Support to Ofcom's review of fees for fixed links and permanent earth stations

A final report for Ofcom

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16 April 2015

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Executive summary

Introduction

Ofcom commissioned this report from Plum and Aegis Systems to support its review of administered incentive pricing (AIP) fees in the frequency bands licensed for fixed links, permanent earth stations (PES) and transportable earth stations (TES)[1]. The objective of the study is to advise on a pricing structure that will incentivise economically efficient use of radio spectrum.

AIP fees for bands used by fixed links and PES/TES were last determined by Ofcom in 2005 and 2007 respectively[2]. This study builds on the analysis undertaken at that time and examines recent and likely future technology and market changes that may affect demand for spectrum in bands used by fixed links and PES/TES. We apply the framework for determining AIP fees set out in 2010 in Ofcom's Statement for the Strategic Review of Spectrum Pricing (SRSP).[3]

This report is structured to follow the four steps for setting AIP fees proposed by Ofcom in the SRSP:

- Step 1 examines the current and potential future alternative uses of the frequency bands for fixed links and PES/TES so as to determine potential sources of demand by band. This is covered in Section 2.
- Step 2 involves assessing whether there is, or is likely to be, excess demand by band for fixed link and PES respectively. Sections 3 and 4 discuss recent trends in demand for spectrum, the future demand outlook and changes in spectrum supply for fixed links and PES/TES respectively.
- Step 3 is concerned with estimating the opportunity cost of spectrum for the relevant frequency bands. This is addressed in Section 5, using auction data and the least cost alternative approach, taking account of both the current (or own use) and alternative uses of the band.
- Step 4 involves deriving fees according to an appropriate algorithm. Sections 6 and 7 review the current algorithms for fixed links and PES/TES respectively and suggest changes to these algorithms so that they generate fees that more closely reflect the opportunity cost of spectrum use.

In Section 8 we estimate the AIP fees implied by the proposals given in previous sections of the report and compare these with current fees.

Current and potential alternative use of bands

The bands currently assigned to fixed links and PES/TES range from 1 to 86 GHz and in many cases fixed links and PES/TES share the bands (see Table 2-1 and Table 2-2 in Section 2). We have assessed potential alternative uses of these bands looking ahead 5-7 years, taking account of

[1] And some additional bands that have been made available through block assignments and assigned by auction e.g. renewal of some 28 GHz licences.

[2] See Spectrum Pricing, Statement, Ofcom, February 2005 and Modifications to spectrum pricing, Statement, Ofcom, January 2007.

[3] Ofcom. December 2010. SRSP: "The revised Framework for Spectrum Pricing." http://stakeholders.ofcom.org.uk/binaries/consultations/srsp/statement/srsp-statement.pdf

international and European spectrum harmonisation activities. We find that only the 3.6-3.8 GHz band is likely to have an alternative use (which is mobile broadband) on a 5-7 year timeframe. It is possible, that the 1.4 GHz and 3.8-4.2 GHz bands might also be harmonised for mobile use but this is highly uncertain and on a longer timescale.

The 3.6-3.8 GHz band has already been harmonised for mobile use at a European level (and a band plan has been agreed) and Ofcom has designated the band for shared fixed and mobile use. When deriving the estimated opportunity cost of spectrum in this band (and so the AIP fees) it is therefore necessary to take account of the value of the spectrum to mobile as well as fixed link and satellite services.

Demand outlook

In Sections 3 and 4 we examine the spectrum demand outlook from fixed links and satellite services respectively for the bands.

In respect of fixed links spectrum demand, we find that:

- Demand from fixed links at 1.4 GHz is broadly static and is very low at 4 GHz.
- The frequency bands used by fixed links in the 6-10 GHz range are, and will continue to be, the most congested. The situation is unlikely to change in future as it is expected that demand for wider bandwidths and high availability links will not always be met by optic fibre for reasons of cost and performance differences (e.g. timeliness and flexibility of deployment).
- Demand from fixed links in the 10-20 GHz frequency range is unlikely to decline, meaning these bands will continue to be moderately congested.
- There is less likely to be excess demand from fixed links in bands above 20 GHz, because of increased spectrum supply in new high frequency bands, high levels of reuse and, in some urban areas, increased availability of optic fibre which can be a substitute for fixed links for some users.

Spectrum use by satellite earth stations has not grown appreciably in the last 3 years. The future outlook is for continued modest demand growth, except possibly at Ka band where demand for spectrum for consumer broadband services could grow substantially. However, demand at Ka band is highly uncertain and it depends in part on government policies in respect of rural broadband. There could be a future loss of available spectrum in the 3.6-3.8 GHz band if this is shared with mobile services, though this may be accommodated by increased use of 3.8-4.2 GHz band and at higher frequency ranges.

In summary, there will continue to be excess demand below 20 GHz and bands above 20 GHz will be relatively uncongested. This implies there is a case for AIP fees in bands below 20 GHz whereas the case is less clear cut above 20 GHz, in which case administrative cost based fees may be applicable.

Opportunity cost estimates

In Section 5 we derive opportunity cost estimates for bands used by fixed links and PES/TES. To do this we first derive estimates of:

- The marginal value of spectrum for a band based on the own use (i.e. fixed links) based on information from market data (i.e. auction and traded values)[4] – Section 5.2.
- The marginal value of spectrum for a band based on the own use (i.e. fixed links) using the least cost alternative approach. Estimates are derived by considering the value of spectrum in a congested band to a user seeking to deploy a new link. The user is assumed to be denied access to the congested band and in practice we find the options available include either using a higher frequency band or a wired link[5]. Neither of these two options will be a perfect substitute for the original fixed link (because of service quality differences) and so the values derived are necessarily approximate. – Section 5.3.
- The marginal value for alternative use of the band, where such use exists and the value can be estimated. In practice mobile is the alternative use in the two lower bands (1.4 GHz and 4 GHz) and the values reported are derived from auction results – Section 5.4.

Using these estimates the opportunity cost for a given band is derived as follows[6]:

- If there is a higher value alternative use, set the opportunity cost between the own use and the alternative use values, but towards the bottom end of the range
- If there is no feasible higher value alternative use, set the opportunity cost using estimates of the value in the existing use derived by market data and/or the least cost alternative approach.

Our estimates of own and alternative use values are listed in columns 2-4 of Table 1. In the fifth column of the table, we report a cap on value by band we derived from the 3.4 GHz auction adjusted for potential reuse of spectrum in different bands[7]. We have applied this cap to the LCA values on the grounds that the value of spectrum to mobile services in any band is likely to be significantly more than that for fixed services. The sixth column gives our best estimate of opportunity cost from the available data. The seventh column gives the current AIP fee for the band assuming the availability and path length factors have a value of 1.

The logic we applied to derive the opportunity cost estimates given in the sixth column of Table 1 is as follows:

- For the 3.6-3.8 GHz band the alternative use value of £1095/2x1 MHz is just above the top end of the LCA values and is a very conservative estimate of the value of the spectrum for mobile use. It could therefore be said to provide a reasonable estimate of the opportunity cost for these bands given the likelihood of future mobile use of the spectrum.
- For the other bands below 20 GHz there is no alternative use. As values at the bottom of the range for each band are several times current fees, there are good reasons to think the opportunity cost is likely to be towards the low end of the ranges given in Table 1. Otherwise Ofcom would be under considerable industry pressure to release more spectrum for fixed links which is not the case.

[4] As proposed by the SRSP, AIP Principle 7 and AIP Methodology 2.

[5] The option of more efficient technology (i.e. higher modulation) was also considered but because equipment costs do not vary by modulation i.e. the user will choose the most efficient modulation scheme available.

[6] Para 1.40-1.42, http://stakeholders.ofcom.org.uk/binaries/consultations/srsp/appendixA.pdf

[7] The cap for each band is calculated as the 1.4 GHz/3.4 GHz value divided by the band reuse values.

- For bands above 20 GHz, the current AIP fees are a factor of 10-100 more than the auction values. Whilst there are good reasons to believe the auction values are likely to be an underestimate of current market values, the opportunity cost of the spectrum seems likely to be well below current AIP fee levels.

Table 1: Estimated values per link, opportunity cost and current fees (£/2x1 MHz)

Band	Own use – Auction value (Note1)	Own use – Least cost alternative (Note 2)	Alternative use – auction value (Note 3)	Capped value derived from 4 GHz auction value (Note 4)	Implied opportunity cost estimates	Current AIP fee (Note 5)
1.4 GHz	-	124-619	n.a.	1095	124	88
3.6-3.8 GHz	-	124 – 619	1095	1095	1095	88
3.8-4.2 GHz	-	124-619	n.a.	1095	124	88
6 & 7.5 GHz	-	124 – 619	n.a.	365	124	65
10 GHz,	1.8	22-221	n.a.	365	42	38
13 & 15 GHz	-	22-221	n.a.	137	42	38
18 GHz	-	22-221	n.a.	137	29	26
23, 25, 28, GHz	0.3-3	n.a.	n.a.	91	~3	23-26
32 GHz	0.16	n.a.	n.a.	55	~3	23
38 GHz	0.02	n.a.	n.a.	55	~3	23
40 GHz and above	0.02	n.a.	n.a.	55	~3	15

Source: Plum and Aegis analysis

Note 1: Values come from Table 5-3 and Table 5-4.
Note 2: Values come from Table 5-8
Note 3: Values come from Table 5-10
Note 4: Values given in Table 5-11
Note 5: The fee is calculated assuming the availability and path length factors each have a value of 1.

Fixed link algorithm

Since 2006 fixed link fees for bi-directional links have been set based on the following algorithm:

$$\text{AIP Fee} = \text{Reference fee} \times \text{Bandwidth factor} \times \text{Frequency band factor} \times \text{Path length factor} \times \text{Availability factor}$$

Uni-directional links pay 75% of the calculated fee. In the case of an additional link operating co-channel and cross-polar over the same path as an existing assigned link the user pays 50% of the fee.

In addition Ofcom has set interim fees for five years (or less if the wider review of fixed link fees proposes lower values) for the managed parts of 71 GHz and 81 GHz bands.[8] .

Our proposals in respect of the fixed link algorithm are that:

$$\text{AIP fee} = \text{Reference fee} \times \text{Bandwidth factor x Frequency band factor x Availability factor x Location factor}$$

where:

- The 13 GHz band should be used as the reference band as the band is used by both fixed links and satellite services and this should also be used as the reference band for the satellite algorithm
- The reference fee for the 13 GHz band should be based on our best estimate of opportunity cost i.e. £42/2x1 MHz. This fee should be applied to all bands together except the 3.6-3.8 GHz band. For this band we propose a reference fee of £365/2x1 MHz (which equals the opportunity cost for the band of £1095/2x1 MHz divided by the band factor of 3) and reflects the potential for use of the band by mobile services.
- We propose a band factor as shown in the table below. This is intermediate between the current band factor and an inverse frequency relationship

Table 2: Proposed band factors

Frequency band range	Proposed Band Factor
1.35 ≤ fb < 3.60	4.0
3.60 ≤ fb < 3.80	3.0
3.80 ≤ fb < 5	3.0
5 ≤ fb < 10	1.8
10 ≤ fb < 16	1.0
16 ≤ fb < 20	0.7
20 ≤ fb < 24	0.4
24 ≤ fb < 40	0.3
40 ≤ fb < 57.0	0.2
57.0 ≤ fb < 100.0	0.1

Source: Plum and Aegis analysis

- The bandwidth and availability factors should be retained in their current form
- The path length factor has been removed as this is a choice for the user and the band factor already provides an incentive to use higher frequency bands for short links.

[8] These fees range from £100 for a 250MHz channel bandwidth to £900 for a 1 GHz channel bandwidth. Spectrum management in the 71-76 GHz and 81-86 GHz bands. Ofcom Statement, December 2013

- A location factor included in the algorithm would be set equal to one except in areas of low spectrum use where a lower value would be set as follows:
  - In bands where mobile is an alternative use (i.e. 3.6-3.8 GHz) lower fees (i.e. discounts) should apply in areas of low population density as defined for the purposes of setting Business Radio fees
  - In bands where there is no alternative use lower fees (i.e. discounts) should apply in bands where there are relatively few fixed link assignments in and crossing an area (i.e. grid square). If it is not practical to assess this measure, then the number of assignments could be used.
  - As a minimum, fees in low demand areas should be set at cost-recovery levels.

At present, uni-directional links currently pay 75% of the calculated fee for a bi-directional link and for an additional link operating co-channel and cross-polar over the same path as an existing assigned link the user pays 50% of the fee. We consider these approaches should be continued.

Satellite algorithm

The algorithm that currently applies to Permanent Earth Stations (PES) is:

$$\text{AIP Fee} = \sum_{bands} \left[\beta \times BF_{band} \times \sqrt{\sum_{paths_{band}} (P_{path} \times BW_{path})} \right]$$

where:

β	=	the reference fee and has a value of 28
P_{path}	=	peak power delivered into the antenna for each transmission path (W)
BW_{path}	=	transmit authorised bandwidth for each transmission path (MHz)
BF_{band}	=	band factor ranging from 2.33 (for frequencies less than 5 GHz) to 0.60 (for frequencies greater than and equal to 24 GHz). The 14 GHz band is defined as the reference band and has a band factor of 1.
Band	=	five defined band ranges with boundaries at 5, 10, 16 and 24 GHz
Path	=	between a transmit earth station and a satellite receiver being defined by frequency, polarisation, peak power and bandwidth.

We propose that in future AIP fees for PES are set based on the following algorithm:

$$\text{Fee} = \sum_{bands} \left[\text{Reference fee} \times BF_{band} x\ Location\ factor \times \sqrt{\sum_{paths_{band}} (P_{path} \times BW_{path})} \right]$$

where:

- The structure of the current PES formula should be retained, although in the longer term and depending on the more general availability of licensing data, a clearer distinction between overlapping transmissions at a site (which effectively achieve a discount) and non-overlapping transmissions could be made.

- The PES reference spectrum fee should be based on the fixed link reference fee for a unidirectional link and adjusted to reflect the difference in denial areas for a representative fixed link and a representative PES. Hence we recommend that the reference fee for PES should set at 1.4 times the reference fee for a unidirectional fixed link. This implies a reference value of £44/2x1 MHz for all bands and a value of £383/2x1 MHz for the 3.6-3.8 GHz band.
- The bandings and band factors for the fixed links and satellite algorithms should be the same (see above).
- There should be a location factor based on the location factor proposed for fixed link fees.

AIP fees for TES and RSA users can be derived from those for PES.

For TES users we propose that the fees be calculated by applying the following ratio to the current TES fees:

$$(Proposed\ reference\ fee \times proposed\ band\ factor)/(Current\ reference\ fee \times current\ band\ factor)$$

For RSA, we propose multiplying the PES band factor by the PES reference fee for the receive band and then multiplying this by the ratio of the transmit denial area to the receive denial area for the reference band, i.e. 0.5.

Implications for AIP fees

The impact of our proposals for AIP fee levels for examples of fixed links and PES are given in Section 8. Fees rise in congested bands and fall in bands not considered congested. The fees for bands above 57 GHz rise, because at present these are set at a very low level on an interim basis. We have recommended that in areas with low density of fixed link use (defined in Section 6) or in the case of the 3.6-3.8 GHz band in areas where population density is low much lower, fees should be applied so that they are closer to cost reflective fee levels.

1 Introduction

1.1 Scope of the study

Ofcom commissioned this report from Plum and Aegis to support its review of administered incentive pricing (AIP) fees for all services in the frequency bands licensed for fixed links and permanent earth stations (PES) and transportable earth stations (TES)[9]. The objective of the study is to advise on a pricing structure that will incentivise economically efficient use of radio spectrum. The results will inform an Ofcom consultation on the introduction of new fees under the Wireless Telegraphy (WT) Act from 2016.

The spectrum covered in this study comprises a range of bands between 1.4 GHz and 86 GHz which can be used by fixed wireless point-to-point links and PES/TES, although some of these bands are also used by other applications.

The study involved two phases. The first phase assessed demand for bands used by fixed services and the opportunity cost of the bands. Estimation of opportunity costs is based on market values (e.g. auction prices) and the least cost alternative approach.

The second phase reviewed existing AIP algorithms and factors for fixed links and PES in order to ensure that they generate incentives for licensees to use spectrum efficiently. This involved assessing whether to include additional factors (e.g. geographical) taking account of changes since the last Ofcom fees review[10] and the practicality of implementing these changes.

The terms of reference for the study required us to take account of:

- ensuring consistency with the core pricing principles and methodologies in Ofcom's SRSP framework for spectrum pricing
- existing and potential alternative uses of and demand for bands when estimating opportunity cost
- previous approaches by Ofcom in determining opportunity cost (Smith Nera 1996, Indepen 2004[11], Ofcom spectrum pricing statement of 2005)
- substitutability for fixed link use between bands which have been auctioned and bands administered by Ofcom
- the need for the recommended fee structure to be supportable by Ofcom's information systems and to be drafted for inclusion in the WT Act Fee Regulations.

[9] And some additional bands that have been made available through block assignments and assigned by auction e.g. renewal of some 28 GHz licences.

[10] See Spectrum Pricing, Statement, Ofcom, February 2005 and Modifications to spectrum pricing, Statement, Ofcom, January 2007.

[11] See http://www.ofcom.org.uk/static/archive/ra/topics/spectrum-price/documents/smith/smith1.htm and http://stakeholders.ofcom.org.uk/binaries/research/spectrum-research/spectrum_pricing.pdf

1.2 Context

Since 1998 spectrum fees have been set above cost recovery levels in numerous frequency bands so as to promote efficient spectrum use. Such fees are referred to as "administered incentive pricing" (AIP). The aim of AIP is for fees to reflect the opportunity cost of spectrum use. In general AIP applies to spectrum access in bands that do, or might in future, experience excess demand and where spectrum access is licensed by Ofcom or authorised under recognised spectrum access (RSA)[12].

AIP fees for bands used by fixed links and PES/TES were last determined by Ofcom in 2005 and 2007 respectively[13]. This study builds on the analysis undertaken at that time and examines recent and likely future technology and market changes that may affect demand for spectrum in bands used by fixed links and PES/TES.

We apply the framework for determining AIP fees set out in 2010 in Ofcom's Statement for the Strategic Review of Spectrum Pricing (SRSP).[14] The SRSP principles and methodologies that are particularly relevant to this study are reproduced below.

Principles

- **"AIP principle 2** – **when AIP should be applied:** AIP should apply to spectrum that is expected to be in excess demand from existing and/or feasible alternative uses, in future, if cost-based fees were applied. In determining feasible alternative uses, we will consider over the relevant timeframe, any national or international regulatory constraints, the existence of equipment standards, and the availability and cost of equipment as well as other factors that may be appropriate.
- **AIP principle 3 – the 'relevant timeframe' to assess future demand of spectrum:** In general we need to determine the time period over which we will seek to assess excess demand, congestion and feasible alternative use. We will do so over a timeframe that reflects the typical economic lifetime of existing users' radio equipment.
- **AIP principle 7 – use of market valuations:** We will take account of observed market valuations from auctions and trading alongside other evidence where available when setting reference rates and AIP fee levels. However, such market valuations will be interpreted with care and not applied mechanically to set reference rates and AIP fees.
- **AIP principle 8 – setting AIP fees to take account of uncertainty:** Where there is uncertainty in our estimate of opportunity cost, for example arising from uncertainty in the likelihood of demand for feasible alternative uses appearing, we will consider the risks from setting fees too high, or too low, in light of the specific circumstances. When spectrum is tradable we will consider the extent to which trading is expected to promote optimal use, and will also have particular regard to the risk of undermining the development of secondary markets.

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[12] For receive only installations wanting protection from interference e.g. receive only earth stations in the 1.7GHz, 3.6-4.2GHz and 7.7-7.8GHz ranges. http://stakeholders.ofcom.org.uk/consultations/rsa-earth-stations/rsa-statement/

[13] See Spectrum Pricing, Statement, Ofcom, February 2005 and Modifications to spectrum pricing, Statement, Ofcom, January 2007.

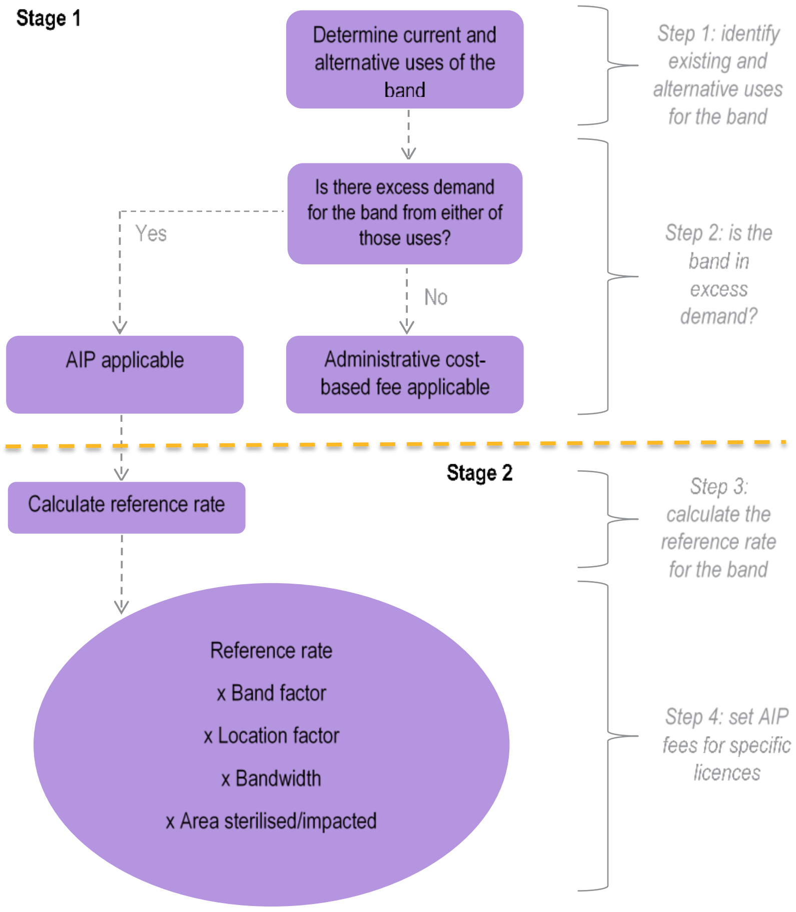
[14] Ofcom. December 2010. SRSP: "The revised Framework for Spectrum Pricing." http://stakeholders.ofcom.org.uk/binaries/consultations/srsp/statement/srsp-statement.pdf

Methodologies

- **AIP methodology 1 – AIP and congestion:** In setting AIP fees, we will assess current and future congestion in existing use and demand for feasible alternative uses in the frequency band in question and at different geographic locations over the relevant timeframe, given technological, regulatory and international constraints and using readily available evidence
- **AIP methodology 2 – reference rates:** Reference rates will be based on the estimated opportunity cost of spectrum use, considering both the current use and any feasible alternative uses. These estimates will be informed, where appropriate, by the available market information (if any), and economic studies of the value of spectrum in different uses.
- **AIP methodology 3 – calculating individual licence fees:** In converting reference rates to fees, we will take account of the opportunity cost and the amount of spectrum denied to others. This will generally be based on frequency, geographical location, bandwidth, geographical coverage or other measure that reflects the geographical extent of coordination requirements and in some cases the exclusivity of an assignment."

The SRSP described four steps in setting AIP and we have structured this report around these steps. A chart from the SRSP summarising these steps is reproduced below in Figure 1-1.

Figure 1-1: Ofcom approach to setting AIP and cost-related fees



Source: Ofcom SRSP consultation, Appendix A

1.3 Definitions

The definitions of the key terms used in this study are provided in Table 1-1.

Table 1-1: Definitions of key terms

Term	Definition
Fixed links	Fixed Terrestrial Links or Fixed Wireless Systems (FWS) refer to terrestrial based wireless systems, operating between two or more fixed points. Fixed terrestrial links are used to provide network infrastructure and customer access applications across a wide range of frequency bands, currently ranging from 450MHz to 86GHz.
Fixed wireless access (FWA)	Fixed wireless access (FWA) systems refer to a means of making fixed connections between users' premises and telecommunication networks. These networks may deliver a range of services, including telephony, high speed data, television and multimedia services.
Permanent earth station (PES)	A Permanent Earth Station (PES) is a satellite earth station operating from a permanent, specified location to one or more satellites in geostationary orbit. A PES is typically used to provide telephony and data backhaul, broadcast feeder links, private corporate networks or satellite tele-command and control.
Transportable earth station (TES)	A Transportable Earth Station (TES) is a satellite earth station operating from a fixed but moveable location to a satellite. TES operations are commonly associated with the broadcasting industry, where they are used to provide outside broadcast links either back to a studio or directly to a broadcasting satellite. Installations range from small fly-away terminals to large vehicles.
Least cost alternative (LCA)	The least cost alternative method is an approach to estimating the opportunity cost of spectrum. It involves estimating the value of spectrum to an average user based on the least cost alternative technology or service to enable the same output to be produced if a user is deprived of a small amount of spectrum. For example, for fixed links this could be achieved via an alternative technology such as fibre or moving to a less congested spectrum band.
Recognised spectrum access (RSA)	Recognised spectrum access (RSA) is a method of recognising the use of radio spectrum by an operator which is not covered by a Wireless Telegraphy Act Licence or a Licence Exemption. It is a spectrum management instrument in which the holder of the grant of spectrum access is provided with the opportunity to identify frequency bands and geographic areas within which Ofcom will endeavour to ensure that agreed levels of interference are not exceeded. RSA provides receive-only earth stations, which are usually exempt from licensing, a means of avoiding harmful interference. Currently RSA is granted to receive only earth stations (ROES) in 1690-1710 MHz, 3600-4200 MHz, and 7750-7850 MHz and radio astronomy sites.
Administered incentive pricing (AIP) fees	Fees charged to spectrum licensees (and holders of recognised spectrum access) that are set by Ofcom and are intended to reflect the opportunity cost of spectrum use.
Cost based fees	Fees charged to spectrum licensees that are set by Ofcom and are intended to reflect spectrum management and administrative costs. These fees apply in cases where spectrum is not scarce or subject to excess demand and therefore the use of AIP is not appropriate.
Opportunity cost	The opportunity cost of spectrum is the value of the best alternative forgone i.e. it is the value of spectrum to the highest value alternative use.

