations around the UK and cannot be used by fixed links in these areas. Although most of the locations are away from heavily populated areas, it is possible that this restriction could hinder the use of the band for longer haul links at certain transmit sites.

2.4.2 13 GHz

Like the 7.5 GHz band, the 13 GHz band was historically used mainly by broadcasters and utilities, but has more recently become dominated by mobile network backhaul links. Geographic distribution of links is in consequence more biased towards the major population centres, as shown below (note the more widespread distribution of the non-network links):

Figure 2.13: Approximate geographic distribution of transmitter sites in the 13 GHz band

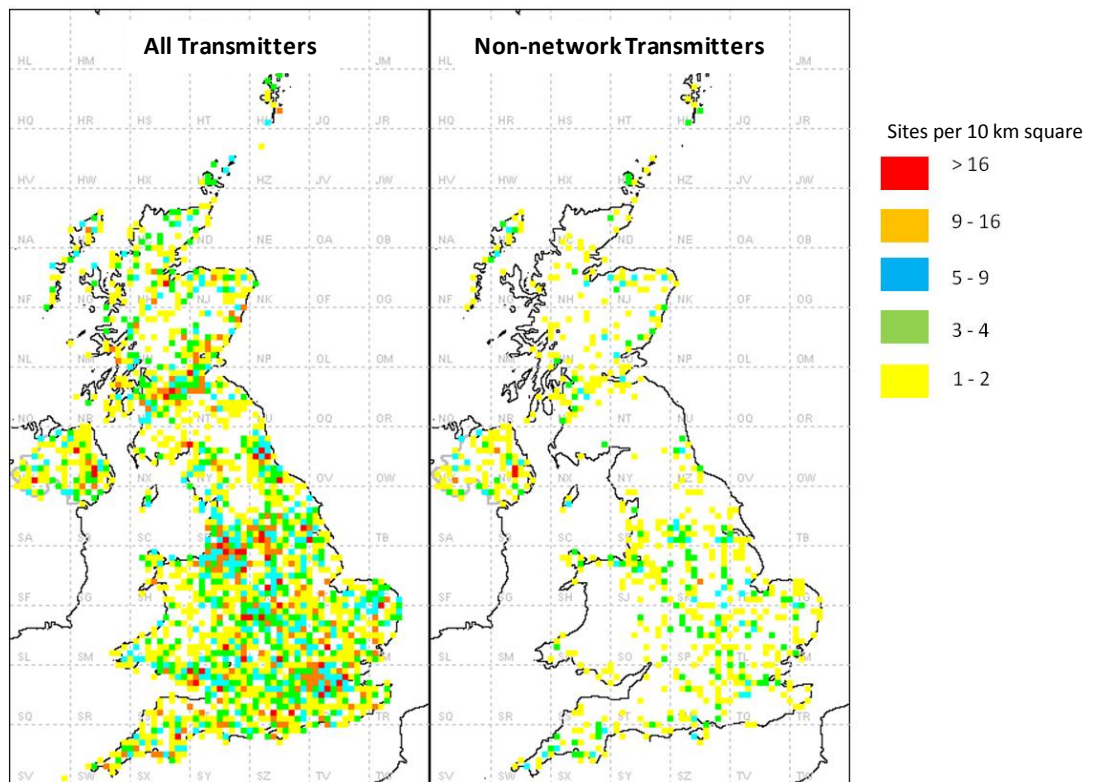
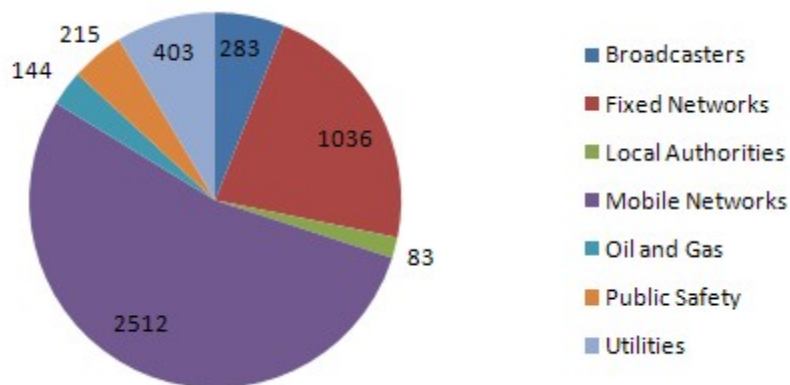


Figure 2.14: Distribution of user types in the 13 GHz band



Again, note that many of the fixed network links in this band may actually be used to support mobile networks.

2.4.3 15 GHz band

The 15 GHz band was formerly an exclusive Cable and Wireless managed band but has since been opened up to other users.

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Geographic distribution of links in the band is broadly similar to the 7.5 GHz band. The band is also becoming increasingly used for mobile network backhaul.

Figure 2.15: Approximate geographic distribution of transmitter sites in the 15 GHz band

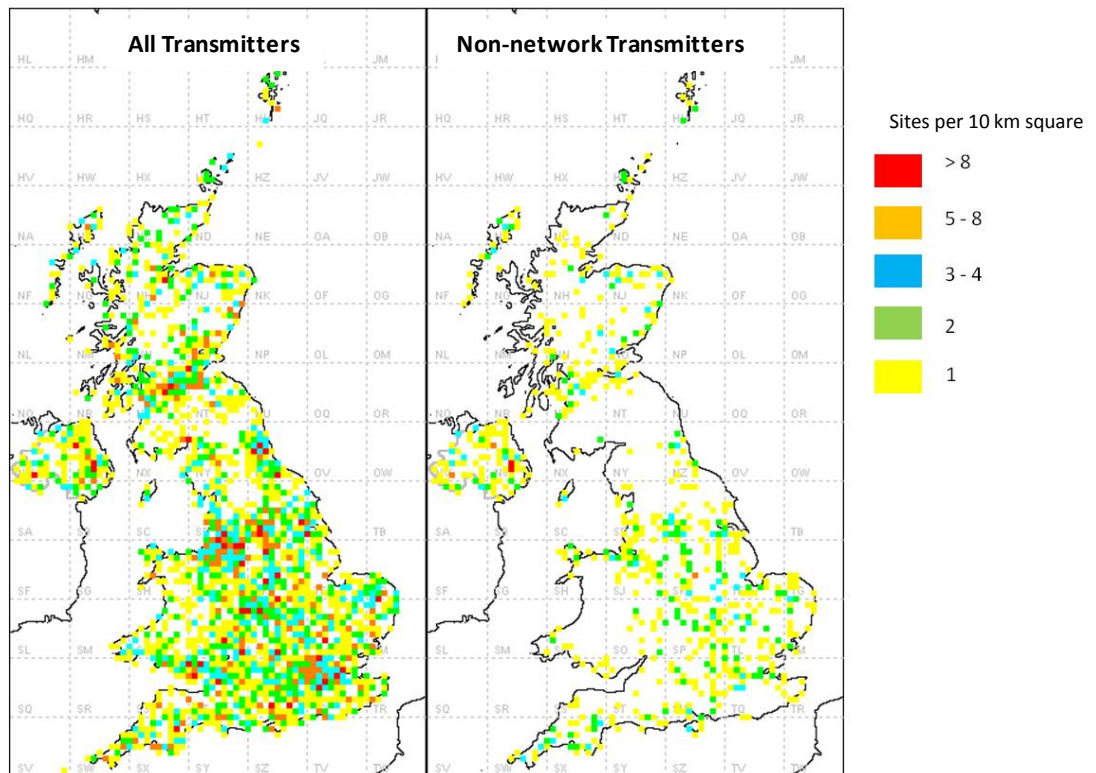
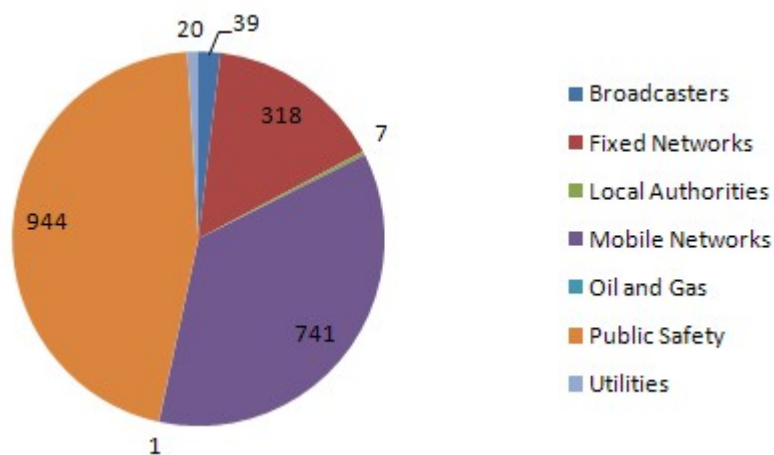


Figure 2.16: Distribution of user types in the 15 GHz band



2.4.4 18 GHz

The 18 GHz band was historically allocated exclusively to BT, which remains the dominant user in the band, although there is increasing use by mobile network operators. We also understand that a proportion of the BT links in the band are used to support the O2 cellular network (in part a legacy of BT's former part-ownership of Cellnet). We have been unable to obtain details of the proportion of links used by BT for mobile backhaul. Geographic distribution of links is broadly in line with population, as shown below.

This whole of the band is shared with satellite downlinks and uplinks also operate in the 17.7 to 18.4 GHz band (broadcast satellite feeder links). The normal coordination process has to be followed and while it can be expected that coordination with gateway stations would be relatively straightforward, coordination with ubiquitous user terminals (HDFSS) would be problematic.

Figure 2.17: Approximate geographic distribution of transmitter sites in the 18 GHz band

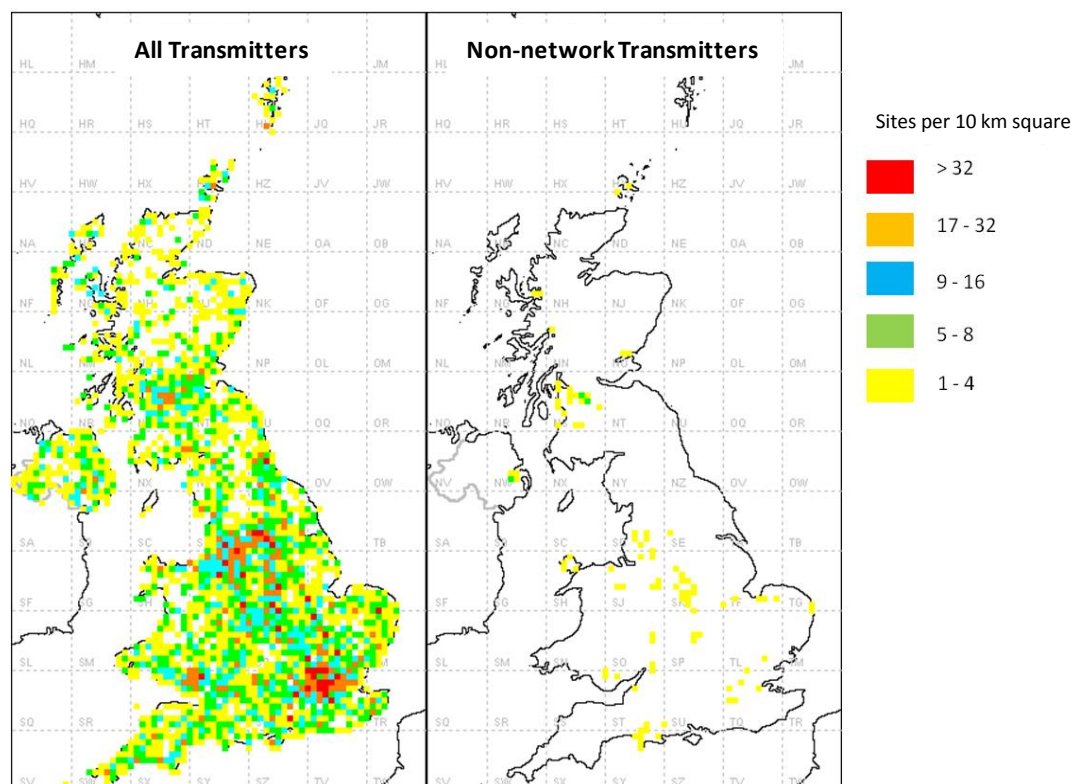
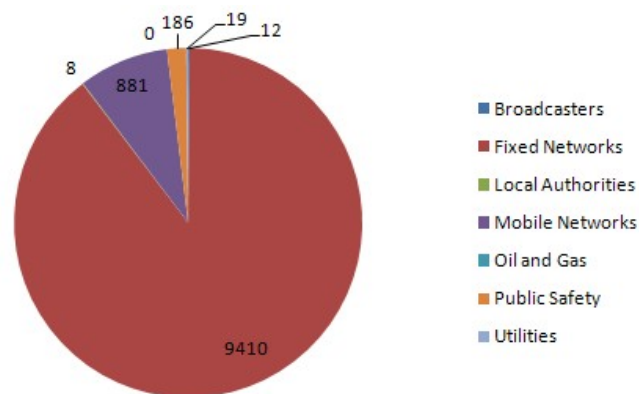


Figure 2.18: Distribution of user types in the 18 GHz band



2.5 20 – 50 GHz

This is the highest frequency range that is currently used for conventionally licensed spectrum and comprises a number of Ofcom managed bands and exclusive operator managed bands as described below.

2.5.1 Ofcom managed bands

The three main Ofcom-managed licensed bands above 20 GHz are 23 GHz, 26 GHz and 38 GHz. Use of all of these bands is currently very much dominated by mobile networks, as can be seen below, and geographic distribution is very much in line with population. Note that in these bands many of the fixed network operator links are likely also to be used to support mobile backhaul.

Figure 2.19: Approximate geographic distribution of transmitter sites in the 23 GHz band

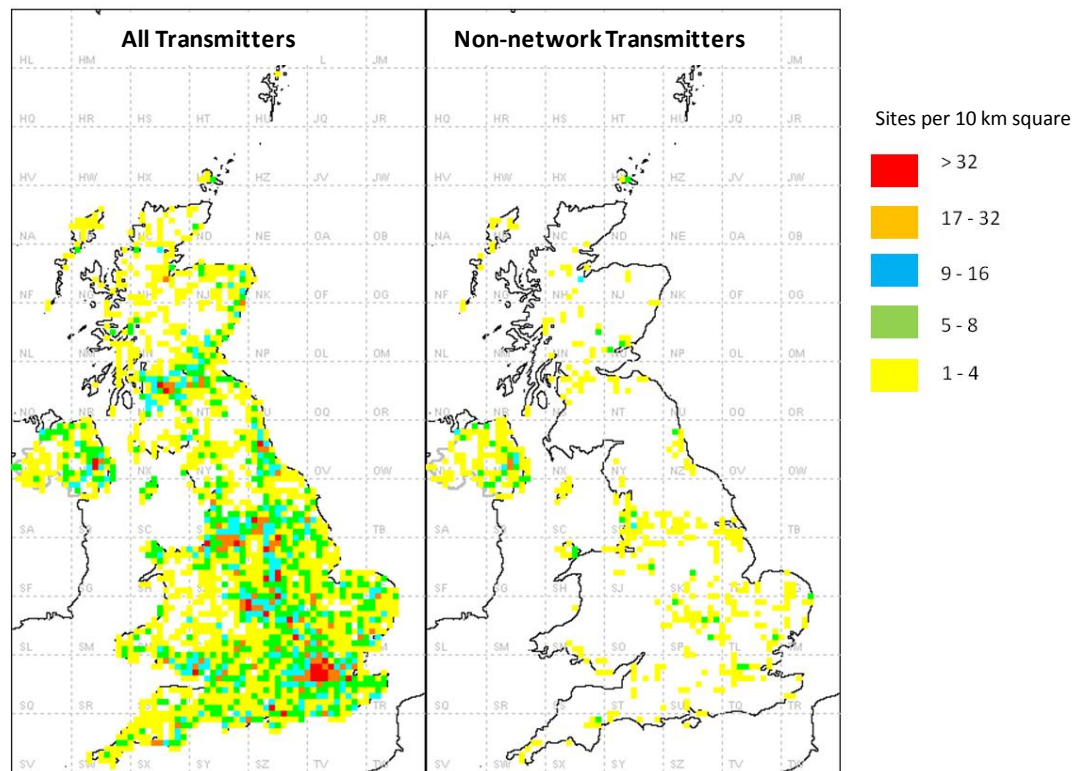


Figure 2.20: Approximate geographic distribution of transmitter sites in the 26 GHz band

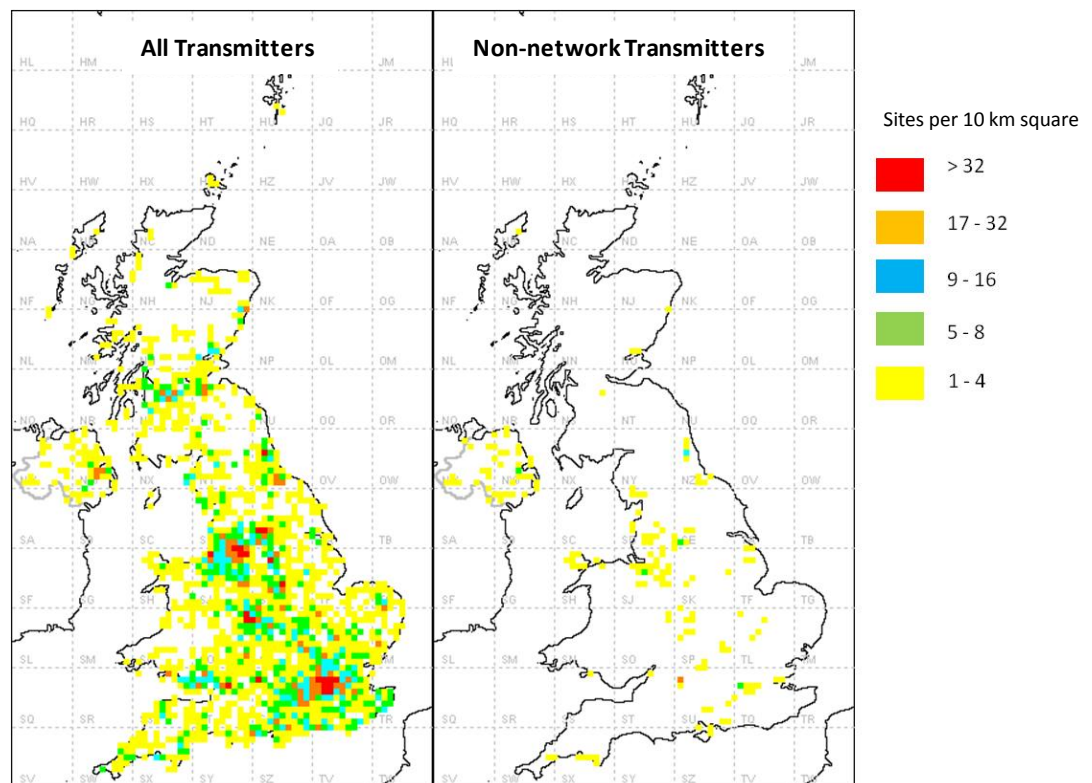


Figure 2.21: Approximate geographic distribution of transmitter sites in the 38 GHz band

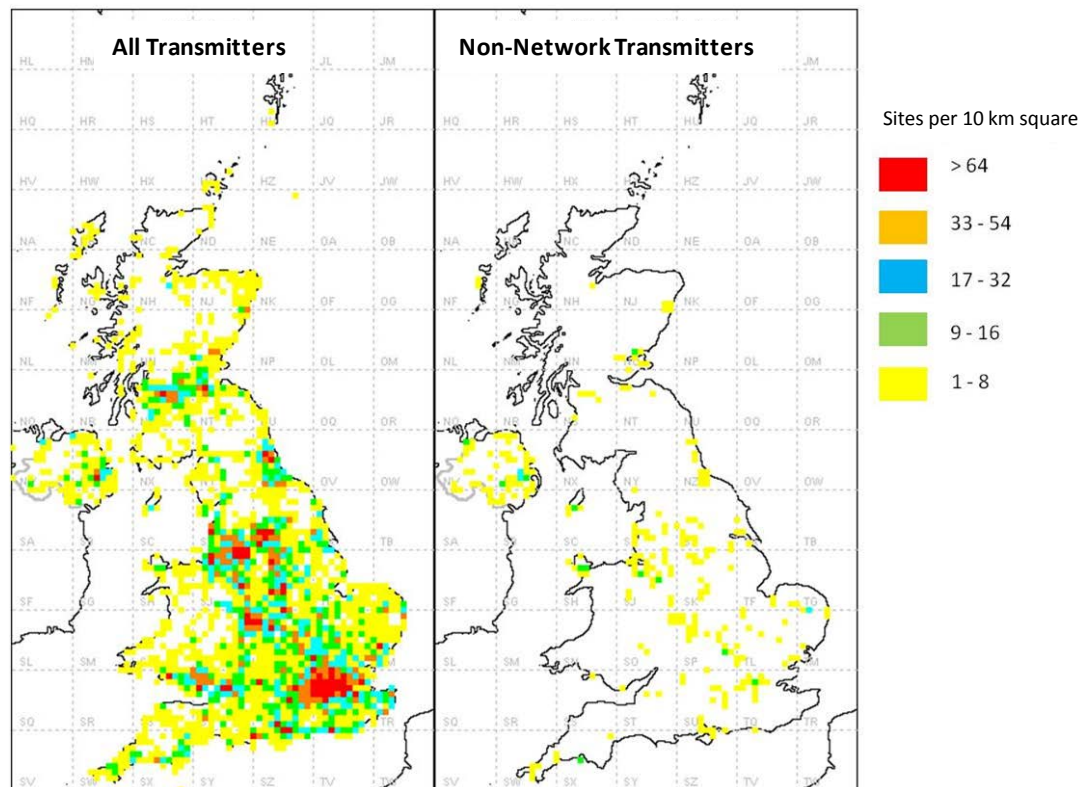
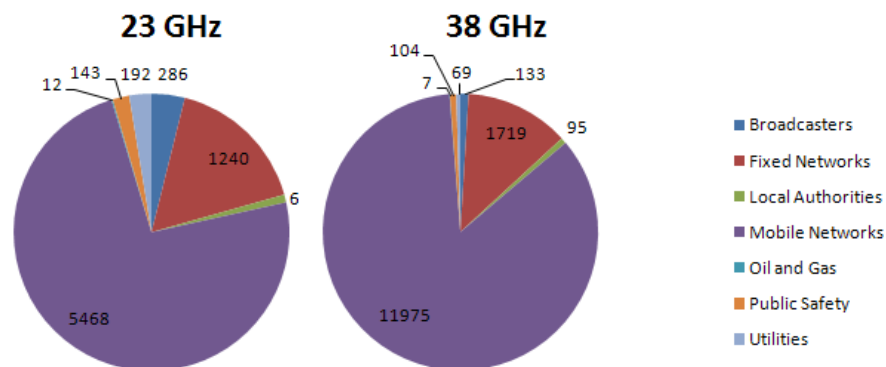


Figure 2.22: Distribution of user types in the 23 GHz and 38 GHz bands



2.5.2 Other fixed link bands

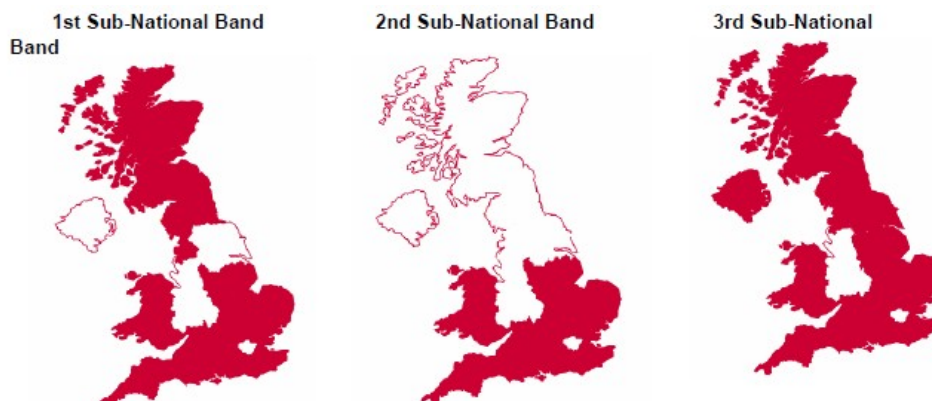
In addition to the Ofcom-managed bands there are also a number of bands above 20 GHz that have been auctioned as spectrum blocks for exclusive use by individual licensees. These bands are summarised below.

2.5.2.1 28 GHz

The 28 GHz spectrum comprises one national licence and three sub-national licences, all of which were auctioned in 2008. The geographic areas covered by the

three regional licences were specified in the 2008 auction information memorandum and are as follows:

Figure 2.23: 28 GHz sub-national licences



At the auction the national licence comprising 2 x 224 MHz was acquired by Arqiva, who are planning to use the band for a variety of point to point and point to multipoint applications. These could include mobile backhaul, rural fixed wireless access or broadcast distribution links. The 1st, 2nd and 3rd sub-national licences, each comprising 2 x 112 MHz, were acquired by Transfinite Systems, RedM and Faultbasic respectively. The RedM and Faultbasic licences have since been traded to UK Broadband, who like Arqiva plan to deploy a mix of point to point and point to multipoint services in the band. Transfinite is offering access to its spectrum in the 28 GHz band.

Despite all these plans, there appears to be little if any active use of the 28 GHz band at the time of writing. According to one stakeholder, one of the reasons for this is that under the current trading mechanism it is not straightforward to “sub-let” spectrum to other parties, i.e. for the spectrum holder to operate as a band manager rather than simply trading its spectrum rights to the other party.

2.5.2.2 32 GHz

Four lots of spectrum in the 32 GHz band were auctioned by Ofcom in 2008. The two larger lots, each comprising 2 x 252 MHz, were acquired by Orange and T-Mobile. The recent merger of these two companies leaves Everything Everywhere with a contiguous block of 2 x 504 MHz in this band.

[X]

The two smaller lots, comprising 2 x 126 MHz each, were acquired by BT and MLL Telecom.

[X]

We have been unable to obtain information from BT on its plans for the 32 GHz band but we would expect this to be used in preference to the 18 GHz band for shorter links, e.g. for supporting backhaul in the O2 mobile network or providing

customer access links. This is something Ofcom may wish to expedite, particularly if increasing demand for 18 GHz spectrum arises from other quarters such as consumer satellite terminals or mobile backhaul.

2.5.2.3 42 GHz

Three lots of spectrum were auctioned in this band in 2008. The two smaller lots, each comprising 2 x 250 MHz, were acquired by T-Mobile and MLL Telecom. The larger lot (2 x 1 GHz) was acquired by UK Broadband. Until recently, equipment has not been readily available in this band and hence there is little or no deployment currently. MLL Telecom plan to start using the band soon and expect to have approximately 50 links in operation by 2014, rising to 100 by 2017. UK Broadband expects the main demand in this band to come from mobile (LTE backhaul) and wireless CCTV systems. Combining these two applications in the same band could be attractive as mobile backhaul is downlink dominated whereas CCTV is uplink limited and this may be a way to reduce traffic asymmetry.

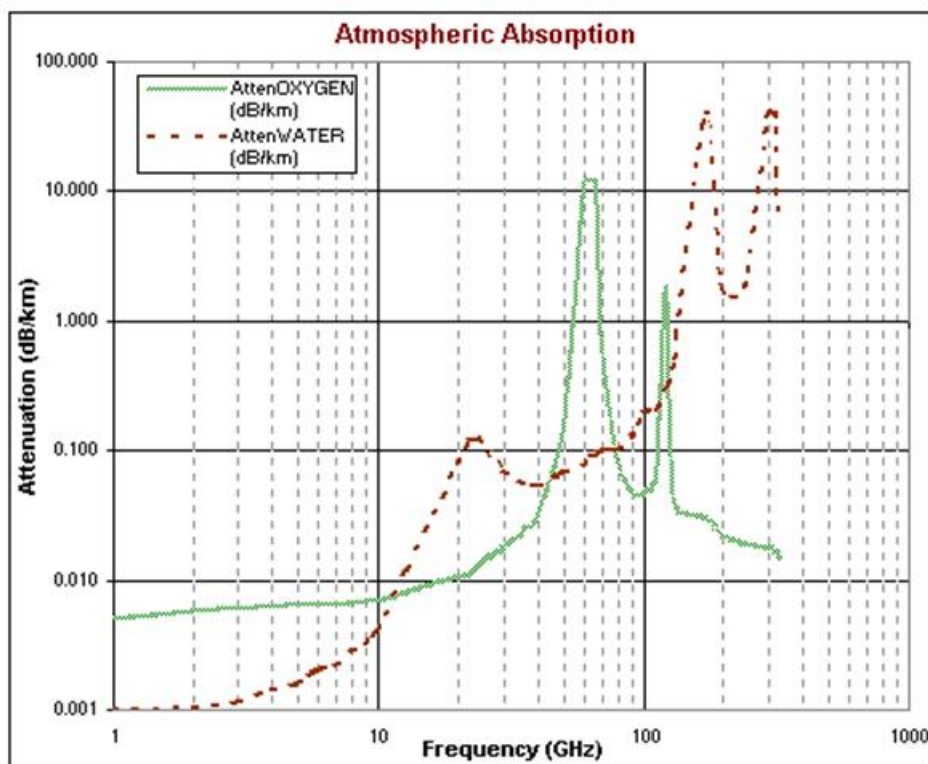
2.6 Bands above 50 GHz

2.6.1 Overview

There are a number of fixed service frequency bands above 50 GHz that are available on either a licence exempt or self-co-ordinated “light licensed” basis. The principal licence exempt band is at 60 GHz, comprising a total bandwidth of 6.8 GHz. The light licensed bands are the 65, 75 and 85 GHz bands, which comprise a total of 11.5 GHz between them. The 75 and 85 GHz bands can be used either as paired FDD bands or individually. There are also two historic licensed bands around 50 and 55 GHz.

There are ERC Recommendations that identified channel plans for the fixed links bands 48.5-50.2 GHz, 51.4-52.6 GHz and 55.78-57.00 GHz (12-10, 12-11 and 12-12) respectively. The latter two bands are shown to be licensed on a first come, first served basis by Ofcom. There was an equipment issue and also the availability of the licence exempt 60 GHz band, self-co-ordinated light licensed 65, 75 and 85 GHz bands has probably meant that any demand is realised by these lower spectrum cost options.

The 60 GHz band, sometimes referred to as V-band, comprises the frequency range 57.1 – 63.9 GHz (there are 100 MHz external guard bands at either end of the band). The spectrum is available on a licence exempt basis subject to a maximum EIRP of 55 dBm, maximum transmitter power of 10 dBm and a minimum antenna gain of 30 dBi. This band exhibits a very high level of free space attenuation due to signal absorption by oxygen in the atmosphere (see figure below).