1.4 Report structure

This draft final report addresses the two phases of the study and is structured to follow the four steps for setting AIP fees as shown in Figure 1-1 above.

Section 2 addresses Step 1. It examines the current and potential future alternative uses of the frequency bands for fixed links and PES/TES so as to determine potential sources of demand by band.

Sections 3 and 4 address Step 2. They consider whether there is, or is likely to be, excess demand for the frequency bands used by fixed links and PES respectively. Each section discusses recent trends in demand for spectrum, the future demand outlook and changes in spectrum supply.

Section 5 addresses Step 3. It provides estimates of the opportunity cost of spectrum for the relevant frequency bands, using auction data and the least cost alternative approach.

Sections 6 and 7 address Step 4. They review the current algorithms for fixed links and PES and TES respectively and recommend changes to the current fees algorithms.

Section 8 summarises the AIP fees implied by the estimates of opportunity cost and the proposed changes to the fees algorithms.

2 Current and alternative use of bands

2.1 Bands under consideration

Table 2-1 and Table 2-2 list the satellite and fixed link bands in the UK that are the subject of this study. The two tables also indicate the bands which are shared between satellite and fixed services on a co-ordinated basis. In these bands AIP is currently applied to licensed fixed links and to satellite earth stations that are licensed or have recognised spectrum access (RSA).

Table 2-1: Bands used by satellite earth stations

Band	Frequency (GHz)		Use	Bandwidth (MHz)	Shared with
	Bottom	Top			
1.7 GHz receive	1.69	1.71	MetSat RSA	20	
4 GHz receive	3.6	4.2	C-band	600	Fixed links 3.6 - 4.2
5 GHz transmit	5.15	5.25	MSS NGSO feeder	100	
6 GHz transmit	5.725	7.075	C-band	1350	Fixed links 5.925 - 7.125
7.8 GHz receive	7.75	7.85	MetSat RSA	100	Fixed links 7.425 - 7.900
11 GHz receive	10.7	12.75	Ku-band	2050	
13 GHz transmit	12.75	13.25	Ku-band	500	Fixed links 12.75 - 13.25
14 GHz transmit	13.75	14.5	Ku-band	750	
17/18 GHz transmit	17.3	18.4	BSS feeder	1100	Fixed links 17.7 - 19.7
18 GHz receive	17.7	19.7	Ka-band	2000	Fixed links 17.7 - 19.7
20 GHz receive	19.7	20.2	Ka-band (exclusive)	500	
28 GHz transmit	27.5	29.5	Ka-band (exclusive segments)	728	
30 GHz transmit	29.5	30	Ka-band (exclusive)	500	

Note: Military satellite bands excluded

Table 2-2: Ofcom managed bands used for terrestrial fixed services

Band	Frequency (GHz)		Bandwidth (MHz)	Shared with
	Bottom	Top		
1.4 GHz	1.35	1.517	49	
4 GHz	3.6	4.2	550	C-band satellite receive
6 GHz	5.925	7.125	1154	C-band satellite transmit
7.5 GHz	7.425	7.9	454	
13 GHz	12.75	13.25	448	Ku-band satellite transmit
15 GHz	14.5	15.35	224	
18 GHz (variable centre gap)	17.7	19.7	2000	Ka-band satellite receive
23 GHz	22	23.6	1200	
26 GHz	24.5	26.5	1886	
31 GHz	31	31.8	600	
38 GHz	37	39.5	2356	
52 GHz	51.4	52.6	1080	
55 GHz	55.78	57	1108	
70 GHz	71.125	73.125	2000	
80 GHz	81.125	83.125	2000	

Notes: Light licensed, licence exempt and auctioned bands are excluded. The amount of spectrum is indicative as in some bands the size of the paired sub-bands are not equal and the guard bands at the band edges are included in some cases.

Table 2-3 lists a number of bands that have been auctioned by Ofcom and that are likely to be used by terrestrial fixed services. While these bands have been licensed on a technology and application neutral basis the main uses of the bands so far have been for fixed link and fixed wireless access (FWA) services. Auction prices for these bands may be relevant to setting AIP in other bands used by fixed services.

Table 2-3: Auctioned bands that could be used for terrestrial fixed services

Band	Frequency (GHz)		Bandwidth (MHz)
	Bottom	Top	
4 GHz	3.48	3.6	40
10GHz	10.125	10.575	200
28GHz	27.8	29.5	1232
32GHz	31.8	33.8	1570

Band	Frequency (GHz)		Bandwidth
40GHz	40.5	43.5	3000

2.2 Potential alternative uses

The purpose of identifying potential alternative future uses of the bands listed in Table 2-1 and Table 2-2 is to inform the analysis of whether there is likely to be excess demand in the bands and to determine the services likely to create that excess demand. To assess whether there is likely to be demand from alternative uses requires an assessment of whether[15]:

- the bands used by the alternative uses are broadly substitutable with the band we are assessing and are likely to be congested
- the band under examination could be used to mitigate congestion in those other bands via AIP.

The starting point is to define a timeframe for the analysis of possible alternative uses. Ofcom's SRSP Principle 3 defines the relevant timeframe to assess future demand as "the typical economic lifetime of existing users' radio equipment"[16]. In the case of terrestrial fixed services, recent rapid changes in technology mean that the economic lifetime (and capital cost) of such equipment has, in general, become shorter. Whereas previously the lifetime of such equipment might have been expected to be of the order of 15 years, newer equipment fulfils a range of expectations; inexpensive equipment made out of materials that would likely be replaced after no more than a few years through to equipment engineered as previously and therefore expected to last 15 years. Our view is that on average an equipment lifetime of 7 years is reasonable. In the case of satellite fixed services typical economic lifetimes for equipment are still likely to be around 15 years.

However, beyond 5-7 years the technology, market and regulatory outlook for radio-based services is highly uncertain. Hence we have limited our analysis to alternative uses that might be deployed in the next 5-7 years, taking into account harmonisation activities at European and international levels[17] and Ofcom's spectrum and mobile data strategies (which cover a 10 year timeframe).

One issue we have considered is whether to take account of recent initiatives aimed at finding bands above 6 GHz for 5G mobile services. There have been proposals to CEPT from equipment vendors and Ofcom for a future agenda item at WRC-19 on mobile broadband applications in frequency bands above 6 GHz.[18] The proposal from equipment vendors called for the identification of contiguous spectrum with bandwidths of 500MHz to 1 GHz in the 20 GHz to 50 GHz range to be allocated on a co-primary basis to mobile services. This could include bands currently used by fixed services. 5G concepts and technology are at a very early stage of development and the possible frequency bands for 5G services are highly uncertain. Therefore we do not consider them further in this study.

[15] Para 1.33, Appendix A, Our current practice in setting AIP fees, An appendix to SRSP: The revised Framework for Spectrum pricing, Consultation, March 2010 http://stakeholders.ofcom.org.uk/binaries/consultations/srsp/appendixA.pdf

[16] This is the lifetime over which the asset is useful to the owner. It may differ from the physical lifetime of the asset and the lifetime over which the asset is written off in the accounts. For example, computer equipment may be replaced more quickly than the physical or accounting lifetime when users upgrade their equipment to take advantage of technology innovations.

[17] This includes activities at EU and CEPT level that are focussed on WRC-15 Agenda item 1.1.

[18] http://www.cept.org/Documents/ecc-pt1/15042/ECC-PT1(14)017_Proposal-for-WRC-18-IMT-Agenda-Item ; http://www.cept.org/Documents/ecc-pt1/15174/ECC-PT1(14)022_Future-WRC-Agenda-item-%E2%80%93-IMT-above-6-GHz

2.2.1 Ofcom's spectrum and mobile data strategies

Ofcom's Spectrum Strategy (2014) provides an analysis of spectrum demand for all services[19]. Ofcom identified a number of priorities namely: demand for additional spectrum for mobile and wireless data services, implementing the 700MHz strategy, spectrum for programme making and special events (PMSE), emergency services broadband communications and machine to machine applications and supporting the public sector spectrum release programme[20]. In addition, opportunities for spectrum sharing and improving radio receiver performance will be facilitated by Ofcom.

Ofcom's Mobile Data Strategy (2014)[21] gives the following prioritisation of bands for mobile services:

- Current priority bands: 700 MHz, 2.3, 3.4 GHz, UHF white space (shared)
- High priority bands: 1452-1492 MHz; 1980-2010 / 2170-2200 MHz (2 GHz MSS); 3.6-3.8 GHz (shared); 5350-5470 MHz, 5725-5925 MHz (shared)
- Medium-High priority bands: 1427-1452 MHz (shared); 3.8-4.2 GHz (shared)
- Medium priority bands: 470-694 MHz (very long term); 1492-1518 MHz; 2.7-2.9 GHz; 5925-6425 MHz (shared).

In addition, the Mobile Data Strategy indicates for illustrative purposes that the 3.6-3.8 GHz band could be available for mobile data in 2022 and that the 1492-1518 MHz and 3.8-4.2 GHz bands could be available for mobile data in 2028[22].

In respect of PMSE, Ofcom is consulting on a proposal to allocate 7110-7250/7300-7425MHz (i.e. just below the 7.5 GHz fixed band) to PMSE[23] to mitigate the loss of spectrum at 3.4 GHz. Hence PMSE will not be competing with fixed services for use of the 7.5 GHz band and so is not considered further as an alternative use.

In respect of emergency services, the future spectrum requirements to support broadband communications are uncertain. The Home Office is currently tendering for a new emergency services network provider to meet emergency services' mobile broadband requirements. At the time of writing no specific frequencies had been assigned for this application and it is possible that services will be provided using spectrum that is already assigned to network operators[24].

The sub-sections below discuss the situation in those bands that may be used in future by mobile services and that are currently designated for fixed use, i.e. 1350-1518MHz, 3.6-3.8GHz and 3.8-4.2 GHz.

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[19] http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-management-strategy/annexes/appendix_spectrum_management.pdf

[20] http://stakeholders.ofcom.org.uk/binaries/consultations/uhf-strategy/statement/UHF_statement.pdf

[21] Table 1, http://stakeholders.ofcom.org.uk/binaries/consultations/mobile-data-strategy/statement/statement.pdf

[22] Table 2, http://stakeholders.ofcom.org.uk/binaries/consultations/mobile-data-strategy/statement/statement.pdf

[23] http://stakeholders.ofcom.org.uk/binaries/consultations/pssr-2014/summary/pssr.pdf

[24] http://www.computerweekly.com/news/2240219431/Home-Office-tenders-for-new-Emergency-Services-Network-ESN-provider; http://www.bapcojournal.com/news/fullstory.php/aid/2507/Emergency_Services_Network__96_Home_Office_places_tender,_deadline_16th_of_May_2014.html

2.2.2 1.4 GHz band (1350-1375/1492-1518MHz)

The future status of the 1.4 GHz fixed link band depends on decisions made at European level concerning future bands for mobile broadband and the outcome of WRC-15. The 1350-1518 MHz band (1.5 GHz band), which includes the 1.4 GHz fixed link band, is among the candidate bands identified in the Radio Spectrum Policy Group (RSPG) Opinion in June 2013[25] as part of the Radio Spectrum Policy Programme (RSPP) target to make available 1200 MHz of spectrum for wireless broadband. Part of the 1.5 GHz band (i.e. 1452-1492 MHz and 1427-1452 MHz) is supported by CEPT as a future band for mobile services and 1452-1492 MHz has been harmonised at European level[26]. 1350-1400MHz and 1492-1518 MHz are subject to further consideration taking into account sharing and compatibility studies[27]. In the UK Ofcom has designated the 1492-1518 MHz band as medium priority for mobile data services and may be available from 2028. It is therefore possible that some or all of the 1.4 GHz fixed link band could be designated for mobile use in future, although the situation is uncertain and is unlikely to be resolved until after WRC-15.

An indication of the value of the 1.4 GHz fixed link spectrum for mobile services could be given by auction values for the 1452-1492 MHz band. This band has already been auctioned in the UK, albeit well before the band was harmonised for mobile services in Europe, and the band is likely to be auctioned in some European countries the next 2-3 years[28] .

2.2.3 4 GHz band

The 3.4-3.8 GHz band is harmonised for mobile broadband in Europe[29] and 150 MHz in the 3.4-3.6 GHz range is expected to be auctioned by Ofcom in 2015/16[30]. There is expected to be excess demand for the spectrum (which is why it is being auctioned) and hence also potentially excess demand for the upper part of the band i.e. 3.6-3.8 GHz. The 3.6-3.8 GHz band could be available for mobile services in the early 2020s. The auction price for the 3.4-3.6 GHz band could provide the basis for an estimate of the opportunity cost of spectrum for mobile use at 3.6-3.8 GHz.

The upper part of the 4 GHz band - 3.8 to 4.2 GHz - has not been harmonised for use by mobile broadband though this may be a long term possibility. The band has been mentioned in the EU's Radio Spectrum Policy Programme (RSPP) and has been identified by Ofcom as a medium-high priority for mobile services on a shared basis. While part of the band (3925-4009 MHz) is licensed to a broadband operator in the UK, the lack of a European harmonisation measure means there is no mass market consumer equipment to use the band for mobile broadband. The recent report from the European Commission on the radio spectrum inventory suggests that studies should be undertaken

[25] https://circabc.europa.eu/d/a/workspace/SpacesStore/c7597ba6-f00b-44e8-b54d-f6f5d069b097/RSPG13-521_RSPG%20Opinion_on_WBB.pdf

[26] http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCDEC1303.PDF

[27] http://www.cept.org/Documents/cpg/17378/CPG15(14)017-Annex-IV-01_-AI-11-Revised-Draft-CEPT-Brief

[28] For example, in Germany there are proposals to auction the band. http://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/BNetzA/Areas/Telecommunications/TelecomRegulation/FrequencyManagement/ElectronicCommunicationsServices/DemandIdentificationProceedings/DraftDocumentForConsultation_Extract.pdf?__blob=publicationFile&v=2

[29] Harmonised frequency arrangements for MFCN operating in the bands, 3400-3600MHz/3600-3800MHz, ECC/DEC/11(06)

[30] http://stakeholders.ofcom.org.uk/binaries/consultations/pssr-2014/summary/pssr.pdf

that could lead to a harmonisation measure for satellite broadband/VSATs in the 3.8-4.2 GHz band. This suggests the band is unlikely to be harmonised for mobile services in the near/medium term.

2.3 Conclusions

Table 2-4 summarises the current and potential alternative uses of bands currently assigned to fixed links and PES/TES. The 3.6-3.8 GHz band is most likely to be used for mobile services, and it is possible though by no means certain that the 1.4 GHz band will also be used for this application in the longer term. This outcome is least likely for the 3.8-4.2 GHz band. For the purposes of setting AIP we propose to assume that mobile broadband is not a likely alternative use of the 1.4 GHz and 3.8-4.2 GHz fixed link/satellite bands in the next 5-7 years.

The 3.6-3.8 GHz band has already been harmonised for mobile use at European level (and a band plan has been agreed) and Ofcom has designated the band for shared fixed and mobile use. The estimated opportunity cost of spectrum in this band (and so the AIP fees) therefore needs to take account of the value of the spectrum to mobile as well as fixed link and satellite services.

Table 2-4: Frequency bands used by fixed services and potential alternative uses over the next 5-7 years

Band	Current uses	Potential alternative uses	Comment
1.4 GHz (1350-1375/1492-1517)	Fixed links	May be mobile broadband in part of the band but highly uncertain.	Alternative use to be decided after WRC-15.
1.7 GHz (1690-1710MHz)	PES (RSA), fixed links	None	PES for meteorological services under RSA
3.6-4.2 GHz	Fixed links, PES and RSA	Mobile broadband in 3.6-3.8 GHz May be mobile broadband in other parts of the band but highly uncertain.	EC Decision harmonises use of 3.4-3.8GHz for WBB; RSA for PES in part of the band
6GHz – lower	Fixed links, PES	None	
6GHz – upper	Fixed links, PES	None	
7.5 GHz	Fixed links, PES, RSA	None	Possible future use by wireless cameras below the band
10GHz	Fixed links, broadband wireless access (BWA)	None	Auction set price
11/12/13/14 GHz	Fixed links, PES	None	
15 GHz	Fixed links	None	Satellite seeking additional spectrum in the band under Agenda item 1.6
18GHz	Fixed links, PES	None	Satellite seeking to improve sharing with fixed links
23 GHz	Fixed links	None	
26GHz	Fixed links	None	Future RSA
28GHz	Fixed, BWA, PES	None	Part of band auctioned Satellite seeking to share allocation used by fixed links
31 GHz	CCTV – point to point and point to multi-point	None	
32 GHz, 40 GHz	Fixed, BWA	None	Auction set price
38 GHz	Fixed links	None	
52 GHz and above up to 86GHz	Fixed links	None	

3 Demand assessment – fixed links

3.1 Introduction

Fixed point-to-point links support the delivery of a wide range of downstream consumer and business services including:

- Mobile network backhauling
- Fixed wireless access (FWA) backhauling
- Broadcasting studio-to-transmitter (STL) links for radio and TV services
- Services for the utilities i.e. connecting scanning telemetry or PMR base stations to communications networks, for interconnection of control centres and (in the future) supporting smart grids rollouts.
- Public safety backhaul links for Airwave network, and bespoke links for broadband communication by emergency services
- Use by local government authorities such as wireless CCTV cameras, broadband links to schools and other local authority premises, backhaul provision for hotspots (e.g. business parks).

The most recently available breakdown of user type by frequency band for fixed links is shown in Table 3-1. Demand from mobile operators dominates usage above 20 GHz, while in the 10-20GHz range, fixed[31] and mobile operators and the oil and gas industry are large users. Below 10GHz the situation varies by band with variously broadcasters, fixed operators and utilities and public safety being significant users.

Ofcom has estimated that the majority of fixed links in the UK are used to provide backhaul for mobile networks and are licensed to MNOs and fixed network operators[32]. Over 90% of all licensed links are held by eight companies. The remaining 10% of individual fixed link licences are spread across more than 300 other licensees, the majority of whom hold only a few licences each.

The variety of user types means there can be different drivers of demand for spectrum for fixed links. For example, while fixed links are used by most user groups in locations where there is no wired alternative (e.g. remote rural locations), they may be used in locations where there is a wired alternative (e.g. urban locations) because they can be deployed more flexibly than wired alternatives (e.g. moved as demand patterns change) and to provide resilience in addition to wired backhaul (e.g. by public safety organisations). Technology choices by major users can also have a significant impact on demand in a particular band i.e. demand can be lumpy. These factors mean a granular approach is necessary to assessing future demand.

Demand for spectrum by fixed links tends to be location specific and excess demand in most bands does not occur in all locations in the UK. We first consider demand in aggregate and then consider demand in specific locations.

[31] It should be noted that some of the use by fixed network providers is for the supply of backhaul services to mobile operators.

[32] Para A10.5, Spectrum Management Strategy, A Consultation, Ofcom, 2013

Table 3-1: Distribution of assignments by type of user by band (% of links) - 2011

User	1.4 GHz	6 GHz	7.5 GHz	13 GHz	15 GHz	18 GHz	23 GHz	38 GHz
Broadcasters	8	8	35	6	2	0	4	1
Fixed networks	20	80	12	22	15	89	17	12
Local authorities	2	1	2	2	0	0	0	1
Mobile networks	1	0.5	30	54	35	9	74	85
Oil and gas	9	7	3	3	45	0	0	0
Public safety	34	0.5	5	4	1	2	2	1
Utilities	26	3	14	9	2	0	3	0
Total	100	100	100	100	100	100	100	100

Source: "Frequency Band Review for Fixed Wireless Service", Aegis, Ovum and dB Spectrum for Ofcom, 2011. Note this report does not contain data for the 26 GHz band.

3.2 Approach to assessment of excess demand

Excess demand for spectrum occurs when the demand exceeds or is likely to exceed the available supply such that new assignments cannot be made without causing interference to existing users. When this situation applies spectrum is said to be congested. An assessment of excess demand (or congestion) needs to consider changes in both spectrum demand and spectrum supply[33].

The SRSP discusses the approaches proposed in 2003 to measure congestion in bands and locations used by fixed point to point links and notes that Ofcom did not implement these proposals. Furthermore, Ofcom states that[34]:

"we currently make no attempt to measure congestion in bands or sites for the purposes of developing relative fee rates:

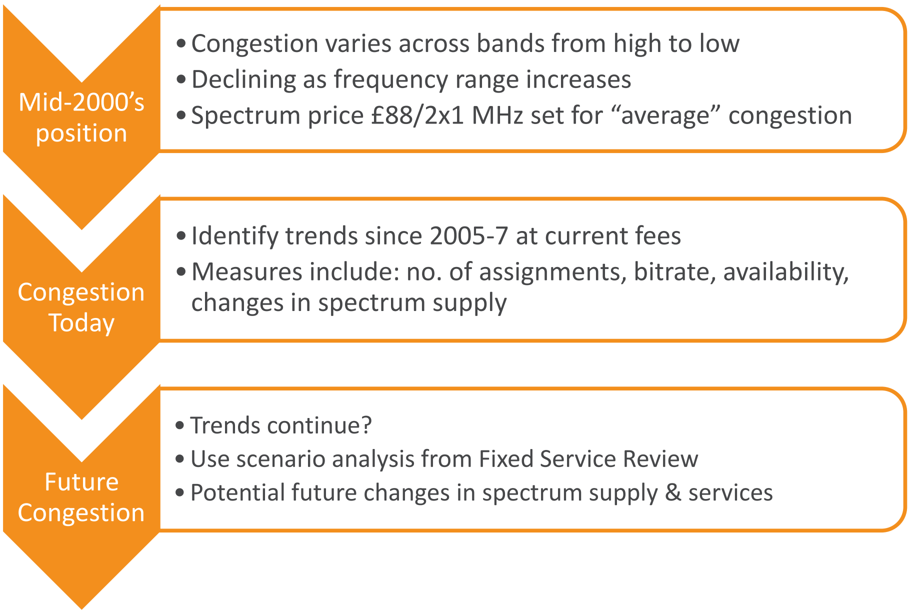
- *As regards congestion by frequency band, the fixed link algorithm includes a band factor that reduces the AIP in higher bands (from 1 at 1.35 GHz to 0.17 at 57 GHz);*
- *As regards geographical congestion, the algorithm does not contain a location factor to reflect variations in congestion."*

A summary of the approach we have used to assessing excess demand (i.e. congestion) is given in Figure 3-1. We start by considering the situation in the mid-2000s, as this is when AIP fees in bands used by fixed finks and satellite services was last assessed by Ofcom, and consider trends in numbers of licences and their characteristics since the mid-2000s.

[33] Section 3 of the SRSP discusses in qualitative terms how both supply and demand factors affect spectrum value. Ofcom. December 2010. SRSP: "The revised Framework for Spectrum Pricing." http://stakeholders.ofcom.org.uk/binaries/consultations/srsp/statement/srsp-statement.pdf

[34] Para 1.32, Appendix A,SRSP op. cit.

Figure 3-1: Summary of approach to assessing future excess demand in bands used by fixed links



3.2.1 Assessing levels of Demand

The demand for spectrum will depend (in part) on the level of fees charged – the higher the fees the lower the demand. Hence our assessment of demand must make an assumption about the level of fees charged. Our approach has been to assess demand and demand trends at current fee levels, on the grounds that the available data on spectrum use shows demand at current fee levels.

We first assessed demand trends since the time current fees for fixed links (and satellite earth stations) were set in 2005 (2007). Ideally we would have a long data series showing trends in the numbers of assignments and their characteristics (e.g. bandwidth, bit rate, availability, location etc.) by band over time. However, data on the use of fixed service bands is available only as a snapshot at a certain point when it is collected for specific purposes. There are two sources for past data namely:

- "Estimating the commercial trading value of spectrum", Plum and Aegis for Ofcom, 2009[35]
- "Frequency Band Review for Fixed Wireless Service", Aegis, Ovum and dB Spectrum for Ofcom, 2011 (referred to hereafter as Aegis et al. (2011)).

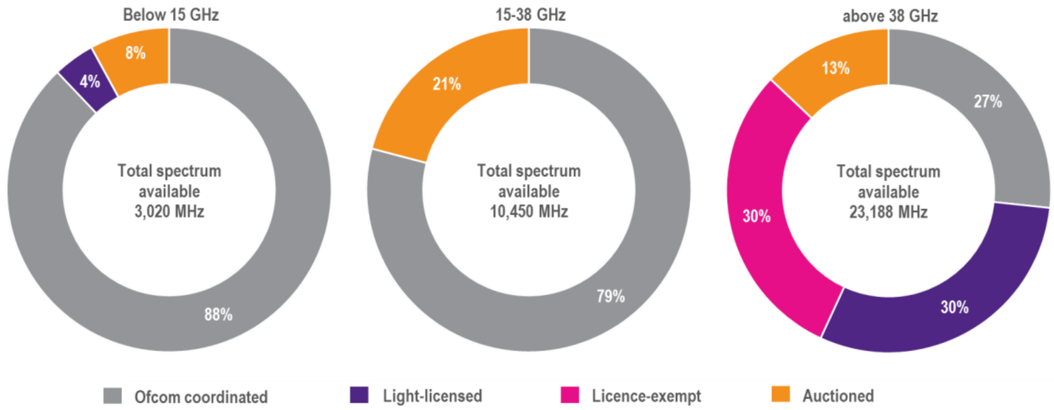
Next, we extracted data from Ofcom's licensing database in March 2014 for this study. The results are presented below in Section 3.3. In Section 3.4 we report the location of assignments in 2011 and in Section 3.5 we consider possible future demand.

[35] http://stakeholders.ofcom.org.uk/binaries/research/technology-research/specestimate.pdf

3.2.2 Effects of Supply of spectrum on observed levels of congestion

Our focus is on demand in bands managed by Ofcom, in which fixed links and PES/TES are licensed or provided protection under RSA. However, fixed links may also be deployed in light licensed, licence exempt and/or auctioned bands and these account for a considerable amount of the spectrum available to fixed link users (i.e. bands where there is equipment available) – see Figure 3-2. Although there are differences in the extent of interference protection, fees paid and degree of spectrum management, we consider whether recent changes in supply in light licensed, licence exempt and auctioned bands may have had an impact on recent demand trends in bands managed by Ofcom.

Figure 3-2: Fixed link spectrum in the UK (% of spectrum by approach)



Note: The amount of spectrum is indicative as the guard bands at the band edges are included in some cases.
Source: Plum, Aegis analysis of Ofcom data

Looking to the future we also take account of initiatives that may reduce the availability of spectrum for fixed links below 6GHz and possible additional supply of spectrum in higher frequency bands.

3.3 Recent trends

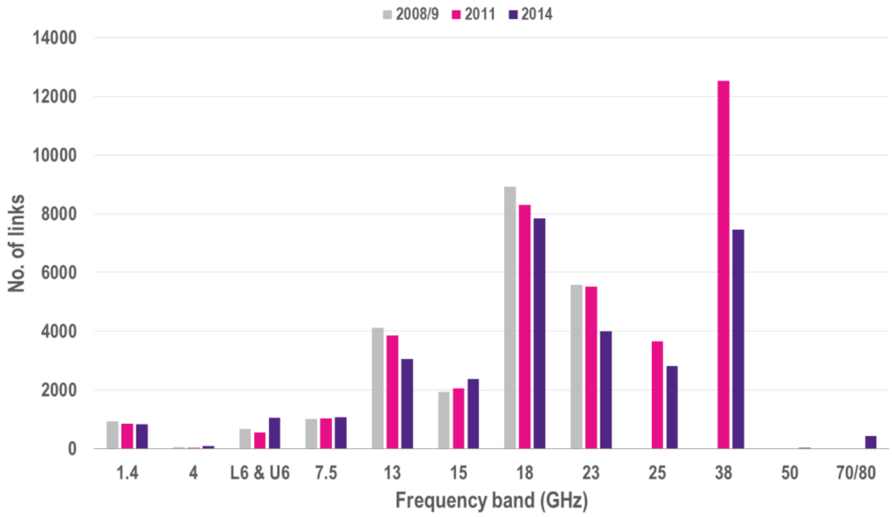
This section reports the demand trends for fixed links based on data from 2008/9, 2011 and 2014. Ideally we would have data showing trends in total bandwidth occupied by band, as a measure of spectrum demand. In the absence of such data we report a number of measures that will affect the bandwidth used (or denied to other users), namely the number of assignments, link bit rates and link availability. In addition, we report the maximum frequency reuse by band in 2014.

3.3.1 Number of assignments

Figure 3-3 reports data on the number of assignments by band in those bands managed by Ofcom. In the majority of the frequency bands the number of links licensed is decreasing, with the exception of the 6 GHz (lower and upper), 7.5 GHz and 15 GHz bands where there have been small increases.

There has been increased demand for links in the 6 GHz band, as a result of a new demand from the finance sector for long distance low latency/high availability links[36]. This has meant that it is difficult to make additional assignments in the 6 GHz band in the south of England[37].

Figure 3-3: Change in total number of assignments between 2008/9 and 2014



Source: Plum and Aegis analysis of Ofcom data

Bands above 20 GHz have experienced substantial declines in demand, particularly the 38 GHz band, where there has been almost a 50% reduction in the number of licensed links since 2011. It seems likely that this is a response to an increase in supply in other high frequency bands, given that:

- The main users of the higher frequency bands are mobile and fixed network operators (see Table 3-1)
- In 2008 Ofcom auctioned 4440 MHz of spectrum in the frequency ranges 10 GHz, 28 GHz, 32 GHz and 40 GHz. This represented a 46% increase in supply in the 10-40 GHz range.
- The current holders of the auctioned spectrum comprise mobile operators (O2, Vodafone and Telefonica), a network operator for the mobile operators (MBNL), fixed network operators (BT, MLL, Chorus, Arqiva, UK Broadband), and fixed wireless access operators (Urbanwimax, Digiweb, UK Broadband)[38].

In addition, mobile network consolidation (particularly the T-Mobile/Orange merger) could have reduced fixed link assignment demand from the mobile sector - although individual assignments may have increased in terms of bandwidth requirements, as discussed below.

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[36] These links provide higher transmission speeds than optical fibre (by approximately one third) and thus can provide timing advantages on high frequency trading. See para A10.13, Ofcom Spectrum Management Strategy, Consultation, Ofcom, 2013

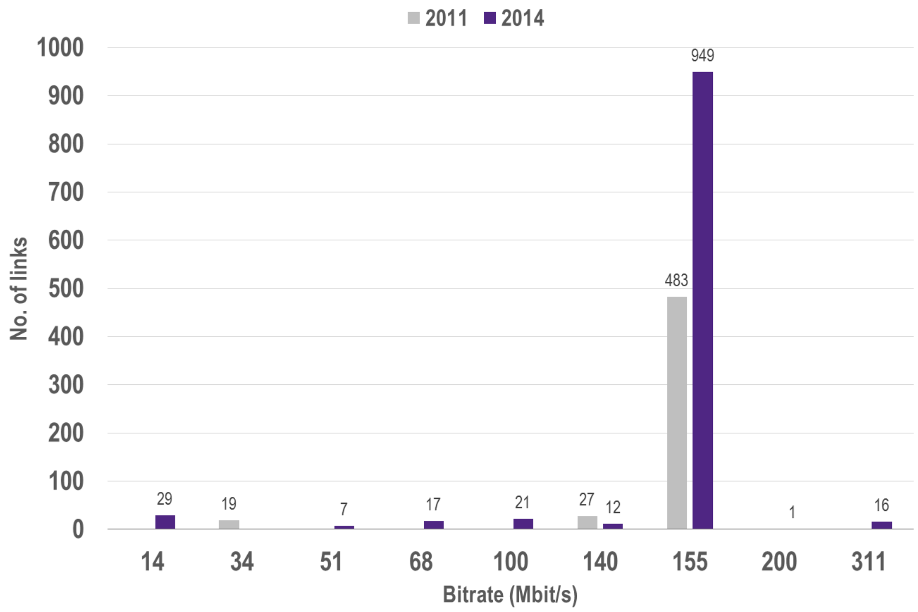
[37] The links mainly connect London across the English Channel and to Lands End and London to Staines and Slough.

[38] See http://licensing.ofcom.org.uk/radiocommunication-licences/mobile-wireless-broadband/cellular-wireless-broadband/policy-and-background/licensee-freq-tech-information/

3.3.2 Link bit rates

There has been an increase in demand for higher bit rate links (and so higher bandwidths) and as a result, Ofcom has offered wider channel spacings in bands below 15 GHz[39]. Figure 3-4, Figure 3-5 and Figure 3-6 show the bitrates for the 6 GHz, 7.5 GHz and 15 GHz bands respectively in 2011 and 2014 and indicate that increases are most noticeable at higher bitrates. In the 6 GHz band there has been roughly a doubling in the number of 155 Mb/s links, while at 15 GHz there has been a doubling of the number of 311 Mb/s links.

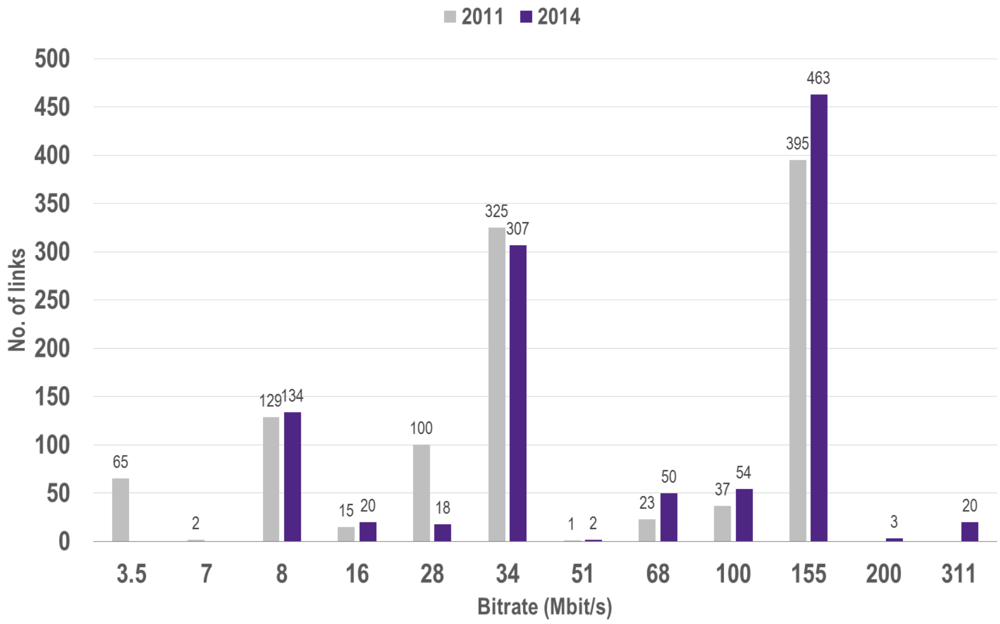
Figure 3-4: Distribution of link bit rates in the 6 GHz band – 2011 and 2014



Source: Plum and Aegis analysis of Ofcom data

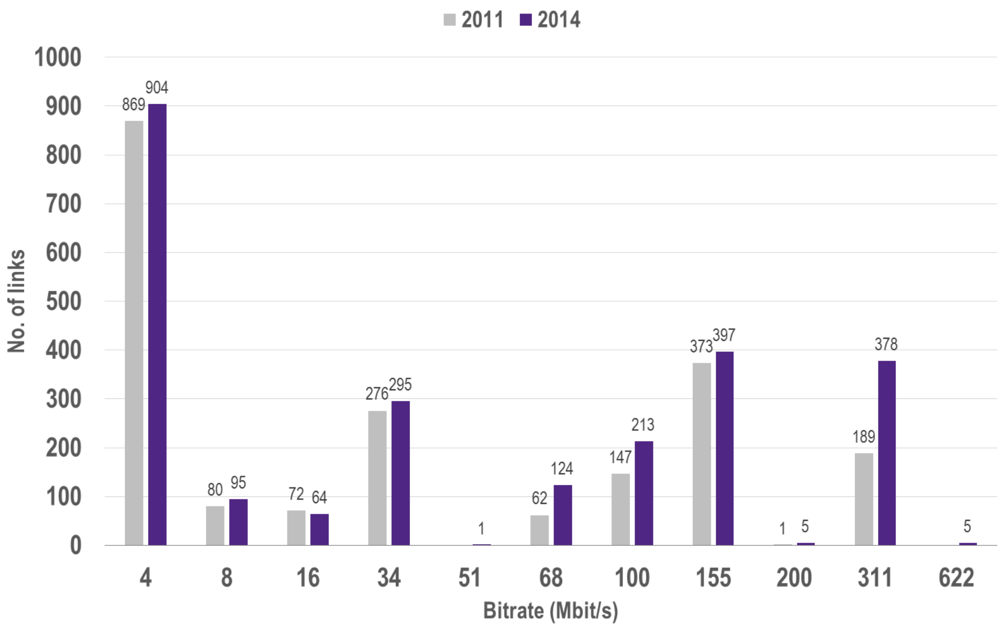
[39] OfW 446, Technical frequency assignment criteria for fixed point-to –point radio services with digital modulation, December 2014 http://licensing.ofcom.org.uk/binaries/spectrum/fixed-terrestrial-links/guidance-for-licensees/tfac/ofw446.pdf

Figure 3-5: Distribution of link bit rates in 7.5 GHz band – 2011 and 2014



Source: Plum and Aegis analysis of Ofcom data

Figure 3-6: Distribution of link bit rates in 15 GHz band – 2011 and 2014



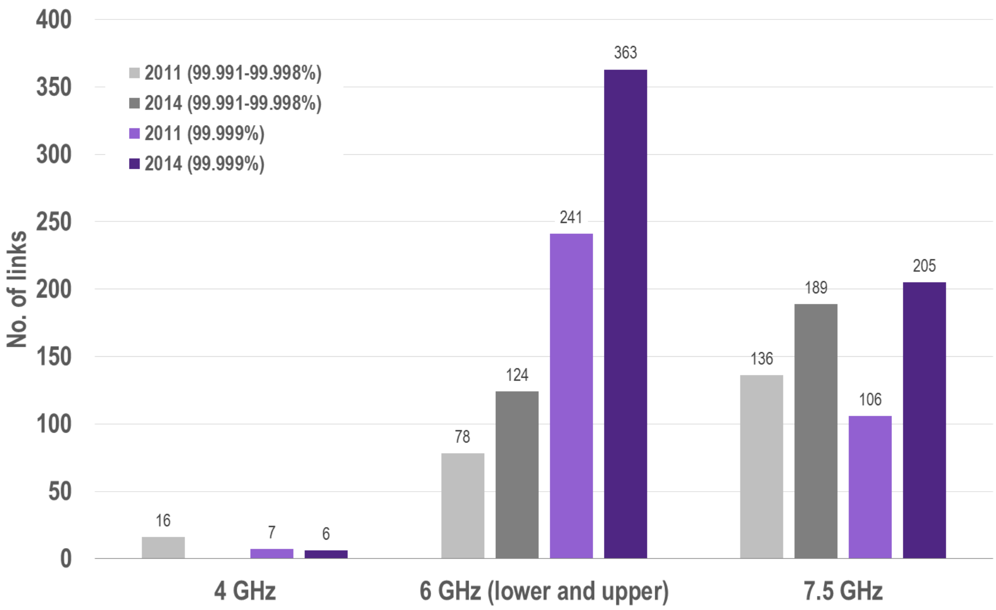
Source: Plum and Aegis analysis of Ofcom data

3.3.3 Link availability

Higher availability links require higher received signal levels to meet a given bit error rate. This requires higher transmitter powers and so there is greater chance of interference into other links. This reduces frequency reuse and so higher availability links deny more spectrum access to others.

Figure 3-7 shows that the number of high availability links (greater than 99.99%) in the 6 GHz and 7.5 GHz bands has risen, indicating increased spectrum demand in these bands, in addition to the growth in the number of assignments. This does not appear to be the case at 4 GHz (where there are less than 100 links currently assigned).

Figure 3-7: Number of high availability links by band in 2011 and 2014



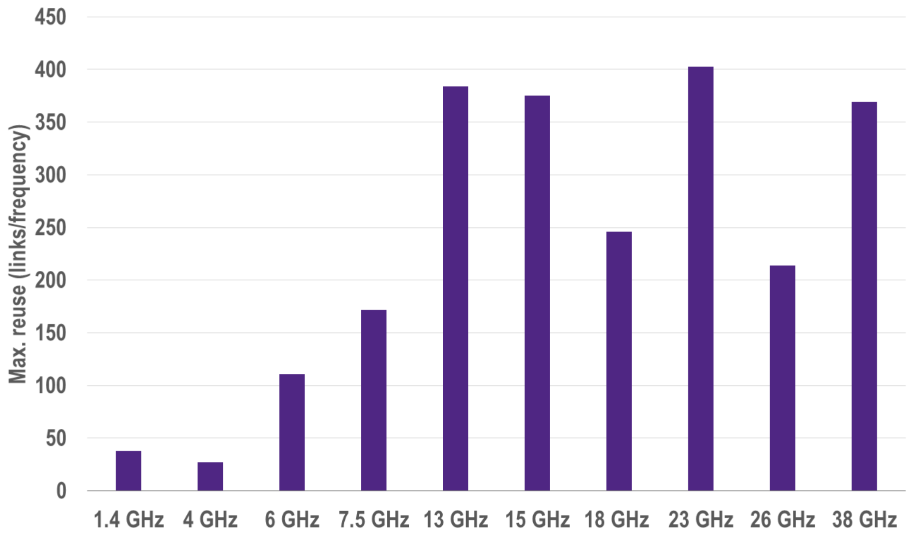
Source: Plum and Aegis analysis of Ofcom data

3.3.4 Reuse of frequencies

A further indicator of the extent of use of a band is the maximum level of frequency reuse in the band. Basic propagation characteristics mean that as frequency increases the achievable link length decreases and the potential for interference decreases. This a non-linear relationship and therefore it would be reasonable to expect that re-use would increase non-linearly with frequency.

We have examined Ofcom's database of fixed links licences to identify the level of actual re-use across frequency bands. Figure 3-8 below provides a comparison of the maximum number of links identified in a single paired frequency for each fixed link band. As expected the reuse factors rise rapidly with frequency up to 13/15 GHz. However, they then flatten out suggesting that there is less likelihood of excess demand at higher frequencies where much higher levels of reuse would be expected, therefore greater capacity is available compared to the lower frequencies.

Figure 3-8: Reuse values by frequency band



Source: Plum and Aegis analysis of Ofcom data

3.3.5 Summary

In summary we find that at current fee levels:

- Demand at 1.4 GHz and 4 GHz appears static for fixed links.
- For the 6 GHz and 7.5 GHz bands, the number of links, link bit rates and requirements for high availability links have increased, suggesting an increase in demand in these bands.
- For bands in the 10-20 GHz range there has been a small increase in supply at 10GHz (an auctioned band). The number of assignments has fallen but link bit rates have increased with an ambiguous impact on demand.
- In bands above 20 GHz supply has increased significantly with numerous bands auctioned. Supply could increase further as new equipment becomes available for other bands opened and managed by Ofcom but not yet used by stakeholders. Demand in Ofcom managed fixed link bands has been in decline.

Hence, we find the lower frequency bands (with the exception of those at 4 GHz and below) are much more likely to be characterised by excess demand from fixed links than the higher bands, particularly those above 20 GHz.

3.4 Location of demand

The demand for fixed links can vary considerably by geographic area depending on the type of user and also the frequency band. To measure the extent of spectrum use from fixed links we would ideally count the number of links in or crossing a geographic grid square. However, there is no published data for this measure.

A second best approach is to count the number of transmitter sites per grid square and this was undertaken by Aegis et al (2011)[40]. This approach in effect ignores spectrum use along, around and beyond the transmission path of the fixed link. An examination of the number of assignments by latitude and longitude co-ordinates therefore gives an incomplete view of the extent of spectrum use denied by existing assignments. This is a particular issue at low frequency ranges where links can span many tens of kilometres and the co-ordination distances are large (see Table 3-2). This is unlike the situation with satellite earth stations or mobile base stations where the use of spectrum will be over an area largely centred on the location of the assignment.

Table 3-2: Co-ordination zones for fixed links by frequency

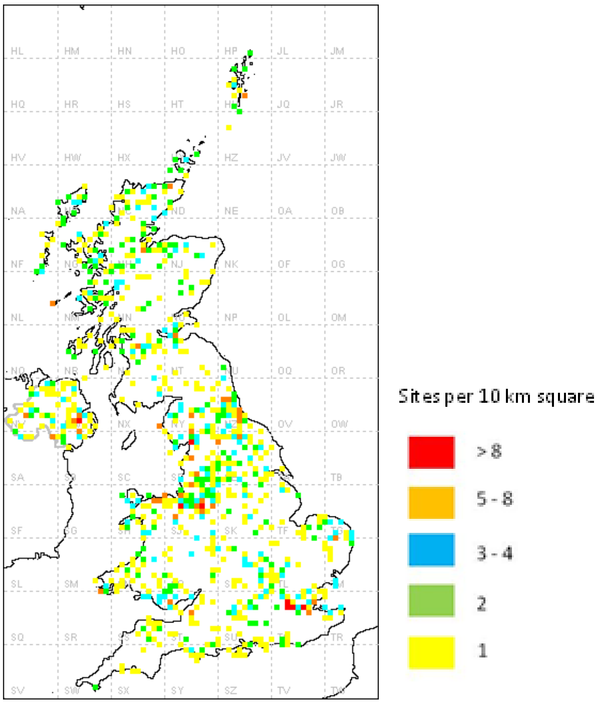
Frequency bands	Coordination zone radius (kms)
1.4, 4, L6 and U6 GHz	250
7.5, 13, 15, 18, 23 and 26 GHz	200
38 and 70/80 GHz	70

Source: Technical Frequency Assignment Criteria (OfW446), Ofcom

Below we reproduce some of the graphics from Aegis et al. (2011) showing link densities by geographic location using the grid square approach. These data indicate that for bands at 13 GHz and above fixed links have a noticeably higher density of use around the main urban areas. The situation is less clear cut at lower frequencies, with a reasonable number of links in rural as well as urban and suburban areas. For example, in the graphics for the 4 GHz and 6 GHz bands, it can be seen that the major use of the bands is to meet the requirements for higher capacity links to the islands off the coast of Scotland.

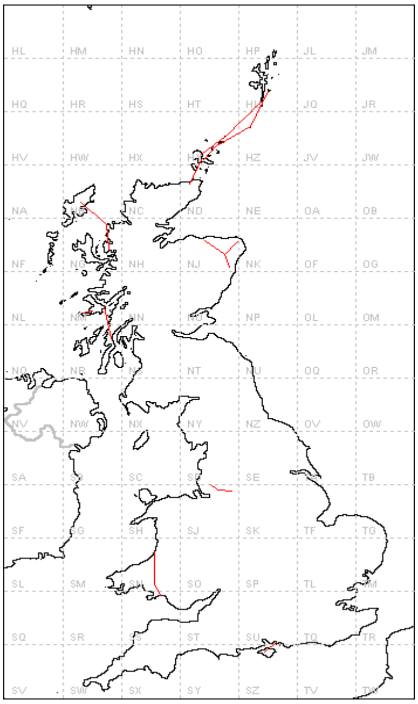
[40] Frequency band review for fixed wireless service, Aegis, Ovum and dB Spectrum, for Ofcom, November 2011 http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-review/annexes/report.pdf

Figure 3-9: Distribution of transmitter sites in the 1.4 GHz band



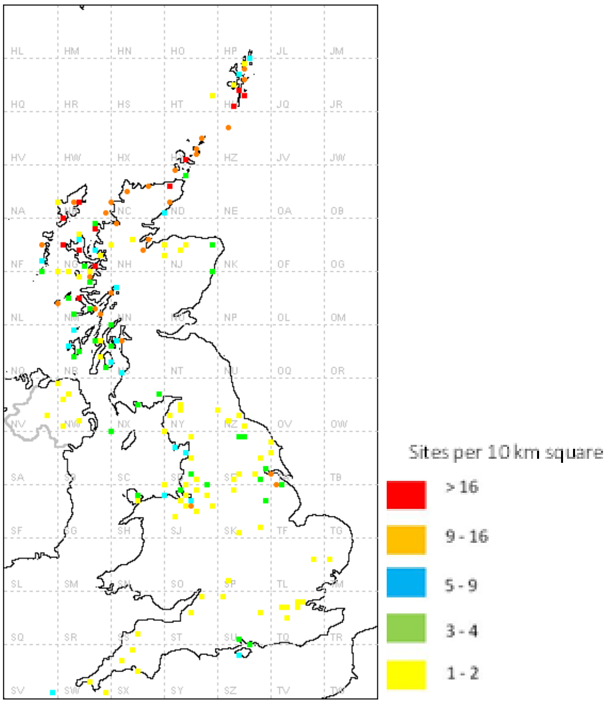
Source: Aegis et al. (2011)

Figure 3-10: Location of links in the 4 GHz band



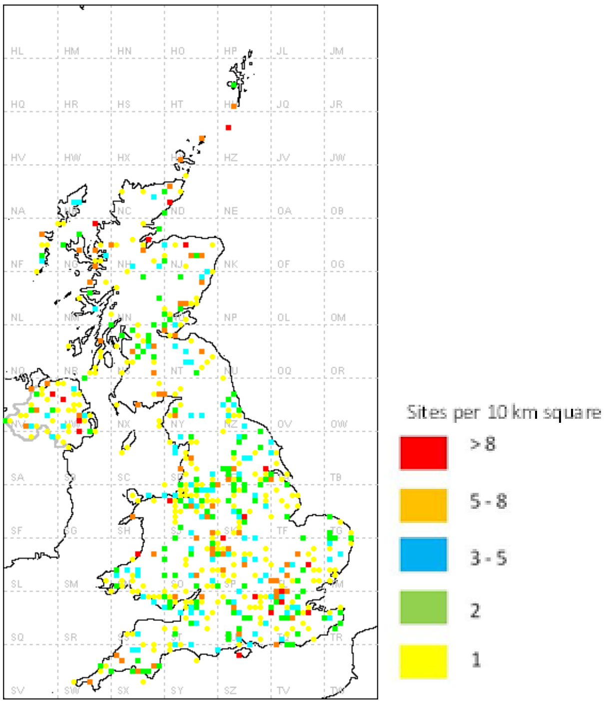
Source: Aegis et al. (2011)

Figure 3-11: Distribution of transmitter sites in the 6 GHz band



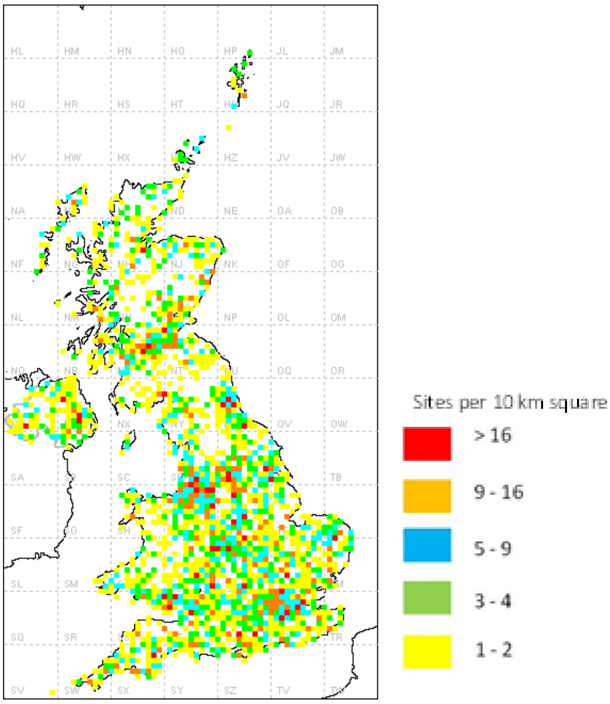
Source: Aegis et al. (2011)