Figure 2.24: Atmospheric absorption of microwave and mm wave signals

This oxygen absorption, combined with high levels of rain attenuation, limits the useful range of the band to distances of less than 1 km. However, it also has the effect of reducing significantly the likelihood of interference from other links operating on the same frequency. This immunity from interference is further reinforced by the minimum antenna gain requirement, which ensures very narrow beamwidths are emitted.

Work is underway in the IEEE 802.11ad standards group to develop standards for very high capacity wireless LANS, including operation in the 60 GHz band. A separate initiative, known as the Wireless Gigabit Alliance (WiGig) is also working to this end. Although the original driver for these initiatives was wireless high definition video, there is growing interest in using the technology as a low cost backhaul option for connecting micro and pico cells to 4G mobile networks. One vendor has suggested that a target capex of £2,000 or less per picocell backhaul link for a 1 Gbps, 1 km link should be feasible². WiGig technologies are expected to be available from 2013 and could be particularly attractive for applications such as connecting 4G base stations in urban “hotspots” to the nearest fibre point.

2.6.2 75 / 85 GHz

These two bands comprise 2 blocks of 4.75 GHz each, which cater for three different channelisation options, namely:

² “Opportunities and Challenges for 60 GHz Communication Systems”, presentation to Cambridge Wireless event, July 2011, by Mark Barrett, TES Electronic Solutions.

- FDD using paired frequencies with the same 4.75 GHz band (either band may be used)
- TDD within either 4.75 GHz band
- FDD using frequencies in the 75 GHz band paired with frequencies in the 85 GHz band (i.e. 10 GHz duplex spacing).

According to industry discussions there is a growing preference for the dual band FDD option. This is likely to be advantageous in terms of filtering requirements (leading to lower costs) and removes the need for an internal duplex gap that would exist in the single band FDD option. The TDD option is better suited to catering for asymmetric uplink / downlink traffic but would be more challenging in terms of synchronisation requirements to avoid interference.

The band is currently licensed on a “light licensing” basis in the UK. Under this scheme, technical and geographic details are published in a register by Ofcom and licensees must use this to co-ordinate links so as to minimise the interference risk. There is a view among some in the industry that a more rigorous licensing approach will be needed in the future to ensure interference free operation in this band (which does not benefit from the 60 GHz band’s very high atmospheric attenuation).

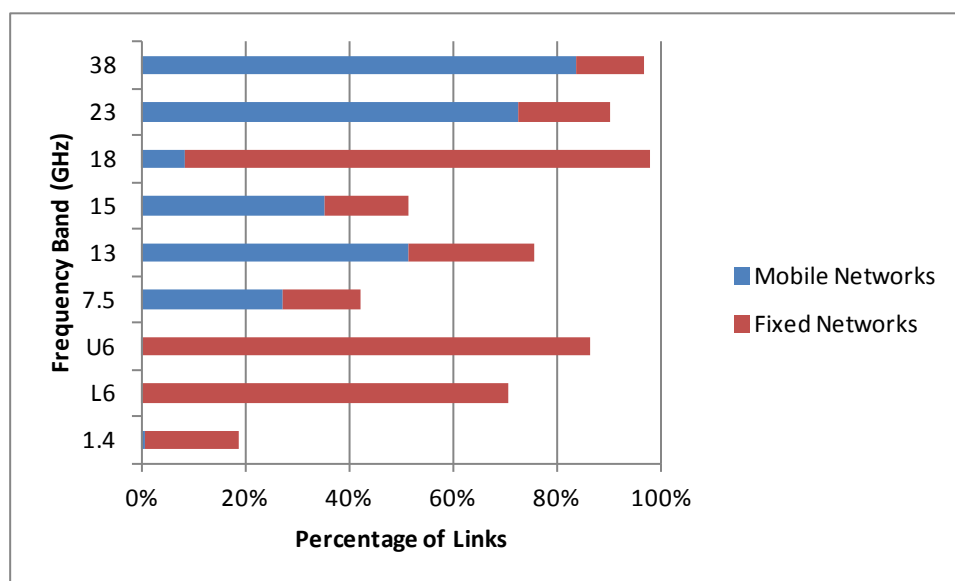
Of the 58 links that have so far been registered with Ofcom, the great majority (50) are less than 3 km. Of the remainder, the longest is 10.3 km, but such a link would be unlikely to meet the availability requirement of a commercial network operator.

2.7 Conclusions regarding current use of bands by fixed links

2.7.1 Main findings

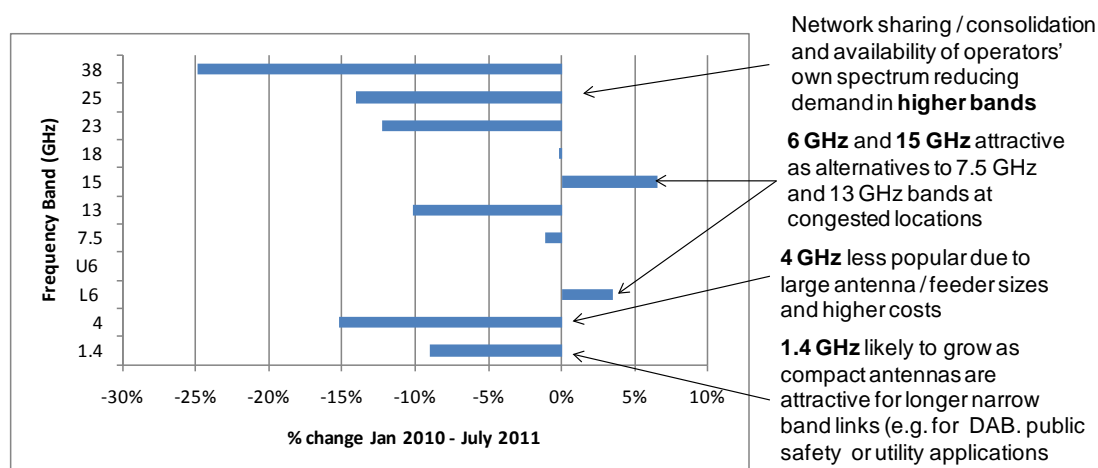
The main conclusion that emerges from our analysis of existing fixed link spectrum use is the extent to which this is currently dominated by mobile network backhaul requirements, particularly in the bands above 10 GHz. This is illustrated in the chart below, which shows the percentage of link assignments in each band for fixed and mobile network operators. Note that some of the fixed network assignments are also used to support mobile network backhaul through outsourcing arrangements.

Figure 2.25: Percentage of link assignments to fixed and mobile network operators



It is also interesting to note, however, that there has been a significant reduction in the number of links assigned in many of the bands over the last eighteen months—again this is particularly so in the higher frequency bands above 20 GHz:

Figure 2.26: Change in total number of assignments in each band over period Jan 2010 to May 2011

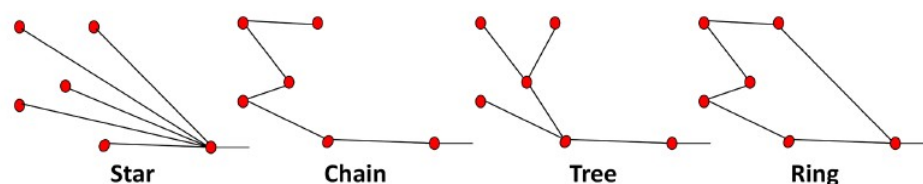


We believe this trend is likely to be in part due to the consolidation that has taken place in the mobile market, in particular the effective merging of the backhaul networks of two of the national 3G networks (Three and T-Mobile). We would expect this trend to continue over the next few years, as the T-Mobile and Orange networks are consolidated following the merger of these two operators. The potential implications of this trend for fixed link spectrum demand are considered further in section 4.5. Also we would expect that there would be increasing use of some of the spectrum that was acquired at auction in support of the mobile networks and this might lead to the return of further spectrum in the Ofcom managed bands.

2.7.2 How Public Networks use Fixed Link spectrum

Fixed radio links play a vital role in mobile network backhaul. Links are primarily deployed to connect to individual base stations, but are also sometimes used further back in the network to carry concentrated traffic back to the core network. There are essentially four network topologies that can be deployed to connect individual base stations to the network and these are illustrated below.

Figure 2.27: Common Backhaul Network Topologies³



Star topologies use a separate link from a hub to connect to each site. This approach is commonly used in today's networks but is relatively inefficient as it requires longer radio links and a line of sight path for each link, which may not always be feasible. The star topology can also degrade frequency reuse by concentrating a large number of links at one site.

Chain topologies overcome some of these problems but are inherently less resilient as failure of a single link in the chain can affect multiple base stations—the only way around this is to protect the links that are higher in the chain. The **tree** topology combines the star and chain approach and requires fewer links to be protected. The **ring** approach is generally recognised as the most efficient approach and is most likely to be adopted in the future.

Backhaul capacity to each base station needs to be sufficient to deliver the peak data rate that the network wishes to offer; however, because of the bursty nature of mobile data traffic these peaks are unlikely to occur simultaneously at different base stations or sectors, and the average instantaneous throughput of a given base station will be much lower than the potential peak capacity. For example, an LTE network operating on a 10 MHz carrier may deliver as much as 50 Mbps to a single user under optimal conditions; however, the average sector throughput, taking account of the statistical variation in user locations, is unlikely to exceed more than 15 Mbps. Hence a tri-sectored site designed to deliver up to 50 Mbps for short bursts to a single user will only require 50 Mbps backhaul capacity for one sector—for the remaining two sectors no more than 30 Mbps should be required to meet the anticipated busy hour throughput, i.e. a total backhaul capacity of 80 Mbps should be sufficient.

³ Source: "Wireless Backhaul Topologies: Analyzing Backhaul Topology Strategies", white paper by Ron Nadiv and Tzvika Naveh of Ceragon Networks, August 2010

In practice, based on Ofcom licensing data, current 2G and 3G networks typically deploy base station backhaul links with the following capacities:

Table 2.1: Typical licensed mobile backhaul link capacities in the UK

	Urban sites	Suburban sites	Rural sites
2G (GSM/EDGE)	8 Mbps	8 Mbps	2 Mbps
3G (HSPA)	68 Mbps	34 Mbps	16 Mbps

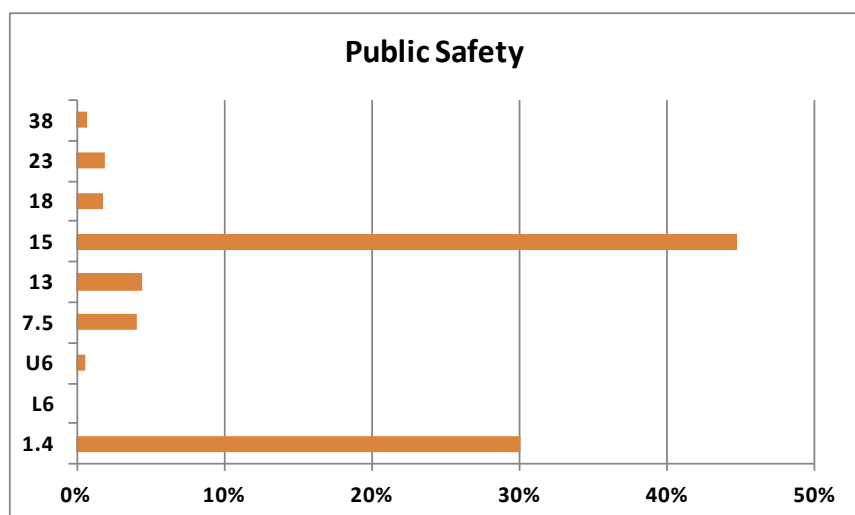
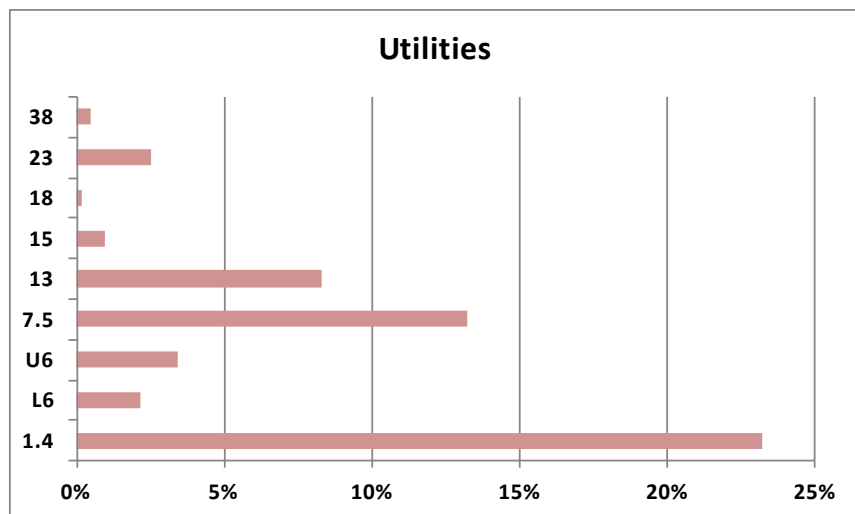
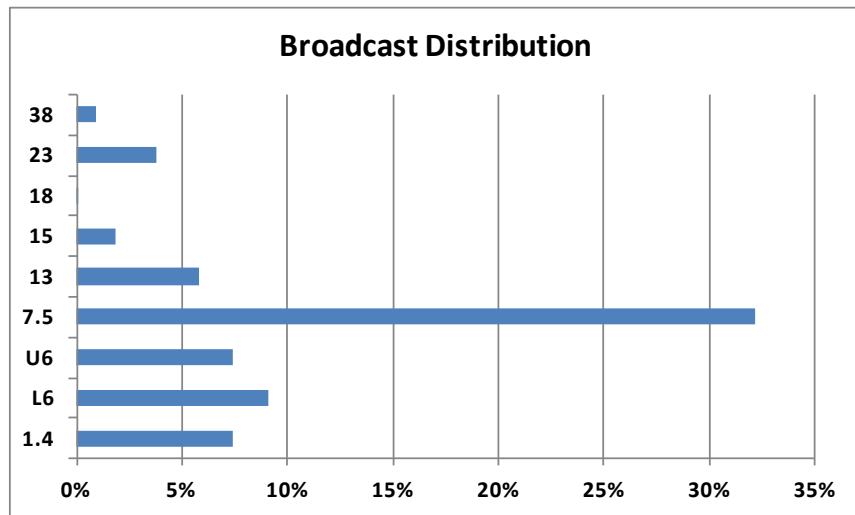
Future 4G networks are likely to require higher bit rates of the order of 68 Mbps for rural links and 155 Mbps for urban and suburban links, to support the higher peak bit rates likely to be available.

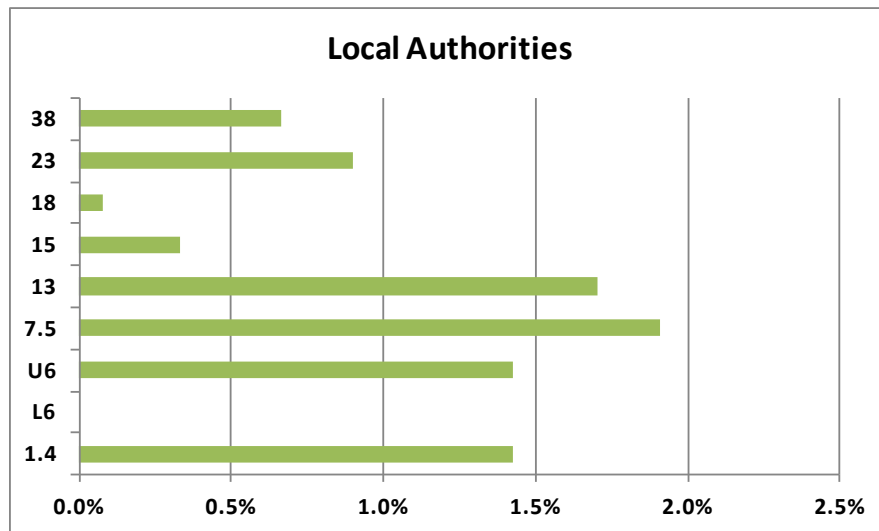
2.7.3 Uses of fixed link spectrum other than by public networks

Whilst public network operators currently dominate use in most frequency bands and in most parts of the country, there are a number of other sectors that also rely heavily on fixed links. These include utilities (fuel, power and water), public safety, local authorities and broadcasters. These other users tend to be most prominent in the longer established fixed link bands, such as 7.5 GHz and 1.4 GHz, which pre-date the launch of the mobile cellular networks, but increasing use is becoming apparent in higher frequency bands, especially for shorter, higher capacity links.

The following graphs show the distribution of links by user type in various frequency bands. The graphs show the percentage of links in each frequency band that are assigned to each user type. It can be seen that broadcasters account for a significant proportion of use of the 7.5 GHz band, utilities and public safety users are the two major users of the 1.4 GHz band and public safety is a particularly heavy user of the 15 GHz band.

Figure 2.28: Distribution of user types by frequency band





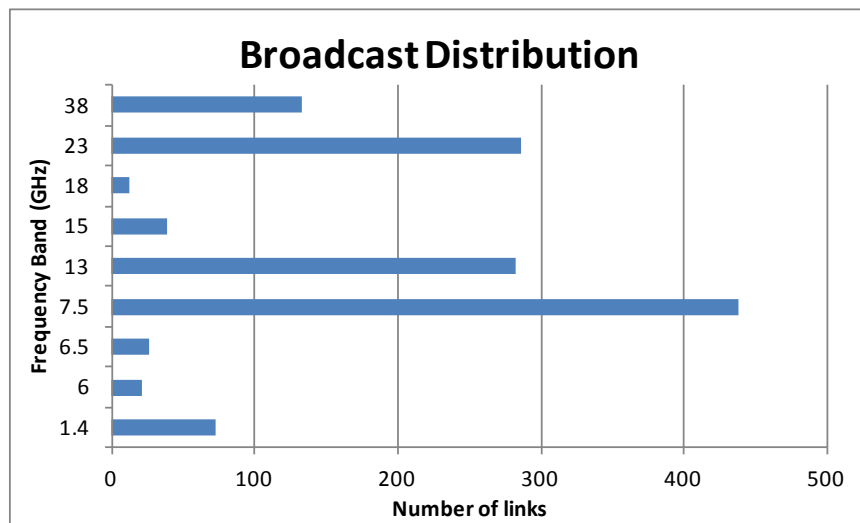
The use of fixed link spectrum by these other sectors is discussed more detail in the following sections.

2.7.3.1 *Broadcasting use of fixed link spectrum*

Broadcasters are long-standing users of wireless fixed links to feed the broadcast radio and television transmitter networks. Although many of the transmitter sites are now served by fibre, radio is still often used as backup and six of the main TV transmitters continue to rely exclusively on radio feeds. Most of these are in rural areas, though backup links are deployed even at some urban transmit sites to maximise reliability. Distribution links are mostly in the 7.5 GHz and 13 GHz band but there is some use of higher bands for shorter links and 1.4 GHz has been popular for feeding DAB transmitter sites, where a much lower bandwidth (less than 2 Mbps) is required. However, interference has been encountered at 1.4 GHz and in future Arqiva may prefer to use its 28 GHz spectrum holding instead for shorter links.

Narrow band links (64 – 576 kbps) are also deployed in the 1.4 GHz band to provide feeds between radio studios and multiplex centres.

Figure 2.29: Distribution of links by frequency band for broadcasters

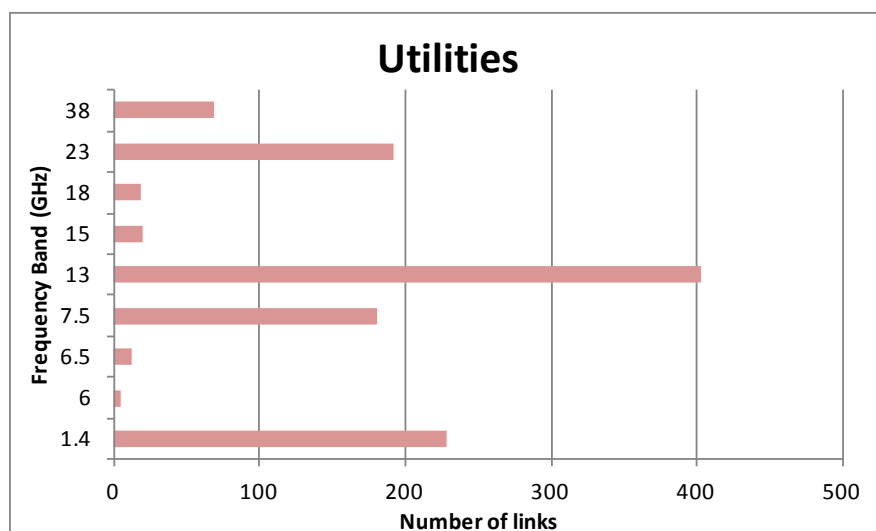


Demand for TV distribution links is expected to be stable over the next decade as all the links required to serve the post-switchover DTT network are now in place. According to Arqiva, who are the principal provider of terrestrial broadcast feeder links, the links have sufficient capacity to cater for any anticipated upgrades to the DTT network, such as DVB-T2 or additional high definition services. Further growth in demand for DAB feeder links is anticipated as the DAB networks continue roll out to match current FM coverage.

2.7.3.2 Utility use of fixed link spectrum

The main use of fixed point to point links by the utilities currently is to connect scanning telemetry base station sites back into the communications network and to inter-connect control centres. There has also been some use of the 5 GHz licence-exempt band by the water industry but there are significant concerns that the potential for interference will make these untenable in the future.

Figure 2.30: Distribution of links by frequency band for utility users



Lower frequency bands are also important for the utilities to provide long haul connections in rural areas. Note also the extensive use of 1.4 GHz, which is particularly attractive for relatively narrow band links to sites where deployment of a large dish antenna would be impractical or excessively costly. This band has also been used for non line of sight links.

In the case of the water industry it is not expected that the demand will change significantly in terms of number of links but with the deployment of digital scanning telemetry, and the ability to provide more data, the links may need upgrading to higher data rates. Future requirements will be associated with security (e.g. monitoring of pumps at reservoirs) and there is a need for CCTV and for it to be relayed back by microwave from many sites especially those in remote locations where broadband is not available.

The major demand in terms of fixed links will come from the creation of a UK Smart Electricity Grid which is a vital enabler for a successful low carbon economy. This will lead to a significant demand in additional links as well as a need to increase the capacity on existing ones. It is expected that microwave radio will be used to provide connectivity to the upper layers of distribution network:

- between new and existing control centres
- in the 132 kV – 33 kV control layer
- to high priority 11 kV sites.

It is expected that the links needed to provide communications for the 11 kV sites will use the 1.4 GHz bands and that all other links could potentially be provided in any of the licensed frequency bands.

2.7.3.3 *Public Safety use of fixed link spectrum*

There are currently two main uses of fixed link spectrum by the public safety community, namely backhaul links for the Airwave network and bespoke links deployed by individual police forces or fire brigades to provide broadband communication facilities like video surveillance.

[3<]

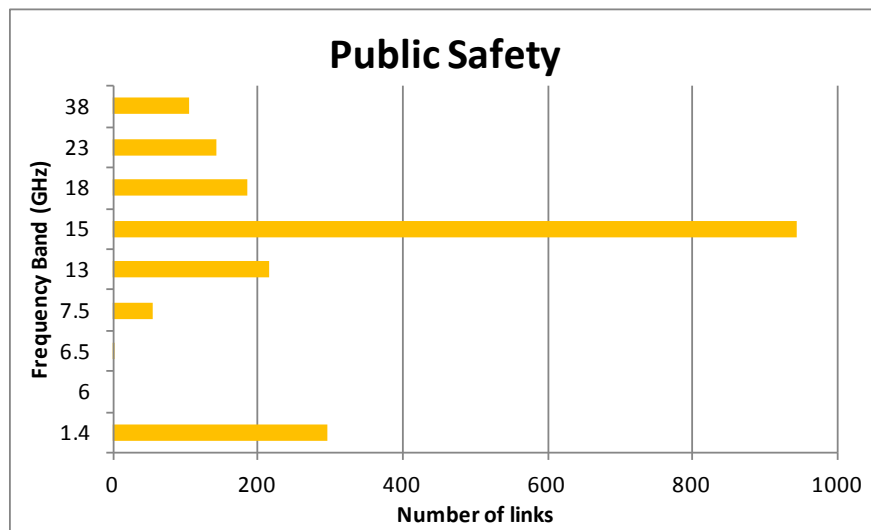
The majority of the Ofcom managed bands are used by public safety organisations (see below).

Table 2.2: Major regional public safety users of fixed link spectrum

[3<]

The higher bands are predominantly used by individual police, fire or ambulance services to meet specific local requirements.

Figure 2.31: Distribution of links by frequency band by public safety users



Additional fixed link spectrum demand from public safety users could potentially come from two main sources, namely individual police forces or fire brigades rolling out their own enhanced communication facilities or from a national public safety mobile broadband network operating along similar lines to the current Airwave narrow band network. We assume that demand will come from one or the other, not from both—i.e. if a national network is rolled out this will cater for the local needs of individual forces.

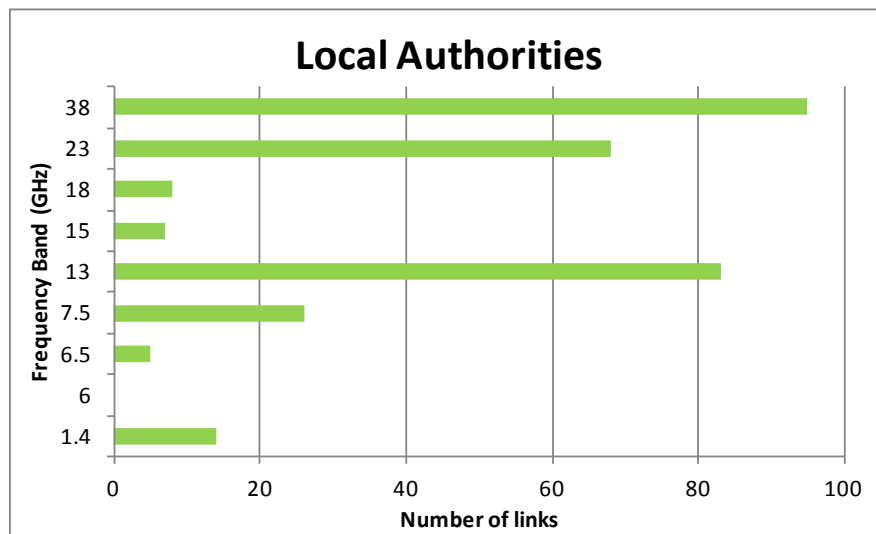
In addition there is a need to interconnect the different regional police HQ due to the increased sharing of resources and this will either be met using fibre or radio links with a minimum capacity of 1 GB.

[3<]

2.7.3.4 Local Authority use of fixed link spectrum

Both lower and higher frequency bands are used by local authorities, largely depending on geographic location (metropolitan councils serve much smaller areas than their rural counterparts and hence are more likely to deploy short links in higher frequency bands).

Figure 2.32: Current use of fixed link frequency bands by local authorities



Although local authorities currently account for a relatively small proportion of national fixed link capacity, this does vary enormously by location. Several individual authorities have recently installed networks of very high capacity fixed links (STM-1 and above), which are sometimes combined with light licensed or licence exempt equipment to cater for a variety of applications. These include wireless CCTV cameras, broadband links to schools and other local authority premises, and backhaul provision for broadband access hotspots located in areas such as business parks where commercial broadband availability is considered inadequate. Typically these new developments involve relatively short links that can be deployed in higher frequency bands above 20 GHz. Some examples are shown below:

Examples include:

- The London Borough of Hounslow, where in 2010 the supplier Tyco Integrated Systems installed a borough-wide 120 camera installation for Hounslow Council as part of a wireless community CCTV network to complement existing traffic enforcement cameras in the area. According to Tyco a cost saving of £100,000 was achieved by using wireless links in preference to leased lines⁴.
- Dundee City Council, where the supplier Airelink used a mix of licensed and “light licensed” fixed link technology to provide backhaul for broadband connections to schools and other local authority sites⁵.

⁴ www.prosecurityzone.com/News/Surveillance/Mobile_and_rapid_deployment_cameras/Hounslow_community_cctv_system_installed_in_record_time_15290.asp#ixzz1YOboV4

⁵ www.aerelink.com/case_studies/

- Anglesey district council commissioned a number of fixed links to support rollout of broadband connectivity to key areas such as industrial estates on the Island⁶.

In each case, a number of very high bandwidth (STM-2 / 311 Mbps) microwave links have been deployed—according to Ofcom data these comprise:

- Hounslow: 8 links (all in the 25 GHz band)
- Dundee: 12 links (10 in the 38 GHz band and 2 in the 18 GHz band)
- Anglesey: 12 links (6 in the 18 GHz band, 2 in the 23 GHz band and 4 in the 38 GHz band).

Currently, only a handful of local authorities seem to be deploying such high capacity backhaul networks; however, the impact on fixed link spectrum demand could be significant if these were to be adopted on a more widespread basis across the country. For example, based on Ofcom licensing data, links licensed to local authorities currently account for 1.8% of fixed link capacity nationally (27 Gbps out of a total of 1.458 Gbps), in the Hounslow area of London the proportion is 48% (5.9 Gbps out of a total of 12.4 Gbps). Whilst Hounslow is clearly not representative of the sector as a whole currently, if the recent initiatives described above were to be widely replicated by other authorities throughout the UK the implications for fixed link spectrum demand could be significant.

⁶<http://broadband.affiliatepartnerships.info/groupe-pathfinder-link-all-of-angleseyaas-schools-and-libraries-with-broadband-network/>

3 CURRENT USE OF FIXED LINK BANDS BY NON-FIXED LINK SERVICES

3.1 Fixed Satellite Service

The fixed satellite service (FSS) shares a co-primary allocation in several fixed link bands and also has a number of exclusive allocations in spectrum that could be used by fixed links. According to Ofcom it is estimated that there are currently approximately 500 permanent satellite earth stations across the UK operating in spectrum that is shared with fixed links. A total of 707 satellite links are deployed from these permanent earth stations.

3.1.1 Fixed Satellite Service (FSS) Frequency Bands

The principal fixed satellite frequency bands are listed below:

Band	Frequency	Direction	FSS Applications
C-band	3600-4200 MHz	Downlink	Telephony, data links, VSAT
	5725-7075 MHz	Uplink	Telephony, data links, VSAT
X-band	7250-7750 MHz	Downlink	MOD managed band
	7900-8400 MHz	Uplink	MOD managed band
Ku-Band	10.7 – 12.75 GHz ⁷	Downlink	DTH, VSAT
	12.75-13.25 GHz	Uplink	Feeder links, VSAT
	13.75-14.5 GHz	Uplink	Feeder links, VSAT, TES
Ka-Band	17.3-18.4 GHz	Uplink	Broadcast satellite feeder links
	17.3-17.7 GHz	Downlink	High density satellite links
	17.7-19.7 GHz	Downlink	Shared with fixed service
	19.7-20.2 GHz	Downlink	High density satellite links
	20.2-21.2 GHz	Downlink	MOD managed band
	27.5-27.82 GHz, 28.45-28.94 GHz, 29.46-30 GHz	Uplink	High density satellite links
	30-31 GHz	Uplink	Military band
Q-band	37.5 – 40.5 GHz	Downlink	As yet unused
V-band	47.2 – 50.2 GHz	Uplink	As yet unused

The current status of these bands in the UK, based on Ofcom data on permanent earth stations and feedback from stakeholders, is as follows, where an “uplink” is

⁷ Includes BSS portions

defined as a unique earth station-to-satellite transmission path and a “downlink” is defined as a unique satellite-to-earth station transmission path. For example, if a single earth station is licensed to operate to three different satellites, this is regarded as three separate uplinks.