Figure 3-12: Distribution of transmitter sites in the 7.5 GHz band



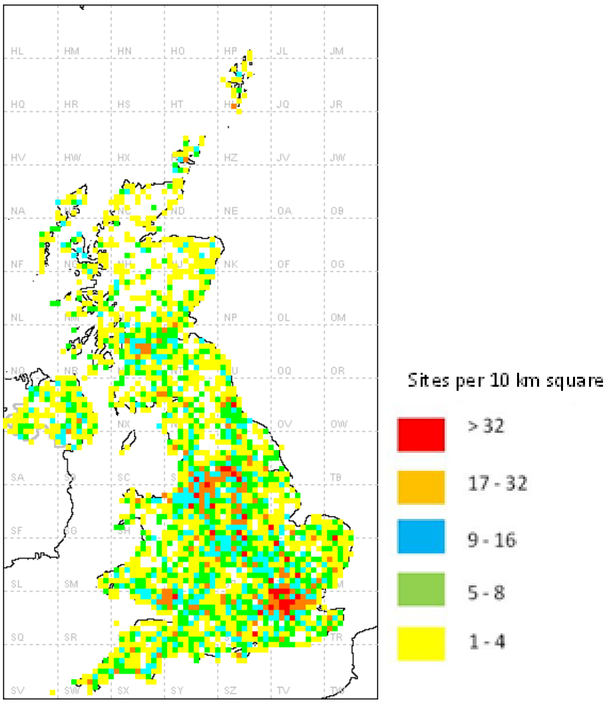
Source: Aegis et al. (2011)

Figure 3-13: Distribution of transmitter sites in the 13 GHz band



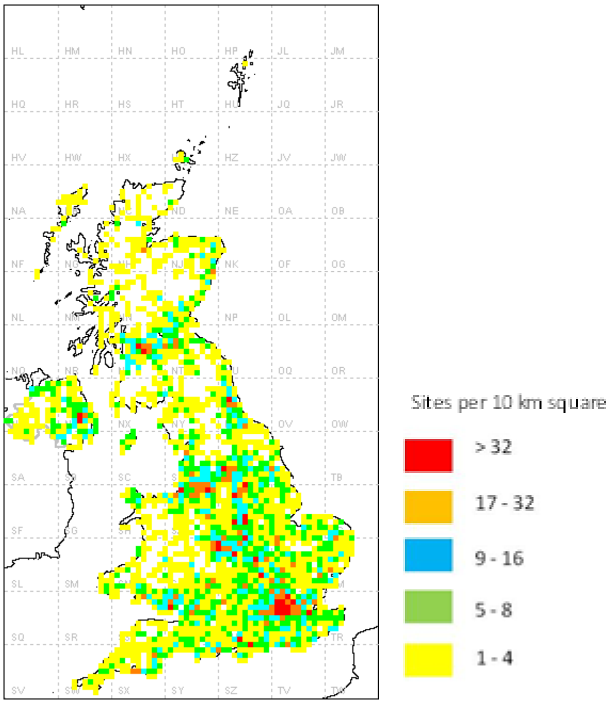
Source: Aegis et al. (2011)

Figure 3-14: Distribution of links in the 18 GHz band



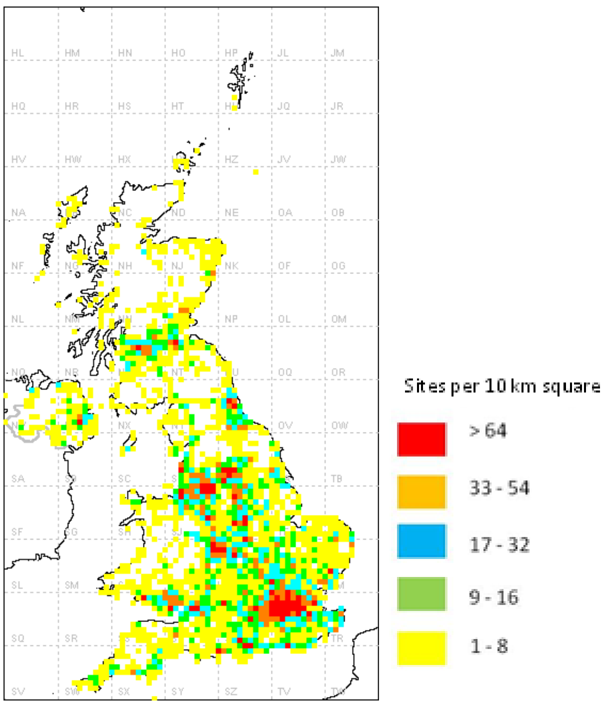
Source: Aegis et al. (2011)

Figure 3-15: Distribution of links in the 23 GHz band



Source: Aegis et al. (2011)

Figure 3-16: Distribution of links in the 38 GHz band



Source: Aegis et al. (2011)

A summary of the findings from the data reported above is given in Table 3-3. These findings are also supported by the scenario analysis undertaken by Aegis et al. (2011) which examined demand in different locations (urban, suburban and rural) over the period 2011-2021 and is reported in the next section.

Table 3-3: Summary of findings on the location of fixed link demand from Aegis et al. (2011)

Band	Location of highest density of assignments
1.4 GHz	Some greater link concentrations near major population centres but significant numbers in rural areas and also for offshore use.
4 GHz	Only significant deployment in mid / South Wales and Northern Islands of Scotland. 147 PES (space to earth) operating at 17 sites and most are in southern half of UK and NE Scotland
6 GHz (upper and lower)	Distribution skewed towards north and west of the UK with few links in South East (reflected migration of BT's legacy trunk links to fibre). Most PES in southern half of the UK, apart from North East Scotland (possibly serving offshore industry)
7.5 GHz	Greater concentration of links near major population centres in NW and SE England
10 GHz	Limited coverage for FWA in Belfast area. Some military restriction in south
13 GHz	Higher link concentrations mainly in and around major population centres. 39 satellite uplinks at 14 sites all in southern UK.
15 GHz, 18 GHz, 23 GHz, 26 GHz and 38 GHz	Higher link concentrations mainly in and around major population centres.
28 GHz, 32 GHz, 40 GHz and above	No information

Source: Aegis et al. (2011)

3.5 Future outlook

3.5.1 Introduction

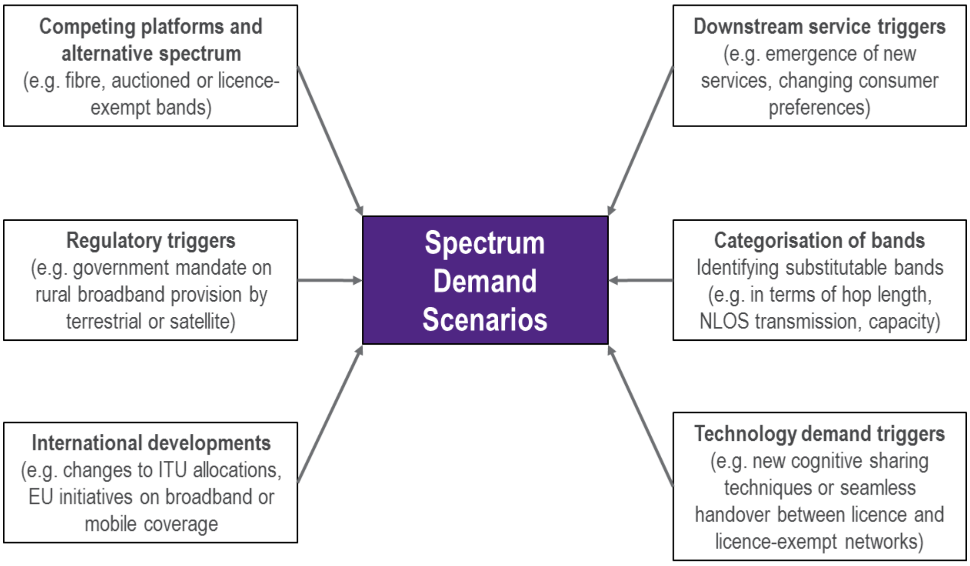
The demand for fixed link spectrum is changing, especially for mobile network backhauling which is the predominant application (particularly in higher frequency bands). The deployment of 4G networks and small cells is increasing the demand for mobile backhaul capacity,[41] although the rollout of fibre will reduce the demand for microwave links particularly in urban areas where increasing amounts of fibre is being installed. Also, some of the increased demand will be met from the increased supply of

[41] This issue has been highlighted by the GSMA in its response to the consultation on the RSPG's 2014 work programme. http://www.gsma.com/gsmaeurope/wp-content/uploads/2014/02/response-RSPG-WP-201-06012014.pdf

fixed link spectrum to support mobile backhauling won at the 10-40 GHz auction in 2008 and as equipment is produced for a growing range of high frequency bands (i.e. at 50 GHz and above).

Aegis et al. (2011) quantified future demand over the period 2011-2021 taking account a range of factors, as shown in Figure 3-17. There was no explicit assumption concerning changes in fee levels i.e. fees were assumed to remain constant.

Figure 3-17: Aegis approach to spectrum demand scenario development



Below we summarise the findings from Aegis et al. (2011) and consider their relevance today in light of changes since 2011. In addition, we report Ofcom's findings from its assessment of demand and supply in the context of its Spectrum Management Strategy[42] which in part drew on the Aegis et al. (2011) analysis. More details of Aegis' analysis can be found in Appendix B of this document.

3.5.2 Aegis et al. (2011) findings

Aegis developed four scenarios for the next 10 years (2011-2021) based on different economic, policy and regulatory factors. The four scenarios are:

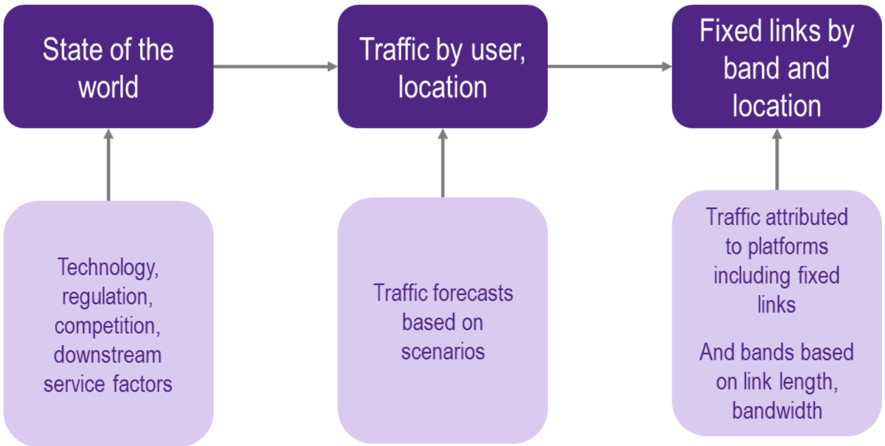
- **Scenario A – Fibred Nation** (weak economy, high regulatory intervention) – characterised by strong fibre deployment which displaces fixed link demand for mobile network backhaul; low consumer spending means low to moderate growth in mobile services
- **Scenario B – Green Agenda** (strong economy, moderate regulatory intervention) – characterised by a focus on green policies, growth in mobile demand (to facilitate teleworking and reduced travel) and increased mobile site sharing; high fibre deployment

[42] See Appendix to spectrum management strategy. Future developments in major spectrum uses. Ofcom, October 2013 http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-management-strategy/annexes/appendix_spectrum_management.pdf

- **Scenario C – Economy constraints** (weak economy, low regulatory intervention) – most pessimistic scenario characterised by reduced consumer expenditure on mobile, constraints on enterprise and utility spending and lower fibre availability due to limited government intervention
- **Scenario D – We want it now** (strong economy, low regulatory intervention) – characterised by strong economic recovery after recession, and strong demand for services and infrastructure investment; mobile networks move to LTE in urban, suburban and rural areas but limited competition in fibre means greater reliance on fixed links for backhaul

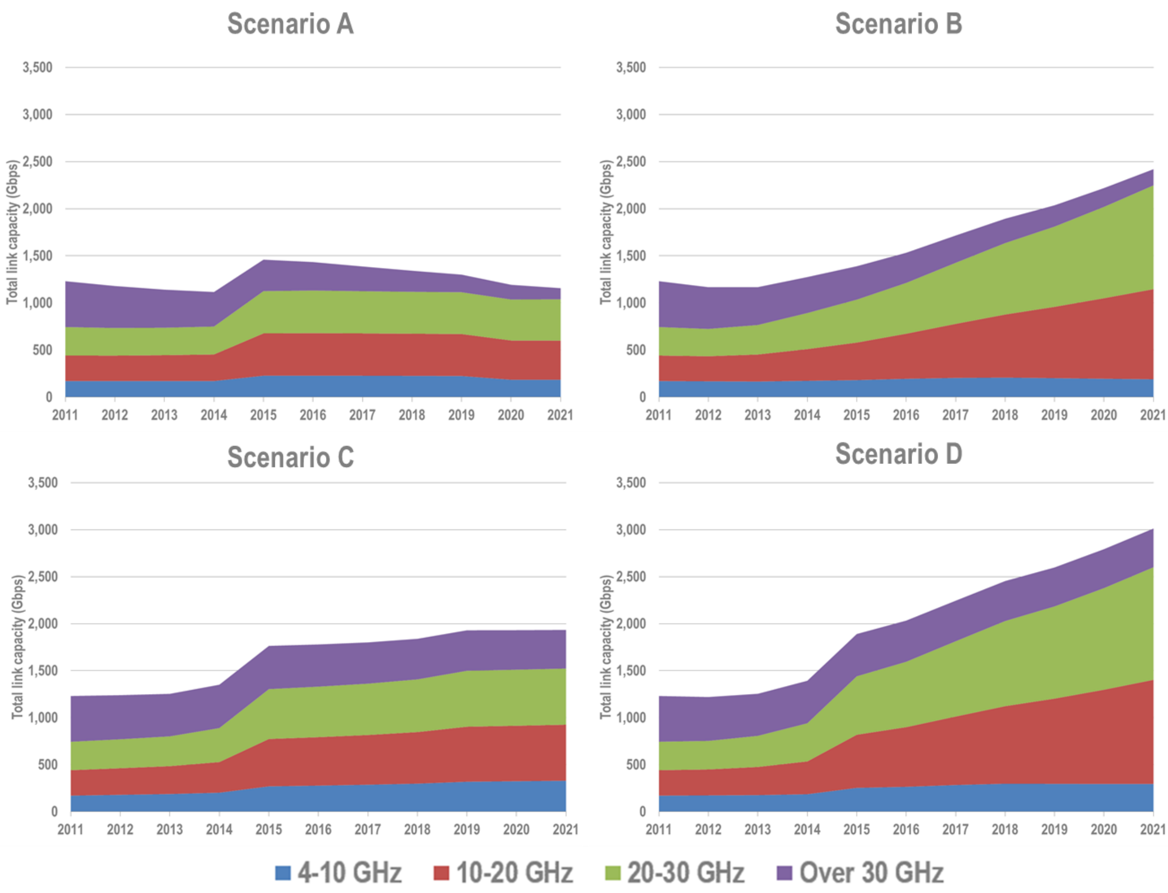
The demand for fixed link spectrum depends on the future development of downstream services which is modelled in the four scenarios based on the technology, user demand, policy, regulatory and economic factors as shown in Figure 3-18. Many aspects of the scenarios remain relevant today although some of the assumptions have since been superseded by market and policy developments (e.g. the UK 4G auction in 2013, wholesale "metrocells" in urban areas). More details on the four scenarios and corresponding assumptions are provided in Appendix B.

Figure 3-18: Assessing fixed link demand by scenario



The projected fixed link capacity demand by frequency band is shown in Figure 3-19. Scenario D is the most aggressive in terms of overall future demand for fixed link spectrum, which is dominated by mobile, public safety and FWA users. This is followed by Scenarios B, C and A. There are significant differences between the scenarios in demand for different frequencies by user and in the geographic distribution of demand.

Figure 3-19: Fixed link capacity demand by frequency band nationally (Gbps)



Source: Aegis et al. (2011)

Taking into account the market and policy developments in the UK since 2011, Scenario B appears to the closest among the four scenarios to the present day situation, for the following reasons:

- There are signs that the economy is picking up, which could translate into stronger take-up and demand for mobile data services supplemented by a high degree of Wi-Fi offload
- Strong growth in the availability and take-up of very fast broadband access services[43]
- Nationwide availability of 4G services is expected to be achieved by the end of 2017 due to coverage obligations on O2's 800 MHz licence[44] and competition between operators
- The decision on a dedicated national public safety network is likely to be later than forecasted and public safety requirements may be met using commercial networks at least in the near term[45]

[43] See Ofcom Infrastructure Report 2013 Update.

[44] The obligation requires coverage in an area in which at least 98% of the UK population lives and 95% of the population of each of England, Northern Ireland, Scotland and Wales lives. http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/IM_Update.pdf

[45] Note that Scenarios A, C and D assume rollout of national public safety begins in 2015 using either UHF or 1.4 GHz spectrum.

Aegis et al. (2011) estimated the spectrum span[46] requirements for the four frequency range groupings based on projected traffic levels in the busiest 10km square of each area. The results indicate that there is ample spectrum above 20 GHz to address the increase in demand for all four scenarios, due to the short path lengths involved and the frequency re-use factor for these higher frequency links.

In Scenario B strong growth in demand for fixed link spectrum in the 10-30 GHz frequency range was expected in the timeframe to 2021 particularly in the suburban and rural areas. Short term congestion was considered likely in dense urban areas but this was expected to be alleviated with the migration to fibre backhaul over time. In suburban and rural areas it was anticipated that significant congestion will arise in the 13 and 15 GHz bands due to mobile and FWA backhaul requirements.

3.5.3 Findings of Ofcom's Spectrum Management Strategy

The Appendix to Ofcom's Spectrum Management Strategy[47] assessed the future outlook for demand and supply of spectrum for fixed links over the next 10 years. It noted there is likely to be increased demand for spectrum for mobile backhaul in the short term and possible repurposing of spectrum for mobile data with potential congestion between 1 GHz and 7.5 GHz.

Spectrum availability was considered unlikely to be constrained above 20 GHz, due to intensive reuse and an expansion in supply. For example, given the increasing interest now emerging in the higher millimetre Wave bands, Ofcom plans to look into the bands above 80 GHz (e.g. around 92 GHz and above) that may be suitable for future fixed wireless applications[48].

In addition, Ofcom noted that excess demand could be mitigated by technology advances, such as higher order modulation techniques, to increase data capacity and improve transmission efficiency on existing fixed links; greater use of high performance antennas, which increase the packing density of fixed links; and improved network topologies, to more effectively route or aggregate traffic.

3.6 Conclusions

In respect of fixed links spectrum demand, we conclude that:

- Demand from fixed links at 1.4 GHz is broadly static and is very low at 4 GHz.
- The frequency bands used by fixed links in the 6-10 GHz range are, and will continue to be, the most congested. The situation is unlikely to change in future as demand for wider bandwidths and high availability links will not always be met by optic fibre for reasons of cost and performance differences (e.g. timeliness and flexibility of deployment).
- Demand from fixed links in the 10-20 GHz frequency range is unlikely to decline.

[46] This refers to the total bandwidth required to meet capacity demand in a given area in a single direction, assuming all links in that areas are uniformly distributed and assigned in an optimum fashion.

[47] http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-management-strategy/annexes/appendix_spectrum_management.pdf

[48] Para A 10.17, Spectrum Management Strategy Ofcom (2013)

- There is less likely to be excess demand from fixed links in bands above 20 GHz, because of increased supply, high levels of reuse and, in some urban areas, increased availability of optic fibre as a substitute for some users[49].

In summary, the future outlook for spectrum demand from fixed links is that excess demand at current fees could continue to be an issue in bands below 20 GHz but this is unlikely in bands above 20 GHz. Regarding the geographic location of excess demand from fixed links, we find that for bands at 13 GHz and above fixed links have a noticeably higher density of use around the main urban areas. Demand is much more evenly spread at lower frequencies, with a reasonable number of links in rural as well as urban and suburban areas.

[49] The extent to which optic fibre is a substitute depends on the cost considerations (including the cost of connecting from a user's premises to a fibre access point) and performance characteristics (e.g. the timeliness and flexibility of deployment.

4 Demand assessment - satellite

4.1 Introduction

Satellite earth stations are used to transmit and receive telecommunications traffic for many different types of users, including telecom operators, broadcasters and other private organisations. Much of the traffic is international in nature and licensed users of the spectrum tend to be telecom operators providing services to third parties. In addition VSAT[50] services providing broadband connectivity, data services and broadcast content are provided directly to consumers and businesses using small dishes fixed on the ground. Transportable earth stations are used primarily by broadcasters for transmitting video content from live events.

Data on the number of earth station to satellite links (deployments) and their location and indications of future demand for spectrum from satellite services are reported below. The frequency bands used by these satellite services can potentially be used by fixed links. The opportunity cost of spectrum in bands used by satellite services has historically been set on the basis of the alternative use being fixed links. We also adopt this approach in this study.

4.2 Current situation

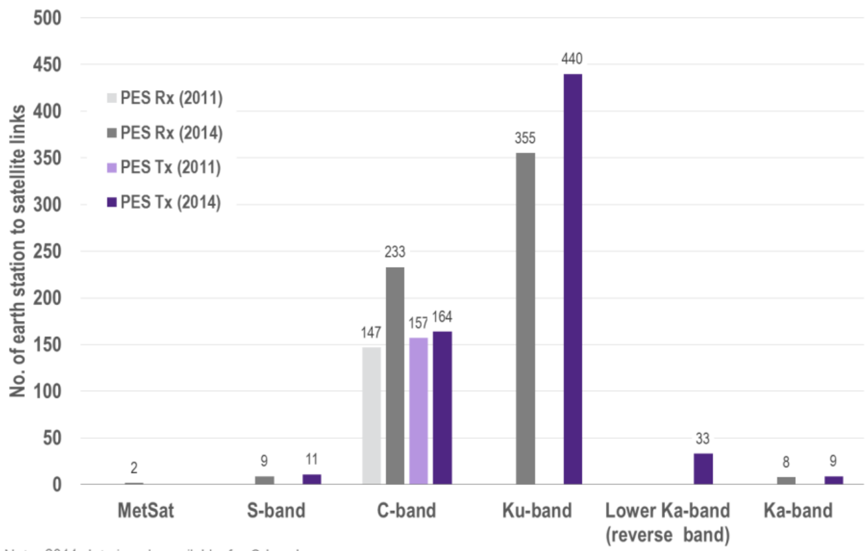
Figure 4-1 shows the number of earth station to satellite links (deployments) by band for 2014 and to a limited extent for 2011. These numbers are based on information held by Ofcom on licences for permanent earth stations, as well as those with Recognised Spectrum Access (RSA), and do not include light licensed or licence-exempt terminals e.g. VSATs at 14 GHz and high density fixed satellite systems at 28 GHz.

The only band for which we have complete data for 2011 and 2014 (C-band) shows that the number of transmitter deployments has increased by a small amount and the number of receive deployments has increased considerably. This is perhaps to be expected here (and in other bands) given Ofcom's decision to extend the offer of RSA in the band at the end of 2011[51].

[50] Very small aperture terminals

[51] http://stakeholders.ofcom.org.uk/consultations/rsa-earth-stations/rsa-statement/

Figure 4-1: Earth station to satellite links by band



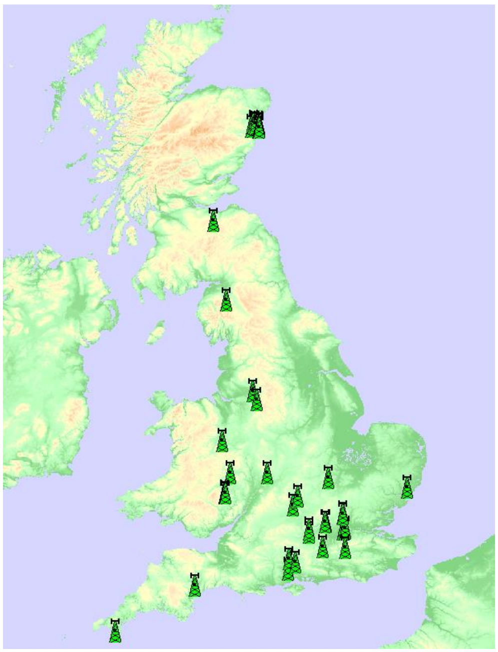
Note: 2011 data is only available for C-band

The location of demand for spectrum by earth stations (authorised transmitters and receivers) is shown in the graphics below provided by Ofcom. It is difficult to be precise about the number of earth stations at each "site", however, visual inspection of 2011 and 2014 data suggests that the following changes have occurred:

i. C-band: Increase in receive sites by 4 due to availability of RSA
ii. C-band: 1 transmit site gone, 1 new transmit site
iii. Ku-band (12.75 – 13.25): London cluster gone
iv. BSS feeders (17.7 – 18.4): London cluster gone. 3 new sites.
v. Ka-band: Static at 3 sites

In other words changes are small. Most sites appear to be rural, though some sites are sufficiently close to urban areas to potentially constrain spectrum access to other users there.

Figure 4-2: 3600-4200 MHz – location of earth station Rx "deployments" in the band - 2014

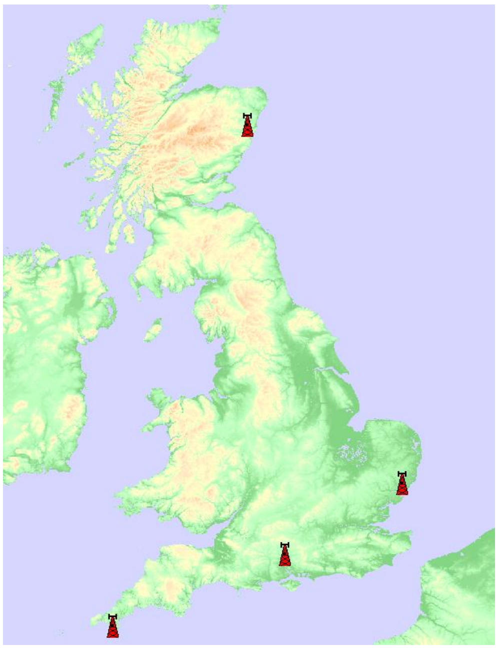


Source: Ofcom

Figure 4-3: 5925-6425 MHz – location of earth station Tx "deployments" - 2014

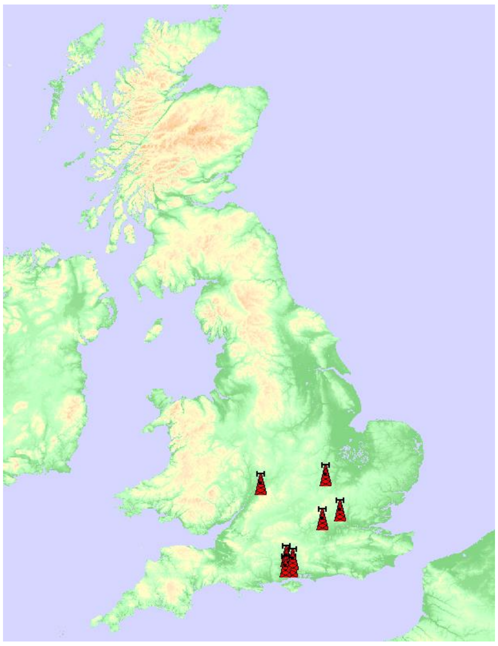
Source: Ofcom

Figure 4-4: 6425-7125 MHz – location of earth station Tx “deployments” - 2014



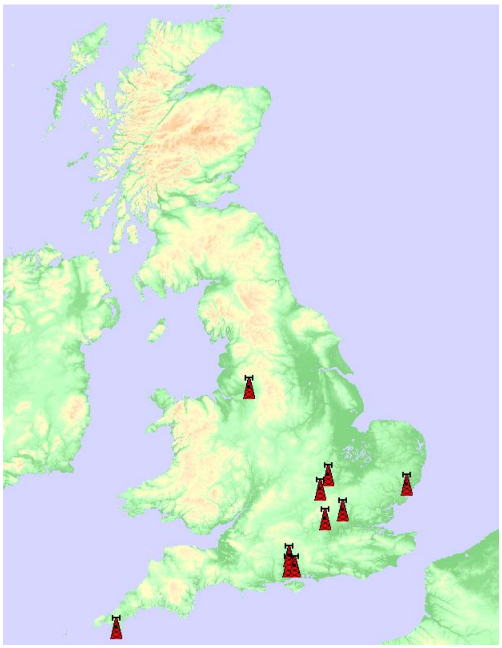
Source: Ofcom

Figure 4-5: 12.75-13.25 GHz – location of earth station Tx “deployments” - 2014



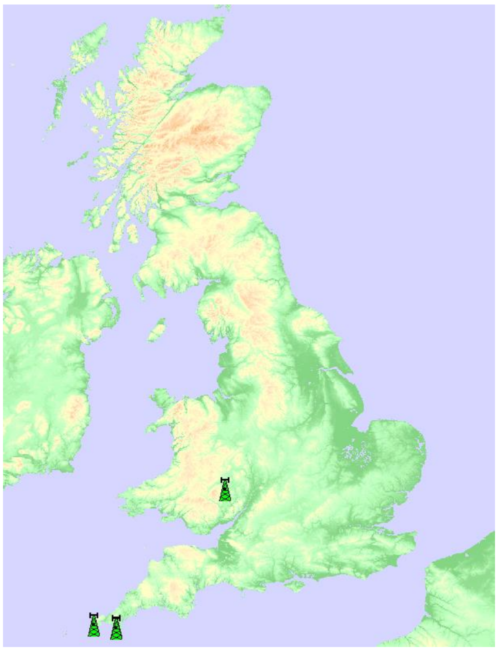
Source: Ofcom

Figure 4-6: 17.7-18.4 GHz – location of 34 earth station Tx "deployments" - 2014



Source: Ofcom

Figure 4-7: 17.7-19.7 GHz – location of earth station Rx "deployments" 2014



Source: Ofcom

4.3 Future outlook

In respect of future spectrum demand for satellite services, there is work on-going under WRC Agenda Item 1.6 to identify an additional 2x250 MHz for FSS (E-S and S-E) in the frequency range 10 to 17

GHz for Region 1 and similar (but not identical) for Regions 2 and 3. This is to balance the uplink and downlink amounts of spectrum, and to balance the amounts of spectrum available across the Regions. Work on Agenda Item 1.9.1 is also investigating the possibility of a new 2 x 100 MHz at 7/8 GHz for fixed satellite use.

We have not identified any recent market studies in support of these requirements but note that a number of submissions to CEPT[52] indicate that spectrum available in Ku band (11/14 GHz) is fully assigned to satellites in use and it is not possible to place any more satellites into the orbital arc without causing interference.

A recent study suggests that demand for satellite capacity at C band is likely to remain flat in the period to 2021[53]. The mobile allocation at 3.6-3.8 GHz and licences for nomadic use in the UK in the 3.6-4.2 GHz range could reduce the future spectrum available for satellite services and so increase demand at higher frequencies at Ku and Ka band. The demand for satellite telecommunications links in these bands is expected to be relatively stable as has been the case in recent years.

However, it is possible that there will be an increased requirement in Ka band (18/28 GHz) to support increased future demand for spectrum for the delivery of consumer broadband services in rural areas[54]. Whether this demand materialises depends in part on the rollout of terrestrial broadband services in rural areas (fixed and mobile) and the extent to which these are subsidised by government. In anticipation of future spectrum demand at Ka band the satellite industry is seeking to share the fixed link allocation at 28 GHz and find ways of improving sharing with fixed links at 18 GHz.

Ofcom's review of future spectrum uses in its Spectrum Management Strategy consultation concluded that (para A9.28)[55]:

> *"We consider the spectrum access that is available for end user services looks broadly sufficient, even though pressure on Ka band spectrum is mounting. Market requirements are generally stable or addressable today, though significant changes in future, e.g. as a result of a significant uptake in rural broadband and mobile platforms over satellite, could pose challenges in future."*

4.4 Conclusions

In summary, there has been relatively little change in spectrum use by satellite earth stations in the last 3 years and the future outlook is for continued modest demand growth except possibly at Ka band where demand could grow substantially. However, demand at Ka band is highly uncertain and it depends in part on government policies in respect of rural broadband.

There could be a future loss of available spectrum in the 3.6-3.8 GHz band if this is shared with mobile services though this may be accommodated by increased use of 3.8-4.2 GHz band and at higher frequency ranges.

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[52] Documents submitted to CEPT's Conference Preparatory Group from the Russian Federation, Norway and Luxembourg (008, 024 and 046) address Ku-band requirements.

[53] Study on spectrum uses, trends and demands in the range 3400-4200MHz (C-band), CGI Business Consulting for the UMTS Forum, UMTS submission to PT1 meeting #46, 22 April 2014.

[54] ADSL services in urban/suburban areas are usually cheaper than satellite broadband, assuming the download speeds, latency and other service aspects.

[55] We understand these interim conclusions will not be updated until later in 2014.

Hence future satellite spectrum requirements are unlikely to change the conclusions in respect of spectrum demand in fixed services bands given in Section 3, namely that there will continue to be excess demand below 20 GHz and that bands above 20 GHz will be relatively uncongested. This implies there is a case for AIP fees in bands below 20GHz whereas the case is less clear cut above 20 GHz, in which case administrative cost based fees may be applicable.

5 Opportunity cost estimates

5.1 Introduction

This Section addresses Step 3 of the four step approach to setting AIP proposed by Ofcom's SRSP (reproduced in Figure 1-1), namely the derivation of an estimate of opportunity cost by band. The reference rate used in the pricing algorithms is the opportunity cost for a chosen reference band. This is considered in Sections 6 and 7 for fixed links and satellite services respectively.

Appendix A of the consultation on the SRSP sets out Ofcom's approach to estimating the opportunity cost (and hence reference rate) for each band. This involves calculating the value of spectrum in own (or existing) use and the value in alternative uses. If there is a higher value feasible alternative use the reference rate is set between the two values, but towards the bottom end of the range. If there is no feasible higher value alternative use the rate is set at the value in the existing use.[56].

Below we derive opportunity cost estimates for bands used by fixed links as follows:

- Estimate the marginal value of spectrum for a band based on the own use (i.e. fixed links) based on information from market data (i.e. auction and traded values)[57] – Section 5.2.
- Estimate the marginal value of spectrum for a band based on the own use (i.e. fixed links) based on least cost alternative estimates[58] – Section 5.3.
- Estimate marginal value for alternative use of the band, where such use exists and the value can be estimated. In practice mobile is the alternative use and the values reported are derived from auction results – Section 5.4.
- In Section 5.5 we provide our best estimates of opportunity cost by band in accordance with Ofcom's methodology, namely[59]:
  - If there is a higher value alternative use, set the opportunity cost between the two values, but towards the bottom end of the range
  - If there is no feasible higher value alternative use, set the opportunity cost at the value in the existing use

First we briefly describe the market data we have used and the least cost alternative approach to estimating values.

5.1.1 Market values

Auctions and trades involving spectrum used by fixed services provide indicators of market values. Traded values are rarely reported and so we focus on auction values. We have examined UK auction results for bands used by fixed services and by the potential alternative uses, including auctions for 28

[56] Paras 1.40-1.41, Appendix A, Our current practice in setting AIP fees, An appendix to SRSP: The revised Framework for Spectrum pricing, Consultation, March 2010 http://stakeholders.ofcom.org.uk/binaries/consultations/srsp/appendixA.pdf

[57] As proposed by the SRSP, AIP Principle 7 and AIP Methodology 2.

[58] The SRSP refers explicitly to the least cost alternative approach to deriving opportunity cost estimates. Para 5.67, SRSP

[59] Para 1.40-1.42, http://stakeholders.ofcom.org.uk/binaries/consultations/srsp/appendixA.pdf

GHz (2000), 3.4 GHz (2003), 10 GHz, 28 GHz, 32 GHz and 40 GHz (2007), and 1452-1492 MHz (2008). [60]

Besides UK data, there have been several awards for bands used by fixed services in Europe. These include BWA licences at 3.4 GHz (Germany, Switzerland, Italy, Sweden) and 3.6 GHz (Sweden) and licences for fixed services at 10 GHz (Sweden, Norway), 11 GHz (Norway), 23 GHz (Norway), 26 GHz (Ireland) and 28 GHz (Sweden). While these could potentially be used as benchmarks, it is questionable whether they are appropriate comparators for the UK given the nature of fixed links and PES applications and the differences between countries in terms of population densities, availability of wired substitutes and so demand. We therefore focus on UK specific data in our analysis.

Auction values are typically lump sum values (for a defined licence duration) for a block of frequencies covering either the whole country or a large region. To be relevant to the development of the AIP fees, which is an annual fee per 2x1 MHz per link, the auction values need to be converted to an annual value and expressed on a comparable basis. To do this we have based the conversion to annual value on the licence duration, a nominal pre-tax discount rate of 8.9% (based on the weighted average cost of capital for a mobile operator) and inflation based on the RPI (to be consistent with the discount rate). Details are given in Appendix E.

Annual values are converted to per link values by dividing the national annual fee for 2x1 MHz by a reuse factor for each band. The theoretical reuse value given by propagation modelling is too high because demand is not evenly spread across the country. Actual reuse for the most heavily used frequency in each band is shown in Figure 3-8 and discussed in Section 3.3.4. The reuse values given in Table 5-1 were obtained by taking values for 1.4 GHz-10 GHz from Figure 3-8 (rounded up a little) and using our judgment for the other bands.

Table 5-1: Assumed reuse factors by band

Band	Assumed reuse
1.4 & 4 GHz	50
6, 7.5 & 10GHz	150
13-18 GHz	400
23-28 GHz	600
32-40 GHz	1000

Source: Based on Ofcom data (see Figure 3-8) and Plum/Aegis estimates for higher frequency bands

5.1.2 Least cost alternative approach (LCA)

The SRSP refers specifically to the use of the Least Cost Alternative (LCA) method for deriving opportunity cost estimates, which it describes as follows[61]:

> *….. this involves estimating the value to an average user of a small additional block of spectrum in the band, in terms of avoided cost and this is generally based on a study of the*

[60] http://stakeholders.ofcom.org.uk/spectrum/spectrum-awards/awards-archive/

[61] Para 5.67, SRSP

cost of long-term alternative network designs or technology choices that would be made in response to a small reduction in spectrum held by a user.

Under the LCA method, values of spectrum are calculated based on the additional cost (or cost saving) to an average or reasonably efficient user as a result of being denied access to a small amount of spectrum (or being given access to an additional small amount of spectrum). The additional cost (or cost saving) depends on the application and is calculated as the estimated minimum cost of the alternative actions facing the user. These alternatives may include:

- investing in more/less network infrastructure to achieve the same quantity and quality of output with less/more spectrum;
- adopting a more efficient technology (e.g. narrower bandwidth equipment or a more efficient modulation scheme);
- switching to an alternative band;
- switching to an alternative service (e.g. a public service rather than private communications) or technology (e.g. fibre or leased line rather than fixed radio link).

It is assumed that the quantity and quality of output produced by the use remains constant. However in practice it is often not possible to take into account the impact of quantity or quality changes because these depend on the specific (and unknown) circumstances of each user.

The LCA approach to estimating spectrum value was used to derive the reference factor for fixed links set by Ofcom in 2005. At that time, the least cost alternative option was found to be an upgrade to a more efficient technology (namely, a more efficient modulation scheme for each type of link). This gave an estimate of opportunity cost of £132 per 2x1MHz[62] and Ofcom set a reference value of £88 per 2x1 MHz. As is discussed below, this approach to estimating opportunity cost can no longer be used because there is now no additional cost associated with using a more efficient modulation scheme.

5.2 Own use market values

5.2.1 Data points

Since 2000 there have been three set auctions in the UK in bands that could potentially be used by fixed services. These include:

- 28 GHz broadband fixed wireless access – November 2000
- 3.4 GHz fixed wireless access – June 2003
- 10 GHz, 28 GHz, 32 GHz and 40 GHz fixed links – February 2008

As the 3.4 GHz band can now potentially be used for nomadic and mobile applications we have treated the auction results for this band as being for an alternative mobile use of the band.

[62] See Indepen et al (2004) op cit.

The 28 GHz auction in November 2000 is unlikely to be a good comparator given that market circumstances and expectations were very different to those present today. In particular in 2000 fixed wireless access was expected to be a key way of delivering consumer broadband access, however, the rapid diffusion of ADSL technology and now VDSL and fibre access mean that fixed wireless access today plays only a niche role in delivering broadband access.

There have been trades involving spectrum for fixed links but the values of most of these are not made public. We are only aware of one trade in which Vodafone reportedly paid £500,000 for Transfinite's 28 GHz sub-national licence in November 2012.[63] Table 5-2 describes the data used to derive own use opportunity cost estimates.

Table 5-2: Description of auction data points

Auction	Frequency (MHz)	Package	National/ regional	Lots/licences sold	Data points
28 GHz (Nov 2000)	28052.5-28164.5/29060.5-29172.5	2x112 MHz (14 regions)	Regional	5 (out of 14)	5 regional
	28192.5-28304.5/29200.5-29312.5	2x112 MHz (14 regions)	Regional	7 (out of 14)	7 regional
	28332.5-28444.5/29340.5-29452.5	2x112 MHz (14 regions)	Regional	4 (out of 14)	4 regional
10, 28, 32, 40 GHz [1] (Feb 2008)	10125-10225/10475-10575	2x10 MHz (10 lots)	National	10 (out of 10)	1 national[2]
	27828.5-28052.5/28836.5-29060.5	2x112 MHz (2 lots)	National	2 (out of 2)	1 national
	28052.5-28164.5/29060.5-29172.5;	2x112 MHz (1 lot)	Sub-national	1 (out of 1)	1 regional
	28192.5-28304.5/29200.5-29312.5	2x112 MHz (1 lot)	Sub-national	1 (out of 1)	1 regional
	28332.5-28444.5/29340.5-29452.5	2x112 MHz (1 lot)	Sub-national	1 (out of 1)	1 regional
	31815-32571/32627-33383	2x126 MHz (6 lots)	National	6 (out of 6)	1 national[3]
	40500-42000/42000-43500	2x250 MHz (6 lots)	National	6 (out of 6)	1 national[4]

Notes: (1) Two participants won spectrum in multiple bands – T-Mobile won 8 lots of 10 GHz, 2 lots of 32 GHz and 1 lot of 40 GHz; MLL won 1 lot of 32 GHz and 1 lot of 40 GHz. Disaggregated prices by band not available

[63] http://www.thetimes.co.uk/tto/business/industries/telecoms/article3604199.ece

and therefore we do not use these results in our calculations. (2) Based on Digiweb's 2 lots. (3) Based on BT's 1 lot and Orange's 2 lots. (4) Based on UK Broadband's 4 lots.

5.2.2 Implied annual values

The annual values for the various bands expressed as a price per 2x1 MHz per link are shown in Table 5-3. The values presented are for national licences. The low values of 10-40 GHz bands are likely to be due to the relative abundance of supply at higher frequencies and the lack of compatible equipment for fixed links in these bands at the time of auction.

Table 5-3: Annual values based on data points from national licences

Frequency band (GHz)	Time of auction	Annual value, £ per 2x1 MHz	Implied annual value per link, £ per 2x1 MHz
10	February 2008	264	1.76
28	February 2008	158	0.26
32	February 2008	162	0.16
40	February 2008	16	0.016

Source: Plum and Aegis analysis

In addition there are a number of regional data points from the 28 GHz auctions. The data for the 28 GHz band come from two separate auctions – November 2000 and February 2008. Table 5-4 summarises the regional values and estimated national values (scaled by population). The values for the 2000 auction are much higher than the 2008 auction. For the November 2000 auction, the values range from £6,800/2x1 MHz (Greater London) to £220/2x1 MHz (Northern Ireland). For the February 2008 auction, the values for the three regional (sub-national) licences sold are around £24/2x1 MHz.

The most recent regional data point is the reported trade in November 2012 between Transfinite and Vodafone for a sub-national 28 GHz licence[64] which suggests that the value of 28 GHz may have increased significantly since 2008. The annualised value paid by Vodafone is £654/2x1 MHz which is 30 times the value paid by Transfinite in February 2008. Scaling up this trade value by population gives a national value of the 28 GHz of about £2,000/2x1 MHz. This may underestimate value on a national basis because the licence does not cover the major cities such as London, Manchester or Birmingham where congestion may be most acute. However the licence does cover some mid-size cities (e.g. Glasgow, Cardiff, Norwich).

[64] First sub-national licence covering Scotland, Wales, and regions in South East England, South West England and East Midlands.

Table 5-4: Estimates for 28 GHz national value based on regional data points

28 GHz data	Regional annual value, £ per 2x1MHz	Estimated national value £ per 2x1MHz	Implied annual value per link, £ per 2x1 MHz
November 2000 (auction)	£220 – £6,800	£36,000	60
February 2008 (auction)	£12 – £32	£44	0.073
November 2012 (trade)	£654	£2,000	3.33

Source: Plum analysis of auction data

The large difference in values for the 28 GHz band between the 2000 and 2008 auctions is likely to be due the different market and technology circumstances. During the late 1990s and early 2000s, it was anticipated that fixed wireless access would have a significant role in delivering broadband data services to consumers. However the widespread deployment of low cost ADSL services during the succeeding 10 years and the development of mobile broadband have arguably undermined the business case for mass market fixed wireless access services. Therefore we do not consider that the 2000 values are relevant today.

5.2.3 Discussion

The recent auction results for bands in the 10-40 GHz range imply values per link which are all much lower than Ofcom's fee levels per link in comparable bands of £15-40/2x1 MHz. While the purchasers of the auctioned spectrum need to make additional expenditures on planning and managing the spectrum they bought we doubt these costs are sufficient to explain differences in value. Two possible reasons for the low auction values for 10-40 GHz bands are the large increase in supply that occurred in the 2008 auction (46% increase in supply in the 10-40 GHz range) and the limited availability of equipment for the higher bands at the time of the auction (which would have reduced demand).

The one publicly reported trade since the auction suggests values may have increased – possibly 30 fold – now that there is more equipment available and mobile operators have started rolling out dense urban networks using the 2.6 GHz band. Mobile operators are the main users of high frequency short links whether these are self-provided or supplied as a wholesale service by third parties. Also the 2012 trade was for a sub-national licence which may not necessarily cover hotspots in dense urban areas, and so it is possible that the value may have risen further than indicated by the traded value.

5.3 Own use least cost alternative value

The least cost alternative approach involves an assessment of the additional costs faced by a typical user denied access to a minimum amount of spectrum that is of practical benefit to the user[65]. These additional costs indicate the value to the user of being able to access the congested band i.e. reflect the value of spectrum in the congested band. Additional costs arise if a user is denied access to spectrum because the user must then meet its communications needs either by using a more efficient technology, choosing a less congested band or using an alternative service.

[65] See para A1.49, Appendix A: Our current practice in setting AIP fees, Ofcom, March 2010

To implement this approach we need to describe the situation being considered including the nature of the typical user. There are a number of options – for example we could assess the value of spectrum to a user seeking to deploy a new link, either because of a new demand or because an old link is being replaced, or to an existing user with links part-way through their economic life and who is denied access to a block of spectrum. In the analysis presented below we derive values for a user seeking to deploy a new link. The case of an existing user being deprived of spectrum is not considered because we do not know the age of fixed link equipment currently in use and so cannot reliably estimate the costs of spectrum deprival. The approach we have taken will give lower values than the case of an existing user i.e. our approach is conservative.

Next we need to consider the choices facing a user wanting to deploy a new link that is denied access to a congested band - a more efficient technology, choosing a less congested band or using an alternative service.. In a 2004 study for Ofcom the LCA value for fixed links was derived based on the additional cost of more efficient i.e. higher modulation fixed link equipment. This can approach can no longer be used because there is no additional cost for higher modulation equipment. It can therefore be expected that a new user will use the highest modulation equipment because it reduces the fees paid (all else being equal). A similar conclusion applies to the use of variable bit rates – these techniques will be implemented by the user if required. Appendix C discusses other technologies offering sspectral efficiencies and we conclude that:

- The use of transmit power control and high performance antennas should be encouraged but the overall benefit obtained by the use of these techniques is difficult to quantify with any precision and is beyond the scope of this study.
- MIMO, mesh networks and NLOS links are either not well enough established or are not applicable to the case of links assigned by Ofcom because they would be deployed in self-managed blocks of spectrum.

Hence we focus our analysis on the options of a less congested band and deploying a wired alternative, recognising that in practice neither of these two options will be a perfect substitute for the original fixed link (because of service quality differences).

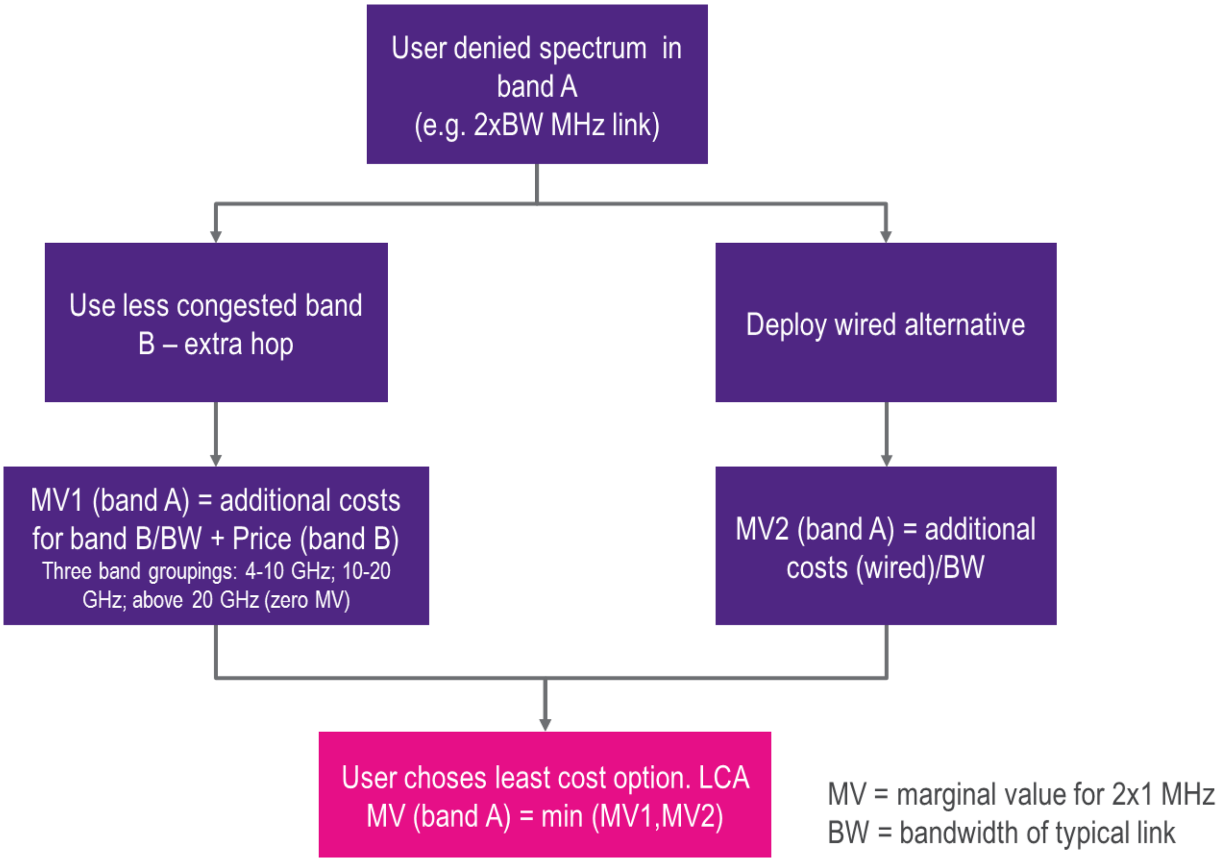
In general higher frequency bands are less congested. This is in part because of the greater capacity of higher frequency bands resulting from the higher levels of reuse that can be achieved and the greater total bandwidth that is available. Users may elect to use higher frequency bands but at the cost of having to install extra hops and so we estimate the cost of implementing additional hops.

Alternatively, rather than using a radio based solution a user could elect to use a “wired” solution from a third party such as BT or a free space optical solution[66]. The latter is less relevant because distances that can be achieved are limited and can only be considered as an alternative for the highest microwave frequencies which in any event experience low levels of congestion.

A summary of our approach is given in Figure 5-1. The marginal value of spectrum is calculated as the difference in costs between deploying a link in a congested band and a realistic alternative option should access to the band be denied (e.g. using a higher frequency band or a wired link) divided by spectrum saved in the congested band. This value is expressed in £ per 2x1 MHz.

[66] A free space optical solution uses light propagating in free space to wirelessly transmit data.

Figure 5-1: Approach to deriving least cost alternative value



The typical user is assumed to be wishing to deploy a fixed link of a typical bandwidth that is of practical use for the frequency range under consideration. We do not consider the case of denying a very small amount of spectrum to an existing user and estimating the additional equipment and other costs incurred to maintain service. This is because if the minimum bandwidth is removed from a link, then the least cost approach is to replace the whole link at a less congested frequency range rather than operating 2 links as fixed link equipment costs are invariant to bandwidth.