3.1.1.1 C-Band

According to Ofcom data, there are currently 147 downlinks and 157 uplinks in the UK, operating from a total of 17 earth station sites. Most of these sites are in the southern half of the UK, apart from a sizeable cluster in North East Scotland (5-6 sites believed to be serving the offshore industry), one in central Scotland and two near Manchester. Most of these operate in the frequency bands 3600-4200 MHz (downlink) and 5925-6425 MHz (uplink), but 14 uplinks extend up to 7075 MHz.

Historically C-band was used on a global basis for telephony and TV inter-continental trunking. This required one or at most two earth station locations in each country and these were often located in relatively remote areas, thereby avoiding the potential for interference to/from fixed links. When the first European regional satellite was designed (Eutelsat) Ku-band was used rather than C-band. One reason for this was the extensive use of C-band band by fixed links across Europe.

With the demise of international trunking over satellites because of the wider availability of undersea fibre routes, the market for C-band satellite capacity has changed somewhat. Now, the focus is on applications requiring a global reach (much as with the inter-continental trunking) with an additional focus on areas of the world that experience heavy rainfall thereby making the use of Ku-band less reliable. While the UK does not fall into this category of experiencing severe rainfall it is the case that earth stations in the UK, and more widely in Europe, do act as the remote end, whether as a gateway or as the final destination, for links to/from rainfall constrained countries.

Coordination between C-band earth stations and fixed links in spite of being time consuming has not proved to be a significant problem and probably rather less so than anticipated when the decision was made to use Ku-band for the Eutelsat system. The main propagation feature that has to be taken into consideration during coordination is ducting. This has a greater impact when considering interference into earth stations as the links supported by C-band earth stations have small margins (as the propagation effects that have to be overcome are small) whereas fixed links at these frequencies have larger margins (to accommodate multipath fading). The probability of a multipath fade occurring on a fixed link (thereby making it vulnerable to interference) at the same time as ducted interference from an earth station is very small. Although reciprocity might be expected the unbalanced impact of interference is largely explained by the propagation behaviour and resulting engineering of the wanted links, recognising that there will be second order differences in power and system noise between the two types of system.

The recent decision to allocate the lower part of C-band (3400 – 3800 MHz) to mobile services may lead to pressure to relocate some existing European use of this band to higher frequencies. For example, Inmarsat's current generation satellites (Inmarsat-4) use the 3400-3800 MHz band for the feeder link and it is anticipated that the generation beyond the Ka-band Inmarsat-5 will also use C-band. One of Inmarsat's feeder link earth stations is located at Burum in the Netherlands, which could lead to greater co-ordination difficulties for fixed links in the UK if the higher part of C-band is adopted.

3.1.1.2 *Ku-Band*

There are currently 39 Ku-band uplinks at 14 sites in the shared 12.75-13.25 GHz band, all in the southern half of the country. Most are believed to be satellite TV feeds. 17/18 GHz Ka-band uplinks also operate from the same locations and are again assumed to be TV uplinks (indeed in this band only TV feeder links are permitted under the Radio Regulations).

Ku-band is seen as a key band by the satellite industry and is generally preferred to C-band due to the greater current availability of exclusive satellite spectrum. Some stakeholders have expressed concern about any further encroachment of other services into Ku-band satellite spectrum, noting for example that the presence of direct to home TV services in the 10.7 – 11.7 GHz downlink band has already reduced the capacity available for VSAT operations in the band.

3.1.1.3 *Ka-Band*

Until recently the only significant use of Ka-band in the UK was for Broadcast Satellite feeder links in the 17.3-18.4 GHz band. Over the last year, however, two satellites have been launched with the intention of providing capacity for high density fixed satellite services (HDFSS) for corporate and consumer broadband applications. Further satellite launches are planned to cater for broadband data communications and the band has also been mooted for providing links to earth stations on moving platforms (ESOMPs).

The potential for growth in Ka-band is discussed later in Section 3.1.2.6 (Consumer satellite broadband services).

3.1.2 **Applications**

There are a number of applications that make use of the fixed satellite service, including voice telephony, international data links, satellite broadcast feeder links, both broadcast contribution(studio traffic) and distribution(direct to home), VSATs and earth stations on ships and other moving platforms. Fixed satellites are also being increasingly used to provide broadband connections direct to corporate users or consumers and this is seen by many in the industry as a major growth market for the future.

3.1.2.1 *Telephony (voice):*

Almost all international traffic has now migrated to fibre and satellite is mainly used to serve remote inland or maritime locations. The market is continuing to decline.

3.1.2.2 *International data links:*

Again most data traffic is carried by fibre but satellite is used to provide connectivity to remote locations and to ships or aircraft. Increasing demand for mobile data is driving demand for the latter. There is also increasing demand for applications such as airborne video feeds (e.g. from unmanned aeronautical vehicles). Although much of this use is by the military or other government agencies (e.g. public safety), at least some of the traffic will be carried over commercial satellite systems.

3.1.2.3 *Satellite Broadcast feeder links*

There has in recent years been considerable growth in demand for satellite TV uplinks, as more channels have become available. Additional capacity has been created by using improved modulation and compression techniques (e.g. MPEG4 and DVB-S2), particularly to support HDTV content. The bands around 11 / 12 GHz are now fully utilised at the main orbital slot that provides TVRO services in the UK (28.2°E), which effectively caps the demand for uplink capacity in that orbital slot in the short term (uplinks to other orbital slots can re-use the frequencies used for the UK satellite broadcasts).

Teleport operators in the UK provide uplinks to satellites other than the main UK slot at 28.2°E. Uplink customers tend to have negotiated the purchase / lease of satellite capacity prior to making uplinking arrangements with a teleport operator. The teleport operator then has to seek frequency clearance (with respect to existing fixed links) from Ofcom for the specific frequency which is determined by the satellite capacity that has been purchased / leased. There is no flexibility in terms of changing the uplink frequency and if coordination with existing fixed links is not possible for the frequency in question the business is lost. It is understood that this has happened on a number of occasions.

Discussions with the UK satellite TV industry have indicated the demand for satellite capacity will experience only modest growth. Whilst there is expected to be increasing demand for HD services, this is largely offset by improvements in compression technology and eventually removal from service of SD services. Existing spectrum is therefore expected to be sufficient for anticipated future needs.

3.1.2.4 *Very Small Aperture Terminals (VSATs)*

VSATs are widely used in the corporate market as a cost effective way of connecting large numbers of widely dispersed terminals. Most services operate in exclusive spectrum that has been set aside internationally for VSAT use in Ku band, although there is some shared use in both Ku and C band (4 / 6 GHz).

3.1.2.5 *Earth Stations on Vessels (ESVs) and Earth Stations on Moving Platforms (ESOMPs)*

One area where it has been indicated that demand is currently growing is capacity for earth stations on vessels (ESVs)⁸. Such capacity supports applications such as Internet access, GSM backhauling and document delivery (e.g. newspapers) for passengers and crew both on commercial vessels and cruise ships. More business oriented applications such as file / data sharing, remote IT support and videoconferencing are also supported.

C-band has historically been favoured because it provides substantially global coverage, whereas Ku-band would be largely limited to Europe. There is some concern in the industry about the restrictions imposed on C-band within 300 km of the UK coastline, to protect fixed link receivers from interference. The industry is supporting moves to allow the use of exclusive Ka-band spectrum for ESOMPs as an alternative to the current shared spectrum in C-band and Ku-band. This could overcome the need to use C-band at inshore locations but would require ships to install dual band terminals. Note that the change in acronym from vessels to moving platforms also signifies a widening user base that now encompasses aircraft, trains and road vehicles.

The other potential major growth area for the satellite sector is consumer broadband terminals⁹ and some in the industry are concerned that if both consumer broadband and ESOMPs are successful there could be a need for additional exclusive Ka-band spectrum to support the growth. This would depend on whether access were to be provided via an existing satellite or via a dedicated satellite—if a dedicated satellite were to be used this could re-use the frequencies already used by consumer terminals, but using the same satellite would require additional frequencies.

3.1.2.6 *Consumer satellite broadband terminals:*

A number of companies are planning to use satellite technology to provide broadband connectivity to areas that are currently underserved by terrestrial broadband platforms. In general these applications use the higher frequency satellite bands above 15 GHz (Ka band).

HYLAS ("Highly Flexible Satellite"), owned by Avanti, was launched in November 2010 and occupies the 33.5° W orbital slot formerly used for the defunct British Satellite Broadcasting TV service. The satellite uses eight spot beams in Ka-band to provide a claimed capacity for between 150,000 and 300,000 simultaneous

⁸ According to statements from two stakeholders and evidenced by activity within CEPT FM44 in trying to secure access to Ka-band spectrum. See also VSAT: Present and Future – A comprehensive survey of maritime VSAT. Stark Moore MacMillan.

⁹ See Annex 2 (Market, subscriber and market ramp-up forecasts for satellite broadband in CEPT) of ECC Report 152 – The use of the frequency bands 27.5 – 30.0 GHz and 17.3 – 20.2 GHz by satellite networks. September 2010. Also forecasts from the ESA BBMED project which are not yet publicly available.

broadband connections supporting peak download speeds of between 2 and 8 Mbps. The assumed speed of these connections is not specified. Each beam caters for a specific geographic market, with a focus on the UK and southern and eastern Europe. A single spot beam covers the entire UK territory, providing capacity for up to 37,500 simultaneous connections.

Ka-Sat was launched in December 2010 in the 9° E orbital slot by Eutelsat and is considerably larger than HYLAS. The satellite has 82 spot beams serving the UK, most of continental Europe and parts of North Africa and the Middle East. According to Eutelsat, Ka-Sat re-uses the available frequencies 20 times across its coverage area to provide a total theoretical throughput of 70 Gbps through 82 spot beams. Eutelsat claims that up to 1 million consumer broadband connections could be provided by Ka-Sat, alongside additional professional services such as satellite news gathering. The UK is served by four partially overlapping spot beams, suggesting a total available capacity of approximately 3.4 Gbps. Ka-Sat has assumed a busy hour throughput per user of 42 kbps in its capacity planning.

As Ka-band is considerably more susceptible to rain fading than lower satellite frequency bands, adaptive modulation will be deployed in the band to provide reliable connectivity (albeit at lower speeds) under adverse weather conditions.

The limited capacity available via the current Ka-band satellites means that consumer satellite connections are likely to remain more expensive than cable or DSL connections and are subject to monthly data caps, in a similar way to mobile broadband connections. If the market for satellite broadband takes off, for example to meet growing demand for rural broadband in areas beyond the reach of terrestrial high speed networks, this could stimulate demand for additional satellite capacity, either by means of additional satellites (a number of which are already planned) or for access to further spectrum.

The growth in satellite broadband foreseen by some and the desire to reduce the unit cost of satellite capacity is likely to lead to demands for additional exclusive spectrum, particularly for the downlink (i.e. in the 17.7 – 19.7 GHz band). Additional exclusive spectrum that might be made available for the user link comes at the expense of the spectrum that can be used by the gateway stations. A knock-on effect of this is a new interest in Q- and V-bands for the gateway links.

3.1.3 Balancing the needs of service links and feeder links

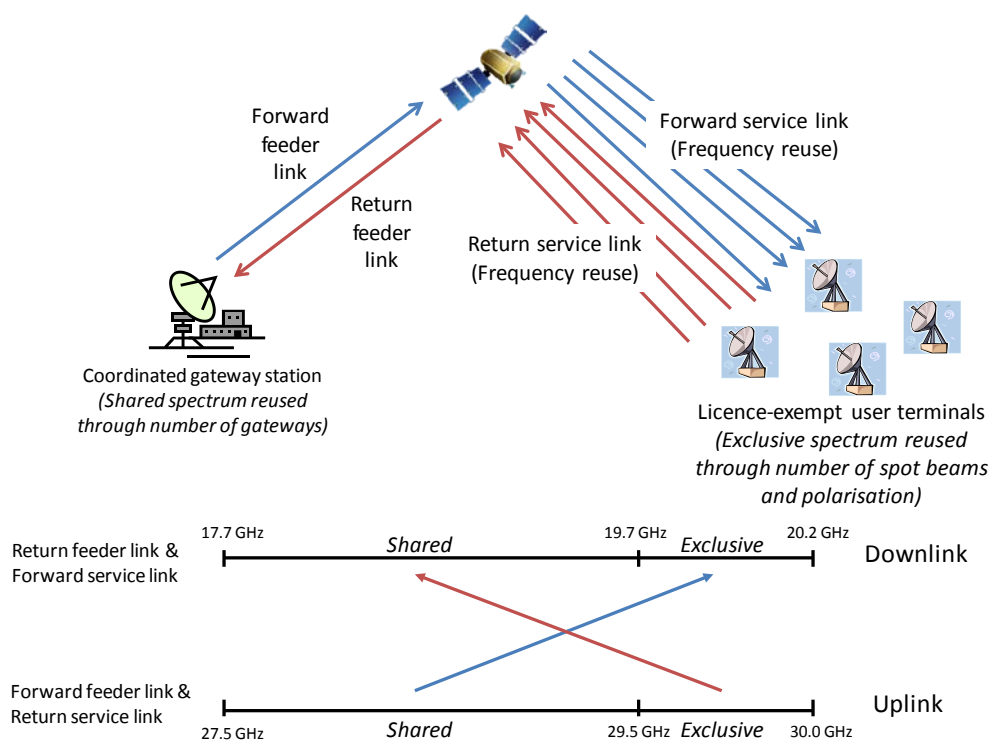
For satellite systems servicing a large number of users whose traffic is then aggregated through gateway stations, the balance of spectrum use on the service link (users) and feeder link (gateways) becomes an important issue. This has been the case for mobile satellite systems for some time and these systems generally elect to use completely different frequency allocations for the service and the feeder links in order to achieve the necessary spectrum balance. Ka-band systems which are expecting to support consumer broadband services have so far used the same frequency allocations for both the service link and the feeder link. The balance

between the spectrum required on these different parts of the end-to-end link has been achieved by:

- using the limited amount of exclusive spectrum (500 MHz) for the service link where it is reused several times through spot beam and polarisation reuse
- using the more extensive shared spectrum (2000 MHz) for the feeder link as the limited number of gateway stations are more readily coordinated with the fixed service.

The current situation, in simplified form, is shown in the figure below, noting that strictly speaking the 27.5 – 29.5 GHz shared band is in fact segmented and in the UK the terrestrial parts of the spectrum have been auctioned. This means that there is less spectrum available for feeder link use on the return link but that coordination is not required.

Figure 3.1: Ka-band satellite service and feeder links schematic



If demand for satellite based consumer broadband increases significantly it is possible that the existing 500 MHz of exclusive spectrum, in particular the downlink part, will be inadequate for future systems. In principle, additional capacity using the existing exclusive spectrum could be provided by launching additional (similar) satellites. However, access to orbital slots is not easy and it can be shown that fewer bigger satellites provide a more cost effective service than a larger number of smaller (similar) satellites.

The implication of providing additional exclusive spectrum is not only the requirement to refarm fixed links, to a greater or lesser extent, in the 18 GHz band

but also that the new exclusive spectrum is effectively lost to the feeder links. In this situation the satellite operator will have to make additional provision for feeder link spectrum, noting that this is a “double whammy”; reduced spectrum availability AND the requirement to carry increased traffic. This can be done by providing a significant number of additional gateway stations or by moving to entirely different frequency allocations. The latter is under consideration by satellite operators and developers with Q- and V-band having been identified as potential candidates. This nomenclature corresponds to the following frequency bands:

- Q-band more generally = 36 – 46 GHz
 - Fixed Satellite Service (Space to Earth): 37.5 – 40.5 GHz
 - Fixed Service: 37 – 39.5 GHz (the 38 GHz band)
- V-band more generally = 46 – 56 GHz
 - FSS (E-S): 47.2 – 50.2 GHz
 - FS: no overlap.

3.1.4 Balancing satellite spectrum availability and infrastructure costs

There are some analogies with satellite services and cellular mobile services, in terms of the trade off between infrastructure costs and spectrum. The tradeoff in mobile networks is between the number of base stations required and the amount of spectrum held—in a capacity driven environment doubling the amount of spectrum available will halve the number of base stations required which could lead to savings of hundreds of millions of pounds for a national network. This accounts for the high value ascribed to mobile spectrum, especially in lower frequency bands where the savings are even greater due to the larger coverage areas that can be realised.

It has been argued that if new consumer satellite broadband services are successful this will lead to a requirement for more exclusive spectrum; however, additional capacity can also be provided by deploying additional satellite orbital slots. This clearly implies a cost for the satellite operator, but this needs to be balanced against the opportunity cost of denying spectrum access for other applications, such as the provision of backhaul links for mobile broadband networks.

Other means to provide additional capacity within existing exclusive spectrum could include improved consumer terminal receiver performance and/or improved satellite performance. Receiver performance might be improved in terms of receive system noise temperature and access/modulation/coding efficiency. Improvements in both these areas can only be small as receive system noise temperatures are already relatively low and transmission efficiencies (e.g. DVB-S2) are very close to the Shannon bound. Improved satellite performance could come from increased frequency reuse (i.e. smaller spot beams). This is being pursued by satellite developers but the capacity increase will be self limiting because of increased levels of intra-system interference and potentially by platform stability which will affect beam pointing.

3.2 Potential impact of other services on fixed link spectrum

We have considered the potential for other uses of fixed link spectrum and concluded that the only applications that might encroach into these bands are automotive radars in the 23 / 26 GHz range and UWB devices, which operate at a very low power level in bands below 20 GHz. Both of these applications are essentially “underlay” services which under certain conditions might result in interference above the fixed service protection criteria at certain locations. ECC Reports 023 & 158 detail the various sharing issues for SRR that have been undertaken in CEPT with regard to automotive radars and fixed links.

In any case our scenario modelling suggests that demand for spectrum in bands above 20 GHz will remain substantially less than the current supply of spectrum and the projected migration of existing mobile backhaul links to operators’ own spectrum in the 32 GHz band will further offset demand for fixed links at 26 GHz.

4 FACTORS LIKELY TO AFFECT DEMAND FOR SPECTRUM IN FIXED LINK BANDS

4.1 Introduction

A number of regulatory, technical and market developments are likely to have an impact on future demand for spectrum in the bands currently used by fixed links. Developments within the public and utility sectors could also have a significant impact. The key demand drivers that we have identified are discussed in the following sections.

4.2 Regulatory developments affecting fixed link bands

4.2.1 Impact of regulatory mandates relating to fixed and/or mobile broadband provision, e.g. with regard to minimum speeds or rural coverage

Both the Government and Ofcom have recently put forward initiatives to improve availability of both fixed and mobile broadband services across the UK. Currently about 5% of the UK population resides in areas where available fixed broadband bit rates are below 2 Mbps. The Government has set a target to deliver at least 2 Mbps to the entire country and it has been mooted¹⁰ that wireless broadband solutions may play a role in achieving this. Wireless broadband connections could take a number of forms, including:

- connection via existing or future mobile networks
- connection via a dedicated broadband wireless access network
- connection via a satellite terminal.

In practice it may be that a combination of the three is required.

3G mobile networks currently deployed in the UK claim to cover up to 97% of the population; however, such claims typically relate to outdoor coverage at the lowest available bit rate, which with current technology is considerably less than 1 Mbps. In its recent consultation on the planned 800 MHz auction, Ofcom proposed a coverage obligation of 95% of UK population on one of the licences, with a minimum specified bit rate of 2 Mbps and a good level of indoor coverage. There has been subsequent lobbying to extend this coverage obligation further in order to address the lack of fixed broadband coverage in many remote areas¹¹. The implications of expanding mobile broadband network coverage and of using a mobile broadband network to provide fixed broadband access are discussed further in the following sections.

¹⁰ See, for example, "Broadband Delivery UK Theoretical Exercise, Conclusions and Lessons learned", December 2010.

¹¹ For example, in May 2011 Parliament put forward a recommendation urging the Government and Ofcom to extend the coverage obligation to 98%.

4.2.1.1 *Implications of extending mobile broadband coverage*

Although 3G coverage is currently claimed to be up to 97%, this figure relates to outdoor coverage at relatively low data rates and the level of indoor coverage at true broadband speeds (2 Mbps or more) are likely to be much lower. Further expansion of coverage is likely to involve upgrading existing rural GSM sites to 3G, deploying 900 MHz (or 800 MHz when it becomes available) at existing 2 GHz sites and adding a further 1200 – 1500 base stations to serve areas that currently have inadequate 2G coverage. The capacity of many base stations, especially in rural areas, will increase significantly due to the upgrade.

This will require a corresponding upgrade to the backhaul capacity to the site. As noted previously, a 2G base station typically requires a backhaul capacity of 2 – 8 Mbps, depending on location, whereas a 3G station requires 16 – 68 Mbps. Future 4G (LTE Advanced) base stations will require at least 80 Mbps in practice this is likely to be 155 Mbps, or more if the LTE network is used to provide a fixed broadband service in some areas (see next section).

In urban and suburban areas, much of this increased backhaul capacity will be provided by fibre, but in rural areas where fibre is less prevalent there is likely to be a substantial increase in the demand for high capacity mobile backhaul links. Many of these will require deployment in lower frequency bands (below 20 GHz) due to the longer paths involved in rural areas.

The UK Government has recently committed to investing £150 million to improve mobile voice coverage throughout the UK. There may be some possible knock-on benefits for mobile broadband coverage.

4.2.1.2 *Implication of using a mobile broadband network or other wireless technology to deliver fixed broadband services where alternative platforms are inadequate*

The implication of using a mobile broadband network to provide a substitute for fixed broadband where the latter is inadequate is significant in terms of the required network capacity and associated backhaul requirement—this is because fixed broadband users typically consume many times more bandwidth than mobile users. For example, Ovum's traffic projections for mobile broadband suggest an average bit rate per user of between 3.2 and 10.2 kbps. By comparison, a 2009 report prepared for the BBC Trust projected per user rates of between 179 and 211 kbps on fixed networks, largely driven by demand for on demand video services¹². In other words, traffic per user on a fixed broadband network is likely to be between 17 and 66 times higher than on a mobile broadband network. Another report prepared for the UK Broadband Stakeholder Group¹³ put forward low, medium and high

¹² "Report to assess impact of Canvas on ISP Costs", prepared for BBC Trust by Value Partners, November 2009

¹³ "Costs and capabilities of wireless and satellite technologies – 2016 snapshot", report for BBSG by Analysis Mason, October 2010

demand scenarios for 2016 with average broadband traffic per household of 85, 700 and 1500 kbps respectively- the latter is considered an extreme scenario.

One potential way to deliver this higher throughput might be to deploy a mobile broadband technology such as LTE in a “fixed” configuration, e.g. using desktop modems or external wall or roof mounted antennas instead of a conventional mobile handset or dongle. This would significantly improve the link budget between the terminal and the base station resulting in as much as an order of magnitude improvement in the connection speed (since a higher modulation / coding scheme can be deployed). There would of course be a knock-on effect on the backhaul requirement to carry the higher traffic throughput and this needs to be taken into account in estimating future link demand.

Although the above discussion focuses on use of a mobile network to deliver broadband capacity, alternative technologies such as WiMAX in the 5.8 GHz band, “white space” technology in the UHF TV band, or even Wi-Fi in the 2.4 GHz band could also be deployed. However, the implications for backhaul capacity will be relatively unaffected by the choice of access technology, since the capacity is ultimately driven by the end user demand. In our scenario modelling, we have defined all such wireless provision of fixed broadband services as fixed wireless access, to differentiate from the much lower assumed throughput per user associated with mobile broadband services.

4.2.1.3 *Satellite*

It is certainly feasible that in some locations satellite may prove to be the most practical and cost-effective means to deliver broadband access and indeed this underpins the business case of recently launched platforms such as HYLAS and Ka-Sat. A report prepared for the Department for Business Innovation and Skills (BIS) concluded satellite may be the most practical broadband platform for between 0.5% and 1% of premises in the UK, suggesting approximately 150,000 to 300,000 connections, primarily in rural areas with very low population density.

The available capacity of the Ka-Sat system in the UK is estimated to be 3.4 Gbps. Assuming a 50% share of the satellite broadband market, the implied capacity per user would be between 22.7 and 45.4 kbps per connection, rather lower than even the lowest projected requirement for fixed broadband traffic. This implies that either additional spectrum or the launch of additional satellites would be required to deliver quality of service comparable to terrestrial broadband networks.

4.3 **Technology developments affecting fixed link bands**

There are three main technology developments that are likely to impact on fixed link bands over the next ten years, namely:

- ability to use higher frequency bands (notably above 40 GHz)
- ability to achieve higher bit rates per link (principally by deploying higher level modulation schemes and adaptive modulation)

- use of alternative configurations such as point to multipoint.

The following sections review each of these developments.

4.3.1 Use of Higher Frequency Bands

As already noted in the previous chapter, both spectrum and the necessary technology are available in the 60 , 65, 75 and 85 GHz bands to accommodate short haul fixed links, typically up to 3 km in length (though 60 GHz is limited to less than 1 km). These bands are likely to prove increasingly attractive for high capacity links to connect 4G mobile networks or wireless hotspots in urban areas, and as equipment costs fall could provide a lower cost substitute for some existing shorter links in the 38 GHz band. One uncertainty, however, is whether the current light licensing regime would afford an adequate level of interference protection in the longer term. A number of stakeholders including mobile operators have expressed concern that the current light licensing regime will not provide adequate quality of service for backhaul provision.

4.3.2 Point to Multipoint

Point to multipoint (PMP) has historically been aimed at the wireless access market but vendors are now identifying the potential for PMP backhaul configurations to support mobile backhaul. The principal advantages of PMP cited by proponents of the technology such as Cambridge Broadband include:

- fewer antennas required, resulting in lower operational costs
- ability to aggregate data traffic from multiple cell sites and use statistical multiplexing to reduce the backhaul bandwidth required.

The bursty nature of much mobile data traffic means that in a local network of multiple base stations the traffic peaks at each station are unlikely to coincide in time. Trials carried out by Cambridge Broadband¹⁴ compared the amount of bandwidth that would be required to handle the peak traffic from eight 3G base stations, depending on whether a conventional point to point “star” or point to multipoint configuration is used. In the point to point case, each individual link must have sufficient capacity to carry the peak traffic from that base station, i.e. the total bandwidth required is the sum of the peak traffic levels from each base station. In the PMP case the traffic from all eight base stations is aggregated into a single PMP node and since the individual base station peaks do not coincide the total bandwidth required is considerably lower.

The trial was carried out on a live HSPA+ network run by a large middle-eastern operator with heavy data usage over a period of seven days. The total backhaul capacity required for the point to point solution was found to be 123.2 Mbps, compared to 77.9 Mbps for the PMP solution. Assuming 256QAM modulation, this

¹⁴ “Spectral Efficiency Through System Architecture in Mobile Backhaul”, presentation by John Naylon of Cambridge Broadband, July 2011 (www.cambridgewireless.co.uk/Presentation/7.John%20Naylon.pdf)

would imply a 37% reduction in the spectrum requirement, from 15.4 MHz to 9.7 MHz.

It should be noted that this comparison does not allow for the potential for point to point links to re-use frequencies at the same nodal point by virtue of the antenna discrimination on the individual links. The hop length available in a given frequency band with a PMP configuration will be substantially less than with point to point because of the lower antenna gain at the hub station. The PMP architecture also raises potential concerns about network resilience as failure of the hub station would lead to the loss of multiple base stations, whereas failure of a point to point link would only affect a single station. The technique is also only really suited to operators with exclusive spectrum assignments and could not be readily deployed in existing shared fixed link bands due to the wide area sterilised by each hub station.

Our assessment of the potential for PMP technology is that it may be attractive as a cost reduction strategy where operators hold exclusive spectrum blocks, but it is unlikely to be a viable option in shared use bands managed by Ofcom unless the existing assignment tool can be modified to take account of point to area assignments or spectrum can be released specifically for licensing point to multipoint on a geographic area basis similar to Business Radio. It is also not clear whether point to multipoint will be able to achieve the same levels of spectrum efficiency as point to point configurations if frequency re-use considerations are taken into account but this would require a separate study.

4.4 Status of alternative non-fixed link platforms

Individually licensed microwave point to point links provide one means of conveying data and/or voice traffic between two points. Alternatives include fibre or copper links and the use of alternative radio platforms. The latter may include use of an operators existing mobile or fixed wireless access spectrum holding to support backhaul traffic, e.g. at locations where demand for the access services is limited, or the use of licence exempt or “light licensed bands” such as 60 GHz, 65 GHz, 75/85 GHz or 5.8 GHz. Each of these alternative options is considered further below.

4.4.1 Copper

Historically many first and second generation cell sites were connected by copper cables, supporting 2 Mbps PDH- or SDH-based TDM leased line services. These would be provided where sites were co-located with network nodes and where the cost of running copper was financially acceptable. In other situations, fixed wireless links would be used. Since the advent of 2.5G and 3G technology and the associated growth in bandwidth requirement the vast majority of sites have now migrated to radio links or fibre, but with some residual copper-based backhaul. In future, copper backhaul might see something of a renaissance in small cell deployments, particularly residential or small business femtocells which are typically backhauled via the existing DSL connection to the premises. The low capacity of the ADSL (and variants) uplink is not suited for small cell backhaul applications, but

VDSL, with uplink capacity to low 10's Mbps could be suitable for pico-cell backhaul, if the mobile network operators and other end customers are satisfied with service reliability. It may also be possible to use software bonding of DSL links, to provide a more cost-effective solution for backhaul than can be provided by fibre Ethernet or radio. Macro and high capacity micro and pico cells will, however, require higher bandwidth and availability than DSL or cable technology can deliver necessitating the use of fibre or dedicated wireless connections.

Copper-based backhaul, including DSL-based solutions, may also be used for a range of lower bandwidth applications, in enterprise networking, CCTV, telemetry, SCADA, etc. where the application is within cost-effective reach. Fixed link services are typically used in remote areas.

4.4.2 Fibre

Fibre has established a solid position in urban areas and is an alternate solution to radio fixed links for many applications. The deployment decision is based on the financial business case and service characteristics, e.g. reliability and time to repair. In urban and some sub-urban areas where there is competitive supply from several communications providers, the price of fibre-based services is attractive when compared with fixed link-based services; however, in more remote locations the costs of fibre deployment can be high. The high costs associated with buried fibre, ploughed or ducted, prevent the medium from being more widely used. Overhead fibre, although less costly to install, can also incur high way-leave charges which may equal or exceed the cost of the fibre and its installation.

As communication providers expand their established fibre networks they will be able to install fibre access links to customer sites more cost effectively. Although the rollout of fibre to mobile base stations has not been as rapid as many operators projected in recent years, competition and falling prices are expected to see a greater proportion of fibre connections in the period to 2021.

Fibre may be configured to support a range of protocols, with IP and Ethernet becoming more prevalent.

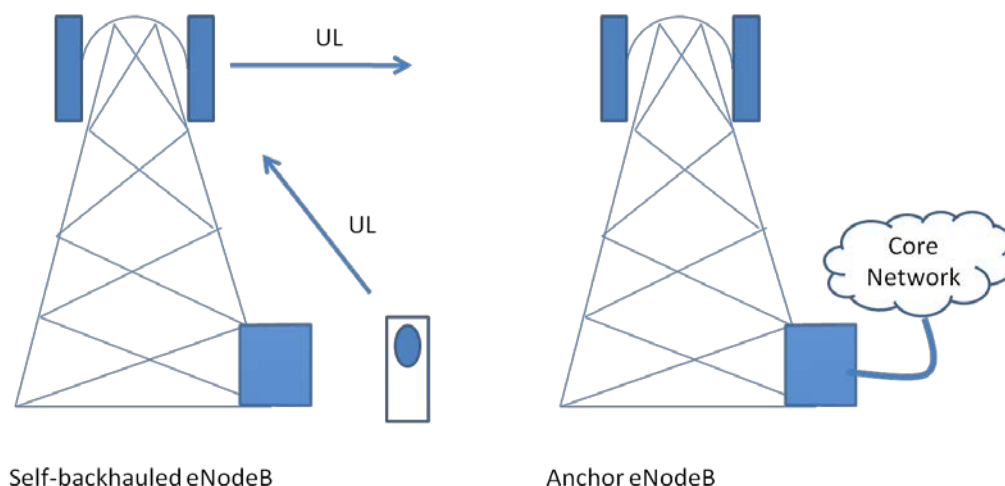
4.4.3 “In-band backhaul”

Some mobile infrastructure vendors have been advocating the potential to use LTE-Advanced technology in mobile frequency bands for self backhauling, i.e. using mobile frequencies and technologies to provide the wireless backhaul link to the base station rather than conventional fixed links¹⁵. This approach could be particularly attractive in unpaired TDD spectrum and at least one UK holder of such spectrum that we have spoken to has expressed an interest in using this approach.

¹⁵ Research Article: “Dynamic Relaying in 3GPP LTE-Advanced Networks” and Ericsson Research paper: “A Self-backhauling Solution for LTE-Advanced”.

The idea of self-backhauling is based on the use of the LTE air interface as a backhaul link to connect a base station, the self-backhauled eNode B, via another base station, the Anchor eNode B, to the core network as shown in the figure below.

Figure 4.1: Access and backhaul link operating in up-link band (source: Ericsson)



In this scheme, a base station requires user equipment like transceiver capabilities as the backhaul traffic is transmitted / received from another base station in a similar way that the radio access traffic is transmitted / received from a user terminal. This implies that a self-backhauled LTE base station should be able to transmit the backhaul traffic in SC-FDMA and receive it in OFDMA format, similar to the LTE user equipment uplink and downlink radio access modulation schemes.

Two different approaches have been proposed for the implementation. The first approach is in-band self-backhauling where physical resources are dynamically shared between self-backhauling and access traffic. In order to overcome potential interference problems between backhaul and access transmissions (as both operate in the same frequency band), either the transmission and reception could be coordinated by time multiplexing the backhaul into the access link or a dedicated antenna could be deployed for the backhaul link at an extra cost.

The second approach is out-of-band self-backhauling where the access and backhaul link operate on separate bands. The drawback of this approach is the extra transceiver costs. Out-of-band self-backhauling provides different implementation options. For example, higher frequencies such as above 3 GHz which are not suitable for non-line-of-sight transmissions could be used for the line-of-sight backhauling. Alternatively, lower-frequency TDD spectrum could be used and might be particularly attractive in situations where a line-of-sight path is not feasible. The spectrum aggregation functionality of LTE-Advanced could allow more efficient out-of-band self-backhauling in that different combinations of carriers could be allocated to the access and backhaul traffic to maximise the available resources.

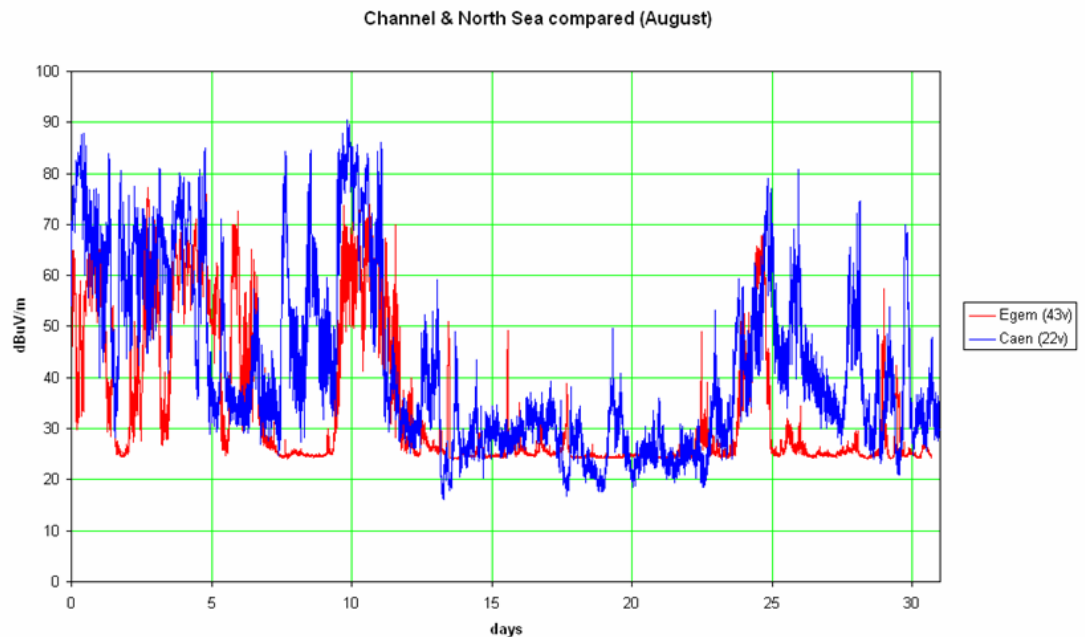
In-band backhaul could be attractive for extending mobile coverage to difficult to reach areas (e.g. in mountainous terrain or deep valleys) where a conventional line of sight link would be impractical. The overall impact on fixed link demand is likely to be small, however, since a connection to the anchor eNodeB would still be required and in a rural area this would almost certainly be a wireless link. In-band backhaul is unlikely to be suitable for higher traffic locations because more spectrum will be required for the access network and any unused spectrum (e.g. in LTE bands) would be unlikely to have sufficient capacity.

4.4.4 Licence Exempt Bands and “White Space” frequencies

Licence exempt bands such as 2.4 GHz and 5 GHz can in principle be used to provide point to point connections, but the path length will be limited by virtue of the low EIRP limits in these bands. Such links would also be prone to interference from other users, in particular conventional Wi-Fi devices, but also ISM and wireless video devices in the 2.4 GHz band. Two other licence exempt bands could have potential in the future as an alternative to fixed link bands, namely 60 GHz and the “white space” frequencies within the UHF TV band (470-790 MHz).

Whilst some proponents of white spaces have suggested they could provide a cost-effective alternative to microwave bands for applications such as mobile backhaul or smart grid networks, in practice the interference environment is likely to limit severely their suitability for such high performance applications. The main problem is the high level of short term interference that white space frequencies would incur from high power TV transmitters operating on the same frequency, even if these transmitters are some distance away. This is due to short term phenomena such as ducting which can cause radio signals in the UHF range to propagate over much longer distances under certain climatic conditions, e.g. during protracted periods of high pressure in the summer months. When such interference occurs it can last for several days and would have a severe impact on the performance of a network deploying outdoor high gain antennas (such as a mobile cellular network). Aegis has undertaken measurements of such interference as part of work to estimate the impact of occasional interference to UK DTT from continental TV transmitters operating on the same frequency which highlight the potential susceptibility of white space frequencies to interference.

Figure 4.2: Interference from Continental TV transmitters along UK South and East coast (August 2010)



In consequence we cannot see any circumstances where white space frequencies would provide a suitable alternative to existing fixed link bands for demanding, high availability (99.9% or higher) applications.

4.4.5 “Light Licensed” Bands

Light licensed bands include the 5.8 GHz microwave band and the 65, 75 and 85 GHz mm wave bands. These bands are very different in terms of their physical characteristics and the services that can be deployed. 5.8 GHz is capable of operating over non-line of sight paths for short distances and is frequently used in point to multipoint or mesh configurations, either to provide fixed wireless access services or to connect networks of Wi-Fi access points to provide wide area coverage. The band can also be used to support point to point links but because these are not co-ordinated they are subject to potential interference from other nearby users of the band.

[3<]

4.4.6 Impact of greater use of operators’ own exclusive fixed link allocations

The mobile operator Everything Everywhere has acquired several blocks of spectrum at auction that can be used to meet backhaul requirements. These include:

- 10 GHz (2 x 50 MHz)
- 32 GHz (2 x 504 MHz)
- 42 GHz (2 x 250 MHz)

Spectrum has also been acquired by BT, MLL Telecom and UK Broadband who are also likely to deploy mobile backhaul links in their spectrum. The likely effect of this spectrum being available will be to reduce demand for links in similar Ofcom managed bands, as operators will seek to reduce their opex by migrating links to bands that do not incur an annual licence fee. It is likely that existing links would be migrated when they are due to be upgraded or replaced, rather than immediately, otherwise the additional capex incurred would outweigh the opex saving. Perhaps more significantly, the bands could prove particularly attractive for supporting the rollout of backhaul infrastructure for 4G/LTE networks. Currently this seems most likely to take place from 2013, although Everything Everywhere (EE) may decide to proceed sooner with an LTE 1800 network (subject to regulatory approval for the necessary licence variation) and is clearly well placed to support the backhaul with the spectrum holdings noted above.

We would expect the availability of EE's 10 GHz spectrum to relieve pressure on the 13 GHz band in particular, and to be ideally suited to supporting the rollout of mobile broadband coverage into rural areas. 32 GHz and 42 GHz are attractive as alternatives to the 26 and 38 GHz bands, although equipment availability is currently a problem in the 42 GHz band.

4.5 Impact of network consolidation and/or sharing

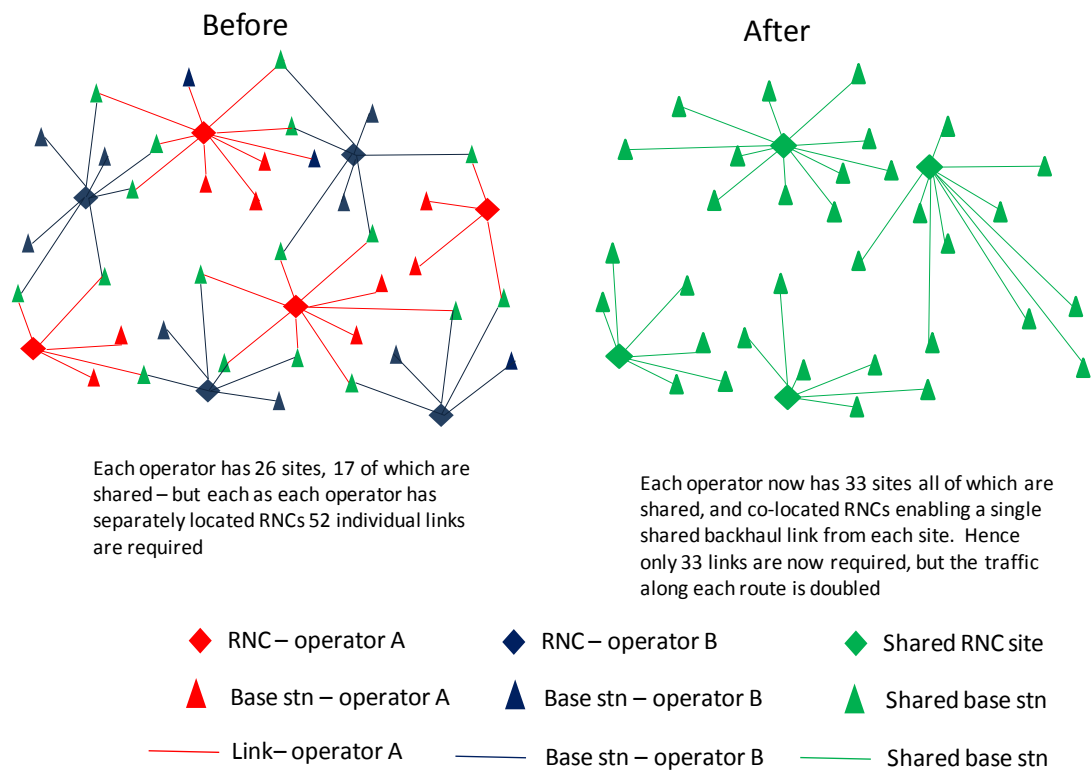
In recent years there has been a growing trend towards sharing of cell sites and other parts of the backhaul infrastructure between mobile operators. For example, the radio access networks of the Three and T-Mobile 3G networks are now managed by a single joint venture company (Mobile Broadband Networks Ltd—MBNL), which has led to a reduction in the total number of cell sites operated by the two networks from approximately 18,000 to 13,000¹⁶. The sharing approach adopted by MBNL uses a single set of equipment on the cell sites and splits the traffic in the Radio Network Controller (RNC). Each site has a single backhaul transmission solution serving both operators.

The impact of network consolidation on backhaul requirements is likely to be somewhat greater than implied by the reduction in the number of sites. Sites that were previously shared by the two operators would still have deployed separate backhaul routes which would in most cases be oriented in different directions to each network's nearest hub site. The joint network replaces each network's formerly separate radio network controller sites with shared sites. The effect is to concentrate the combined traffic from both networks along a smaller number of specific routes, reducing the extent to which frequencies can be re-used and potentially increasing the spectrum demand along the highest capacity routes, if a fibre solution is not adopted. This could potentially lead to a doubling or more of traffic along specific routes, depending on the number of operators involved in the

¹⁶ Source: Ericsson press release, February 13, 2009

sharing arrangement—for example the recent merger of Orange and T-Mobile could mean that in the future individual links deployed by 3, T-Mobile and Orange are consolidated into a single link carrying three times the traffic that the individual links would have carried.

Figure 4.3: Illustration of potential impact of network sharing on backhaul requirements



5 DEVELOPMENT OF FUTURE DOWNSTREAM SERVICE SCENARIOS

5.1 Downstream services and their parameters

There is a broad range of services which require fixed link spectrum and each service has a number of factors which will influence the service's impact on spectrum demand. In the previous chapter we discussed how some of these factors will have a more direct influence than others on the fixed link spectrum demand.

We now consider each of the major downstream services in turn and discuss the parameters that are used to build the scenarios.

5.1.1 Mobile services

There are many factors which affect the usage of mobile services and the demand that they may ultimately make on fixed link spectrum. The volumes of traffic generated by mobile broadband users will greatly exceed those generated by voice and simple data (SMS) traffic. Our modelling therefore focuses on the factors which will have most effect on the volumes of traffic generated by mobile broadband users, namely:

i) **Number of mobile users and service use.**

The UK is a saturated market, with most of the population already using mobile services. The total number of mobile users will therefore not change significantly, but the types of services used will continue to evolve and the relative use of smartphones and large-screen devices will continue to grow, relative to 'standard' phones. There will be greater use of video and content services, which will significantly increase the average traffic per user. Usage will also be encouraged by lower service prices which result from competition, lower network operating costs (resulting from the introduction of more efficient network technologies), infrastructure sharing between operators and more cost-efficient base station backhaul (both radio and fibre).

ii) **Device technology and capabilities.**

There will be a variety of different types of devices that use mobile broadband, for example gaming devices, e-book readers, smartphones, tablets, netbooks and laptops. The performance of devices will continue to improve, but no step changes in the look and feel of devices, which will significantly impact the volumes of data consumed, are anticipated during the period to 2021.

For the purpose of our analysis, we have grouped devices into two categories, namely small-screen and large-screen devices. The former will mainly comprise high performance smartphones, which require a reasonable level of mobile broadband performance and capacity, and may be characterised as consuming shorter content streams, e.g. YouTube and social networking content. The latter will include netbooks, laptops and

tablets, and will be more likely to be used for accessing rich media (films, TV, newspapers, etc). Ovum's analysis indicates that in 2011 small-screen devices accounted for approximately 88% of mobile broadband connections and large-screen devices 12% and that this ratio is projected to evolve to 92% vs. 8% by 2021. An average large-screen device is expected to generate approximately 20-30 times more traffic than a small-screen device. In nearly all cases, large screen devices are an additional resource—they complement, rather than displace smartphones, and the market for smartphones is still growing (Ovum projects over 13% CAGR¹⁷ to 2016), as non-smart phones are withdrawn from use. However, if the market evolves such that large screen devices do take up a larger proportion of mobile devices than we have included in our scenario projections, we would expect only a small increase in demand for fixed link spectrum. Although large screen devices consume considerably more data than small screen devices and despite the increased spectrum efficiencies of LTE access services, the network operators will still be challenged to sustain the data traffic on their RAN and backhaul networks.

Our scenarios therefore assume that there would be a number of developments: the mobile network operators would invest further in additional traffic offload services e.g. Wi-Fi nodes and femto-cells, and these nodes will seamlessly take traffic when they are available; device power efficiency continues to improve, such that consumers are less averse to leaving Wi-Fi permanently enabled; and the volume-related costs of data services would be adjusted to encourage users to seek Wi-Fi and other offload services.

iii) **Fixed-Mobile Substitution.**

Mobile services continue to be used as a substitute for fixed network services. In 2011, about 15% of UK households use only mobile telephony services¹⁸. As the availability and performance of mobile broadband services increase, we expect that mobile broadband will increasingly substitute some fixed broadband services. However, the degree of substitution will not be as great as for voice services, as it is not expected that the price, access speeds, download caps and performance of mobile services will match those offered by fixed network services. Fixed-mobile substitution is a separate factor, the impact of which is included in the mobile traffic demand assessment.

¹⁷ Compound annual growth rate

¹⁸ Ofcom: Communications Market Report: UK, August 4, 2011

iv) **Network connections.**

Ovum's analysis indicates that the mix of network connections is estimated to be 44% 2G and 56% 3G (WCDMA and HSPA) in 2011. This is projected to evolve to between 44% and 59% 3G in 2021, with between 56% and 41% 4G (LTE). We have projected that between 60% and 80% of large-screen devices will have migrated to 4G (LTE) by 2021, to take advantage of the higher performance that their devices will require. We have assumed that 2G will have essentially become obsolete by 2021, apart from some limited legacy use for roaming and machine to machine (M2M) communication.

The evolution of mobile broadband services (including the launch of 4G /LTE networks) and the resulting increase in traffic to the device will drive two factors which may over time reduce fixed link spectrum demand, namely:

- the off-load of traffic from the mobile network to other networks, e.g. Wi-Fi or femto cells connected by fixed broadband backhaul (DSL or cable), and
- the deployment of fibre as the backhaul solution of choice.

5.1.2 **Satellite services—broadband and DTH**

A recent Satellite Broadband Steering Group (SBSG) report¹⁹ estimates that satellite operators will have the capacity to deliver up to 150,000 functional broadband connections in the UK by mid-2011 using satellites that have been recently launched, increasing to 225,000 connections by 2012 and 300,000 connections by the end of 2014 as further satellites on order are added to the network. This is comparable to the projections in the BIS report referred to in section 4.2.1.3. These satellites are expected to offer headline broadband speeds of up to 10 Mbit/s with service level agreements. However, these projected capacities imply a relatively high degree of contention; as previously noted in Section 4.2.1.3, the average bit rate per user at such take-up levels with currently available spectrum would fall far short of projected demand required by terrestrial fixed broadband users under medium and high usage scenarios.

The management of satellite capacity is complex but currently consumers are expected to have an entry-level fair usage cap of around 4 GB per month, which is similar to some mobile broadband services but much lower than typical DSL or cable networks. Installation costs are expected to be between £400 and £600 before operator subsidy and monthly costs are expected to be between £20 and £25. Higher capacities will be available at higher cost, with a doubling of the fair usage capacity for a user approximately doubling the monthly cost. Longer term consumer contracts with operators may reduce installation or monthly cost.

¹⁹ Satellite Broadband Steering Group: Satellite Broadband Services Report to the UK Space Leadership Council, June 2011

The SBSG report notes that there are around 2 million homes and businesses in the UK that cannot currently access a good level of broadband. In order to meet the Coalition Government's objective of providing virtually all homes and businesses in the UK with functional broadband, Broadband Delivery UK (BDUK) estimates that between 100,000 and 200,000 of these homes and businesses will be served by satellite as there is no sensible economic alternative. Satellite broadband service providers anticipate that their services will be used for enterprise networking and broadband applications (estimated at around 15%-20% of demand), consumer broadband services (60-70%) and government services (15%-20%), particularly in areas which are poorly served by fixed network (DSL and cable) and mobile broadband or will be used where required to provide resiliency. Satellite broadband will be an important component of service provision to support universal service objectives. However, the high initial installation costs are likely to inhibit mainstream take-up if alternative services are available.

If the levels of take-up of satellite broadband projected by BIS and the SBSG are realised and that traffic demand per user is in line with projections by the BBC Trust or BDUK, the existing Ka-band spectrum may prove insufficient to meet fully the projected demand and access to additional spectrum in the 18 GHz and 28 GHz bands would be required.

We note that the satellite operators' own projections are stronger than those from BDUK, and they see a potential need for additional spectrum in the Ka-band for consumer terminals across the full 27.5 – 29.5 GHz and 17.7 – 19.7 GHz bands to go with the already available 29.5 – 30.0 and 19.7 – 20.2 GHz bands.

5.1.3 Broadcast / media

The five major broadcasting organisations in the UK (BBC, ITV, Channel 4, Channel 5 and BSkyB) and their contracted network infrastructure partners use fixed links primarily on the studio to transmitter links (STL) and the access networks to major sources of content. Sports stadia and other major event venues are predominantly permanently connected by fibre, which can be used as needed to handle live content. Where fibre is not available, then satellite is the preferred medium, with point to point links being used for smaller venues, as needed. With the increase in fibre in the access networks there is less need for media companies or their network agents to require fixed links.

A recent Europe-wide study undertaken by Ovum (with commercial and public-sector broadcasters, pay-TV platform operators and studios) indicates that in the contribution side (content to/between studios) fixed links account for about 10% of the methods used to carry data. Satellite links, fibre & copper networks and physical media take the other 90%. On the distribution side the use of fixed links rises to about 15% of the total. A fuller description of the current use of fixed link spectrum in the UK by broadcasters was presented in section 2.7.3.1.

5.1.4 Utilities, Smart Grids and Smart Meters

There is expected to be a continuing need for the utilities to self-provide their own networks for point to point communications and telemetry, because there are a number of uncertainties in respect of what the commercial IP (carrier Ethernet) networks will be able to deliver, for example with regard to:

- Latency. The current latency available over IP networks is not sufficient to meet the needs for the control of Grid Networks and avoid, for example, unwarranted shut down of parts of the grid network in the case of faults.
- Redundancy. The nature of IP networks make it extremely difficult to ensure that there is sufficient redundant working 24/7 which is a requirement for safety critical communications.
- Resilience. In the case of power outages it is necessary for the carrier network to remain operational and this may require use of standby power for 24 hours plus. There is no way of checking that this would be achieved.

IP networks have significantly different network architectures from legacy networks and the IP networking needs to be proven before it will be a viable solution for the operational utility networks.

The key driver for radio will be the deployment of Smart Grids and specifically the EU renewable energy targets which have to be met by 2020. It will be necessary to roll-out an ICT structure for these Smart Grids to provide distributed intelligence to support these objectives—for example, wind turbines are being deployed in remote areas of Scotland, Wales and also off-shore which will require radio infrastructure to manage these electricity grid sources.

The use of solar cells in domestic and commercial premises is increasing and these need to be connected to the grid to manage any excess power generated. Whilst in the case of solar cells in sub-urban and urban areas there may well be commercial services or access to fibre available that could be used to control this generation, in the more rural and remote areas radio is likely to be the main solution. There will also need to be means of controlling the demand side of the electricity supply associated with, for example, electrical vehicles and heat pumps.

The demand from utilities will not be for significantly higher data rates but a substantial increase in the number of points of presence in the network that will need to be connected back to a central point. So, for example, while the existing SCADA (telemetry) requirements are 9.6 kbps for 1,000 points of presence, in the future there may be a need for 10 Mbps to 1,000 points of presence but also 9.6 kbps to several hundred thousands of points of presence. Even if a fraction of these are carried over radio this will be a significant increase in demand.

There are currently 10,000 on-shore and off-shore generators in 900 wind farms operational in the UK or in various stages of the planning process.

5.2 Downstream service scenarios

The fixed link spectrum bands, including those which have shared use by fixed links and satellite services are used by a very wide range of downstream services, either directly for the provision of the service itself or to provide backhaul. It is not straightforward therefore to develop scenarios in which all of the downstream services are influenced by the same set of factors. We have therefore developed a set of four scenarios, with some underlying themes, which generate four different sets of outcomes. The driving factors and the impacts of each scenario are discussed in this section of the report. The impact of the scenarios and the resulting influence on the demand for fixed link spectrum is discussed in chapter 4.

Each of the four scenarios is described in the following sections.

5.2.1 Scenario A—The Fibred Nation

This scenario leads to a situation in which the deployment of fibre increases strongly. This has a particular impact on the largest current users of fixed links, namely mobile network backhaul. The key characteristics of Scenario A are as follows:

5.2.1.1 *Economy*

The economy remains weak which has an impact on consumer spending. The high cost of capital reduces the incentive for mobile network operators to invest in new network infrastructure and services, such as LTE. LTE coverage therefore does not extend beyond urban areas in this scenario.

5.2.1.2 *Policy and regulation*

There are clear and supportive regulatory and policy drivers which encourage the deployment and availability of fibre services, for example:

- A review of the conditions for Passive Infrastructure Access (PIA—i.e. access to the ducts and poles required to rollout fibre) and the supply of dark fibre in the access network to enable the competitive supply of cost-effective fibre and leased line services in increasingly wide areas. These services become available from 2014.
- In support of the BDUK programme, there are regulatory requirements for universal broadband services with escalating capacity.

There are increasing government requirements for local government and utilities to improve public safety monitoring and utility infrastructure, through CCTV and telemetry.

5.2.1.3 *Service demand*

The rate of growth of mobile services and applications usage is depressed by economic conditions. There is low or moderate growth in demand for mobile services over the period, with overall compound traffic growth of 20% per annum.

In 2011, small screen mobile devices (e.g. smartphones) consume around 100 MB of mobile broadband capacity per month, and large screen devices (e.g. tablets, laptops) around 2 GB per month. In this scenario, the consumption increases at 13% and 19% CAGR, to 354 MB per month and 11.4 GB per month respectively. We have used an Ericsson guideline²⁰ that 1 GB per month of mobile broadband consumption translates to a requirement for 5 kbps backhaul capacity in the busy hour. With smartphones representing 92% of mobile broadband devices, this translates to an average of 4.8 kbps busy hour traffic per mobile broadband user on a 3G network and 8.3 kbps busy hour traffic per mobile broadband user on a 4G network in 2021.

In those areas which have fixed wireless solutions (FWA, 3G or LTE based) to meet the government and BDUK objectives for broadband availability, the average busy hour traffic per user will increase in line with our mid-range estimates, to around 200 kbps per user by 2021. The scenario assumes that about 900,000 consumers will use such services by 2021.

5.2.1.4 *Mobile network investment*

Low growth in traffic reduces operator revenues, leading to further cost-reduction initiatives: further network consolidation, site sharing and backhaul sharing. These changes increase the incentives for operators to deploy fibre backhaul to shared sites as sunk costs are shared.

The deployment of LTE remains limited to main urban centres. In rural areas, modest broadband mobile obligations lead to good mobile coverage but limited capacity.

5.2.1.5 *Satellite service demand*

Lack of investment in terrestrial broadband networks and limited coverage of 4G mobile networks leads to relatively strong demand for satellite broadband provision in rural areas, potentially exceeding the 300,000 users suggested by the SBSG.

5.2.1.6 *Other factors*

The government target of 2019 for Smart Grids/ Meters are met, and dedicated spectrum is available for these services. There is limited impact on the fixed link spectrum bands to support some backhaul within the networks.

The broadcast sector deploys additional sites for DAB and DTT coverage to improved rural coverage and in-car reception.

A dedicated public safety mobile broadband network is rolled out in 2015, using spectrum in a second digital dividend band around 700 MHz (this is identified as the lowest cost option and demand for this spectrum for commercial mobile is muted somewhat by the depressed economy).

²⁰ <http://www.ericsson.com/res/docs/whitepapers/hspa.pdf>

Scenario impact on fixed link spectrum

The impact of the scenario is that:

- Mobile base stations are increasingly connected by fibre which reduces the demand for fixed links, particularly in urban and suburban areas.

Locations served by fibre	2011	2021
Sparse Rural	0%	15%
Medium Sub-urban	20%	85%
Dense Urban	70%	98%

- There is sizeable demand for satellite broadband, to meet broadband universal service objectives, which is likely to lead to demand for additional exclusive Ka-band spectrum. The number of satellite broadband users grows to 300,000 or more nationally by 2021, virtually all of these in rural areas.
- Broadcasters migrate to fibre where available and economic. They provide additional coverage / expansion in rural areas to provide DAB & DTT services, with some demand for fixed links to support this expansion.
- Utilities and local government have to meet regulatory reporting obligations, which together with emergency services requirements and wireless CCTV drive spectrum demand, but mainly in rural areas.
- There is a high demand for fixed link backhaul for the new national public safety network from 2015, which must use radio links to all sites to ensure resilience.
- Smart Grids/ Meters WAN is served with dedicated spectrum but some backhaul links are required in fixed link bands.

5.2.2 Scenario B—The Green Agenda

A major focus on green policies stimulates growth in mobile service demand (to facilitate teleworking and reduce travel) and increased site sharing between mobile operators. Similarly to Scenario A, this scenario leads to a high level of fibre deployment which displaces fixed radio link demand in the mobile sector.

5.2.2.1 Economy

The economy remains weak in 2011 and 2012 but strengthens during the period to 2021, enabling greater levels of investment. Consumers are inclined to spend more on communications products and services, which stimulates spending in the local authority, government, utility and communications provider sectors.