Our analysis of Ofcom data given in Section 3 of this report suggests that a typical bandwidth would be 2x28 MHz (which could accommodate typical data rates of 155-311 Mb/s) [67]. In the case of the wired connection BT's wholesale services support either 100Mb/s or 300-1 Gbps which does not match well to the fixed link data rates. For the lower 100Mbps data rate a 2x28 GHz link could support the service, however, this is not necessarily the case for bit rates towards the top end of the 300-1 Gbps range and so we show results assuming a 2x56 MHz bandwidth.

[67] Choice of smaller bandwidths will result in higher estimated values, because equipment costs are invariant to the bandwidth deployed.

plum

5.3.1 Move to higher frequency band

In this situation, a user is denied spectrum in a particular frequency band (because it is congested) and switches to a higher, less congested frequency band. Use of the higher band is assumed to involve an additional hop and therefore the need to install an additional site to achieve the same communications link[68]. The additional cost will include installation, site rental, infrastructure and two sets of transceiver equipment with associated antennas[69]. The value of the lower more congested band arises from the fact that less infrastructure is required to provide the communications link. The value of say 2x1 MHz in the lower (more congested) band is the additional cost of using a higher band divided by bandwidth used plus the price (per 2x1 MHz) of spectrum in the higher band. In other words,

$MV_L = C_H/BW + P_H$

Where:

MV_L = marginal value of 2x1 MHz in the lower (more congested) band

C_H = additional equipment and other costs of using the higher (less congested) band

BW = bandwidth of the link in the lower (preferred) band

P_H = price of 2x1 MHz in the higher (less congested) band

We start the calculations with the situation in which P_H is zero, namely bands above 20 GHz where spectrum is in less demand, and estimate the marginal value for 10-20 GHz. Next we estimate the value for below 10 GHz using the marginal value for 10-20 GHz just calculated (as the price of the higher band).

In particular we undertake calculations for the following two cases, each of which involves deriving values for a different set of frequencies:

- A user denied access to 10-20 GHz spectrum and switches to a band above 20 GHz. This gives the value of spectrum in the 10-20 GHz range.
- A user denied access to spectrum below 10 GHz and instead switches to a band in the 10-20 GHz range. This gives the value of spectrum below 10 GHz.

In Appendix D we provide the details of these calculations.

Table 5-5 shows a summary of the marginal values obtained under three site sharing assumptions:

- Base case assumptions for site occupancy – 3 occupants in rural areas and 1 occupant in urban/suburban areas
- Increased site sharing assumptions – 6 occupants in rural areas and 3 occupants in urban/suburban areas

[68] We have assumed that on average a single additional hop would be required when moving to a higher frequency band, although we recognise that this will not always be the case. Sometimes no additional hop is required while in other cases more than one additional hop is required. See Plum-Aegis. “Estimating the commercial trading value of spectrum”. For Ofcom, July 2009.

[69] Equipment costs do not vary with link capacity.

- No incremental mast construction or site rental costs associated with the additional hop because the costs are already incurred for another application used by the licensee (e.g. a transmitter site used by a mobile or fixed operator)[70].

Table 5-5: Value per 2x1MHz link under different site sharing assumptions (£) – additional hop comparisons

Situation (user/site)	Base case assumptions 2 x 1 MHz	Increased site occupancy assumptions 2 x 1 MHz	No mast construction / site rental costs 2 x 1 MHz
Value of <10 GHz			
Rural	520	195	124
Urban or suburban	619	370	124
Value of 10-20 GHz			
Rural location	221	22	76
Urban or suburban	89	161	76

Source: Plum and Aegis analysis given in Appendix D – see Table D-10.

If we had access to data on site occupancy across the UK we could calculate a weighted average of the values shown in Table 5-5. We do not have this data but do have data on user types by band as presented in Section 3. This indicates that fixed and mobile network operators are the highest users across bands below 20 GHz, though at 1.4 GHz, 7.5 GHz and 15 GHz public safety and utilities, broadcasters and the oil and gas sector respectively have significant numbers of assignments. The scenario analysis by Aegis et al (2011) suggests that the user types that could experience rapid growth in demand for links include mobile, fixed wireless access operators and public safety if a standalone public safety broadband network is built (which is now uncertain). On balance, the typical user seems likely to be a fixed or mobile network operator which means we place more emphasis on the value estimates for the cases where there is more rather than less sharing of sites in columns 3 and 4 of Table 5-5.

5.3.2 "Wired" alternative

Here we consider the situation in which a user is denied access to spectrum and considers the costs of the use of a wired alternative from BT Openreach – this could be a leased line or an Ethernet product. We recognise that in some circumstances fixed links are used because wired products do not provide an adequate substitute, for example, because they are not as flexible (e.g. cannot be easily redeployed or deployed as quickly) or are much more expensive because of the long distances between the user site and the point of connection with the wired network. The values presented below could therefore *underestimate* the value of spectrum to some users because they do not count the loss of the other benefits (e.g. flexibility) associated with wireless solutions.

[70] We note Ofcom's model for computing mobile termination rates makes this assumption.

The spectrum value estimates we obtain depend importantly on whether civil work is required to connect the user's site (e.g. office) to a wired network access point. In the case where no civil work is required, the resulting values of spectrum are negative indicating it is cheaper to use a wired technology (see Appendix D). Users in this situation would not be applying for fixed link spectrum licences (as they would already opt to use cheaper wireless options). Hence we focus on the situation for a potential licensee where significant civil work is required to connect the user's site to a network access point.

In Appendix D we report the costs of providing a 100Mbps link and a 300Mbps – 1Gbps link using wired[71] and wireless technology, and take the cost difference divided by the spectrum required on the wireless link to derive a spectrum value. Values depend on:

- The transmission distance is more or less than 25km[72]. Transmission distances above 25km typically require frequencies below 10 GHz.[73] At shorter distances higher frequencies (in say the 10-20 GHz range) can be used and this results in lower equipment costs and site costs.
- The length of connection from the user's site to existing wired network infrastructure – we test the impact of 1km, 5km and 15km connection distances[74]. The greater the connection distances the more expensive the 'wired' alternative and so the higher the spectrum value
- Assumptions about the number of occupants at sites used by the wireless link – higher spectrum values are obtained with lower assumed site costs (more site sharing).

In Table 5-6 and Table 5-7 below, we report the range of values obtained for the different cases modelled and in particular each cell of the table gives the range of values across different assumptions concerning the number of site occupants at sites used by the wireless link. Negative values are not reported as in these cases the user would not be seeking to use spectrum – the wired alternative costs less than a wireless link. The ranges of spectrum values are similar for below 10 GHz and 10-20 GHz bands, falling in a range from very low values to around £1250/2x1 MHz.

Table 5-6: Value of spectrum – 100Mbps wired link plus connection to network access point versus 2x28 MHz wireless link

Type of wired connection	Value per 2x1 MHz		
	Wired link +1 km connection to network access point	Wired link +5 km connection to network access point	Wired link +15 km connection to network access point
100 Mbps link from BT (wholesale) < 25 kms and 10-20 GHz link	0 to 19	0 to 378	310 to 1276
100 Mbps link from BT (wholesale) > 25 kms and below 10 GHz link	0	0 to 354	286 to 1251

Source: Plum and Aegis analysis. See Appendix D

[71] BT Openreach does not offer products for bandwidths between 100Mbps and 300Mbps.

[72] The price of a BT Openreach Ethernet service depends on whether the transmission distance is more or less than 25km.

[73] See Table 6.2, Aegis et al (2011)

[74] It is assumed a connection from the user's site to the wired network is only required at one end of the link. However, as the costs vary almost linearly with distance the connection distance considered could as well be split between each end of the link.

Table 5-7: Value of spectrum – 300Mbps-1 Gbps wired link plus connection to network access point versus 2x56 MHz wireless link (£ per 2x1 MHz)

Type of wired connection	Value per 2x1 MHz		
	Wired link +1 km connection to network access point	Wired link +5 km connection to network access point	Wired link +15 km connection to network access point
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms and 10-20 GHz link	0 to 139	0 to 319	285 to 767
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms and below 10 GHz link	0 to 178	0 to 357	323 to 806

Source: Plum and Aegis analysis. See Appendix D

5.3.3 Summary

The LCA assessment presented above is based on the choices confronting a potential user of fixed links when the user is denied access to its desired frequency range. In this event the user may either use a higher frequency band or a wired alternative. For both of these situations there are several variables that have an impact on deployment costs:

- For a wireless link the costs depend importantly on site costs and the number of other occupants at a site with whom costs are shared.
- For a wired link the key variables are distance and the amount of civil work required to get from a user's site to wired network access point (e.g. to a local exchange or carriageway box).

A summary of the spectrum value estimates we have obtained is given in Table 5-8. The estimates for the wired alternative are arguably less reliable than those for an additional hop because: they do not count the flexibility benefits offered by fixed links; some users may receive substantial discounts on the published Ethernet and connection cost charges we have used; and there can be large variability in the civil works required to link a user's location to a network connection point.

Table 5-8: Summary of value estimates (£ per 2x1 MHz)

Frequency range	Additional hop	Wired alternative
< 10 GHz	124-619	0-1276
10-20 GHz	22-221	0-1251

5.4 Alternative use values

In Section 2, mobile was identified as a potential alternative use of the 3.6-3.8 GHz band. In this case there is UK auction data (for the 3.4 GHz band) that could be used to give an indication of the value of the band for mobile use. There is also auction data for the 1452-1492 MHz band which is harmonised for mobile use and which we also report for comparison. Table 5-9 describes the auction data points.

In the case of the 3.4 GHz band there were 15 (non-overlapping) regional licences which together cover the entire UK. We have aggregated these licence values to give the national value for 3.4 GHz shown in Table 5-10.

Table 5-9: Description of auction data points

Auction	Frequency	Package	National/ regional	Lots/licences sold	Data points
3.4 GHz (Jun 2003)	3480-3500/3580-3600	2x20 MHz (15 regions)	Regional	15 (out of 15)	15 regional
1.4 GHz (May 2008)	1452-1479.5, 1479.5-1492	1.7 MHz (16 lots), 12.5 MHz (1 lot)	National	17 (out of 17)	1 national

Source: Ofcom

Table 5-10: Annual values for national licences

Frequency band (GHz)	Time of auction	Annual value, £ per 2x1 MHz	Implied annual value per link, £ per 2x1 MHz
1.4	May 2008	55,724	1,114
3.4	June 2003	54,760	1,095

Source: Plum and Aegis analysis

The auction data for 1.4 GHz and 3.4 GHz suggests the opportunity cost of spectrum in the 3.6-3.8 GHz band could be much higher than that implied by current fee level of around £88/2x1 MHz. Furthermore, the auction values we have for the 1.4 GHz and 3.4 GHz bands are now quite old and there is good reason to expect the value of these bands to have risen further as they have recently been harmonised (at European level) for LTE.[75] The annualised auction price for the unpaired 2.6 GHz spectrum auctioned in 2013 was around £150,000/MHz i.e. around six times the annualised values given in Table 5-10 which suggests the values reported in Table 5-10 are conservative estimates.

Further information on the value of the 3.6-3.8 GHz band could become available in Europe in the next 2-3 years when the 3.4-3.8 GHz band is assigned in some countries (including the UK in the case of the 3.4 GHz band).

[75] An ECC Decision 13(06) on use of 1452-1492 MHz for mobile/fixed communications networks (MFCN) supplemental downlink was adopted in November 2013. The ECC has also updated its existing Decision on the use of 3.4-3.8 GHz for MFCN, ECC/DEC/ (11)06, to provide harmonised technical conditions for coexistence between MCFN and other users in the band.

5.5 Implied opportunity costs

The estimates of own and alternative use values derived in the above sections are listed in columns 2-4 of Table 5-12 below.

In the fifth column of the table, we report the LCA own use value capped by values derived from the 4 GHz auction values (i.e. values for the auction of spectrum in the 3.4 GHz band). The cap for each band is calculated as the 4 GHz value divided by the ratio of the band reuse values given earlier in Table 5-1. The capped values are therefore as shown in Table 5-11.

Table 5-11: Assumed reuse factors by band

Band	Assumed reuse	Reuse relative to the 1.4 and 3.4 GHz bands	Capped value (1095 divided by the relative reuse value in previous column)
1.4 & 4 GHz	50	1	1095
6, 7.5 & 10GHz	150	3	365
13-18 GHz	400	8	137
23-28 GHz	600	12	91
32-40 GHz	1000	20	55

Source:Plum and Aegis analysis

We have applied the capped values given in the right hand side column of Table 5-11 as an upper bound on the opportunity cost for each band on the grounds that the value of spectrum to mobile services is likely to be significantly more than that for fixed services.

Our best estimate of the opportunity cost is given in the sixth column of Table 5-12. The logic we applied to derive these values is as follows:

- For the 3.6-3.8 GHz band the alternative use value of £1095/2x1 MHz is just above the top end of the LCA values and is a very conservative estimate of the value of the spectrum for mobile use. It could therefore be said to provide a reasonable estimate of the opportunity cost for these bands given the likelihood of future mobile use of the spectrum.
- For the other bands below 10 GHz there is no alternative use. As LCA values at the bottom of the range for each band (see column 3) are 40% to 90% in excess of current fees, there are good reasons to think the opportunity cost is likely to be towards the low end of the ranges given in Table 5-12. Otherwise Ofcom would be under considerable industry pressure to release more spectrum for fixed links which is not the case.
- For bands between 10 and 20 GHz, values at the bottom end of the range are below current fees. As the bands are moderately congested, there is good reason to think that opportunity cost is in excess of current fees. We suggest values slightly (around 10%) above current fee levels so that the value for 10-16 GHz is £42/2x1 MHz and the value for 16-20 GHz is £29/2x1 MHz.
- For bands above 20 GHz, the current AIP fees are a factor of 10-100 more than the auction values. Whilst there are good reasons to believe the auction values are likely to be an

underestimate of current market values, the opportunity cost of the spectrum seems likely to be well below current AIP fee levels.

Table 5-12: Estimated values per link per 2x1 MHz, implied opportunity cost and current fees (£)

Band	Own use – Auction value (Note1)	Own use – Least cost alternative (Note 2)	Alternative use – auction value (Note 3)	Capped value derived from 4 GHz auction value (Note 4)	Implied opportunity cost estimates	Current AIP fee (Note 5)
1.4 GHz	-	124-619	n.a.	1095	124	88
3.6-3.8 GHz	-	124 – 619	1095	1095	1095	88
3.8-4.2 GHz	-	124-619	n.a.	1095	124	88
6 & 7.5 GHz	-	124 – 619	n.a.	365	124	65
10 GHz,	1.8	22-221	n.a.	365	42	38
13 & 15 GHz	-	22-221	n.a.	137	42	38
18 GHz	-	22-221	n.a.	137	29	26
23, 25, 28, GHz	0.3-3	n.a.	n.a.	91	~3	23-26
32 GHz	0.16	n.a.	n.a.	55	~3	23
38 GHz	0.02	n.a.	n.a.	55	~3	23
40 GHz and above	0.02	n.a.	n.a.	55	~3	15

Source: Plum and Aegis analysis

Note 1: Values come from Table 5-3 and Table 5-4.
Note 2: Values come from Table 5-8
Note 3: Values come from Table 5-10
Note 4: Values given in Table 5-11
Note 5: The fee is calculated assuming the availability and path length factors each have a value of 1.

6 Fixed link algorithm

6.1 Introduction

Since 2006 fixed link fees have been set based on the following algorithm:

$$\text{AIP Fee} = Reference\ fee \times \text{Bandwidth factor (Bwf)} \times \text{Frequency band factor (Bf)} \times \text{Path length factor (Plf)} \times \text{Availability factor (Avf)}$$

The purpose of different factors in the current fixed link fee formula for bi-directional links is to reflect the opportunity cost of use and spectrum use denied to others by a licensee[76]. Specifically the bandwidth, path length and availability factors all potentially relate to the spectrum use denied to others. The frequency band factor reflects variations in the value of spectrum by band that may arise, for example, from differences in the physical properties of bands and demand for the band. It needs to be recognised that the algorithm is not (and cannot be) based on a precise set of engineering and/or economic relationships but rather is intended to provide appropriate incentives for efficient spectrum use. Table 6-1 sets out the values of parameters in the fixed link algorithm.

Table 6-1: Current fixed link spectrum fees formula

Parameter	Value / Range
Reference fee	£88 per 2 x 1 MHz
Bandwidth factor	Directly relates to amount of bandwidth licensed per link
Frequency band factor	Values are: • 1 for below 4.2 GHz; • 0.74 for 5.92-7.9 GHz; • 0.43 for 10.7-15.35 GHz; • 0.3 for 17.3-23.6 GHz; • 0.26 for 24.5-39.5 GHz; • 0.17 for 49.2-57 GHz.
Path length factor	Varies between 1 and 4. It is higher than 1 if the path length is less than the minimum path length for the band as defined by Ofcom.
Availability factor	0.7 for 99.9% availability. A higher value if higher availability requested.

Source: Schedule 3, Electronic Communications, The Wireless Telegraphy (Licence Charges) Regulations 2011, Statutory Instrument 2011 No. 1128.

A uni-directional link pays 75% of the calculated fee for a bi-directional link. This reflects, in part, that the use of the return frequency will be restricted as the majority of assignments are for paired frequencies. In the case of an additional link operating co-channel and cross-polar over the same path as an existing assigned link, the user pays 50% of the fee. This reflects the re-use of the same

[76] See Para 1.67-1.69, Appendix A, SRSP op cit.

frequencies but also takes into account the impact of having to account for both horizontal and vertical polarisations being used.

In addition Ofcom has set interim fees for five years (or less if a review of fixed link fees proposes lower values) for the managed parts of 71 GHz and 81 GHz bands as shown in Table 6-2. The fees are based on the average link fee in the 38 GHz band[77].

Table 6-2: Interim fees for 71 GHz and 81 GHz bands

Channel size ranges (MHz)	Pro-rated interim fee (£)
<250	100
250	225
500	450
750	675
1000	900

Source: Spectrum management in the 71-76 GHz and 81-86 GHz bands, Ofcom Statement, December 2013

A pricing algorithm might include other factors to reflect the opportunity cost of the spectrum used and/or spectrum occupancy, such as use of more efficient technologies. Before implementing such factors, it is necessary to check that the deployment of more efficient technologies results in less spectrum occupancy by the individual user (and not just wider benefits to other users[78]) and that the factors used in the algorithm can be taken into account in Ofcom's assignment and licensing process.

A number of new and specific fixed link technologies have been identified in the course of our work namely MIMO, Mesh and non-line of sight (NLOS) in built-up environments (see Appendix C). The impact of these technologies on spectrum denial is uncertain – they may benefit the user but cause interference to others. Also in the case of MIMO the scale of any impacts is too uncertain and mesh and NLOS links in urban areas are most likely to be deployed by users in self-managed spectrum bought at auction in which case the fixed link algorithm does not apply. In particular:

- In the case of MIMO it is possible to increase the link capacity without requiring further bandwidth but there could be increased interference to other links. Lack of experience with MIMO means it is too soon to know the scale of these impacts with any certainty.
- Mesh networks may improve system and spectrum efficiency by statistically multiplexing traffic from multiple transmitter sites so that the traffic peaks from one site may cancel out the troughs from another. Overall the data throughput requirements are reduced as it is not necessary to cater for the maximum data requirements on each individual link and this could lead to less bandwidth being required to connect the same transmitter sites as shown in Figure 6-1 below. However, deployment of mesh networks will require users to have flexibility to add and remove nodes as required and this will be most easily implemented by users in self-managed blocks of

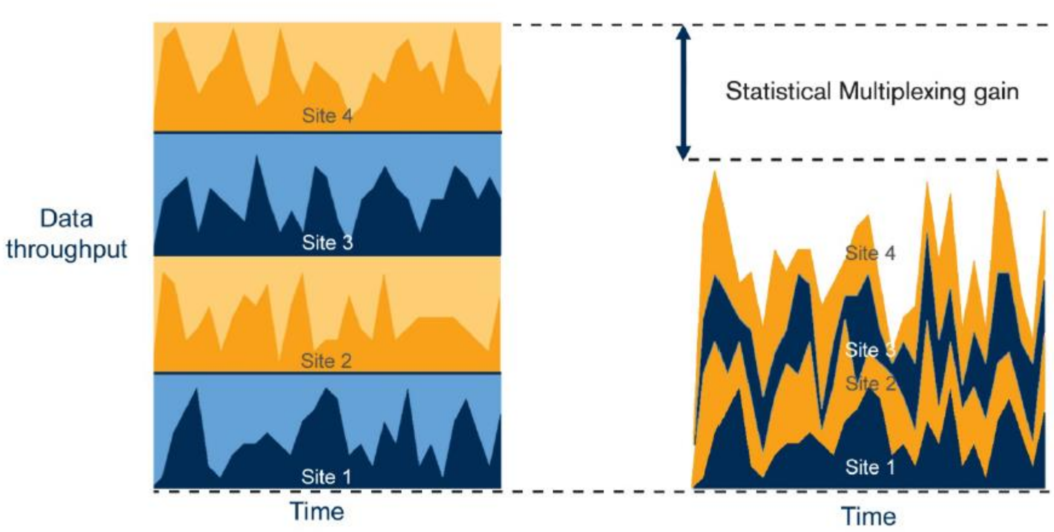
[77] See paras 5.53-5.61, Review of the spectrum management approach in the 71-76 GHz/81-86 GHz bands, Consultation, Ofcom August 2013 http://stakeholders.ofcom.org.uk/binaries/consultations/70-80ghz-review/summary/condoc.pdf

[78] For example some equipment options might directly benefit the applicant / licensee, such as adaptive modulation so they can transmit more data, whilst other options might not benefit the applicant / licensee directly.

spectrum. Hence mesh networks are not likely to be deployed on a per link basis in bands managed by Ofcom.

- Similarly NLOS links in urban locations are likely to be deployed in self-managed blocks of spectrum because of the need to change their deployment in response to changes in urban clutter. Again the fixed link algorithm is not applicable.
- While NLOS links outside of urban areas (mainly rural) do not face these issues, we note that Ofcom's assignment tools do not support such an option. It is a matter for Ofcom to decide to whether they want to implement the non-line of sight option within their planning tool, for example, by including data to take account of topography, buildings and other physical obstacles to radio transmissions.

Figure 6-1: Comparison of data throughput of conventional point to point links versus mesh network



Source: ECC Report 173, Fixed Service in Europe, March 2012

In summary, we conclude that it is not appropriate at present to include factors in the fixed link algorithm for MIMO, mesh and NLOS links. In future Ofcom may wish to consider whether it is worthwhile enhancing its planning tool to take account of topography, buildings and other physical obstacles to radio transmissions to facilitate NLOS links. If this is done then the algorithm could also include a NLOS parameter. Until these new planning methods are established it is not known how this might be taken into account in fees.

The following factors for the algorithm are discussed below: reference fee, frequency band, bandwidth and modulation, power and availability, link length, power control and variable bit rate; high performance antennas and geographic location.

6.2 Reference fee

The reference fee is set for a reference band and then fees for other bands vary according to the frequency band factor. The current reference band for the fixed links algorithm is the 4 GHz band while the reference band for satellite algorithm is the 14 GHz band. As the satellite fees are based on those for a typical unidirectional fixed link it would be seem preferable (for reasons of consistency and transparency) to use the same band as the reference band in the fixed link and the satellite algorithms.

We propose to use the 13 GHz band (12.75 – 13.25 GHz) for this purpose, as it is shared between fixed links and satellite transmit earth stations (unlike the 14 GHz band which is only a satellite transmit band). Also, the status of the 4 GHz band for the purposes of setting AIP is complicated by the fact that part but not all of the band has mobile as a potential alternative use and the estimated opportunity cost for the part of band available for mobile use could change following the 3.4-3.6 GHz auction scheduled for 2015/2016.

The reference fee for the 13 GHz band is our best estimate of opportunity cost as given in Table 5-12, namely £42/2x1 MHz for a typical fixed link. If the current reference fee is rebased to the 13 GHz band (and not 4 GHz), then it would be £38/2x1 MHz – see Table 5-12). Hence the proposed reference fee of £42/2x1 MHz is around 10% more than current levels.

We propose that a separate reference fee is set for the 3.6-3.8 GHz band based our conservative estimate of opportunity cost for the band, namely £1095/2x1 MHz.

6.3 Frequency band factor

The frequency band factor should in principle be revised to reflect the opportunity cost estimates given in Table 5-12.

For comparison we have also calculated the band factors implied by the physical characteristics of transmissions as given by the relative transmission range that can be achieved by different bands. There are two options:

- **Option 1**: Set the factor based on the inverse of the frequency: Transmissions in lower bands tend to travel further and interference is therefore more likely thereby reducing the potential for frequency re-use and so increasing opportunity cost (all else being equal). We note that in Germany fixed link fees are inversely related to frequency (though with minimum and maximum fees set)[79] and in France a similar inverse relationship applies though the schedule is not quite as steep as that implied by a strict inverse relationship to frequency[80].
- **Option 2**: Set the factor based on the inverse of frequency squared: The impact of one fixed link on another is determined by the capture of the signal by a receiver which is inversely proportional to frequency squared. It could be argued that this better reflects opportunity cost but in practice propagation conditions less perfect than free space will reduce this effect.

A comparison between these two approaches and the current band factor is shown in Figure 6-2. It can be seen that the current factor is similar to the simple inverse frequency approach, though less steep, and that a factor based on the inverse of frequency squared would give a steeper change in the factor.