5.2.2.2 Policy and regulation

There are strong regulatory and policy drivers to support and develop the “green” agenda. The GSM Association’s policy paper *Mobile’s Green Manifesto*²¹, which is internally guiding the mobile industry, is also influential in informing the development of government policy and regulation. These initiatives impact network deployments and the demand for mobile services, which affect the demand for fixed link spectrum:

- Universal service objectives are revised to encourage better rural mobile coverage and capacity.
- Tele-commuting is encouraged, leading to increased demand for mobile services in suburban and rural areas.
- Site sharing is both a green and an economic imperative, resulting in a reduced environmental and physical footprint of mobile infrastructure.
- Revised planning legislation and incentives support new investment in energy-efficient systems and speed the development of new network technologies.
- Smart Grid and Smart Building policies encourage the deployment of embedded mobile solutions with respect to smart grids, buildings and transport.
- The review of the conditions for Passive Infrastructure Access allows competitive supply of fibre for leased line services from 2014. This encourages a greater level of fibre-based backhaul in rural areas.
- Mobile networks are obliged to offer preferential access to public safety users as a condition of acquiring additional spectrum.

5.2.2.3 Service demand

The economy and policies encourage greater use of services in all sectors and particularly higher speed mobile broadband services.

The average mobile broadband data consumption by small screen mobile devices increases from 100 MB per month in 2011 to 3.8 GB per month in 2021. The consumption of large screen devices from around 2 GB per month to 31.5 GB per month. This is an increase in consumption of 28% CAGR in both cases. This translates to an average of 24 kbps busy hour traffic per mobile broadband user on a 3G network and 35 kbps busy hour traffic per mobile broadband user on a 4G network in 2021.

In those areas which have fixed wireless solutions (FWA, 3G or LTE based) to meet the government and BDUK objectives for broadband availability, the average busy hour traffic per user will increase in line with our higher estimates, to around

²¹ http://www.gsmworld.com/documents/mobiles_green_manifesto_11_09.pdf

700 kbps per user by 2021. The scenario assumes that about 1,350,000 consumers will use such services by 2021. FWA therefore becomes a major driver of fixed link demand in this scenario.

5.2.2.4 *Mobile network investment*

Strong demand for advanced services (especially mobile broadband), and the resulting revenues, enable mobile network operators to increase their investments in network upgrades and expansions. LTE networks are deployed from 2014, requiring many more, smaller cells in urban and suburban areas. LTE coverage extends to 95% or more of the UK population by 2021 and provides broadband services in areas poorly served by ADSL, to meet government broadband availability objectives. Cell sites in rural areas are mainly shared, but operators deploy their own pico-cells in most urban areas to ensure adequate capacity.

Wi-Fi offload facilities (discussed in Section 5.1) are made widely available by network operators through their own network of Wi-Fi nodes or through arrangements with established Wi-Fi service providers. The availability of these nodes provides a strong selling proposition which is used as part of multi-play service bundles. Wi-Fi offload capability becomes readily available in urban / suburban regions, which coupled with Wi-Fi and femto-cell facilities in commercial, business and residential properties, leads to a significant reduction in demand on mobile base station backhaul requirements.

5.2.2.5 *Satellite service demand*

The demand for satellite broadband is limited as universal service objectives are mainly met by mobile / FWA services. There is some satellite demand in rural areas for in-fill and to support mobile backhaul, but this can be comfortably accommodated in existing spectrum.

5.2.2.6 *Other factors*

The costs of deploying fibre beyond the fixed network operator's established core and aggregation networks are reduced and this encourages its use for mobile base station backhaul. Utility and local government bodies increasingly use fibre/ high speed broadband for voice / data services, but retain mobile broadband for telemetry.

Fibre is used for some CCTV services, but there is increased use of higher spectrum bands for commercial and local government CCTV services.

The public safety community requires fixed and mobile broadband services primarily to support video surveillance but these are acquired on a regional basis by individual forces, with reliance on commercial mobile networks for national coverage as there is a lack of spectrum to support rollout of a dedicated national public safety network.

Broadcasters, who already make extensive use of fibre to transmitter sites, where available and economic, make further use of fibre in more rural areas. However,

wireless services are used to provide resilience and strengthen coverage in remote areas and to further the expansion of DAB in rural areas.

Smart Grids and Smart Meters are promoted by the green agenda and widely implemented by 2019, in line with government objectives. Wireless-based services have dedicated spectrum available and have only marginal impact on the fixed links bands.

Automotive radar take up is stimulated by EC Decision, but as noted in section 3.2, we do not expect any major impact on the demand for spectrum in the fixed link bands given the current EC Decision approach.

5.2.2.7 Scenario impact on fixed link spectrum

The impact of the scenario is that:

- Mobile base stations are increasingly connected by fibre which reduces the demand for fixed links, particularly in urban and suburban areas.

Locations served by fibre	2011	2021
Sparse Rural	0%	15%
Medium Sub-urban	20%	75%
Dense Urban	70%	98%

- There is low demand for satellite broadband which can be met with existing spectrum. The number of satellite broadband users does not exceed a few tens of thousands in this scenario.
- In this scenario, the impact on fixed link spectrum demand of traffic offload to Wi-Fi and femtocells is projected to be secondary to that of fibre backhaul. The reason for this is that the fibre will totally displace the need for a mobile cell site fixed link. Offload will decrease the demand on any cell, but not totally displace the fixed link backhaul demand, which in any case is often driven by the peak bit rate offered to users rather than the average traffic throughput (see section 2.7.2).

5.2.3 Scenario C—the economy constrains

This is the most pessimistic of the four scenarios. With a sluggish economy, there is reduced consumer spending on mobile services; enterprise and utility spending is constrained and there is lower availability of fibre for backhaul and access services. This means that the demand for services which require fixed link spectrum is sustained to a greater degree than in the previous two scenarios.

5.2.3.1 Economy

Economic difficulties in UK, European and global markets weaken the economy further and UK enters a long period of flat growth or recession. There is consumer resistance to high prices for mobile services, which constrains demand for mobile

broadband, although much of the total consumer spend goes to devices and applications.

5.2.3.2 *Policy and regulation*

There are low levels of regulatory intervention to support the objectives of the Broadband Delivery UK programme, and there is no further funding to support deployment in underserved areas, after the initial round. This means that rural broadband availability remains patchy with some poorly served areas which have to be served at market rates, further depressing demand.

5.2.3.3 *Service demand*

The economic situation reduces the discretionary spend of consumers, businesses and government sectors, which depresses the take-up and usage of smartphones and large screen devices.

The average mobile broadband data consumption reflects that of Scenario A. Small screen mobile device usage increases from 100 MB per month in 2011 to 354 MB per month in 2021. The consumption of large screen devices increases from around 2 GB per month to 11.4 GB per month in 2021. This is an increase in consumption of 13% and 19% CAGR respectively. This translates to an average of 4.8 kbps busy hour traffic per mobile broadband user on a 3G network and 8.3 kbps busy hour traffic per mobile broadband user on a 4G network in 2021.

In those areas which have fixed wireless solutions (FWA, 3G or LTE based) to meet the government and BDUK objectives for broadband availability, the average busy hour traffic per user will increase in line with our lower estimate, to around 85 kbps per user by 2021. The scenario assumes that only about 450,000 consumers will use such services by 2021. Most rural consumers remain content to make do with more limited but cheaper DSL offerings, but there is substantial demand for satellite access for rural enterprises.

5.2.3.4 *Mobile network investment*

Low growth in traffic reduces operator revenues, leads to further cost-reduction initiatives—further network consolidation, site sharing and backhaul sharing.

The mobile industry is less inclined to invest in LTE deployment and HSPA satisfies much of the market demand for mobile data services. With initial focus on urban hotspots, LTE coverage expands slowly to reach 80% population by 2020. Some additional 3G sites are deployed to improve 3G coverage, as sites upgrade from 2G, requiring some additional fibre and fixed wireless backhaul.

5.2.3.5 *Satellite service demand*

Whilst there is some demand resulting from the Broadband UK supported programmes, the economic conditions and suppressed consumer demand means that the take-up consumer satellite broadband services is limited. There is, however, strong demand from enterprise users in rural areas, driving the number of satellite broadband connections to between 100,000 and 200,000 by 2021.

5.2.3.6 *Other factors*

Despite the economic downturn, utilities and local government bodies need to sustain their activities, and have installed additional monitoring CCTV to help address an increase in petty street crime and also to reduce the costs of staff visits to monitored sites.

Pressure to improve the performance of the public safety organisations and the limited coverage of commercial networks drives the rollout of a national public safety broadband network in 2015, using newly released spectrum around 700 MHz.

Automotive radar is introduced but lack of market interest means that it is limited to high end vehicles.

The initiatives to develop Smart Grids/ Meters have stalled, resulting in fragmented deployments. Dedicated spectrum is available to serve the sector and fixed link spectrum is used for backhaul.

5.2.3.7 *Scenario impact on fixed link spectrum*

The impact of the scenario is that:

- The proportion of mobile base stations connected by fibre increases marginally from the situation in 2011. This reduces the demand for fixed links, particularly in urban and suburban areas. The availability of fibre is, however, less than in the previous scenarios.

Location	2011	2021
Sparse Rural	0%	2%
Medium Sub-urban	20%	30%
Dense Urban	70%	75%

- There is demand for satellite broadband to meet the needs of rural enterprise users, which may need access to some additional exclusive spectrum (but not the whole of the 18 GHz band).
- Broadcasters do not expand their coverage in weak-signal areas, and they continue to deploy fixed links at current levels.

5.2.4 **Scenario D—We want it now**

A strong, growing economy, after a period of recession, leads to strong demand for services and investment in infrastructure, in all sectors. Mobile networks move rapidly to LTE in urban, suburban and rural areas.

5.2.4.1 *Economy*

The world economy recovers rapidly which stimulates consumer and business confidence, and enables the government to release funds to encourage service and infrastructure development.

5.2.4.2 *Policy and regulation*

Whilst government and regulators would be willing, if required, to take action to stimulate investment and take up of services, the strong economy leads to market-led growth and investment. The market provides widely available and competitively priced services. There are, however, no policy initiatives to encourage further deployment of fibre for backhaul and access services, which continues to limit competition in this area, hence greater reliance on radio for backhaul.

5.2.4.3 *Service demand*

The buoyant economy encourages greater use of services in all sectors and particularly higher speed mobile broadband services. Broadband fixed-mobile substitution (FMS) replicates the trends with voice FMS and some households are truly mobile-only.

The average mobile broadband data consumption is the same as that in Scenario B: small screen mobile devices increases from 100 MB per month in 2011 to 3.8 GB per month in 2021. The consumption of large screen devices increases from around 2 GB per month to 31.5 GB per month. This is an increase in consumption of 28% CAGR in both cases. This translates to an average of 24 kbps busy hour traffic per mobile broadband user on a 3G network and 35 kbps busy hour traffic per mobile broadband user on a 4G network in 2021.

In those areas which have fixed wireless solutions (which may often delivered over mobile LTE networks), the average busy hour traffic per user increases in line with our higher estimates, to around 700 kbps per user by 2021. The scenario assumes that about 1,350,000 consumers will use such services by 2021.

5.2.4.4 *Mobile network investment*

The strong demand for services drives rapid deployment of LTE nationally, with smaller cells in urban and suburban areas to provide adequate capacity and rural coverage which helps to bridge the broadband divide for remote consumers.

The new networks can cope with higher levels of data traffic and the lower costs of LTE that result from economies of scale and lower operating expenses enable mobile networks to offer data services at attractive prices. Operators collaborate with network sharing in remote areas, which further aids the wide-scale availability of mobile broadband services.

Consumers have less incentive to use Wi-Fi offload networks than was the case in other scenarios.

5.2.4.5 *Satellite service demand*

The strong growth in the take-up and use of mobile services, and the development of mobile services in rural areas means that there is low demand for satellite broadband services.

5.2.4.6 Other factors

Broadcasters expand their networks to provide additional DAB coverage—this overcomes many consumer concerns about service availability and aids reception for road-based listeners. They continue to deploy fixed links and expand coverage in rural areas.

Utilities and local government demand remains steady, but mobile broadband displaces some fixed links.

A national public safety network is deployed, but, as spectrum below 1 GHz has all been acquired by commercial operators, the network has to use the former DAB spectrum at 1.4 GHz, which requires approximately twice the number of base stations as the 700 MHz network assumed in scenarios A and C.

Smart Grids/ Meters rollout driven by industry but no dedicated spectrum is made available and the services are aggregated through established commercial networks and use fibre and fixed link backhaul.

5.2.4.7 Scenario impact on fixed link spectrum

The impact of the scenario is that:

- There is modest growth only in the number of mobile base stations which are served by fibre backhaul, which sustains the demand for fixed links, particularly in rural and suburban areas.

Locations served by fibre	2011	2021
Sparse Rural	0%	2%
Medium Sub-urban	20%	35%
Dense Urban	70%	80%

- A more limited availability of fibre and high prices of backhaul lead to high demand for fixed links in all areas.
- Network growth, especially LTE and limited Wi-Fi offload leads to excess demand for backhaul spectrum.
- There is very high demand for backhaul for the national public safety network from 2015, reflecting the larger number of smaller cells and the need for radio to each site.
- There is low demand for satellite broadband which can be met with existing spectrum. The number of satellite broadband users does not exceed a few tens of thousands in this scenario.

5.2.5 Summary of downstream service scenario assumptions

The high level scenario assumptions focus on the state of the national economy, the extent of government / regulatory policy and other influences on the various sectors likely to use fixed link spectrum. The table below summarises the key assumptions and the implications for downstream service demand.

Table 5.1: Summary of high level scenario assumptions and implications for downstream services

	Scenario A Fibred Nation	Scenario B Green Agenda	Scenario C Economy Constrains	Scenario D We Want It Now
Economy	Weak	Strong	Weak	Strong
Level of regulatory intervention	High	Moderate	Low to moderate	Low - considered unnecessary as market is thriving
Fibre cost and availability	Improving due to economic PIA access. Becomes very good in urban/suburban areas, poor in rural	Improving due to economic PIA access	No change from present, leading to slight increase in usage.	Little change from present
Fixed broadband status	Regulatory push for universal broadband	Regulatory push and strong market demand for rural broadband	Terrestrial platforms see little improvement, especially in rural areas w/o cable provision	Strong market demand in all areas
DEMAND FOR MOBILE AND SATELLITE SERVICES				
Mobile demand	Low to moderate growth	High growth in all areas	Low growth due to state of economy	High growth in all areas
Mobile coverage (3G)	Good due to coverage obligations	High demand and ARPU stimulates rural expansion	Slow rollout in rural areas	High demand and ARPU stimulates rural expansion
Mobile coverage (4G/LTE)	Limited to main urban areas	Rural coverage stimulated by incentives to use as substitute for fixed broadband in notspots	Limited to urban traffic hotspots	Rural coverage stimulated by high level of market demand
Mobile capacity	Limited due to low revenue / investment	High, supplemented by widespread WiFi offload in urban hotspots and subscribers' homes	Limited due to low revenue / investment	Very high to meet soaring consumer demand
Satellite broadband	Strong demand in rural areas to meet universal service objective	Demand limited as fixed / mobile alternatives widely available	Moderate demand in rural notspots but limited by high tariffs	Some demand in rural notspots but unable to compete with terrestrial offerings in longer term
Network sharing	Pervasive in order to reduce costs	Increasing sharing in macro networks but operators deploy own micro / pico cells in busy areas	Pervasive in order to reduce costs	Networks co-operate in rural areas to maximise coverage and capacity
Network consolidation	Further consolidation to three networks to reduce costs	No consolidation - 4 operators	Further consolidation to three networks to reduce costs	No consolidation - 4 operators
Satellite broadband	Strong demand in rural areas to meet universal service objective	Demand limited as fixed / mobile alternatives widely available	Moderate demand in rural notspots from enterprise users. Little consumer demand	Some demand in rural notspots but unable to compete with terrestrial offerings in longer term
DEMAND FOR OTHER APPLICATIONS				
Broadcasting	More fibre migration in urban areas; expansion of DAB network in rural areas	More fibre migration in urban areas; expansion of DAB network in rural areas	Demand for improved mobile DTT / DAB reception leads to additional relay transmitters	Continued expansion of DAB network to match current FM coverage by 2015
Local Authorities	Mainly use fibre except in rural areas	Mainly use fibre except in rural areas	Many local authorities invest in wireless CCTV to tackle crime and cut costs	Widespread deployment of wireless CCTV in all areas
Public Safety	Slow development of public networks drives expansion of private networks by individual regional users. Dedicated LTE public safety network rolled out in part of digital dividend spectrum.	Agreement reached to use public networks - no dedicated network. Supplemented by ongoing rollout of regional broadband networks by individual users.	National public safety broadband network rolled out in 2015 using UHF spectrum.	Public safety broadband network rolled out in 2015 but high spectrum demand from mobile networks means higher frequency has to be used.
Utilities	Fast rollout of smart grid network with dedicated spectrum	Regulatory push provides dedicated spectrum for smart grids but weak economy slows rollout of smart grids despite availability of dedicated spectrum	Slow development of smart grids using dedicated spectrum	No dedicated spectrum for smart grids - have to make use of existing fixed link bands for backhaul, public networks or licence-exempt for WAN
Fixed wireless broadband	Deployed in some areas to support USO	Requirement largely met by mobile LTE networks	Localised demand for dedicated broadband wireless using LTE or WiMax in fixed mode	Some deployments using LTE technology

6 DEVELOPMENT OF FIXED LINK SPECTRUM DEMAND SCENARIOS

6.1 Approach to developing the spectrum demand scenarios

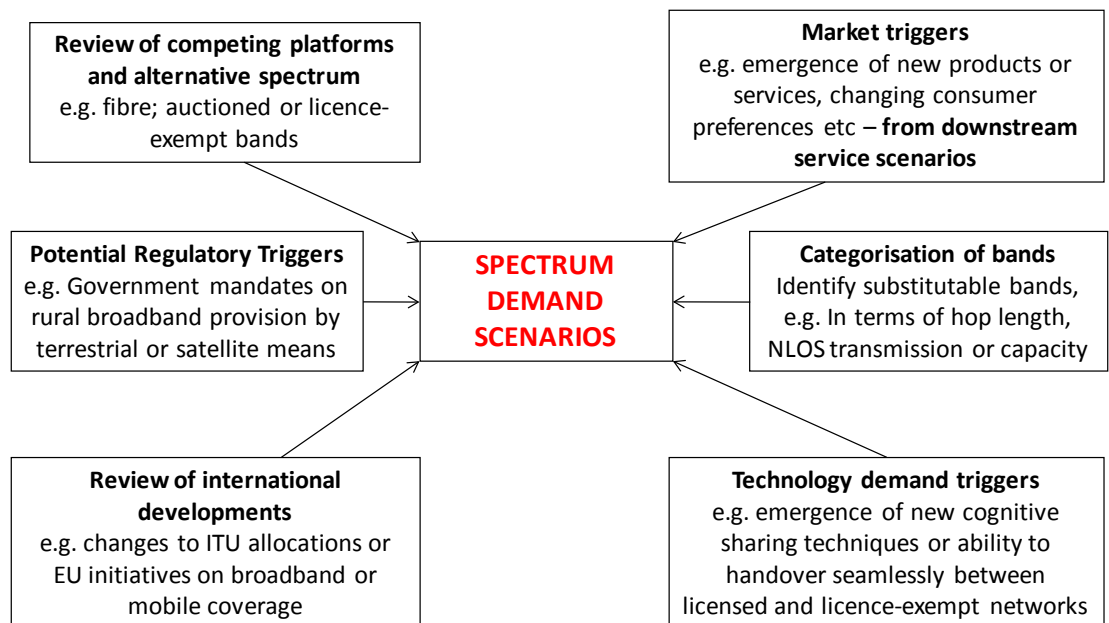
6.1.1 Introduction

Having developed the downstream service scenarios described in the previous chapter, these were then converted to a set of corresponding spectrum demand scenarios for the frequency bands under analysis. This involved a process of:

- i) analysing the current use of each frequency band, as presented in chapter 2
- ii) considering the impact that the various downstream service scenarios would have on demand for wireless fixed links with particular characteristics that favour particular bands or frequency ranges
- iii) factoring in the potential effect of the various market, regulatory and technical developments discussed in chapter 4.

Spectrum demand for both fixed links and other alternative uses of fixed link spectrum, such as satellite services, short range devices or mobile applications, was considered. The overall approach is illustrated in the following schematic:

Figure 6.1: High level approach to spectrum demand scenario development



6.1.2 Categorisation of fixed link bands in terms of frequency and supportable link characteristics

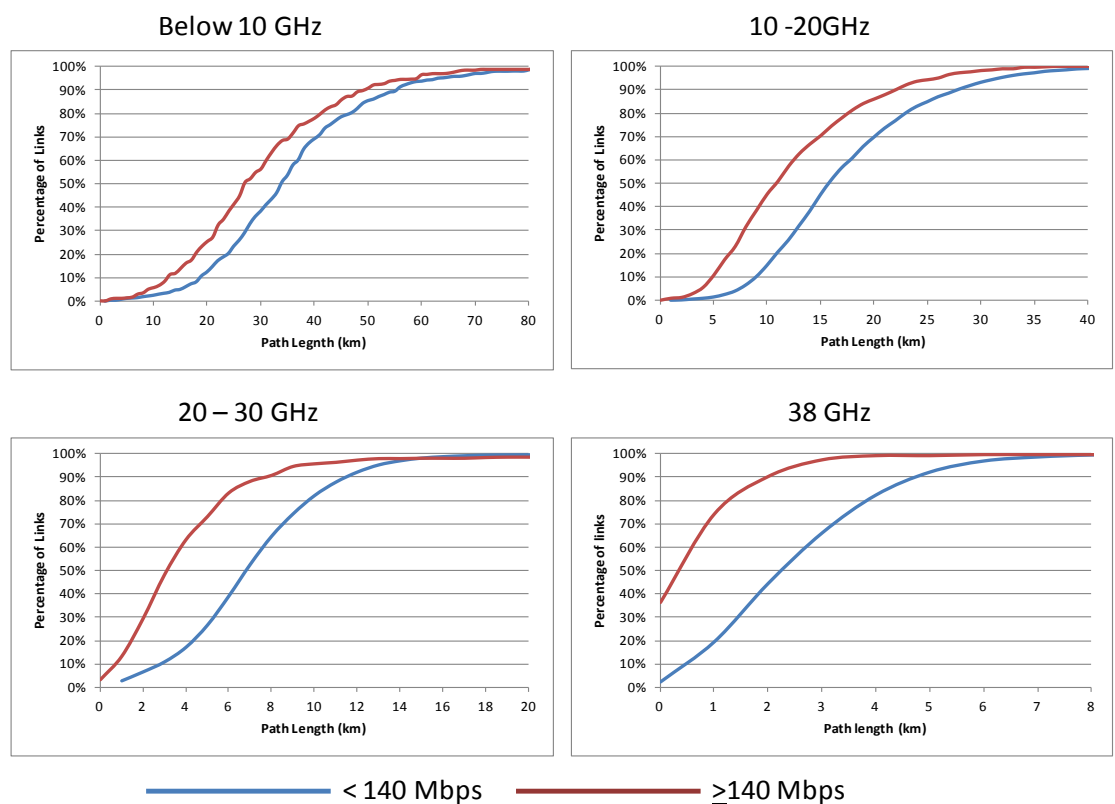
In chapter 2 we defined the various fixed link bands into six broad frequency categories, namely:

- Below 3 GHz
- 3 – 10 GHz
- 10 – 20 GHz
- 20 – 30 GHz
- 30 – 50 GHz
- Above 50 GHz.

The bands below 3 GHz and above 50 GHz have particular characteristics that limit their use to particular applications (narrow bandwidths and very short hops respectively) and have therefore been considered separately from the microwave bands in the 3 – 50 GHz range, where the greatest demand currently exists.

Within this range, lower frequency bands are used to support longer link lengths. The typical link lengths supported in each frequency range can be illustrated by the following analysis of the link length distribution based on current Ofcom licensing data. Note that the 18 GHz band has been excluded as this currently includes a large number of legacy links operated by BT which are considerably shorter than would typically be the case for more recently licensed links.

Figure 6.2: Distribution of link lengths in each frequency band category



Minimum path lengths are also defined in the Ofcom licence fee schedule as part of the formula for determining fixed link licence fees, as follows:

Figure 6.3: Minimum path lengths defined in Ofcom Fee Regulations

MINIMUM PATH LENGTH		
Table 1		
<i>Column 1: Range of frequency band (fb)(in GHz)</i>	<i>Column 2: MPL (km) where the data rate is < 2 MBit/s or, for analogue systems, where the channel width is < 2 MHz</i>	<i>Column 3: MPL (km) where the data rate is ≥ 2 MBit/s or, for analogue systems, where the channel width is ≥ 2 MHz</i>
$1.35 \leq fb < 2.69$	0	30

Table 2		
<i>Column 1: Range of frequency band (fb)(in GHz)</i>	<i>Column 2: MPL (km) where the data rate is < 140 MBit/s or, for analogue systems, where the channel width is < 140 MHz</i>	<i>Column 3: MPL (km) where the data rate is ≥ 140 MBit/s or, for analogue systems, where the channel width is ≥ 140 MHz</i>
$3.60 \leq fb < 4.20$	24.5	16
$5.92 \leq fb < 7.13$	24.5	16
$7.42 \leq fb < 7.90$	15.5	9.5
$10.70 \leq fb < 11.70$	10	6
$12.75 \leq fb < 15.35$	9.5	5.5
$17.30 \leq fb < 19.70$	4	2.5
$21.20 \leq fb < 23.60$	4	2
$24.50 \leq fb < 29.06$	3	2
$31.00 \leq fb < 31.80$	0	0
$31.80 \leq fb < 33.40$	2	1.5
$37.00 \leq fb < 39.50$	0	0
$49.20 \leq fb < 57.00$	0	0

High capacity links (140 Mbps and above) typically require a higher link margin due to higher availability requirements and/or the use of higher level modulation schemes to maximise bandwidth efficiency, therefore the typical link lengths in a given band are lower as reflected by the minimum path length values in the fee schedule.

In our spectrum demand scenario analysis, we apportion links to a specific frequency category based on the projected path length and data capacity. The assumed category as a function of these two parameters is based on our analysis of the licensing data and the minimum path length values in the Ofcom fee schedule, and is summarised below:

Table 6.1: Assumed frequency range for links of a specified link length and capacity

Path Length	Capacity < 140 Mbps	Capacity ≥ 140 Mbps
Less than 2 km	Above 30 GHz	Above 30 GHz
2 – 5 km	Above 30 GHz	20 – 30 GHz
5 – 10 km	20 – 30 GHz	10 – 20 GHz
10 – 25 km	10 – 20 GHz	Under 10 GHz
Over 25 km	Under 10 GHz	Under 10 GHz

Within each of the four identified frequency ranges (less than 10 GHz, 10-20 GHz, 20-30 GHz and above 30 GHz), there are typically several bands that are to a large degree substitutable for one another, although as already noted lower frequency

bands will be able to support longer link length than higher bands. Different bands are likely to become congested at different locations, depending on how the band has been used historically—for example the 7.5 GHz band may be particularly heavily used at TV broadcast sites and former BT or Cable & Wireless managed bands (such as 18 GHz or 15 GHz) may be heavily used at these operators' hub sites. The intention of our demand analysis is to estimate the extent to which the available spectrum in each of the four identified frequency ranges is likely to be sufficient in various geographic areas to meet demand.

6.2 Estimating Demand for Fixed Link Capacity

As an intermediate step to estimating the spectrum demand, we need to estimate what the likely demand for fixed link capacity will be under each scenario and the nature of this demand in terms of individual link lengths and bandwidths. In order to do this we have attempted to translate the projected downstream service demand into an equivalent demand for fixed link capacity, using assumptions appropriate to the downstream service in question. We have then used spreadsheet models to estimate the total fixed link capacity requirement for each service under each of the four scenarios in four pre-defined geographic areas, namely national (entire UK), inner London, Surrey and Cumbria. The three regional areas have been selected to be representative of a densely populated urban area, a mixed urban, suburban and rural area and a predominantly rural area.

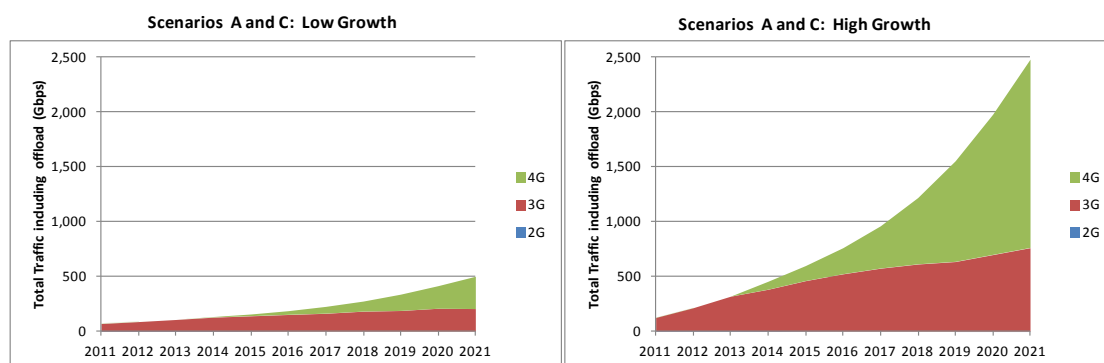
The specific approaches taken for each downstream service are described in the following sections.

6.2.1.1 *Approach to estimating mobile backhaul spectrum demand*

To estimate the demand for mobile backhaul spectrum over time we have prepared a spreadsheet model that generates estimates of the numbers of base stations required for network coverage and capacity over a ten year period, based on assumed coverage and capacity parameters. The latter are defined in the downstream service scenarios presented in chapter 5. The number of base stations is calculated by assuming that traffic is distributed broadly in line with population and that spectrum efficiency (i.e. the average traffic throughput per base station per MHz of spectrum will increase steadily over the period as technology migrates from 2G to 3G and 4G. The coverage per base station is estimated for urban, suburban and rural areas assuming a typical network link budget based on a reasonable coverage quality. The network parameters assumed for the modelling are summarised in Annex B.