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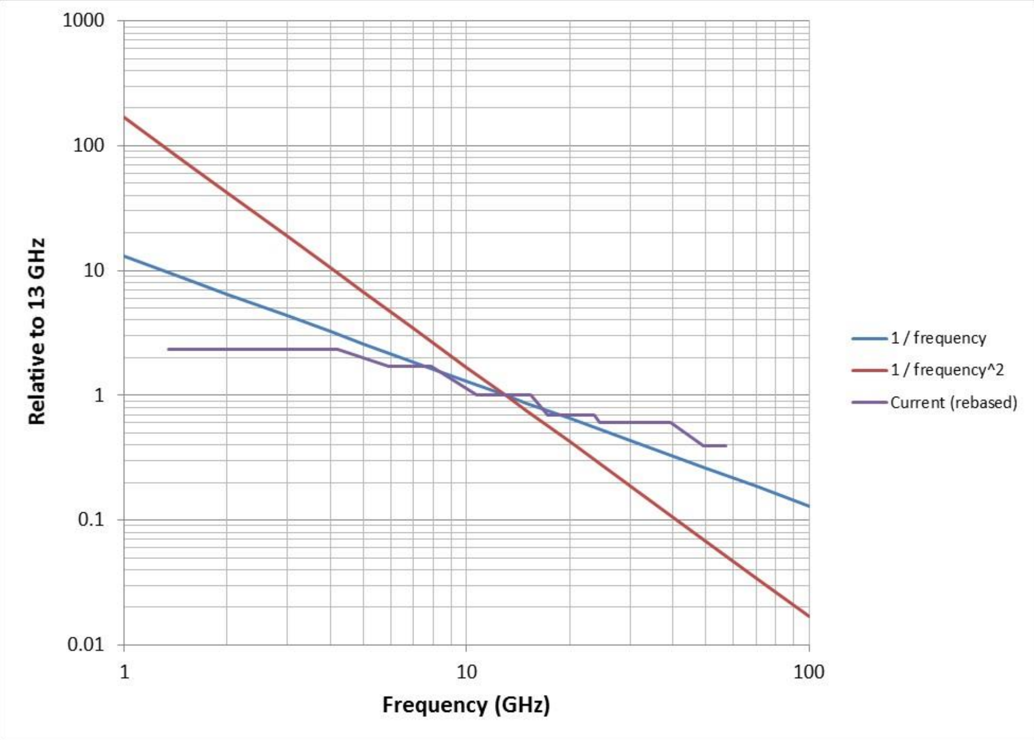
79 http://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/BNetzA/Areas/Telecommunications/TelecomRegulation/FrequencyManagement/FrequencyAssignment/CalculationoffrequencyassigId599pdf.pdf?__blob=publicationFile&v=2

80 http://www.arcep.fr/sides/index.php?id=8082

Figure 6-2: Relation to inverses of frequency and frequency squared



Source: Aegis analysis relating frequency to distance and distance squared assuming 13 GHz to be the reference point (i.e. equal to 1)

Table 6-3 shows the implied band factors using the two approaches just described and an **Option 3** in which the opportunity cost estimates given in Table 5-12 are used to derive a band factor. We assume that the 13 GHz band is used as the reference point and use continuous frequency ranges based around breakpoints in the current fees schedule and breakpoints given by the opportunity cost analysis in Section 5 with values normalised accordingly (though with a higher upper limit to accommodate the 70/80 GHz band).

As can be seen, all three options for the band factor imply relatively lower fees for bands above 20 GHz and (the approaches based on propagation imply) relatively higher fees below 10 GHz assuming the reference fee is the same in all cases. In some cases the changes in fees – up and down – could be large and impacts on demand could be correspondingly large. For example in the case of Option 1 (inverse relationship to frequency) fees for bands below 16 GHz would increase by 0-180% while those above 16 GHz would decline by 7-35%. We do not know the likely scale of the demand response to such large changes in fees. However, there are clearly risks of spectrum being left idle at low frequencies (if fees increase substantially) and excess demand at higher frequencies (if fees fall substantially).

This suggests taking a more gradual approach to changing the band factor than those implied by the three options shown. We propose an intermediate option between the current band factor and an inverse frequency relationship as shown in the final column of Table 6-3. In doing this we have assumed the high opportunity cost of the 3.6-3.8 GHz band is addressed through a different reference value.

Table 6-3: Band factors from propagation model, opportunity cost estimates and current factors (assuming 13 GHz band is the reference band)

Frequency band range	Option 1: Band factor based on inverse of frequency	Option 2: Band factor based on inverse of frequency squared	Option 3: Band factor implied by opportunity cost estimates in Table 5-11	Current band factor – rebased to 13 GHz reference band	Proposed Band Factor
1.35 ≤ fb < 3.60	6.50	42.25	1.79	2.33	4
3.60 ≤ fb < 3.80	3.25	10.56	18	2.33	3
3.80 ≤ fb < 5	3.25	10.56	1.79	2.33	3
5 ≤ fb < 10	1.86	3.45	1.79	1.72	1.8
10 ≤ fb < 16	1.00	1.00	1.00	1.00	1
16 ≤ fb < 20	0.65	0.42	1.00	0.7	0.7
20 ≤ fb < 24	0.59	0.35	0.05	0.7	0.4
24 ≤ fb < 40	0.43	0.19	0.05	0.6	0.3
40 ≤ fb < 57.0	0.26	0.07	0.05	0.4	0.2
57.0 ≤ fb < 100.0	0.19	0.03	0.05	-	0.1

Source: Plum and Aegis analysis

6.4 Factors impacting on spectrum use denied to others

The reference fee is derived as the value of 2x1 MHz for a typical link in a reference band and the band factor may partly reflect variations in the geographic area denied by a typical link in each band.

In this section we consider ways in which the following factors impact on spectrum use denied to others: bandwidth and modulation state; link availability and transmitter power; link length; power control and antenna efficiency.

6.4.1 Bandwidth / Modulation

The amount of bandwidth that is assigned per link will have a direct impact on the amount of spectrum available for use by others. Users are already encouraged to use the minimum amount of bandwidth through the existing bandwidth factor in the fees formula e.g. this incentive will ensure that higher more spectrally efficient modulation states will be used where possible (noting that there is no longer an equipment cost differential associated with the use of different modulation states). We therefore do not propose to modify the algorithm to include a modulation factor.

6.4.2 Availability/transmitter power

The current fees formula uses availability as a multiplier as shown in Table 6-4 below:

Table 6-4: Availability factor depending on link percentage of availability requested

Percentage of availability	Availability factor (Avf)
Availability ≤ 99.9%	Avf = 0.7
99.9% < Availability < 99.99%	Avf = 0.7 + (Availability x 100 – 99.9) x (0.3/0.09)
99.99% ≤ Availability	Avf = 1.0 + (Availability x 100 – 99.99) x (0.4/0.009)

We have considered whether transmitter power should be introduced into the formula as an alternative to availability. Transmitter power and availability are to some extent interchangeable as the transmitter power required to operate over a link is determined by Ofcom as part of the assignment process, taking into account the receiver antenna gain and the requested availability. Hence availability can be considered to be a proxy for transmitter power encouraging licensees to only apply for the minimum necessary power to meet their overall system / link requirements. If transmitter power were used it might be necessary to set different values for the factor by frequency range / band. The one disadvantage of using availability is it does not necessarily encourage the use of higher performance antennas with higher gain and associated improved off-axis polar patterns[81].

Overall, as this is a managed service by Ofcom on behalf of the users, we consider availability an appropriate factor to include in the algorithm. The licensee is fully aware of the fee implications when requesting an assignment with higher availability values and the availability factor can be applied across all the frequency bands. Also the current formula appears to be sufficient to influence decisions as there is a wide mix of availabilities requested by fixed link users.

6.4.3 Link length

Originally Ofcom had a link length policy that meant if a licence application in a band had a link length that was less than the allowed minimum link length for the band then the application was refused[82]. This policy was later reflected in the fees algorithm by charging higher fees for shorter links and allowing the applicants to decide whether they were willing to pay a premium to deploy short links, for example, to minimise their spares holdings by using equipment operating in one band.

The current path length factor is as shown in Table 6-5. It is unclear how the factor was derived.

[81] A licensee may not exceed the allowed EIRP from the antenna stated in the licence and the options available are to either use a higher transmitter power and lower gain antenna or a lower transmitter power and a higher gain antenna.

[82] The aim of the policy was to prevent all users opting for the lower frequency bands for which equipment was cheaper. Longer links, because of the propagation characteristics, are cheaper to deploy in lower frequency bands.

Table 6-5: Multipliers depending on relationship between path length and minimum path length

Relationship between PL and MPL	Path length factor, Plf = √(MPL / PL)
MPL ≤ PL	1
MPL > PL	Smaller of $(MPL / PL)^{0.5}$ and 4

We consider that this factor is not required as the frequency band factor in the fee algorithm already provides an incentive for operators to select higher bands for shorter links. This incentive will be even greater if the band factor is adjusted (made steeper) in line with the earlier discussion of Section 6.3.

6.4.4 Power control

Historically, fixed links have been planned on the basis of providing a static throughput that is available for a very high percentage of time, with only the severest of fades (due to self-interference caused by multiple paths along the link or attenuation caused by rain) making the link unavailable. This meant that a significant amount of power is transmitted continuously and a correspondingly high signal received most of the time. The difference between “continuously” at one end of the link and “most of the time” at the other end of the link represents the small amount of time when the signal fades due to the varying behaviour of the propagation medium. The additional transmitter power overcomes such fading.

Rather than basing link operations on a static transmit power level and throughput / bit rate, it is possible to obtain advantage by varying the transmit power level or the bit rate:

- Transmit power level: Rather than transmitting at a relatively high power level continuously, automatic transmit power control is used so only the power that is needed at any instant is transmitted. This has the effect of reducing the overall power transmitted and therefore decreases the likelihood of interference to other users, potentially allowing for more links to be planned.
- Bit rate: Rather than transmit at a fixed throughput that has been sized around the faded state, the bit rate can be varied as the signal on the faded path changes. This means that a higher bit rate can be used most of the time when the link is unfaded.

One or other of these two options is advantageous as they both increase the efficiency of spectrum use. From a users’ perspective the benefits are as follows:

- Implement a variable bit rate on the link so that additional capacity is available on the unfaded link and the “core” rate is guaranteed during a fade[83]. Current planning is based on the “core” rate so there is no change to the planning but there is a benefit to the fixed link licensee.
- Implement automatic transmit power control (ATPC) so that additional power is only used during a fade. There is no benefit to the fixed link licensee[84] but there is potential benefit to the fixed link community in terms of accommodating more links overall.

[83] Licensees can do this at present.

[84] Although less power is used, the financial saving is minimal as the magnitude of the EIRP is largely determined by the gain of the antenna. For example, the transmitter without power control will have a representative steady state power level of 1 Watt

Licensees will implement variable bit rate links if the benefits outweigh the additional cost which we understand is minimal. Similarly most recent equipment supports ATPC[85] but there is no benefit to the user in using the equipment and we understand that the current Ofcom planning process is not able to take it into account.

On the basis that new equipment will support ATPC and that its use should be encouraged, there are two further considerations, namely:

- Is Ofcom able to include ATPC in its planning processes?
- What is the efficiency gain from ATPC? Deriving an answer to this question is a major piece of work.

Both issues need to be addressed before including a factor for power control in the algorithm.

6.4.5 High performance antennas

In general there is a benefit for fixed link planning in terms of allowing for a higher density of links through the use of high performance antennas. The extra discrimination available from high performance antennas to mitigate against interference to and from other fixed link transmitters depends on the exact geometry involved, so the benefit ranges from insignificant to significant.

The benefit of using high performance antennas to the user will depend on the circumstances of the link deployments:

- In situations where there is little or no congestion using a high performance antenna is of no benefit to the user but is potentially of benefit to subsequent users in the band were there to be congestion in the future.
- Where there is congestion however the use of a high performance antenna might allow the user to implement a link without causing / receiving interference whereas use of a standard (lower performance) antenna might not allow the user's link to be accommodated.

In the second case one would expect the user to deploy a high performance antenna in order to gain access to the frequency band without any specific financial incentives. However, given the possibility of future congestion in some bands there could also be potential benefits to future users from use of high performance antennas. Thus, we consider that in principle incentives should be in place to promote use of high performance antennas in bands that are or are expected to be congested (e.g. below 20 GHz).

We note that Ofcom does not allow the use of specific classes[86] of antennas with lower performance. It is also mentioned in the Point-to-point Fixed Wireless Interface Requirement (IR 2000) that

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(representative) and with power control a level of 1 mW (representative) for most of the time. If it is assumed that the power amplifier efficiency is 50% then the power control saving is (365 days x 24 hours x ~1 Watt) / 0.5 efficiency = 17.52 kWh/year which amounts to approximately £2 per year assuming a tariff of 10p per kWh.

[85] ETSI standards have recommended the use of ATPC.

[86] As defined in the OfW 446 (Technical Frequency Assignment Criteria): "Ofcom will accommodate antennas that comply with ETSI Class 1 (ETSI EN 302 217) co-polar and cross-polar Radiation Pattern Envelopes (RPEs) or better in the 1.4 GHz frequency band and ETSI Class 2 co-polar and cross-polar RPEs or better in all other frequency bands". Also it is noted Ofcom have defined minimum spectral efficiency classes in the UK Interface Requirement 2000 so the approach of specifying minimum requirements is already established.

"Operators will be encouraged to use higher performance antenna options on congested sites. They may also be advised to use a higher performance antenna when assignments are otherwise impossible". In other words the assignment policy contains rules to promote the use of higher performance antennas. These rules could be made more demanding (e.g. require the use of higher performance antennas) in locations where there is high spectrum demand.

Alternatively, a factor in the fixed link fee algorithm could be introduced to incentivise use of high performance antennas more generally. The approach to setting this factor could be based on detailed modelling of assignment efficiency using real data or based on a simplified approach, much akin to denial areas used elsewhere, using relative areas determined by the different antenna patterns of the different antenna classes. This is beyond the scope of this study.

6.5 Geographic location

When AIP was first implemented by the Radiocommunication Agency (RA) in 1999 higher fees were charged in congested areas as defined by grid squares[87]. Areas were defined as congested or not based on the number of links in the grid square and mainly urban locations were defined as congested. If a link started or ended in a congested grid square (or both) then a higher fee was charged. A more granular approach to defining areas was subsequently considered by the RA in 2003 focussing on specific transmission sites. A site was defined as congested if more than half the available frequency slots at that site were assigned. This approach however proved impractical to implement and there was concern that it would reduce incentives for site sharing. Any variation in fees by location was dropped from 2005.

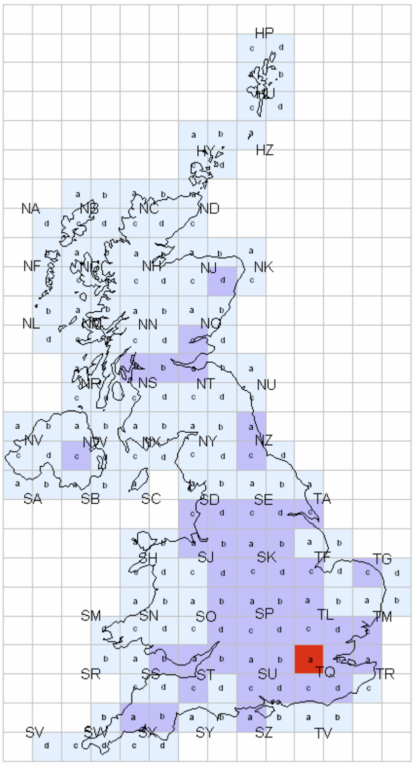
Below we review evidence on the geographic variation in use of spectrum consider whether there is evidence suggesting a geographic variation in congestion and whether this justifies the application of a location factor, taking account of any implementation issues. We distinguish between bands where the alternative use is mobile and those where there is no alternative use.

6.5.1 Bands where the alternative use is mobile

To reflect the geographic nature of demand for business radio frequencies, current business radio fees vary by location. This is based on population density with three categories of location – high, medium and low density in 50x50km grid squares as shown in Figure 6-3. Arguably the value of spectrum to MNOs is also greater in areas of high population density as can be seen in auction prices in those countries that offer regional licences (e.g. Canada and the US).

[87] The approach is summarised in paras 1.28-1.32, Appendix A, SRSP, op. cit.

Figure 6-3: Population density categories used for Business Radio



Key:

Category A – High Population (red) – 3m or more per 50km square;

Category B – Medium Population (purple) – 300,000-3m per 50km square;

Category C – Low Population (light blue) – less than 300,000 per 50km square

To give appropriate incentives for efficient use by fixed services where mobile is a higher value alternative use, fees should be higher in areas where frequencies for mobile use are in greatest demand. We suggest the same or a similar approach to that used for Business Radio could be applied to, say, the 3.6-3.8 GHz band - with any link originating in, ending in or crossing a low density area or any PES operating in a low density area attracting a lower fee (i.e. receiving a discount).

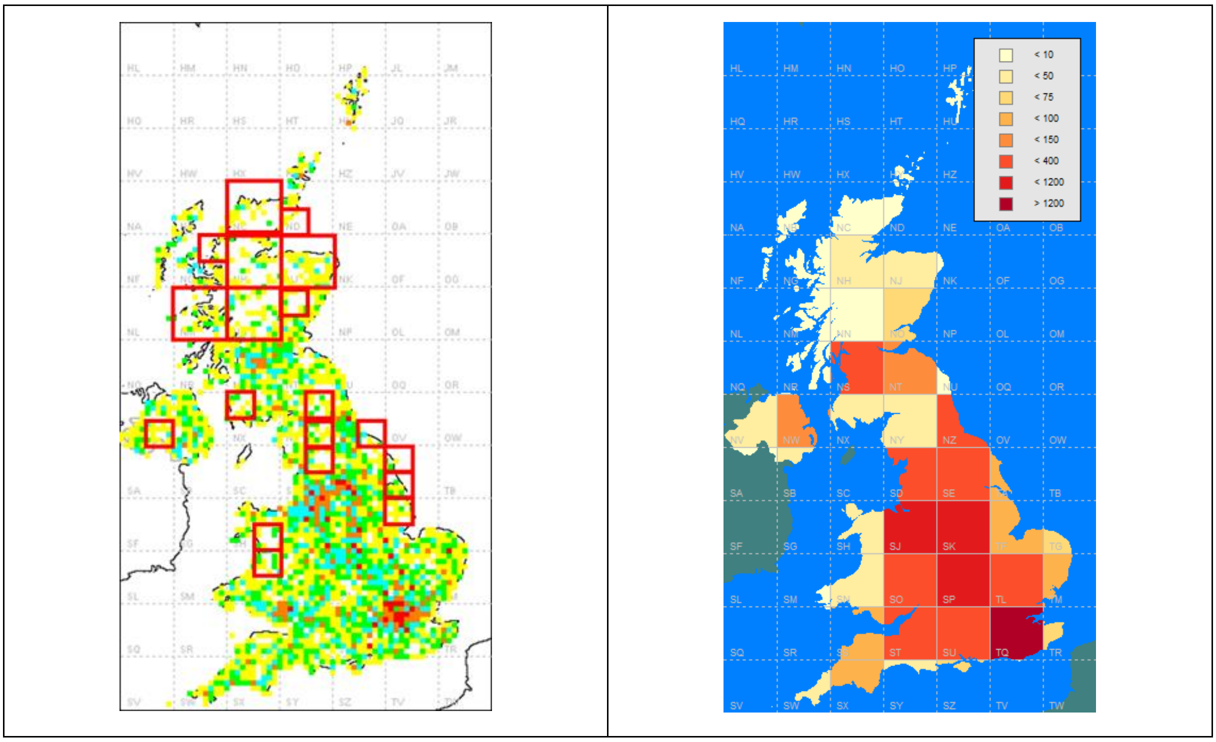
We suggest using an approach based on grid squares. While this can create incentives to locate just outside high/medium density squares to take advantage of lower fees while still denying others in the grid square spectrum access, we consider that these risks are small because of the way such systems are deployed and are outweighed by the benefits from incentives to locate further away from high/medium density areas. However, consideration should be given to using larger grid squares than the 50km squares used for Business Radio (e.g. 100kmx100km) as exclusion areas for both fixed links and satellite use at low frequencies are likely to be larger than for Business Radio.

6.5.2 Frequency bands where there is no alternative use

In Section 4, we noted the density of fixed link assignments varies by location and a higher density of links is apparent in and around urban areas for frequencies at 10 GHz above. We have considered the possibility of a discount to opportunity cost based fees in areas of low link density for bands above 10 GHz.

For example, on the left hand side of Figure 6-4, we have identified areas with a low density of links in the 18 GHz band as shown by the red squares[88]. Comparison with the right hand graphic in Figure 6-4 (reporting population density) shows the red grid squares (on the left hand side) tend to correspond to areas of very low population density – less than 75 people per square kilometre (shown in yellow on the right hand side). A location discount could therefore be justified in areas with low population density. While the approach is approximate it is in our view better than no differentiation by location.

Figure 6-4: Areas of low density of links in the 18 GHz band (LHS) and UK population density data from 2011 census (RHS)



We do not have access to the link data required to identify low use areas more precisely. Ideally low use areas would be identified by the number of assignments located in and crossing each grid square. If this is too complex then the number of assignments per grid square could be used as a measure of congestion, with areas of low use offered a discount.

6.5.3 What discount should apply?

In principle the scale of the discount could be based on the ratio of the population or link density in the low versus the high demand areas, subject to all fees being set at least at levels that recover Ofcom's spectrum management costs. Based on the population data this could imply discounts of up to 90%.

[88] The geographic areas were determined on a visual basis as we do not have access to the raw data. They are based on no 10 km x 10 km squares with higher density of links (red or orange equating to >32 links or between 17 and 32 links respectively) and also some 10 km x 10 km squares with no links.

Geographic discounts for low population areas in Business Radio AIP fees vary depending on the cell radius of the business radio transmissions and range from 30% to 90%. The basis for these discounts is not known. As there is little, if any, congestion in low use locations, AIP principles suggest that fees in these areas should be set based on cost-recovery fees.

6.6 Conclusions

Our proposals in respect of the fixed link algorithm are:

- The 13 GHz band should be used as the reference band (and this should also be used for the satellite algorithm)
- The reference fee for the 13 GHz band should be based on our best estimate of opportunity cost i.e. £42/2x1 MHz. This fee should be applied to all bands together except the 3.6-3.8 GHz band. Here we suggest a high reference fee of £365/2x1 MHz which is based on an opportunity cost for the band of £1095/2x1 MHz reflecting the potential for use of the band by mobile services.
- We propose a band factor as shown in the table below. This is intermediate between the current band factor and an inverse frequency relationship

Frequency band range	Proposed Band Factor
1.35 ≤ fb < 3.60	4
3.60 ≤ fb < 3.80	3
3.80 ≤ fb < 5	3
5 ≤ fb < 10	1.8
10 ≤ fb < 16	1
16 ≤ fb < 20	0.7
20 ≤ fb < 24	0.4
24 ≤ fb < 40	0.3
40 ≤ fb < 57.0	0.2
57.0 ≤ fb < 100.0	0.1

Source: Plum and Aegis analysis

- The bandwidth and availability factors should be retained in their current form
- The path length factor should be removed as this is a choice for the user and the band factor already provides an incentive to use higher frequency bands for short links.
- A geographic location factor should be included in the algorithm, with discounts given in areas of low spectrum use as follows:
  - In bands where mobile is an alternative use (i.e. 3.6-3.8 GHz) lower fees (i.e. discounts) should apply in areas of low population density as defined for the purposes of setting Business Radio fees

- In bands where there is no alternative use lower fees (i.e. discounts) should apply in bands where there are relatively few fixed link assignments in and crossing an area (i.e. grid square). If it is not practical to assess this measure, then the number of assignments could be used.
- As a minimum, fees in low demand areas should be set at cost-recovery levels.

At present, uni-directional links currently pay 75% of the calculated fee for a bi-directional link and an additional link operating co-channel and cross-polar over the same path as an existing assigned link the user pays 50% of the fee. We consider these approaches should be continued.

We suggest that Ofcom also considers:

- The introduction of a factor related to the use of high performance antennas, as these can affect the area over which spectrum use is denied. Further, detailed modelling using representative deployments (based on Ofcom licence data) is required to determine appropriate parameter values.
- The inclusion of a factor for ATPC. This will require that the following two issues are addressed:
  - Is Ofcom able to include ATPC in its planning processes?
  - What is the efficiency gain from ATPC?

7 Satellite algorithm

7.1 Current algorithm

The algorithm that currently applies to Permanent Earth Stations (PES) is:

$$\text{AIP Fee} = \sum_{bands}\left[\beta \times BF_{band} \times \sqrt{\sum_{paths_{band}}(P_{path} \times BW_{path})}\right],$$

where:

β = the reference fee and has a value of 28

P_{path} = peak power delivered into the antenna for each transmission path (W)

BW_{path} = transmit authorised bandwidth for each transmission path (MHz)

BF_{band} = band factor equal to: 2.33 for frequencies less than 5 GHz; 1.72 for 5-10 GHz; 1 for 10-16 GHz; 0.7 for 16-24 GHz; and 0.60 for frequencies greater than and equal to 24 GHz. The 14 GHz band is defined as the reference band and has a band factor of 1.

Band = five defined band ranges with boundaries at 5, 10, 16 and 24 GHz

Path = between a transmit earth station and a satellite receiver being defined by frequency, polarisation, peak power and bandwidth.

The reference fee for the algorithm was derived from AIP fees for a typical unidirectional fixed link in the 14 GHz band and assuming typical earth station power and bandwidth values for the band[89]. A unidirectional link was chosen because it has a transmit and a receive component that are protected as is the case for a satellite earth station. The band factors in the satellite algorithm are the same as those used for the fixed links algorithm normalised to the 14 GHz band (and not the 4 GHz band as is used in the fixed link algorithm).The inclusion of power and bandwidth in the fee formula reflect the spectrum use denied to others.

7.1.1 Power / bandwidth aggregation

The 2006 spectrum pricing consultation explains the application of a square root function to the product of these two parameters as follows:

A discount for co-location of earth stations (the square root function)………reflects the fact that spectrum denial does not increase linearly with each additional earth station where usage of spectrum overlaps. The previous fee algorithm provided discounts for co-located earth stations irrespective of which frequency bands were in use. The current fee algorithm provides discounts for co-located earth stations operating within the same band.

In theory, and under free space conditions, two overlapping transmissions of equal power could effectively double the denial area and this would be achieved in the algorithm through a straightforward summation without a square root being applied. However, less benign propagation

[89] Annex 5, Modifications to spectrum pricing, Statement, Ofcom, 2007
http://stakeholders.ofcom.org.uk/binaries/consultations/pricing06/statement/statement.pdf

conditions and an imbalance in power between overlapping transmissions will reduce the aggregation effect significantly such that, for the example given, the result would fall between a factor of 1 and 2. Given the uncertainty of the aggregation effect within this range it is reasonable to use a square root function to reflect such a reduced impact.