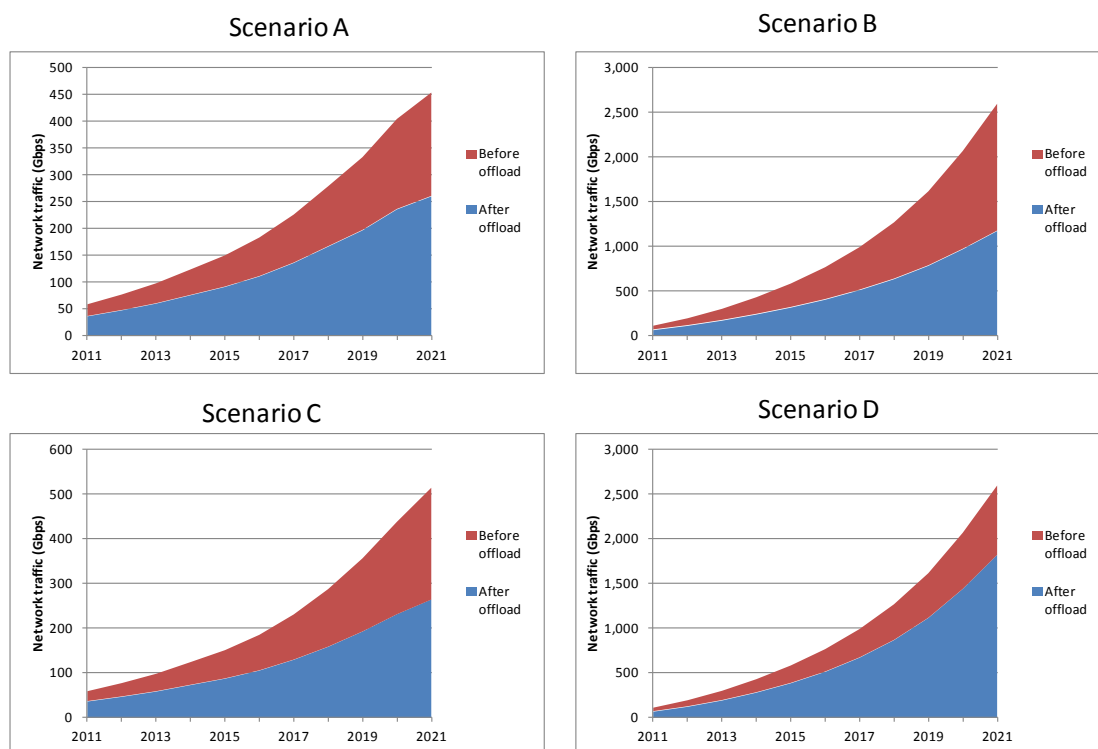
Two levels of mobile traffic growth have been assumed, based on the downstream scenarios presented in chapter 5. These are illustrated in the figure below, which shows the higher and lower assumptions for total assumed mobile busy hour traffic demand each year in Terabits per second.

Figure 6.4: Assumed total busy hour mobile data traffic (Gbps)



The above traffic levels do not allow for traffic that is “offloaded” onto Wi-Fi or femtocells and therefore not carried on the main mobile networks (i.e. does not impact on backhaul requirements). In each scenario we have assumed a specific level of offloading over time and deducted this traffic from our estimations of the backhaul link requirement. The impact of traffic offload on the total network traffic in each scenario is shown below:

Figure 6.5: Impact of traffic offload in each scenario



To take account of the number of operators and the extent of site sharing, we initially estimate the total number of coverage and capacity sites required for a single network, assuming that traffic is apportioned equally between all the competing networks. We then multiply that per-operator site number by the number of operators, which yields the total number of sites that would be required if there were no site sharing. Finally, we divide this number by the average number of

operators sharing each site, to provide an estimate of the total number of sites required after sharing is taken into account.

Having estimated the total number of base station sites, we then estimate how many radio links of various lengths and bandwidths are required to connect to these sites. To do this, we factor in the percentage of sites that are projected to be connected by fibre in each area type (urban, suburban, rural), the typical length of each link and the bandwidth. The link length is assumed to be twice the assumed cell radius for each base station type, as presented in Table A.2, which reflects current link statistics and is consistent with the assumption that in future links will tend to be connected in a mesh or ring configuration (hence the typical link length will approximate to the distance between two cells, or twice the cell radius). The bandwidth required will reflect the assumed capacity of the base station, which will in turn reflect the type of base station (2G, 3G or 4G) and the assumed spectrum efficiency and spectrum availability for the technology concerned.

In addition, we also allow for further deployment of fixed links in the backbone network, assuming that each backbone link carries the concentrated traffic of ten base stations.

Estimates of the number of links required of various length and bandwidth combinations are then generated, as in the example shown below, which relates to national coverage under Scenario A.

Figure 6.6: Illustration of link estimates by length and bandwidth combination, for mobile backhaul

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
No of Radio Links required	24,248	22,196	20,052	17,998	16,044	14,180	12,428	10,712	9,156	7,554	5,941
Very short links (<2km)											
8	144	132	127	123	119	114	110	107	103	99	96
16	11	33	34	35	38	43	51	56	66	63	60
34	5,204	4,690	4,195	3,704	3,175	2,668	2,269	1,883	1,511	1,151	803
68	152	135	119	77	66	55	44	34	24	15	6
155	0	0	0	41	108	170	140	112	85	110	74
311	168	153	139	124	111	98	86	74	63	0	0
620	0	0	0	0	0	0	0	0	0	0	0
0											
Short links (2 - 5 km)											
8	363	333	322	310	300	289	279	269	260	251	242
16	29	84	86	90	97	109	129	142	167	160	153
34	7,218	6,516	5,840	5,176	4,488	3,827	3,268	2,729	2,209	1,706	1,220
68	134	119	105	68	58	49	39	30	22	13	5
155	0	0	0	36	96	150	124	99	75	223	164
311	553	506	457	410	366	323	283	244	209	0	0
620	0	0	0	0	0	0	0	0	0	0	0
0											
Medium links (5-10 km)											
8	487	447	432	417	402	388	374	371	399	445	451
16	39	113	115	120	130	147	174	190	224	214	205
34	5,227	4,724	4,240	3,770	3,297	2,842	2,435	2,042	1,663	1,330	987
68	54	48	42	27	23	19	16	12	8	5	2
155	0	0	0	14	38	60	50	40	30	264	203
311	782	716	647	581	518	458	401	346	295	0	0
620	0	0	0	0	0	0	0	0	0	0	0
0											
Long links (>10km)											
8	622	571	551	532	513	495	478	461	445	430	415
16	50	145	147	154	167	187	222	243	286	274	262
34	2,290	2,070	1,858	1,653	1,448	1,250	1,072	899	733	573	417
68	20	18	16	10	8	7	6	4	3	2	0
155	0	0	0	5	14	22	18	15	11	226	176
311	702	642	580	521	464	410	360	310	265	0	0
620	0	0	0	0	0	0	0	0	0	0	0

Each category of link identified above (in terms of the length / bandwidth combination) is assumed to be assigned to a band within a specific frequency range, based on the path length criteria discussed in section 6.1.2 above. The result is presented as in the following example (again relating to Scenario A, national coverage).

Figure 6.7: Illustration of link estimates by frequency and bandwidth combination, for mobile backhaul

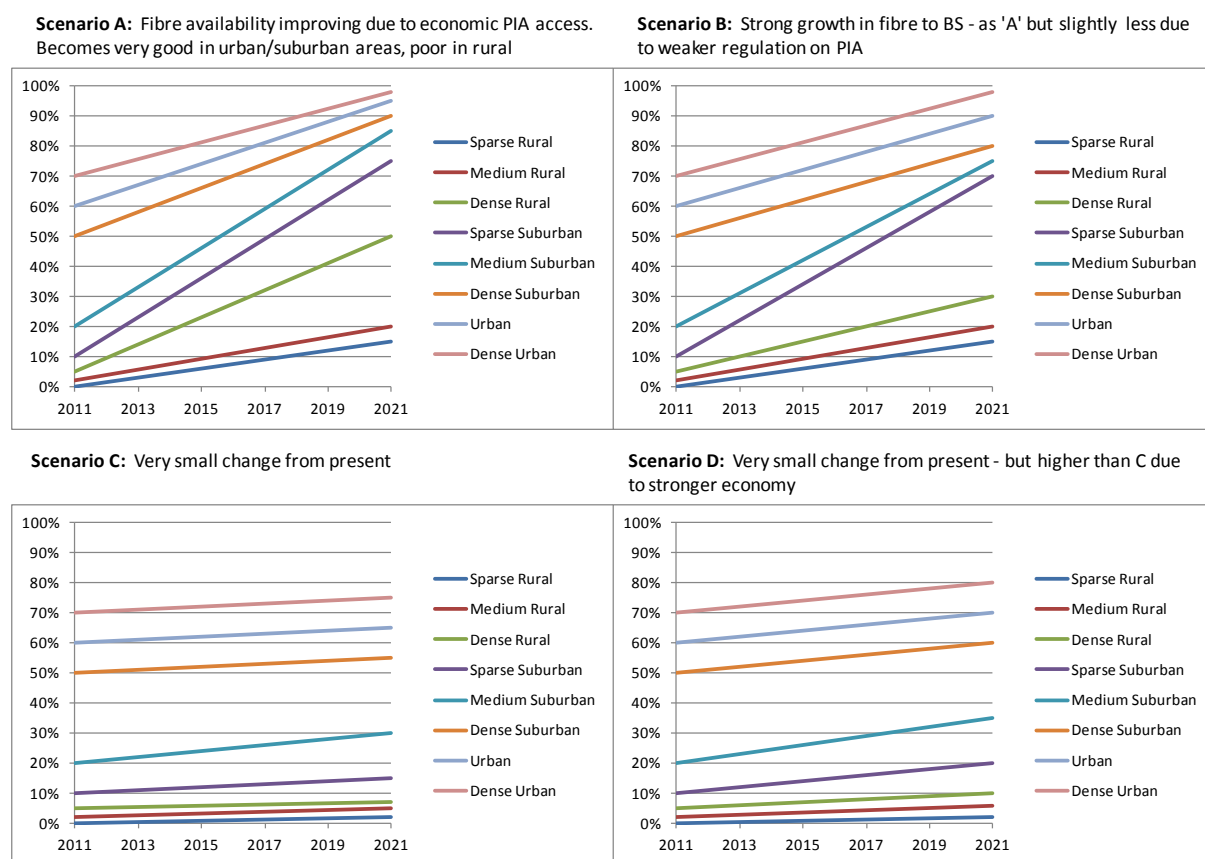
LINKS BY FREQUENCY RANGE											
Below 10 GHz	702	642	580	526	478	432	378	325	276	226	176
8 Mbps	0	0	0	0	0	0	0	0	0	0	0
16 Mbps	0	0	0	0	0	0	0	0	0	0	0
34 Mbps	0	0	0	0	0	0	0	0	0	0	0
68 Mbps	0	0	0	0	0	0	0	0	0	0	0
155 Mbps - over 10 km	0	0	0	5	14	22	18	15	11	226	176
311 Mbps - over 10 km	702	642	580	521	464	410	360	310	265	0	0
620 Mbps - over 10 km	0	0	0	0	0	0	0	0	0	0	0
Total capacity Mbps	218,223	199,751	180,457	162,750	146,553	131,024	114,634	98,726	84,108	34,965	27,267
Capacity per sq km Mbps	0.898	0.822	0.742	0.669	0.603	0.539	0.472	0.406	0.346	0.144	0.112
10 - 20 GHz	3,764	3,520	3,219	2,944	2,692	2,457	2,229	1,993	1,792	1,543	1,297
8 Mbps - over 10 km	622	571	551	532	513	495	478	461	445	430	415
16 Mbps - over 10 km	50	145	147	154	167	187	222	243	286	274	262
34 Mbps - over 10 km	2,290	2,070	1,858	1,653	1,448	1,250	1,072	899	733	573	417
68 Mbps - over 10 km	20	18	16	10	8	7	6	4	3	2	0
155 Mbps - 5 to 10 km	0	0	0	14	38	60	50	40	30	264	203
311 Mbps - 5 to 10 km	782	716	647	581	518	458	401	346	295	0	0
620 Mbps - 5 to 10 km	0	0	0	0	0	0	0	0	0	0	0
Total capacity Mbps	328,325	301,223	272,237	246,381	223,436	201,523	176,693	152,105	129,795	68,320	53,108
Capacity per sq km Mbps	1.351	1.239	1.120	1.013	0.919	0.829	0.727	0.626	0.534	0.281	0.218
20 - 30 GHz	6,360	5,838	5,286	4,780	4,314	3,869	3,406	2,958	2,578	2,217	1,809
8 Mbps - 5 to 10 km	487	447	432	417	402	388	374	371	399	445	451
16 Mbps - 5 to 10 km	39	113	115	120	130	147	174	190	224	214	205
34 Mbps - 5 to 10 km	5,227	4,724	4,240	3,770	3,297	2,842	2,435	2,042	1,663	1,330	987
68 Mbps - 5 to 10 km	54	48	42	27	23	19	16	12	8	5	2
155 Mbps - 2 to 5 km	0	0	0	36	96	150	124	99	75	223	164
311 Mbps - 2 to 5 km	553	506	457	410	366	323	283	244	209	0	0
620 Mbps - 2 to 5 km	0	0	0	0	0	0	0	0	0	0	0
Total capacity Mbps	357,785	326,590	294,442	268,425	247,556	227,136	196,963	167,523	140,388	87,134	66,065
Capacity per sq km Mbps	1.472	1.343	1.211	1.104	1.018	0.934	0.810	0.689	0.577	0.358	0.272
Above 30 GHz	13,423	12,195	10,967	9,748	8,560	7,422	6,415	5,436	4,510	3,568	2,659
8 Mbps - 2 to 5 km	363	333	322	310	300	289	279	269	260	251	242
8 Mbps - 0 to 2 km	144	132	127	123	119	114	110	107	103	99	96
16 Mbps - 2 to 5 km	29	84	86	90	97	109	129	142	167	160	153
16 Mbps - 0 to 2 km	11	33	34	35	38	43	51	56	66	63	60
34 Mbps - 2 to 5 km	7,218	6,516	5,840	5,176	4,488	3,827	3,268	2,729	2,209	1,706	1,220
34 Mbps - 0 to 2 km	5,204	4,690	4,195	3,704	3,175	2,668	2,269	1,883	1,511	1,151	803
68 Mbps - 2 to 5 km	134	119	105	68	58	49	39	30	22	13	5
68 Mbps - 0 to 2 km	152	135	119	77	66	55	44	34	24	15	6
155 Mbps - 0 to 2 km	0	0	0	41	108	170	140	112	85	110	74
311 Mbps - 0 to 2 km	168	153	139	124	111	98	86	74	63	0	0
620 Mbps - 0 to 2 km	0	0	0	0	0	0	0	0	0	0	0
Total capacity Mbps	498,634	451,596	405,052	362,301	325,725	290,400	248,318	207,730	169,104	122,495	87,124
Capacity per sq km Mbps	2.051	1.858	1.666	1.490	1.340	1.195	1.021	0.854	0.696	0.504	0.358
Total link capacity Gbps	1,403	1,279	1,152	1,040	943	850	737	626	523	313	234

6.2.1.2 Percentage of mobile transmission sites that are fibred

In each scenario for mobile and local authorities, we have assumed that a certain proportion of transmission sites will be connected by fibre in any given year. This proportion will vary by area type—dense urban areas will have a much higher proportion of fibre connections than suburban or rural sites. These values are used to estimate how many radio links will be needed to provide the necessary backhaul

or transmission infrastructure and have been applied when projecting future demand for the mobile, and local authority users (different assumptions have been used for broadcast, public safety and utility users based on discussions with those sectors). The estimates are based on discussions with stakeholders (including mobile operators and fibre capacity providers) and Ovum's in-house research in this area.

Figure 6.8: Percentage of sites assumed to be connected by non-radio means (predominantly fibre) in each scenario



6.2.1.3 Approach to estimating fixed wireless access backhaul spectrum demand

As discussed in section 4.2.1.2, there is likely to be demand in areas outside the reach of high speed wire line connections for wireless fixed broadband connectivity. This could be delivered in a number of ways, including use of 4G (LTE) mobile networks, WiMAX in bands such as 3.5 GHz or 5.8 GHz, or using white space frequencies in the UHF TV band. As the areas served will generally be remote and unlikely to be close to fibre backhaul connections, point to point links will be required to serve the base stations. The backhaul capacity for fixed wireless provision is essentially independent of the access medium and is a function of the assumed busy hour traffic per user and number of users. We have made assumptions regarding the anticipated busy hour fixed broadband traffic per user in 2021, based on recent reports by Analysys Mason prepared for Broadband Delivery UK and by

Value Partners for the BBC Trust (previously referenced in section 4.2.1.2). These are as follows:

- Scenario A—200 kbps (mid-range estimate based on Value Partners report, reflecting weak economy but strong regulatory push).
- Scenarios B and D—700 kbps (higher estimate based on Analysys Mason report, reflecting strong economy).
- Scenario C—85 kbps (lower estimate based on Analysys Mason report, reflecting weak economy and low regulatory intervention).

We have also made assumptions regarding the likely take-up of wireless fixed broadband in areas outside the reach of high speed DSL connectivity, based on Ovum forecasts. The assumed extent of the areas outside of DSL connectivity is equivalent to 12% of UK premises, reflecting recent statements by Broadband Delivery UK. The current level of busy hour fixed broadband traffic per user is assumed to be 60 kbps and we have assumed this will grow linearly between now and 2021.

Projected traffic and take up levels for each scenario are therefore as follows:

Table 6.2: Projected average busy hour traffic per user

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Scenario A	60	74	88	102	116	130	144	158	172	186	200
Scenario B	60	124	188	252	316	380	444	508	572	636	700
Scenario C	60	62.5	65	67.5	70	72.5	75	77.5	80	82.5	85
Scenario D	60	124	188	252	316	380	444	508	572	636	700

Table 6.3: Projected take up of BFWA in areas beyond high speed DSL connectivity

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Scenario A	0.0%	0.0%	3.3%	6.7%	10.0%	13.3%	16.7%	20.0%	23.3%	26.7%	30.0%
Scenario B	0.0%	0.0%	5.0%	10.0%	15.0%	20.0%	25.0%	30.0%	35.0%	40.0%	45.0%
Scenario C	0.0%	0.0%	1.7%	3.3%	5.0%	6.7%	8.3%	10.0%	11.7%	13.3%	15.0%
Scenario D	0.0%	0.0%	3.3%	6.7%	10.0%	13.3%	16.7%	20.0%	23.3%	26.7%	30.0%

6.2.1.4 Approach to estimating Broadcasters' fixed link spectrum demand

Our discussions with representatives of the broadcast community indicate that fixed link demand to support the national digital terrestrial TV networks will remain essentially stable over the next decade, as links have already been commissioned for the planned post-switchover network. These links include spare capacity to allow for anticipated future upgrades, such as the extension of HDTV services. It is, however, possible under some scenarios that commercial multiplex coverage may be expanded or that there may be greater demand for local TV services and either of these developments may stimulate additional fixed link demand in certain areas.

A more concrete future requirement will be to support the further expansion of DAB coverage. For example, in response to a recent Ofcom consultation²² the BBC indicated that it planned to roll out a further 180 transmitters to extend DAB coverage to 97% of the population. The main impact of these on fixed link spectrum is likely to be in the 1.4 GHz band, since the links are generally narrow band (less than 2 Mbps for a single DAB multiplex) and most of the sites are in rural areas where relatively long links are likely to be required.

For the purposes of our scenario development, we have assumed that TV feeder links will remain unchanged (i.e. any additional demand from commercial multiplex expansion will be offset by migration of existing links to fibre) and that future growth will be concentrated on 2 Mbps links for expansion of DAB coverage. The timing and extent of DAB coverage expansion will depend on the scenario, as follows:

- Scenario A: 180 additional DAB sites (in line with current BBC plan) by 2015, reflecting regulatory pressure to expand coverage but limited funding due to weak economy prevents further expansion.
- Scenario B and D: 2015, 180 additional DAB sites (in line with current BBC plan), expansion continues with further 200 sites by 2020 to provide FM equivalent coverage.
- Scenario C: No further expansion of DAB coverage due to lack of regulatory pressure and weak economy.

6.2.1.5 *Approach to estimating Local Authorities' fixed link spectrum demand*

Our research has indicated that future local authority demand for fixed links is likely to be dominated by two particular requirements, namely wireless CCTV systems and broadband backhaul links, based on recent initiatives such as those in Hounslow, Dundee and Anglesey described in section 2.7.3.4.

To assess the impact of such developments if rolled out more widely throughout the UK, we have considered scenarios where in the longer term broadband networks similar to that deployed in Hounslow, but with the bandwidth requirement scaled pro-rata to local population, are deployed across authorities across a specified proportion of the UK population. The assumed coverage of these networks in 2021 is assumed to be:

- Scenario A: 50%—reflects weak economy, with high level of crime and pressure to cut costs driving CCTV rollout. Broadband provision generally good so less pressure for local authorities to address this area.
- Scenario B: 25%—strong economy and widespread availability of fixed and mobile broadband networks reduces need for bespoke networks.

²² "BBC National DAB Network Coverage & Indicative Expansion Plans", A BBC Input to the Ofcom consultation on the Approach to planning DAB build-out, 14 June 2011

- Scenario C: 75%—reflects weak economy, with high level of crime and pressure to cut costs driving CCTV rollout. Broadband provision remains patchy prompting many rural authorities to invest in their own broadband networks.
- Scenario D: 25%—strong economy and widespread availability of fixed and mobile broadband networks reduces need for bespoke networks.

6.2.1.6 *Approach to estimating the Public Safety community's fixed link spectrum demand*

Our research has indicated that the primary source of demand for fixed links spectrum from the public safety community is to support mobile broadband communications, such as video surveillance. Some police forces and fire brigades have already commissioned such systems on a local basis but we would expect these to be superseded by a national mobile broadband network within the next 10 years. This assumption is based on discussions with stakeholders and reflects initiatives underway within Europe to identify spectrum options to meet the needs of the public safety community for broadband communications²³.

In three of our scenarios we assume this will be a dedicated network, either in former UHF TV spectrum (part of a second digital dividend band) in scenarios A and C, or in a band above 1 GHz (Scenario D—the 1.4 GHz former DAB band has been assumed in this case). In Scenario B we have assumed that public safety communications will continue to evolve on a localised basis, with broadband capability extending from the current estimated 13% of UK population to 100% by 2021. National coverage in the meantime would be served by the commercial mobile networks under this scenario.

Our analysis of Ofcom's licensing data indicates that the current total fixed link capacity licensed to public safety users is 33.1 Gbps,

[X]

In Table 2.2 we estimated that the eight largest regional public safety users of fixed link spectrum (i.e. those who have already established broadband communication facilities) had access to fixed link capacity equivalent to approximately 4.2 kbps per head of population. Extrapolating this to the entire UK population would imply a total link capacity of 252 Gbps.

In the absence of a dedicated national public safety broadband network we have assumed that the link capacity assigned to regional users will grow linearly from the current level of 25.6 Gbps to reach 252 Gbps by 2021 under the most favourable economic scenarios (B and D), i.e. that the broadband communication facilities deployed by the eight existing users highlighted in Table 2.2 would be extended steadily to the whole country over the next ten years. In the economically

²³ See for example "[PPDR Spectrum Harmonisation in Germany, Europe and Globally](#)", report prepared by WIK-Consult and Aegis Systems for the German Ministry of Economics (BMWi), December 2010

constrained scenarios A and C we have assumed the capacity will only reach half this level (i.e. 126 Gbps) by 2021. Upon rollout of a national broadband network (which we assume will take place in 2015 in scenarios A, C and D) we assume this growth will cease and the existing capacity will be absorbed into the national network, i.e. the total capacity required for public safety will not exceed that required by a national public safety broadband network.

Unlike commercial network operators, who we expect largely to migrate their backhaul links to fibre, we believe public safety users will continue to use radio backhaul throughout their networks to provide sufficient resilience, perhaps deploying such links alongside fibre where it is available.

Although in principle a degree of sharing with public networks would be possible, the public safety community have so far been insistent that a dedicated network would be required to provide the necessary degree of security and resilience. Our discussions with UK public safety representatives have indicated that backhaul requirements for such a network would be of the order of at least one STM-1 link per base station, in order to cater for the high traffic demand generated by major incidents. The number of base stations required will depend on the frequency band deployed—in two of our scenarios (A and C) we have assumed the spectrum would be in the 700 MHz region, which we estimate would require 3,636 base station sites to provide national coverage. Scenario D assumes a higher band (1.4 GHz) must be used because all the lower mobile frequencies have been acquired by commercial operators—this would increase the required number of base stations to 7,170, with a corresponding increase in the number of STM-1 backhaul links required. Note that Scenario B assumes there is no dedicated public safety network and that traffic is instead carried by the public networks and regional dedicated networks.

6.2.1.7 *Approach to estimating the Utility industries' fixed link spectrum demand*

Our understanding from stakeholder discussions is that the main future demand growth in the utility sector for fixed links will be related to the rollout of “smart grid” technology. The estimated requirement for radio links to support a smart grid network is as follows:

- Approximately 10,000 sites will be needed to be connected via point to point radio links. Of these 2,000 will be required to connect UHF base stations used for high priority connections in the 11 kV distribution layer, 1,000 for the control layer and the remaining 7,000 for the 132 kV – 33 kV layer.
- The 2,000 UHF base stations will require a maximum of 50 kbps capacity links and are assumed to be most likely to operate in the 1.4 GHz band. We have assumed that these UHF stations are evenly spread across the UK broadly in line with population distribution.
- The 1,000 control layer links will typically need 10 Mbps and have link lengths of greater than 10 km.

- The remaining 7,000 links are assumed to be 2 Mbps capacity and the distribution of these links across the country is projected to be as follows:
 - 6% in rural areas (population density below 300 per sq km)
 - 34% suburban (population density 300-3,000 per sq km)
 - 70% urban (population density over 3,000 per sq km).
- In addition we have assumed that the existing fixed links licensed to utility companies will remain in operation.

The following assumptions have been made about the rollout of smart grid networks in each of the scenarios:

- Scenario A: Rollout over four year period from 2016 – 2019.
- Scenario B: Rapid rollout in 2014/2015, reflecting strong green agenda.
- Scenario C: Only limited rollout by 2021 (25% of country).
- Scenario D: Gradual rollout from 2015, reaching 75% of country by 2021.

6.2.1.8 *Approach to estimating demand in fixed links spectrum from satellite users*

The need for additional exclusive spectrum will be determined by two demand factors; numbers of users and user expectation in terms of throughput. The forecasts relating to user numbers are approximately 1 million, 3 million and 5 million after 10 years²⁴.

User throughput is generally described in terms of average busy hour traffic²⁵ for an individual user. For comparison purposes in 2010 the busy hour throughput of mobile user was approximately 2 kbps and 60 kbps for a fixed user. Analysys Mason expect the busy hour throughput for a household to increase to 85 kbps, 700 kbps or 1.5 Mbps by 2016 depending on scenario, noting that the highest figure is an extreme case.

The recently launched Ka-Sat has a capacity of 70 Gbps of which 42 Gbps is dedicated to the forward link. It is said that Ka-Sat will accommodate 1 million users which implies user busy hour traffic to be 42 kbps. If it is assumed that user expectations increase with time at a rate of 10, 20 or 30% per annum then user busy hour traffic will be 109, 260, or 579 kbps after 10 years. These figures are broadly in line with Analysys Mason figures if one excludes their extreme scenario.

The tables below combine the numbers of users forecast with throughput expectations to estimate the number of satellites that would be required with and without additional exclusive spectrum. It can be seen that for the lowest forecast and lowest throughput expectation a manageable (i.e. single figures) number of

²⁴ Sources: ECC Report 152, ESA BBMED project

²⁵ Note that this measure comes from a statistical aggregation of users and is not the same as peak or burst data rates which will be considerably higher.

satellites using the existing exclusive spectrum would be required. Conversely, for the higher forecasts and higher throughput expectations an impractical number of satellites would be required if constrained to the existing exclusive spectrum. Additional exclusive spectrum (i.e. the whole of the 17.7 – 19.7 GHz band used as an example in the last table below) brings the number of satellites required to more manageable levels although there is still one case where the number is in double figures. It might be expected that some improvements in frequency reuse will also reduce the number of satellites required but this will be limited in scope.

Table 6.4: In-orbit forward link throughput required (Gbps)

	109 kbps user rate	260 kbps user rate	579 kbps user rate
1 million users	109	260	579
3 million users	327	780	1737
5 million users	545	1300	2895

Table 6.5: Number of satellites required (500 MHz exclusive spectrum)

	109 kbps user rate	260 kbps user rate	579 kbps user rate
1 million users	3	7	14
3 million users	8	19	42
5 million users	13	31	69

Table 6.6: Number of satellites required (2500 MHz exclusive spectrum)

	109 kbps user rate	260 kbps user rate	579 kbps user rate
1 million users	1	2	3
3 million users	2	4	9
5 million users	3	7	14

It can be seen from the tables above that at the lower end of the range there is no requirement for additional exclusive spectrum whereas at the higher end of the range the requirement is very real. Ofcom will therefore need to monitor the growth in users and the throughput expectation of those users in order to determine the likely requirement for additional exclusive spectrum.

It should not be forgotten that there is also a knock-on effect regarding feeder links. If additional exclusive spectrum is made available for the consumer links this will effectively displace the feeder links which will then have to use spectrum elsewhere (e.g. Q- and V-band).

6.3 Demand Scenario Outputs: Microwave Bands (above 3 GHz)

The following sections present the results of the demand modelling, in terms of the projected total fixed link capacity (in Gbps) nationally and in each of the three representative regions, by user type and frequency range.

6.3.1 Impact of Downstream Service Scenarios on specific frequency ranges

Note: in the following tables symbols are used to indicate the anticipated trend in fixed link spectrum demand, as illustrated in the key below.

- ▼▼ Large decline in spectrum demand
- ▼ Small decline in spectrum demand
- ◀▶ Little or no change in spectrum demand
- ▲ Small increase in spectrum demand
- ▲▲ Large increase in spectrum demand

Note that the tables show projected trends within each service rather than an absolute comparison between services (i.e. one service using more than another). The latter is illustrated in the graphs in Figure 6.9 below.

Table 6.7: Impact of mobile cellular networks on fixed link spectrum demand

Impact by Frequency Range	Scenario A	Scenario B	Scenario C	Scenario D
Below 10GHz	▼▼	▼	◀▶	▲
10 – 20 GHz	▼▼	▼	◀▶	▲
20 – 30 GHz	▼▼	▼	◀▶	▲
Above 30 GHz	▼▼	▼▼	▼	▼

In Scenario A there is a substantial decline in demand across all bands due to the relatively weak growth in data traffic, limited rural mobile broadband coverage and increased use of fibre for backhaul. In Scenario B the decline is smaller, especially below 30 GHz, due to increased traffic growth and greater coverage expansion in rural areas. There is little change in Scenario C as fibre migration is more limited, whilst in Scenario D high traffic growth and rural coverage expansion increases demand below 20 GHz, Note than in both scenarios C and D fibre migration in urban areas reduces demand above 30 GHz.

Table 6.8: Impact of Rural FWA on fixed link spectrum demand

Impact by Frequency Range	Scenario A	Scenario B	Scenario C	Scenario D
3 – 10 GHz	◀▶	◀▶	◀▶	◀▶
10 – 20 GHz	▲	▲▲	▲	▲▲
20 – 30 GHz	▲	▲▲	▲	▲▲
30 – 50 GHz	◀▶	◀▶	◀▶	◀▶

The impact of FWA deployment is likely to be limited to rural areas beyond the reach of high speed DSL services and would predominantly require medium to long haul high capacity links operating in the 10 – 30 GHz range. Demand growth would be higher under scenarios B and D due to the assumed higher take-up and higher user data rates associated with the more favourable economic conditions.

Table 6.9: Impact of the broadcast sector on fixed link spectrum demand

Impact by Frequency Range	Scenario A	Scenario B	Scenario C	Scenario D
3 – 10 GHz	◀▶	◀▶	◀▶	◀▶
10 – 20 GHz	◀▶	◀▶	◀▶	◀▶
20 – 30 GHz	◀▶	◀▶	◀▶	◀▶
30 – 50 GHz	◀▶	◀▶	◀▶	◀▶

Backhaul links for the digital terrestrial TV networks are substantially complete and no further significant changes are anticipated. With the exception of Scenario C we expect continued expansion of the national DAB networks into rural areas. This is likely to increase demand for spectrum in the 1.4 GHz band but will have little impact on the microwave bands.

Table 6.10: Impact of the public safety sector on fixed link spectrum demand

Impact by Frequency Range	Scenario A	Scenario B	Scenario C	Scenario D
3 – 10 GHz	▲▲	▲	▲▲	▼
10 – 20 GHz	▲▲	▲▲	▲▲	▲▲
20 – 30 GHz	▲▲	▲▲	▲▲	▲▲
30 – 50 GHz	◀▶	◀▶	◀▶	▲▲

The main demand driver for the public safety sector is likely to be the rollout of a national dedicated mobile broadband network to complement the existing narrow band Airwave network, which is assumed to take place in all the scenarios except B.

In scenarios A and C it is assumed that the network will operate in the UHF band with relatively large cells requiring backhaul links in the 3 – 10 GHz range in rural areas, 10-20 GHz in suburban areas and 20-30 GHz in urban areas. In Scenario D the use of a higher frequency band (L-band) is assumed for the mobile network with consequently smaller cells and backhaul links in higher frequency bands above 10 GHz. The decline in spectrum demand below 10 GHz in Scenario D reflects the assumed decommissioning of existing regional deployments when the national network is launched. In Scenario B, these regional deployments are expected to continue using a mix of backhaul frequencies but mainly in the range 10-30 GHz. Significant growth arises in all scenarios due to the high bandwidths required to support video applications and the assumption that radio links will be deployed at all sites to optimise network resilience.

Table 6.11: Impact of Local Authority use on fixed link spectrum demand

Impact by Frequency Range	Scenario A	Scenario B	Scenario C	Scenario D
3 – 10 GHz	▲	▲	▲▲	▲
10 – 20 GHz	▲	▲	▲▲	▲
20 – 30 GHz	▲	▲	▲▲	▲
30 – 50 GHz	▲	▲	▲▲	▲

Demand growth is anticipated under all scenarios as local authorities make greater use of radio links to support wireless CCTV and corporate data networks. Demand growth is highest in Scenario C due to a combination of crime and security concerns and a drive to reduce operational costs (driving increased CCTV take-up), limited fibre availability and limited capacity / coverage on commercial mobile networks.

Table 6.12: Impact of utilities on fixed link spectrum demand

Impact by Frequency Range	Scenario A	Scenario B	Scenario C	Scenario D
3 – 10 GHz	▲	▲▲	▲	▲
10 – 20 GHz	▲	▲▲	▲	▲
20 – 30 GHz	▲	▲▲	▲	▲
30 – 50 GHz	▲	▲▲	▲	▲

An increase in demand across all frequency ranges is anticipated under all scenarios, reflecting the mix of link lengths used in urban, suburban and rural areas. The impact is greatest in Scenario B due to the greater emphasis on smart grid deployment to support energy efficiency improvements.

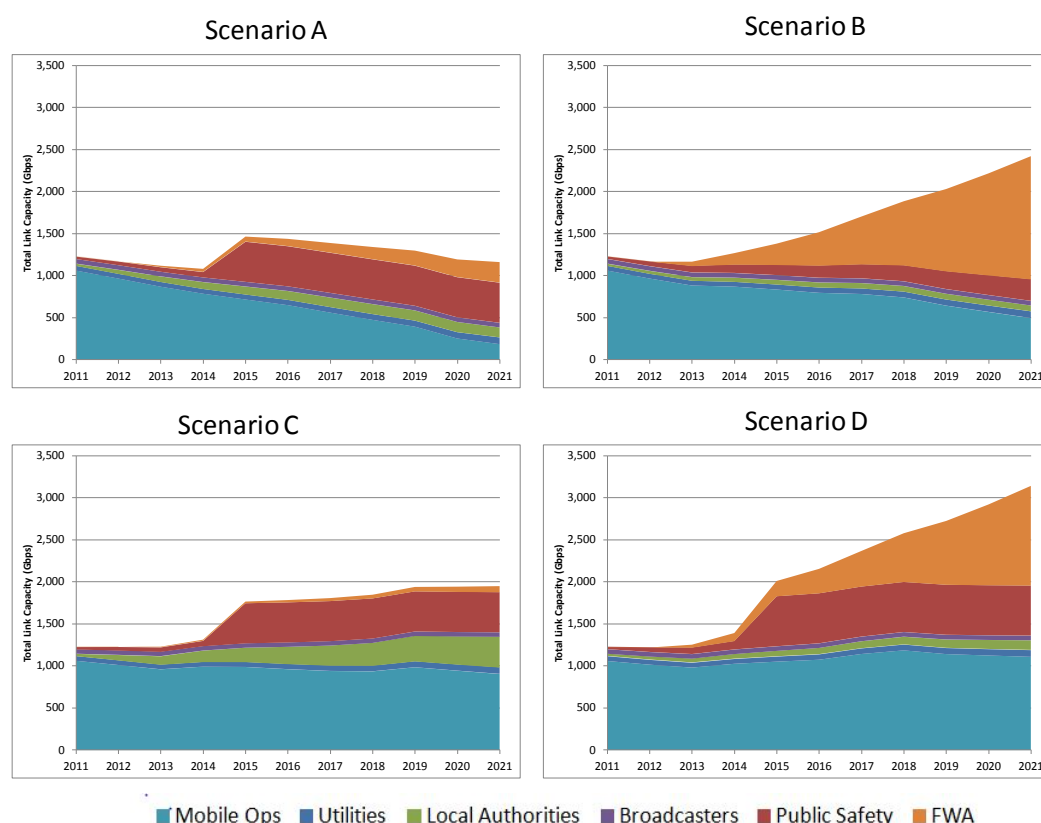
Table 6.13: Impact of broadband satellite on fixed link spectrum demand

Impact by Frequency Range	Scenario A	Scenario B	Scenario C	Scenario D
3 – 10 GHz	◀▶	◀▶	◀▶	◀▶
10 – 20 GHz	▲▲	◀▶	▲	◀▶
20 – 30 GHz	◀▶	◀▶	◀▶	◀▶
30 – 50 GHz	◀▶	◀▶	◀▶	◀▶

High demand for consumer broadband satellite terminals could lead to pressure for more satellite spectrum to be made available in the 18 GHz band and is most likely to arise under Scenario A where the weak economy results in limited terrestrial coverage in rural areas but there is a strong regulatory drive to make high speed broadband available to all.

6.3.2 Projected fixed link capacity nationally across the UK

Figure 6.9: Projected fixed link capacity demand by user type (total capacity nationally in Gbps)



Projected national demand and how this is distributed geographically and between users varies significantly by scenario. In **Scenario A**, demand for mobile links falls away strongly as networks progressively migrate from radio links to fibre. There is a steady growth in demand for local authority links to support CCTV and broadband

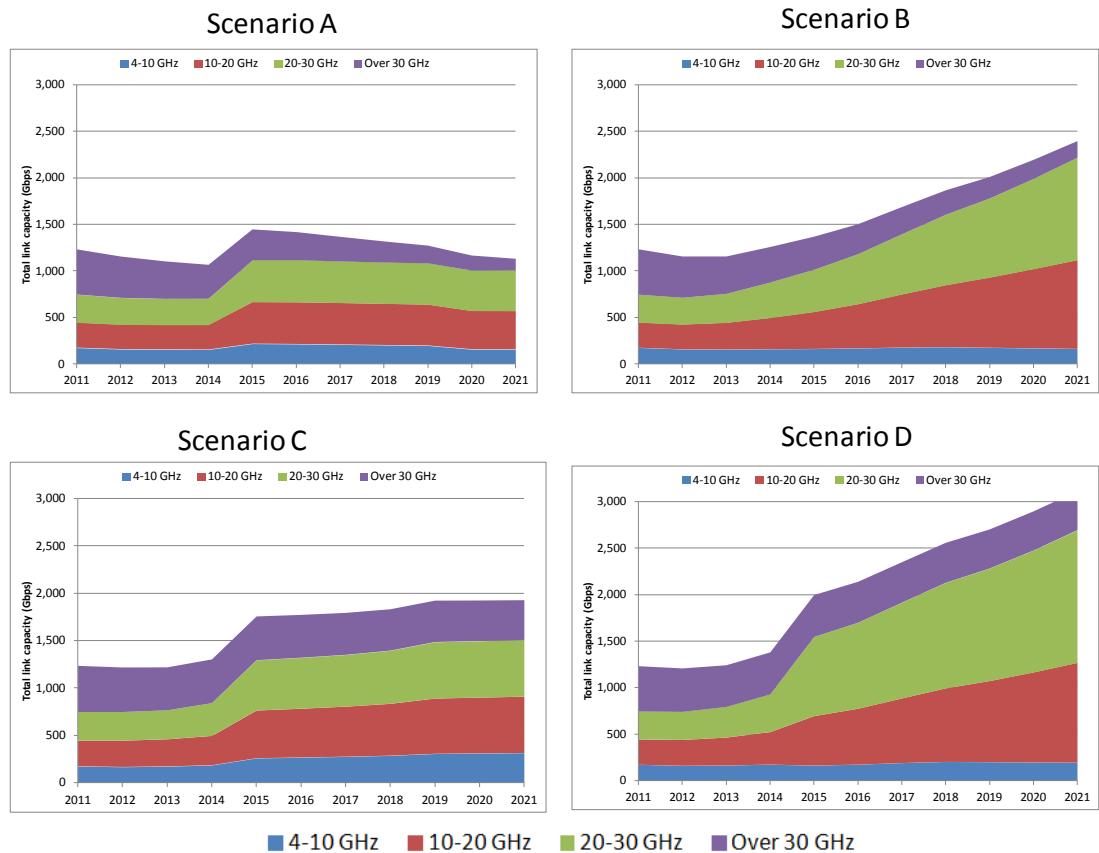
infrastructure, and in demand for FWA in rural areas, but the most significant factor increasing demand is the launch of a national public safety broadband network, assumed to take place in 2015. The extensive reliance on radio backhaul to provide resilience, high level of coverage required and the need for 155 Mbps capacity at every base station to cater for major incidents means public safety account for the largest share of fixed link capacity from 2018.

In **Scenario B**, we have assumed public safety requirements would be met by a combination of reliance on commercial networks and individual regional bodies deploying their own systems. This results in a more gradual demand growth in this sector and considerably lower absolute demand in 2021. Mobile backhaul demand falls less slowly in this scenario, mainly due to the more extensive take-up of 4G services, reflecting the more favourable economic climate. However, the biggest long term demand driver in this scenario is the growth in wireless fixed access demand, driven by high user traffic levels and high demand for service in rural areas.

In **Scenario C**, mobile backhaul demand remains steady as there is less migration to fibre than in scenarios A and B. High crime levels and pressure to minimise costs drive strong growth in wireless CCTV deployments by local authorities and as in Scenario A the launch of a dedicated public safety broadband network results in a sharp increase in demand in 2015. Mobile backhaul remains the biggest source of demand in this scenario.

Scenario D shows the highest level of demand for fixed link capacity, driven largely by fixed wireless access (as in Scenario B) and by the launch of the public safety broadband network, which in this scenario has to use a higher frequency band for the access network (the 1.4 GHz former DAB band has been assumed), requiring considerably more backhaul links than in scenarios A and C. Despite the growing demand from FWA and public safety, the high demand for mobile broadband services means mobile backhaul remains the largest source of demand until 2019.

Figure 6.10: Projected fixed link capacity demand by frequency band (total capacity nationally in Gbps)



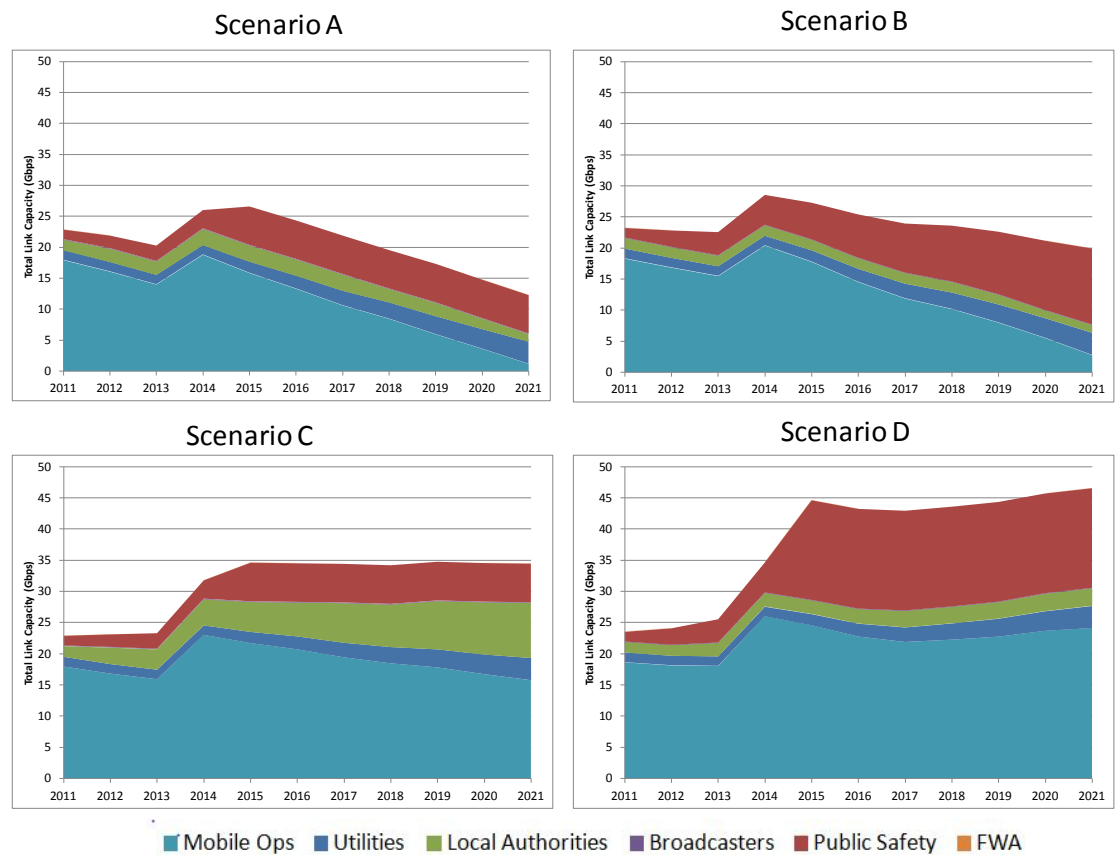
In **Scenario A**, there is a sizeable reduction in demand for links above 30 GHz as the majority of urban mobile backhaul links (which currently dominate use of these frequencies) are migrated to fibre. Demand in the 10-20 GHz and 20-30 GHz ranges grows significantly over the period, driven mainly by the launch of the public safety broadband network in 2015. Demand below 10 GHz also rises during the first part of the period but then declines—this reflects the rollout of 3G/4G mobile networks into increasingly rural areas (requiring longer link lengths) and the gradual migration of some of these links to fibre towards the end of the period.

In **Scenario B** the demand growth between 10 and 30 GHz is even more marked but in this case is mainly driven by the massive growth in fixed wireless access traffic in rural areas. **Scenario C** shows similar growth in this frequency range to Scenario A but there is also steady demand above 30 GHz and considerable growth below 10 GHz, reflecting the slower migration to fibre under this scenario. **Scenario D** shows particularly high growth in the 20 – 30 GHz range, largely a result of the higher frequency public safety network, which requires a larger number of smaller cells, favouring the use of frequencies above rather than below 20 GHz.

6.3.3 Projected fixed link capacity in a typical dense urban environment

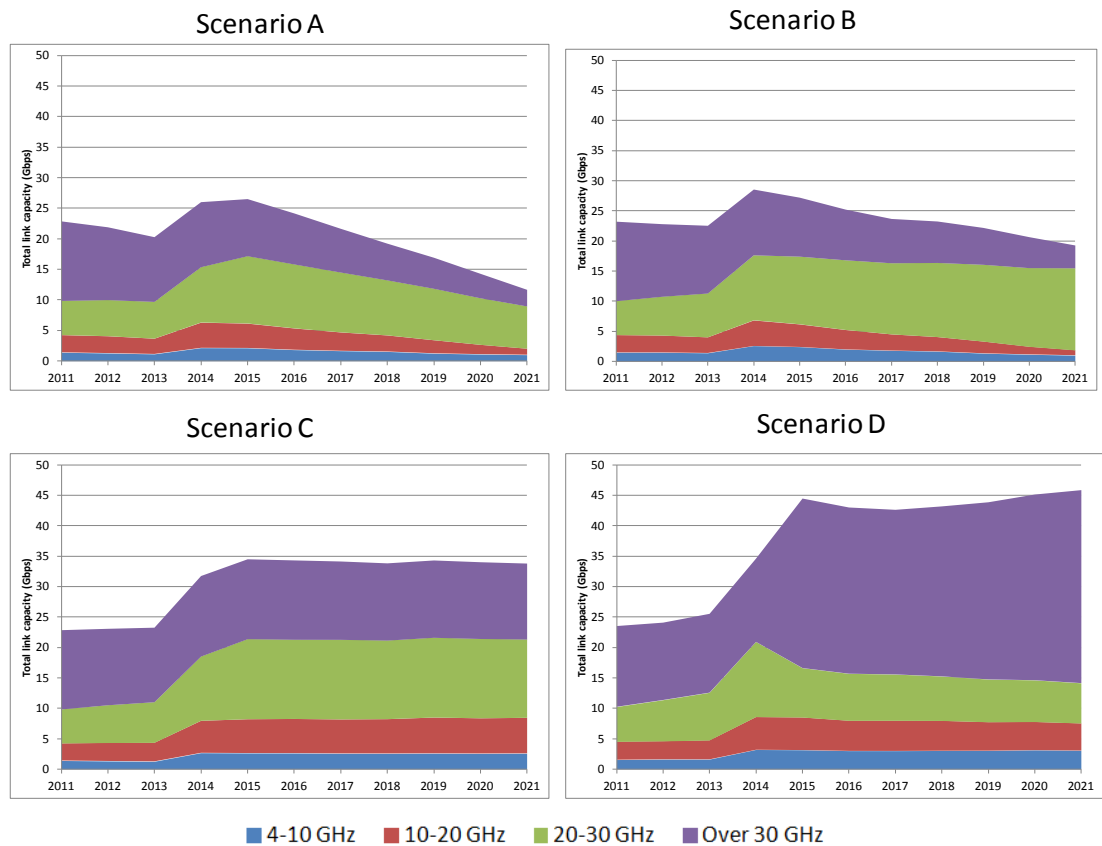
The following analysis refers to the inner London area, defined approximately by the UK national grid squares TQ27, TQ28, TQ37 and TQ38.

Figure 6.11: Projected fixed link capacity demand by user type (total capacity in inner London in Gbps)



In an urban setting like London, the great majority of commercial network links are expected to migrate to fibre, particularly under scenarios A and B where availability and cost of fibre is improving over time. However, the high resilience required by public safety users is likely to require deployment of radio links at all sites, in which case this sector will come to dominate fixed link capacity demand in these areas. The effect is particularly stark in Scenario D due to the large number of sites required to operate at the assumed higher frequency for the public safety network. Note also that public safety still dominates even in the absence of a national public safety network (Scenario C), due to the high level of local network deployments anticipated around the city. Note also the high proportion of local authority demand in Scenario C, reflecting the high level of wireless CCTV deployment similar to that already seen in the London Borough of Hounslow.

Figure 6.12: Projected fixed link capacity demand by frequency range (total capacity in inner London in Gbps)



Here we see a large drop in demand above 30 GHz in scenarios A and B, due to migration of existing links to fibre. There is less migration in Scenario C so the demand in this range remains steady and in Scenario D the demand increases significantly as the smaller cells deployed in the 1.4 GHz public safety network can use frequencies above rather than below 30 GHz for backhaul.

6.3.4 Projected fixed link capacity in a typical mixed urban / suburban / rural environment (Surrey County)

Figure 6.13: Projected fixed link capacity demand by user type (total capacity in Surrey in Gbps)

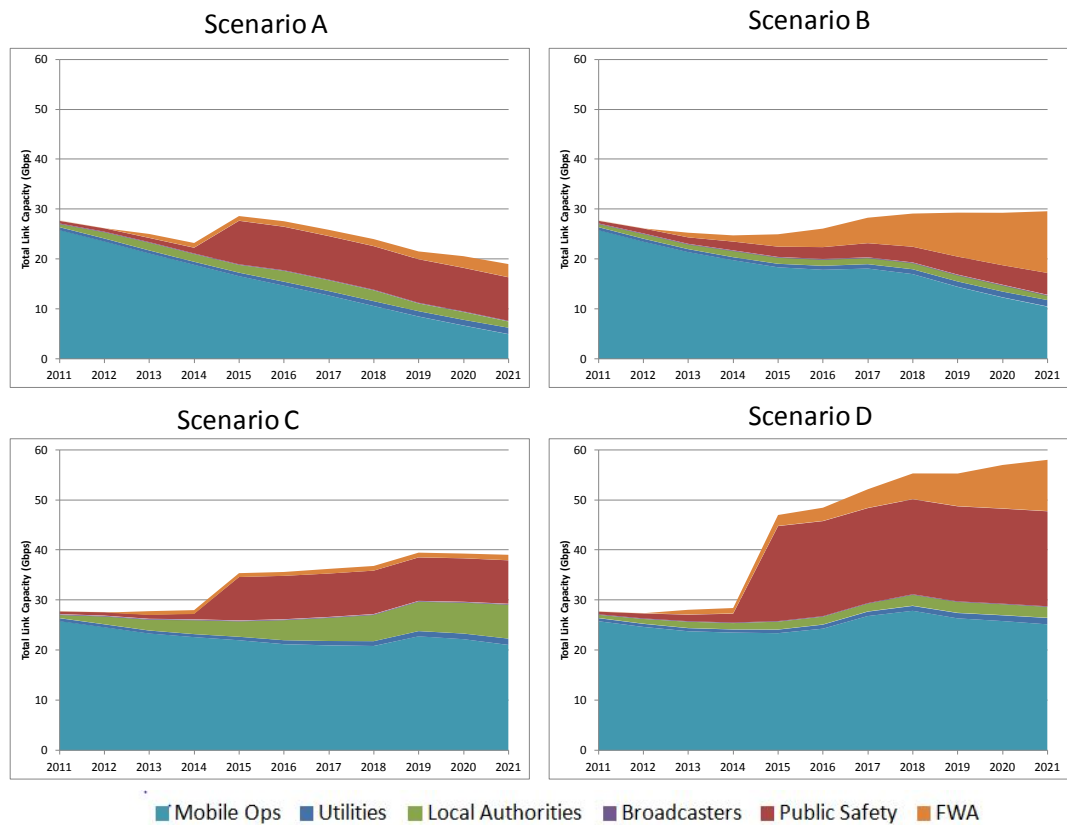
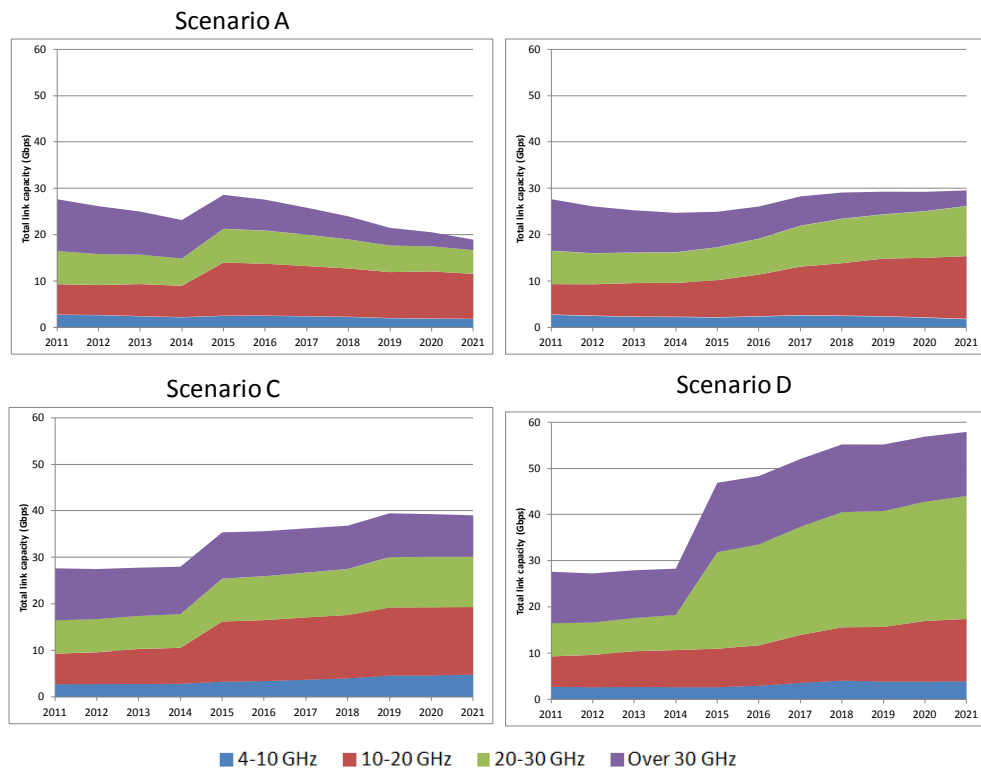


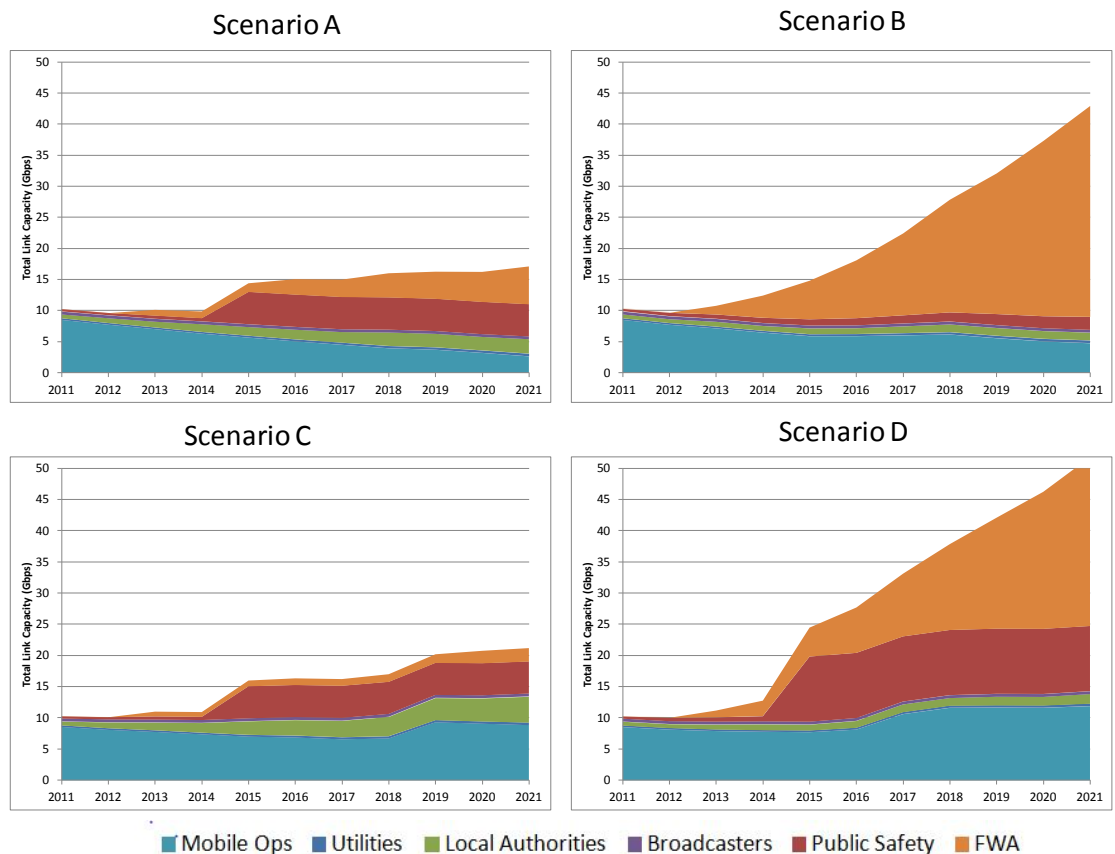
Figure 6.14: Projected fixed link capacity demand by frequency range (total capacity in Surrey in Gbps)



The overall trends here are broadly similar to those seen in London, except that the impact of fibre migration is less and the take-up of FWA in some rural premises is apparent, especially in scenarios B and D where the assume traffic per user is highest.

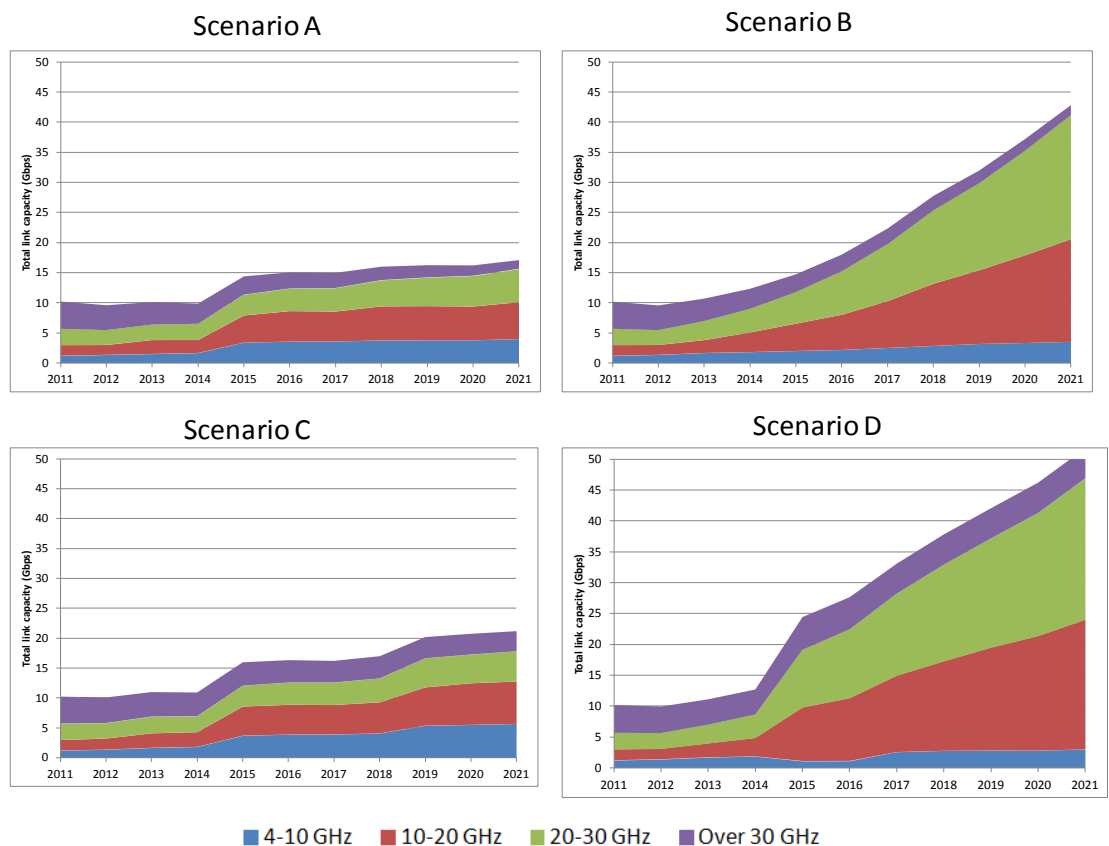
6.3.5 Projected fixed link capacity in a typical predominantly rural environment (Cumbria County)

Figure 6.15: Projected fixed link capacity demand by user type (total capacity in Cumbria in Gbps)



In this predominantly rural environment fixed wireless access take-up has a significant impact and is the largest driver of demand in scenarios B and D. Mobile backhaul demand declines slightly in scenarios A and B due to fibre migration (but note the rate of decline is much less than in the urban and suburban environments) and increases in Scenario C and D as existing 2G coverage is upgraded to 3G and 4G. The rollout of 4G services into rural areas causes a noticeable increase in demand which occurs in 2017 in Scenario D and 2019 in Scenario C. This is less pronounced in Scenario B (as it is partially offset by increasing fibre migration) and is not apparent at all in Scenario A as we assume 4G does not extend to rural areas in that scenario. Note that the need for longer links, reflecting the larger mobile cell sizes in rural areas, means the greatest demand falls in the bands below 30 GHz.

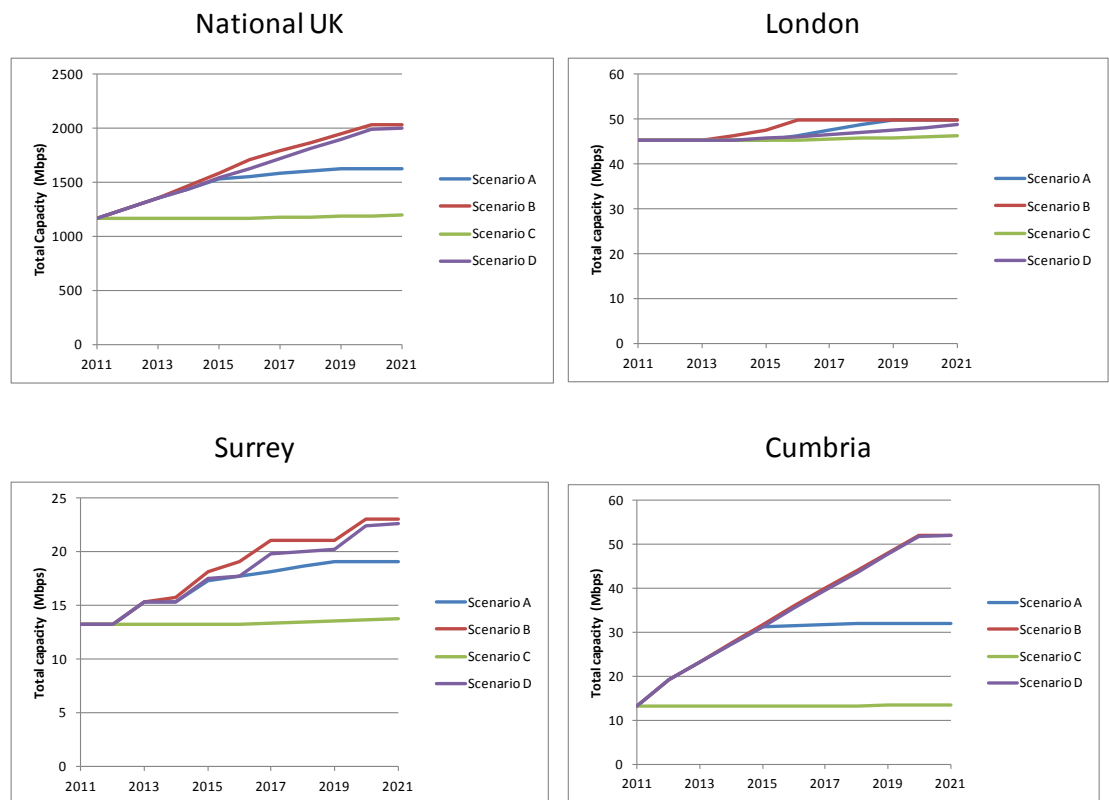
Figure 6.16: Projected fixed link capacity demand by frequency range (total capacity in Cumbria in Gbps)



6.4 Demand Scenario Outputs: 1.4 GHz Band

Our discussions with stakeholder suggests that existing use of the 1.4 GHz band will continue and additional demand will be driven primarily by expansion of DAB coverage and the rollout of smart grid networks. The impact of DAB expansion is considerably greater because of the much wider bandwidth per link (2 Mbps compared to 50 kbps), but is concentrated in rural areas. The projected total demand nationally and in each of the three representative regions under each scenario is shown below. Growth is highest in scenarios B and D as those are the scenarios where DAB coverage expansion is greatest (reflecting the stronger economy). There is negligible growth in Scenario C, due to a combination of a weak economy and less regulatory intervention.

Figure 6.17: Projected demand for 1.4 GHz capacity



6.5 Implications of satellite demand

It is clear from our research that the main driver of demand for fixed link spectrum from the satellite sector is likely to be for consumer satellite terminals and associated feeder links. There is by no means a consensus on how successful this market might be; however, it can be concluded that if the market does grow then demand for access to additional spectrum in the 18 GHz band (17.7 – 19.7 GHz) may arise. In the worst case scenario this could lead to all of the band being lost to the fixed service; however, this appears unlikely given the recent growth in fixed link deployment in the band across Europe.

With regard to the scenarios, our projections for satellite demand were as follows:

- **Scenario A:** Strong demand in rural areas to meet universal service obligations. Assumed bit rate per user for fixed broadband in 2020: 200 kbps. There is a strong likelihood that additional spectrum may required in this scenario, possibly extending to the full band.
- **Scenario B:** Demand limited as fixed / mobile alternatives are widely available. No additional spectrum requirement anticipated.
- **Scenario C:** Moderate demand in rural notspots. Likely that additional spectrum will be required but only part of the 18 GHz.

- **Scenario D:** Some demand in rural notspots but unable to compete with terrestrial offerings in the longer term. No additional spectrum requirement anticipated.

The implications of all or part of the 18 GHz band being denied for fixed links due to satellite demand growth is discussed further in the following chapter, which estimates the spectrum required for fixed links and compares this with availability.

7 ESTIMATION OF SPECTRUM REQUIREMENTS IN SPECIFIC FREQUENCY RANGES

7.1 Introduction

Based on the estimates of fixed link capacity in section 6.3 above, we have generated estimates of the total frequency span in MHz required in each of the four frequency ranges. The estimation methodology is described in the following section.

7.2 Methodology

Spectral requirements are estimated on the basis of a spectral utilisation factor (F_u) developed in a previous study for Ofcom²⁶. Although spectral "efficiency" may be referred to in a relative sense, it is not realistic to define what is meant by 100% spectral efficiency. It is, however, possible to define various spectral utilisation factors which can be used in the absolute sense. For fixed links the factor F_u defined in Reference 1 is given by a value function divided by a cost function.

The value function is obtained by calculating the following sum, for all links within a given geographic area A (km²):

$$V = \sum_{n=1}^N d_n m_n \quad (\text{km} \cdot \text{bits/s}) \quad (1)$$

where N is the total number of links, and for the n -th link, d_n is the path length inside the test area (km) and m_n is the link capacity (bits/s).

The cost function is:

$$C = S.A \quad (\text{Hz} \cdot \text{km}^2) \quad (2)$$

where S is the total spectral span consumed by all occupied channels (Hz).

The utilisation factor is the ratio of the two functions:

$$F_u = \frac{V}{C} = \frac{\sum_{n=1}^N d_n m_n}{S.A} \quad (\text{bits/km}) \quad (3)$$

To avoid edge effects it is necessary to include all path lengths within the test area, even where either or both terminals are outside, and to account for only that part of each path length that is inside the test area. The spectral span S will normally consist of two blocks in the lower and upper parts of the band.

The work carried out in the 2007 study consisted of simulated band planning using different assignment strategies. An important feature of the simulations is that actual link details were used. In effect each simulation consisted of a re-assignment of a complete band for links with typical distributions of path length, channel width

²⁶ Aegis Report to Ofcom "Assignment Strategies for fixed links", 31 July 2007.

and capacities. Results obtained for the 38 GHz band provided relationships between link densities, utilisation factors and assignment failure rates.

The *spectral span* required for links envisaged by a given scenario may be estimated by representing them as the combination of M populations of links with geographic densities, U_n , length d_n km and capacity m_n bits/s. The spectrum span required to give a utilisation factor F_u is then obtained by substitution in equation (3) and solving for S , giving:

$$S = \frac{\sum_{n=1}^M U_n d_n m_n}{F_u} \quad (\text{Hz}) \quad (4)$$

The spectrum span is the total bandwidth required to meet the capacity demand in a given area in a single direction, assuming that all the links in that area are uniformly distributed and assigned in an optimum fashion. The actual spectrum required will in fact be twice this value assuming that all the links are bidirectional.

In practice, links are not distributed uniformly but tend to be concentrated at particular sites, especially in the lower frequency bands where hop lengths are longer and the number of sites smaller. To replicate this non-uniformity we have analysed the distribution of traffic throughout each of our three representative areas and based our spectrum estimation on the busiest 10 km square in each area.

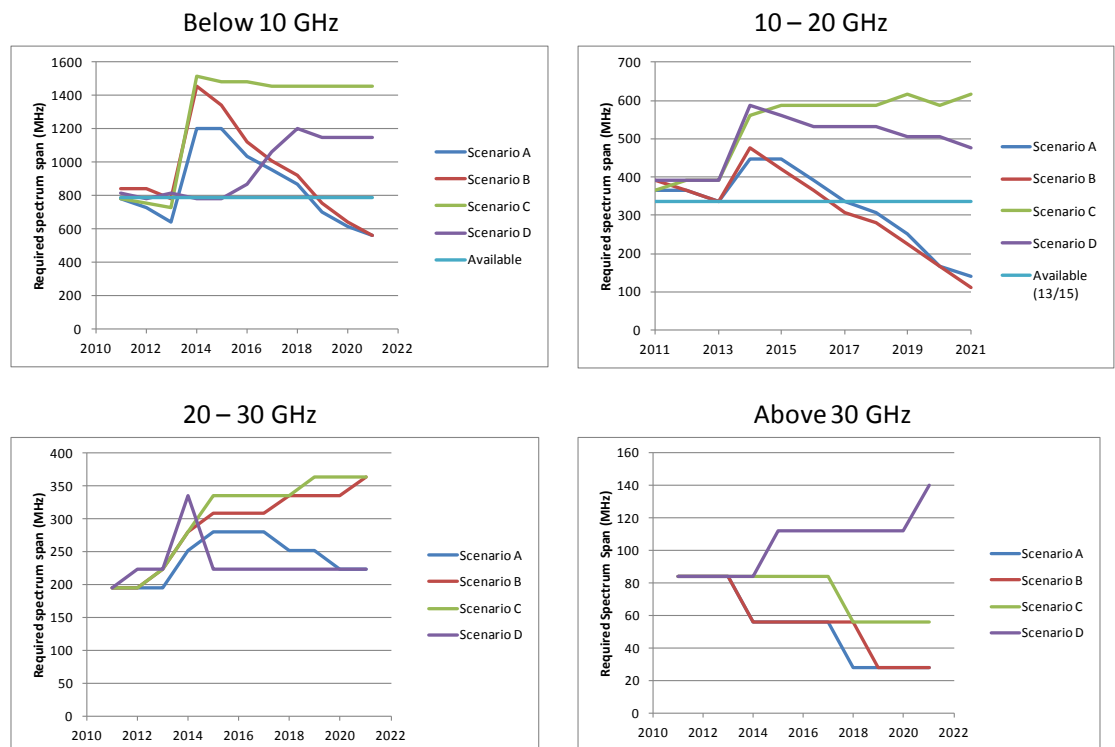
7.3 Spectrum Demand Estimates

Using the methodology described above we have estimated the spectrum span requirement in the frequency ranges below 10 GHz, 10-20 GHz, 20-30 GHz and above 30 GHz, based on projected traffic levels in the busiest 10 km square in the region concerned. The results indicate that in the spectrum above 20 GHz relatively little spectrum is required to meet capacity due the short path lengths involved and the intensive frequency re-use that can be achieved. For example, in London our modelling suggests that no more than 2 x 224 MHz would be needed in the 20 – 30 GHz range and 2 x 140 MHz above 30 GHz to meet current and future demand if links were distributed uniformly across the area. In practice of course, significantly more spectrum may be needed at specific sites, e.g. hub sites accommodating a large number of links.

In the range below 10 GHz, the modelling suggests congestion will arise in certain scenarios; however, this is very dependent on assumptions made about average link length and will also be very site specific. Nevertheless, it seems likely that congestion will remain a problem in this frequency range for the foreseeable future.

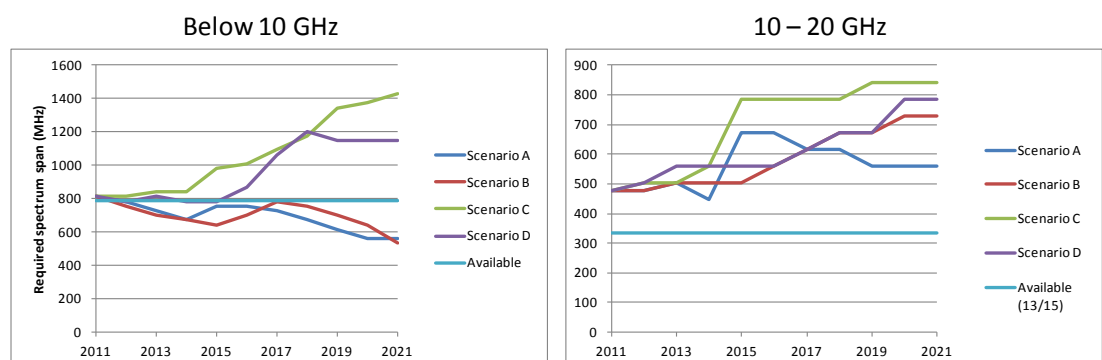
In the 10 – 20 GHz range, if the 18 GHz band is allowed for, there appears to be ample spectrum to meet future projected demand in all scenarios. However, if the 18 GHz band ceases to be available (e.g. due to high demand from consumer satellite terminals) significant congestion will arise in the 13 and 15 GHz bands under certain scenarios.

Figure 7.1: Projected spectrum span requirements for London



The high spectrum demand in both frequency ranges for scenarios C and D arises predominantly from a relatively small number of very high capacity mobile backbone links, i.e. links connecting hub sites or radio network controllers (RNCs) back to the core network, as opposed to base station links. In practice it is likely that links in the London area will be short enough to be accommodated in bands above 10 GHz, but the effect of this could be to increase even further the demand for spectrum in the 10 – 20 GHz range. This will not cause a problem if the 18 GHz band remains available; however, if all of this band were to be lost to satellite use this could result in significant congestion in the 13 and 15 GHz bands. The sharp decline in demand in scenarios A and B reflects the high degree of fibre migration in these scenarios.

Figure 7.2: Projected spectrum span requirements for Surrey

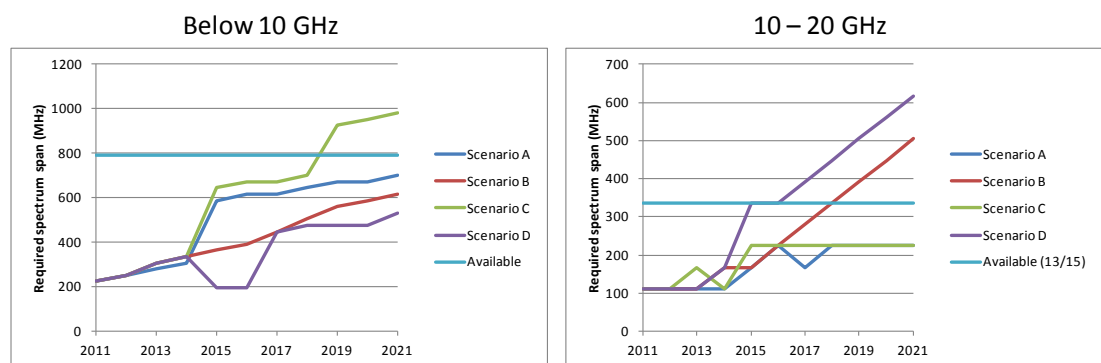


As in London, the demand for spectrum below 10 GHz is dominated by mobile backbone links, which are likely to be longer in this less urban environment and

therefore less likely to be deployable in bands above 10 GHz. This is also a significant factor in the 10 – 20 GHz range but is compounded by the demand for FWA backhaul links in this range in the more rural parts of the county. Note that demand in this range exceeds the capacity of the 13 and 15 GHz bands in all scenarios, necessitating continued access to at least part of the 18 GHz band.

Demand for spectrum above 20 GHz is relatively low outside London and other major conurbations and is therefore not shown for Surrey and Cumbria.

Figure 7.3: Projected spectrum span requirements for Cumbria



In this case demand below 10 GHz is highest in Scenario C, driven by the low use of fibre in mobile network backhaul and the needs of the public safety network—the latter has less impact in Scenario D because the cells are smaller (due to the higher access network frequency) and the rural links are therefore shorter and able to use bands above 10 GHz. This also accounts for Scenario D having the highest demand above 10 GHz, followed by Scenario B with is largely driven by fixed wireless access backhaul. In scenarios A and C there is sufficient spectrum in the 13 and 15 GHz bands to meet projected demand and continued access to the 18 GHz band does not appear to be essential.

7.4 Impact of reallocating all or part of the 18 GHz band for satellite

In the previous chapter we identified the following potential demand for additional 18 GHz spectrum for satellite use:

- Scenario A: all of the band
- Scenario B: no additional spectrum required
- Scenario C: part of the band
- Scenario D: no additional spectrum required

From the previous section, demand for spectrum in the London and Surrey areas in the 10 – 20 GHz range exceeds the capacity of the 13 and 15 GHz bands in Scenario A, so the assumption under this scenario that all of the 18 GHz band is reallocated for satellite use would result in congestion in those bands. However, in Cumbria there appears to be sufficient capacity in the 13 and 15 GHz bands in Scenario A so use of the band by satellite would appear to be feasible in that area.

The implication is that geographic sharing between satellite terminals and terrestrial fixed links in the 18 GHz band would be feasible, with satellite use restricted to more remote rural areas such as parts of Cumbria but the spectrum retained for fixed links in urban and suburban areas. This could fit well with demand patterns, as satellite demand is likely to be greatest in the more remote areas, but would required further study to assess feasibility.

8 CONCLUSIONS

We have identified four distinct scenarios, each of which has associated projections of demand growth for the following downstream services and user types:

- Mobile (cellular)
- Fixed wireless access
- Broadcasters
- Public safety
- Local Authorities
- Utility companies
- Satellite.

We have modelled the impact of the demand trends among these sectors on likely total demand for fixed link capacity, taking account of factors such as the availability of alternative platforms (notably fibre) and degree of traffic offload onto other networks (such as Wi-Fi or femtocells connected to DSL or cable broadband). We have then used the typical characteristics of fixed links in the various available frequency band and the projected capacity to demands to estimate the likely future spectrum demand in the following frequency ranges:

- Below 10 GHz
- 10 – 20 GHz
- 20 – 30 GHz
- Above 30 GHz.

Our analysis has indicated that spectrum demand above 20 GHz will be considerably less than the available spectrum in all scenarios, due to the short hop lengths and very intensive frequency re-use at these frequencies. The availability of additional spectrum above 60 GHz to cater for very short links and the migration of network operators' links from existing Ofcom bands to their own bands will further reduce pressure on these higher bands. Our analysis of 1.4 GHz also indicates there will be sufficient spectrum to meet anticipated demand in all the scenarios.

The situation in bands between 3 and 20 GHz is more challenging due the more limited availability of spectrum and demand growth arising from initiatives such as the rollout of mobile broadband and FWA into rural areas and the anticipated launch of a broadband public safety wireless network. There is considerable uncertainty about whether all or part of the 18 GHz band, which accounts for the lion's share of fixed link spectrum in the 10 -20 GHz range, may be required to accommodate consumer satellite terminals in the future. If the whole or the majority of the band were to be re-allocated to satellite this would lead to congestion in the 13 and 15 GHz bands, which would occur mainly in urban and suburban areas. There may,

however, be scope for geographic sharing between urban / suburban fixed links and rural satellite terminals.

Key trigger points and trends likely to influence fixed link demand have been identified as follows:

- Cost and availability of fibre has a strong bearing on demand for fixed links in urban and suburban areas in particular; effect is concentrated in higher frequency bands (mainly above 20 GHz). Likely to be an ongoing, gradual trend over the ten year period.
- Demand for fixed wireless broadband access in rural areas—this would require significantly higher backhaul capacity per user than mobile broadband and is likely to drive demand in all bands below 30 GHz (higher bands are less likely to be suitable for rural deployment due to the larger cell sizes in those areas).
- Launch of 4G (LTE) mobile services—likely to take place initially in urban areas in 2013 following the auction of 800 MHz and 2600 MHz spectrum, rollout into suburban and rural areas dependent on scenario. This will result in step increase in fixed link demand prior to service launch due to the higher peak bit rate compared to existing 3G services.
- Roll out of a national public safety broadband network. This will be one of the biggest demand drivers for fixed link capacity if such a network goes ahead and would result in a large step increase in demand. If a band below 1 GHz is used for the access network all of this demand will be in bands below 30 GHz; if a higher frequency is used some of the demand will arise in higher bands (above 30 GHz) but the total demand will be higher due to the larger number of cells required.
- Expansion of DAB service is likely to be the largest driver of demand growth in the 1.4 GHz band and demand will be concentrated in rural areas. Smart grid networks by comparison will have a relatively minor impact due to the narrow bandwidths involved, although the numbers of links are likely to be high.
- Perhaps the biggest uncertainty identified relates to potential demand for satellite consumer terminals and whether these will necessitate access to more exclusive spectrum in the 18 GHz band. If such demand does arise, this could lead to congestion in some areas, although geographic sharing may provide an opportunity to overcome this.

In terms of timing, there are two events that appear likely to result in a “step change” in demand for fixed links, namely the rollout of 4^G (LTE) mobile services and the rollout of a national public safety broadband network. The latter is likely to have the greatest impact because of the necessity to deploy radio at every site (whereas 4G will mainly use fibre in urban and suburban areas) and because coverage is likely to be rolled out quickly to all areas of the country to meet the demanding needs of the

public safety community. Ofcom should therefore monitor closely any developments relating to the potential future launch of such a network.

Another potentially significant development would be the emergence of a real market demand for consumer satellite broadband terminals which could under some scenarios lead to demand for more exclusive spectrum for satellite in the 18 GHz band. Ofcom should therefore monitor developments in this sector closely and may wish to investigate the feasibility of geographic sharing in this band to facilitate rural deployment of satellite terminals in rural areas whilst retaining fixed links in urban areas where demand is highest. Other developments that we have identified tend to be more gradual in nature and unlikely to cause any sudden change in demand for fixed link spectrum.

We note from our analysis of the Ofcom licensing data that there are a substantial number of links assigned to fixed network operators such as BT, but have been unable to obtain details about what these links are used for and have therefore been unable to factor these into our analysis. Altogether these links account for approximately 27% of current total fixed link capacity, but almost half of this capacity (and two thirds of the link count) is in the 18 GHz band. There appear to be a large number of relatively short links in this band that could be readily accommodated in higher frequency bands, potentially freeing up capacity to relieve congestion in the 13 and 15 GHz bands, or to allow part of the band to be used for satellite terminal should such demand arise.

A ANNEX A: MOBILE NETWORK PARAMETERS USED IN THE MODELLING

A.1 Spectrum Efficiency

Spectrum efficiency for base station traffic throughput is based on estimates for various mobile technologies originally sourced from Vodafone and Qualcomm and presented in a 2009 white paper published by the Digital Communications Knowledge Transfer Network. The values are reproduced below:

Table A.1: Comparison of data throughput and spectrum efficiency for various mobile data technologies

Technology	Throughput	RF bandwidth	Freq Re-use	Efficiency
2G (GPRS)*	115 kbps	200 kHz	12	48 bps/Hz
2.5G (EDGE)*	240 kbps	200 kHz	12	100 bps/Hz
3G (UMTS R99)*	750 kbps	5 MHz	1	150 bps/Hz
3.5G (HSDPA)**	1.7 Mbps	5 MHz	1	340 bps/Hz
3.5G (HSPA+) **	4.2 Mbps	5 MHz	1	840 bps/Hz
4G (LTE)**	15 Mbps	10 MHz	1	1500 bps/Hz

Sources: *Qualcomm²⁷ **Vodafone²⁸

For modelling purposes we have assumed the throughput efficiency for 2G, 3G and 4G networks will evolve as follows over the next decade:

- 2G: improving from 75 to 100 bps/Hz by 2016 (i.e., initially a roughly equal mix of GPRS and EDGE, evolving to 100% EDGE by 2016)
- 3G: improving from 440 bps/Hz to 840 bps/Hz by 2016 (i.e. initially a roughly equal mix of UMTS, HSPA and HSPA+, evolving to 100% HSPA+ by 2016)
- 4G: assumed to be 1500 Mbps/Hz from inception.

The backhaul capacity per base station sector in each year is estimated by multiplying the available mobile spectrum for each technology by the spectrum efficiency—the backhaul capacity required per base station is assumed to be three times this on the basis that most base stations will have three sectors.

²⁷ “HSDPA for Improved Downlink Data Transfer”, white paper, 2004

²⁸ “Broadband through Wireless – the unfolding story of the mobile web”, presentation by Prof. Michael Walker OBE FREng to Silicon South West Wireless 2.0 Conference, 2009

A.2 Cell Sizes

The following cell sizes have been assumed when estimating the number of coverage sites required. The values are derived using the COST-Hata propagation model assuming a link budget of 140 dB, which we believe to be representative of both current and future mobile cellular networks.

Table A.2: Assumed cell radii for 2G, 3G and 4G coverage cells

	2G	3G (2 GHz)	4G
Urban	1.5	0.75	1.5
Suburban	3	1.25	3
Rural	10	5	10

3G coverage cells operating in the 900 MHz band (which we assume will be deployed for coverage expansion from 2012 onwards) are assumed to have the same cell radius as the 2G and 4G cells.

In order to estimate the total number of base stations, we first estimate the number of coverage cells required to achieve the specified level of coverage each year, then estimate the number of additional capacity cells that are required to carry the estimated traffic demand for that year, assuming that the traffic is distributed around the network in line with population.

ANNEX B: STAKEHOLDERS CONTACTED AND WHO PROVIDED INFORMATION FOR THE STUDY

The authors are grateful for the helpful inputs to the study provided by the following organisations:

- Fixed Networks: BT, MLL Telecom, UK Broadband (including 802 Global), Surf Telecom
- Mobile and Wireless Networks: 3, O2, Networks by Wireless
- Equipment vendors: Alcatel Lucent, Bridgewave, Cambridge Broadband, Ceragon, Ericsson, NEC, Nokia Siemens Networks, Westica

Public Safety: Airwave, NPIA (National Police Improvement Agency),

- Home Office
- Satellite operators and related bodies: Avanti, Cable and Wireless (teleport operator), European Space Agency, Global Teleports UK, Inmarsat, Hughes Network Systems, Science and Technology Facilities Council, Meteorological Office
- Utilities: Joint Radio Company (fuel and power industry), Perenco (oil and gas platform operator), Telecommunications Association of the UK Water Industry
- Broadcasting: Arqiva
- Other: National Air Traffic Service, ETSI TM4 Chairman

ANNEX C: GLOSSARY

ADSL	Asynchronous DSL
Backhaul link	Connection between an access network node (e.g. base station) and the core network
CAGR	Compound Annual Growth Rate
CCTV	Closed Circuit Television
CEPT	Conference of European Post and Telecommunications Administrations
DAB	Digital Audio Broadcasting
DSL	Digital Subscriber Line (digital broadband access technology)
DTH	Direct to Home (satellite TV broadcasting)
DTT	Digital Terrestrial Television
DVB-T	DTT Technical Standard most commonly deployed currently
DVB-T2	Evolved version of DVB-T standard providing greater capacity and spectrum efficiency
ECC	European Communications Committee
EIRP	Equivalent Isotropically Radiated Power (from a non-isotropic antenna)
eNode B	3G mobile base station
ESOMP	Earth Station on a Moving Platform
FDD	Frequency Division Duplex
HDFSS	High Density Fixed Satellite Service
ITU	International Telecommunications Union
LTE	Long Term Evolution of International Mobile Telecommunications (ITU standard)
Mbps	Megabits per second
OFDMA	Orthogonal Frequency Division Multiple Access
PDH	Plesiochronous Digital Hierarchy (legacy digital transmission technology generally being replaced by SDH)
QAM	Quadrature Amplitude Modulation
ROES	Receive Only Earth Station
RSA	Recognised spectrum access

SCADA	Supervisory Control and Data Acquisition
SC-FDMA	Single Carrier Frequency Division Multiple Access
Smart Grid	Combination of traditional power distribution grid with sensing and monitoring technology, information technology, and communications to enhance electrical grid performance and support additional services to consumers.
SDH	Synchronous Digital Hierarchy (digital transmission technology)
SRR	Short Range Radar
STM-1	Synchronous Transport Module of data capacity 155 Mbps
TDD	Time Division Duplex
TDM	Time Division Multiplex
TES	Transportable Earth Station
TVRO	TV Receive Only (satellite terminal)
VDSL	Very high bit rate DSL
VSAT	Very Small Aperture Terminal (satellite terminal)