More importantly, the algorithm as currently implemented provides the square root discount when transmissions (or accessible bandwidth in licensing terms) from co-located earth stations operate within the same frequency band but when they do not necessarily overlap. Mathematically there could be two summations for a band which can then be added; one with a square root as currently where transmissions overlap, and one without a square root where transmissions do not overlap. Strictly speaking the square root should only apply to those parts of transmissions that actually overlap rather than complete transmissions. Ofcom's licensing database includes entries for centre frequencies and associated accessible bandwidths so in principle the square root operation could be applied solely where actual overlap occurs. However, such a refinement cannot be implemented at present because licensees need to be able to calculate what fee is to be paid for their own transmissions without having access to Ofcom's licensing database which contains the necessary information regarding the transmissions of other parties.

7.1.2 Receive-only terminals

The PES algorithm applies only to the licensed transmitting earth station in a situation where the installation is both transmitting and receiving signals, as the receiver is not licensed but it is protected. In the case of a receive-only PES that has protection under RSA, a fee derived from the PES algorithm is applied to the receiver. The derivation of the RSA fees is based on the relative impact areas of a transmit and a receive earth station[90]. The starting point is the fee currently charged for a C-band PES transmitting at 6 GHz (£49/MHz)[91]. The fee is then modified according to the ratio of relative receive (4 GHz) and transmit (6 GHz) denial areas which is approximately a factor 0.25 and further modified by the ratio of applicable band factors (approximately 1.35 from the band factors 2.33 at 4 GHz and 1.72 at 6 GHz). This provides a baseline C-band RSA fee of £17/MHz with the opportunity to reduce this to £9/MHz or £4/MHz through the application of 10 or 20 dB of site shielding. Conversely, for earth stations with a more sensitive receiver (2 dB lower noise floor) that require protection the fee is £20/MHz.

7.1.3 Transportable terminals

Transportable Earth Stations (TES) are charged as shown in Table 7-1, where these fees are derived from the PES algorithm according to three ranges for the product of maximum power and bandwidth (p) and assuming a single path[92].

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[90] See Annex 6 of Recognised Spectrum Access ("RSA") for Receive Only Earth Stations in the Bands 1690 – 1710 MHz, 3600 – 4200 MHz and 7750 – 7850 MHz, Consultation, Ofcom, July 2010

[91] There is also a minimum fee per earth station of £500.

[92] See Annex 5, http://stakeholders.ofcom.org.uk/binaries/consultations/pricing06/statement/statement.pdf and Annex 5 in Additional spectrum for TES, Ofcom, Consultation, 2010 http://stakeholders.ofcom.org.uk/binaries/consultations/tes-additional-spectrum/summary/tes-additional-spectrum.pdf

Table 7-1: Fees schedule for TES

Range of p (defined below)	5.925 – 7.075 GHz	13.78 – 14.5 GHz	27.5 – 27.8185 GHz 28.4545 – 28.8265 GHz 29.4625 – 30 GHz
0 < p ≤ 100	£500	£300	£200
100 < p ≤ 2,500	£2,400	£1,400	£800
p > 2,500	£7,400	£4,300	£2,600

Notes: “p” is the product of *OMP* and *WBW*, where *OMP* is the Operational Maximum Power in Watts declared by the licensee *WBW* is the Widest Bandwidth in MHz declared by the licensee

7.2 Reference fee

The linkage between satellite and fixed link fees is based on the assumption that a typical satellite transmitter can be characterised as a unidirectional fixed link. The approach takes explicit account of the relative geographical areas impacted by spectrum used by PES versus fixed links installations. To do this it is necessary to:

1. Determine the area that a typical fixed link denies to another fixed link.
2. Determine the area that a typical earth station denies a typical fixed link.
3. Obtain the ratio of impacted areas which sets the difference in reference values.

Note that step 2 can be considered twice; when the earth station is a transmitter and when it is a receiver.

Using representative parameter values for both services as shown in Table 7-2 (for the 12.75 – 13.25 GHz band), and using the smooth earth diffraction model of ITU-R Recommendation 452, we have derived the relative areas denied as a PES / fixed link ratio. The ratio falls in the range 0.71 ±0.03 for a receiving PES and 1.42 ±0.04 for a transmitting PES where the ranges given relate to the range of assumed elevation angles of 3 to 35 degrees. It can be seen from Figure 7-1 that there is little elevation dependence since the increased PES horizon gain at low elevation angles is mitigated by the diffraction loss.

The transmit capability of the representative PES results in a greater geographic area impacted than the protection of receive capability from interference. It is therefore the transmit PES / fixed link area ratio that should be used to relate PES fees to fixed link fees. For the receive-only case addressed at the end of this section, consideration could be given to adjusting this factor from 1.4 to 0.7 in order to reflect the different denial areas that are obtained when using typical receive characteristics rather than typical transmit characteristics.

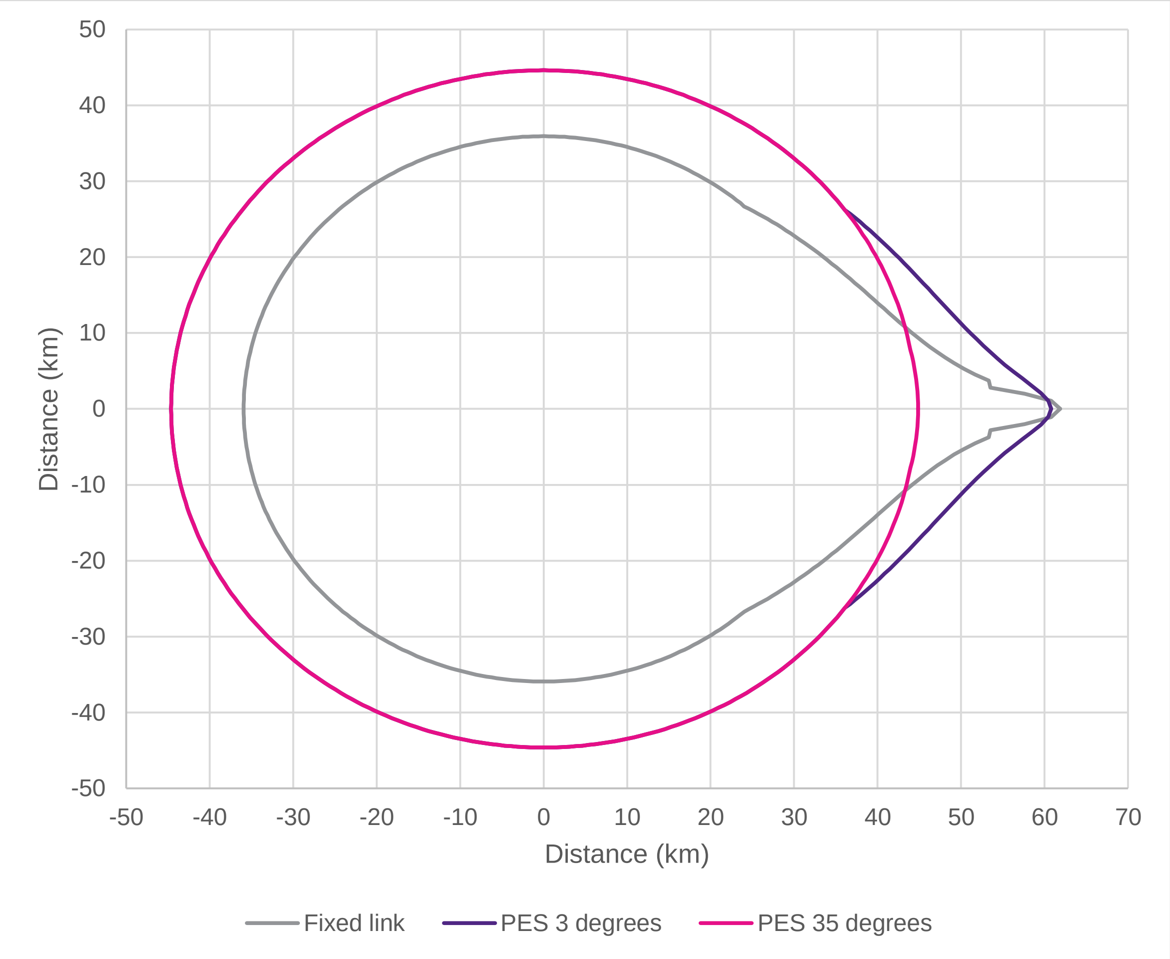
Table 7-2: Assumed operating parameters for fixed links and PES (median values)

Fixed link		
Antenna gain	35.8 dBi	
Antenna pattern	ITU-R Recommendation 699	
Height a.g.l.	22 m	
Transmitter power density	-29.9 dBW/MHz	
Receiver noise power density	-135.1 dBW/MHz	
Criterion	-147.1 dBW/MHz	I/N = -12 dB
PES		
Antenna gain	59 dBi	
Antenna pattern	RR Appendix 7	
Height a.g.l..	5 m	
Transmitter power density	3 dBW/MHz[93]	
Receiver noise power density	-147.8 dBW/MHz	T = 120 K
Criterion	-157.8 dBW/MHz	I/N = -10 dB

Source: Ofcom database

[93] 72 Watts in 36 MHz assumed later on.

Figure 7-1: Relative transmit denial areas of a PES and a fixed link – using ITU parameter values

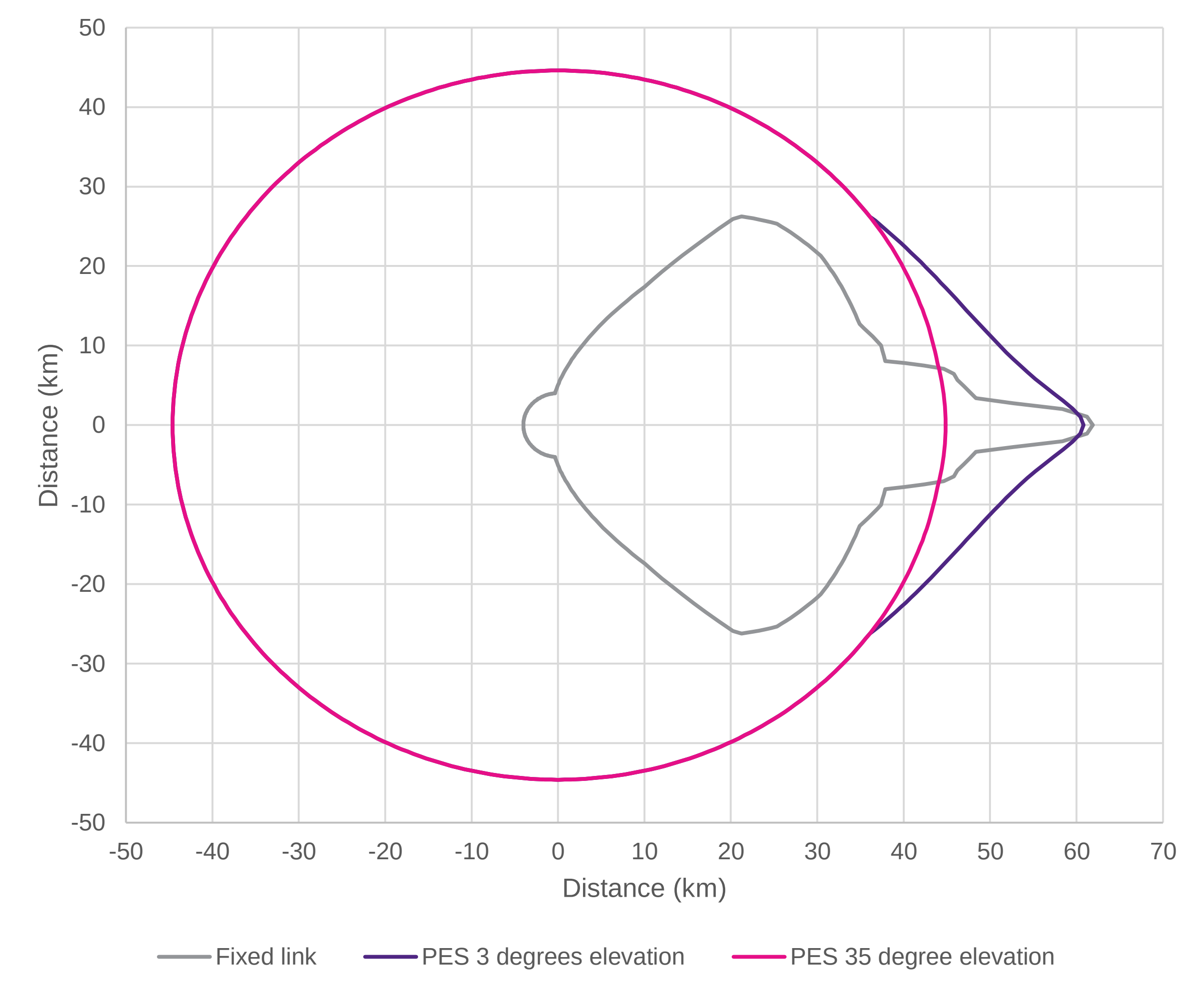


Source: Plum and Aegis analysis using the parameters given in Table 7-2.

The above analysis is based on the standard ITU-R Recommendation 699 antenna pattern for the fixed link. If alternatively we use more efficient antenna performance assumptions such as the antenna pattern for a commonly used antenna at 13 GHz, namely an Andrews 2 foot parabolic antenna[94], the fixed link denial area shrinks considerably as shown in Figure 7-2 below.

[94] Reference A/13/H/05/021/AA from Ofcom's antenna database

Figure 7-2: Relative transmit denial areas for a specific fixed link antenna



In this second case the relative areas denied (defined as a PES / fixed link ratio) fall in the range 1.95 ±0.07 for a receiving PES and 3.90 ±0.11 for a transmitting PES where the ranges given relate to the range of elevation angles 3 to 35 degrees. As before, there is little elevation dependence since the increased PES horizon gain at low elevation angles is mitigated by the diffraction loss.

It is our view that the ITU parameters should be used to estimate denial areas as we are seeking to derive AIP fees that apply in general across all fixed link/PES bands and so the parameters used should not be specific to a particular band and fixed link installation. Hence we recommend that the reference fee for PES should set at 1.4 times the reference fee for a unidirectional fixed link, and so:

Reference fee PES = 1.4 x 0.75[95] x Reference fee for a bi-directional fixed link = 1.05 x Reference fee for a bi-directional fixed link.

In the previous section we recommended that the reference fee for fixed links should be £42/2x1 MHz in all bands except the 3.6-3.8 GHz band where we suggest a value of £365/2x1 MHz should be applied. This implies the reference values for the algorithm are:

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[95] Where this is the rate of discount applied for a unidirectional fixed link – see Section 6.1.

- £44/MHz for all bands except the 3.6-3.8 GHz band
- £383/MHz for the 3.6-3.8 GHz band

We have found that the impacted area for the receive capability is half that for the transmit capability. This suggests that for receive- only systems with RSA the reference fee should be set as follows:

Reference fee RSA = 0.7 x 0.75[96] x Reference fee for a bi-directional fixed link = 0.525 x Reference fee for a bi-directional fixed link.

This implies the reference values for the algorithm for RSA are:

- £22/MHz for all bands except the 3.6-3.8 GHz band
- £192/MHz for the 3.6-3.8 GHz band

One further issue that needs to be considered here is: in which band should a PES be said to be operating – the transmit or the receive band? The current approach is to use the transmit band for the purposes of setting AIP for transmit and receive PES installations, as it is the transmission that is licensed, and the receive band for receive only earth stations with RSA. This means, for example, at C band that at present different fees apply to receive only stations operating under RSA and transmitting earth stations (because of differences in the band factor below and above 5 GHz). These differences will be much larger if our recommendations are implemented. Ofcom may wish to consider whether applying much higher fees to receive only installations as compared with transmit/receive installations at C band gives appropriate incentives for efficient use of the band.

7.3 Review of factors in algorithm

There are four main components to both of the satellite algorithms:

- The power (into the antenna) transmitted
- The bandwidth used
- A band factor that decreases as frequency increases
- An aggregation method (square root and summations) that represents the combined denial effect of multiple carriers over multiple frequencies operating at an earth station site, noting that the effect of different frequency bands is kept separate.

Power and bandwidth

The power and bandwidth components are fundamental to the method and require no change, noting that aggregation effects at a site are appropriately accommodated by the square root function (see the aggregation method discussion below).

[96] Where this is the rate of discount applied for a unidirectional fixed link – see Section 6.1.

Band factor

For consistency the satellite band factor should be the same as that for fixed links (see Section 6).

Aggregation method

The aggregation method for a site has been refined over the years and provides a straightforward means for making an allowance that reduces the impact to more realistic levels. However, it is assumed that any transmission in a given frequency band will overlap with any other transmission in that band regardless of whether it overlaps wholly, partially or not at all in practice. This potentially overstates the case and since Ofcom has the necessary information from the licensing process a modification could be introduced to the fee algorithm such that the square root "allowance" only applies to actual overlaps. However, the current principle that a licensee needs to be able to know what fee is to be paid without having access to Ofcom's licensing database means that such a refinement cannot be implemented at the moment.

Location factor

In respect of variations in fees by location, we suggest the approach used should depend on variations in demand for spectrum from the potential alternative use of the band – fixed links or mobile services. The variations in fees by geographic location described in Section 6 would then apply. This approach can be applied to PES, but is not practical for transportable earth stations where the location of use may vary daily. In this case, we suggest it is assumed all use is in congested locations.

7.4 Implications for fees for TES and RSA

Transportable Earth Stations (TES) are charged as shown in Table 7-1, where these fees are derived from the PES algorithm according to three ranges for the product of maximum power and bandwidth (p) and assuming a single path. This means that TES fees are proportional to the reference fee and band factor in the PES algorithm. Hence the proposed fees for TES can be calculated by multiplying the current TES fees by the following ratio of PES reference fees and band factors:

$$(Proposed\ reference\ fee \times proposed\ band\ factor)/(Current\ reference\ fee \times current\ band\ factor)$$

The implied TES fees with current fees shown in brackets are given in Table 7-3. As with the PES fees increases occur in bands below 20 GHz and fees above 20 GHz fall.

Table 7-3: Fees schedule for TES – proposed fees per TES (current fees in brackets)

Range of p (defined below)	5.925 – 7.075 GHz	13.78 – 14.5 GHz	27.5 – 27.8185 GHz 28.4545 – 28.8265 GHz 29.4625 – 30 GHz
0 < p ≤ 100	£822 (500)	£471 (300)	£157 (200)
100 < p ≤ 2,500	£3947 (2400)	£2200 (1400)	£629 (800)
p > 2,500	£12169 (7400)	£6757 (4300)	£2043 (2600)

Notes: “p” is the product of *OMP* and *WBW*, where *OMP* is the Operational Maximum Power in Watts declared by the licensee *WBW* is the Widest Bandwidth in MHz declared by the licensee

RSA currently applies to receive only stations at C band, 1.7 GHz and 8 GHz. Fees for RSA are currently set by taking the PES transmit fee/MHz and multiplying this by the ratio of the transmit denial area to the receive denial area for C band. We found this ratio equals 0.5.

As discussed above, the proposed reference values for the algorithm for RSA are:

- £22/MHz for all bands except the 3.6-3.8 GHz band
- £192/MHz for the 3.6-3.8 GHz band

These values are multiplied by the bandwidth of the receive signal to give the AIP fee. There would clearly be a strong financial incentive to use frequencies in the upper part of C band.

7.5 Conclusions

Based on the analysis given above we conclude that:

- The factors in the current PES formula should be retained
- The structure of the current PES formula should be retained, although in the longer term and depending on the more general availability of licensing data a clearer distinction between overlapping transmissions at a site (which effectively achieve a discount) and non-overlapping transmissions could be made.
- The PES reference spectrum fee should be based on the fixed link reference fee for a unidirectional link and adjusted to reflect the difference in denial areas for a representative fixed link and a representative PES. Hence we recommend that the reference fee for PES should set at 1.4 times the reference fee for a unidirectional fixed link. This implies a reference value of £44/2x1 MHz for all bands and a value of £383/2x1 MHz for the 3.6-3.8 GHz band.
- The bandings and band factors for the fixed links and satellite algorithms should be the same.
- There should be a location factor based on the location factor proposed in Section 6 for fixed link fees.
- For TES users we propose that the fees be calculated by applying the following ratio to the current TES fees:

  $$(Proposed\ reference\ fee \times proposed\ band\ factor)/(Current\ reference\ fee \times current\ band\ factor)$$

- For RSA, we propose multiplying the PES band factor by the PES reference fee for the receive band and then multiplying this by the ratio of the transmit denial area to the receive denial area for the reference band, i.e. 0.5. Hence the proposed formula for calculating RSA licence fees for a given band – say Band A - is as follows:

  RSA fees for band A = *PES reference fee x PES band factor for band A x 0.5*

8 Implications for AIP fees

8.1 Introduction

In this section we illustrate the potential impact of our proposals in respect of the reference values and AIP fee algorithms for the levels of AIP fees.

The results presented below reflect our findings in Sections 3 and 4 that there is continuing excess demand for spectrum in the frequency bands below 20 GHz. This suggests fees in these bands should rise.

We found falling demand in Ofcom managed bands above 20 GHz and noted the large recent increases in supply in these bands (and low auction values). This suggests fees in these bands should fall or even be set at cost based levels.

We also note that the last time fixed link and satellite fees were changed in 2005 and 2007 respectively:

- Fixed link fees overall increased 13.5% from the previous values that were determined in 1998 (though phased in over the period 1998-2001)[97]
- Satellite fees rose by 40-228%. However, this increase was from a low base. After these increases were implemented fees were still lower than in 2002. Ofcom noted this was because AIP for satellite services was introduced in 2002 on a basis which did not correctly reflect the opportunity cost of spectrum.[98]

8.2 Fixed links

In Section 6 we have proposed:

- $\text{AIP fee} = \text{Reference fee} \times \text{Bandwidth factor x Frequency band factor x Availability factor x Location factor}$
- The reference fee for all bands is £42/2x1 MHz except the 3.6-3.8 GHz band which has a reference fee of £365/2x1 MHz
- The proposed band factor with 13 GHz as the reference band is as follows:

[97] Exhibit 2, Spectrum pricing: A Statement on proposals for setting Wireless Telegraphy Act licence fees, Ofcom, February 2005

[98] Table 8, para 4.19 and para 4.35. Modifications to Spectrum Pricing, Statement, January 2007

Frequency band range	Proposed Band Factor
1.35 ≤ fb < 3.60	4.0
3.60 ≤ fb < 3.80	3.0
3.80 ≤ fb < 5	3.0
5 ≤ fb < 10	1.8
10 ≤ fb < 16	1.0
16 ≤ fb < 20	0.7
20 ≤ fb < 24	0.4
24 ≤ fb < 40	0.3
40 ≤ fb < 57.0	0.2
57.0 ≤ fb < 100.0	0.1

- The availability factor is unchanged and is as follows:

Percentage of availability	Availability factor (Avf)
Availability ≤ 99.9%	Avf = 0.7
99.9% < Availability < 99.99%	Avf = 0.7 +(Availability x 100 – 99.9) x (0.3/0.09)
99.99% ≤ Availability	Avf = 1.0 + (Availability x 100 – 99.99) x (0.4/0.009)]

- The location factor would be 1 in areas where there is excess demand and a discount applied in other areas. The level of discount is for Ofcom to determine but we have indicated it could be similar to that for business radio use in low demand areas (i.e. 30% - 90%) though fees should always be set above cost recovery levels.
- Uni-directional links should continue to pay 75% of the calculated fee for a bi-directional link and an additional link operating co-channel and cross-polar over the same path as an existing assigned link for the same licensee would pay 50% of the bi-directional link fee.

The implied fees by band, the current fees and the percentage change per 2x1 MHz for a bi-directional link are as shown in Table 8-1. Fees rise in congested bands and fall in bands not considered congested. The fees for bands above 57 GHz rise, because at present these are set at a very low level on an interim basis. We have recommended that in areas with low density of fixed link use (defined in Section 6) or in the case of the 3.6-3.8 GHz band in areas where population density is low much lower fees should be applied so that they are closer to cost reflective fee levels.

Table 8-1: Proposed AIP fees and percentage change compared with current fee per 2x1 MHz

Frequency band range	Proposed fee (£/2x1 MHz)	Current fee (£/2x1 MHz)	% change
1.35 ≤ fb < 3.60	168.00	88.00	91
3.60 ≤ fb < 3.80	1095.00	88.00	1144
3.80 ≤ fb < 5	126.00	88.00	43
5 ≤ fb < 10	75.60	65.12	16
10 ≤ fb < 16	42.00	37.84	11
16 ≤ fb < 20	29.40	26.40	11
20 ≤ fb < 24	16.80	26.40	-36
24 ≤ fb < 40	12.60	22.88	-45
40 ≤ fb < 57.0	8.40	14.96	-44
57.0 ≤ fb < 100.0	4.20	0.90	367

Source: Plum and Aegis analysis

Table 8-2 shows the impact of these changes for some typical examples of fixed links deployments in geographic areas where there is excess demand. As expected fees rise for bands below 20 GHz and fall for bands above 20 GHz except in the case of bands above 57 GHz where very low interim fees apply at present. The increase in the 1.4 GHz is large (at 91%) but we note the absolute level of proposed fees for a typical link is still low at around £235. The largest increases are in the 3.6-3.8 GHz band reflecting the potential for mobile use of the band and so the much higher opportunity cost of the spectrum as compared with other bands.

Table 8-2: AIP Fees for typical fixed links (£)

Frequency band (GHz)	Bandwidth (2x1 MHz)	Availability (%)	Fees proposed (£)	Fees now (£)[99]	Percentage change (%)
1.4	1	99.999	235	123	91
4	14	99.999	21,462	1,725	1144
7.5	28	99.99	2,117	1,823	16
15	56	99.999	3,293	2,967	11
18	3.5	99.99	103	92	11
23	56	99.99	941	1,478	-36
38	56	99.99	706	1,281	-45
70/80	250	99.99	1,050	225	367

Source: Plum and Aegis analysis

[99] We assume the link exceeds the minimum path length to calculate current fees.

8.3 Satellite

In section 7 we have proposed the following for PES AIP fees:

- Fees are set based on the following algorithm:

$$Fee = \sum_{bands} \left[\text{Reference fee} \times BF_{band} x\ Location\ factor \times \sqrt{\sum_{paths_{band}} \left(P_{path} \times BW_{path}\right)} \right]$$

- Reference fee = £44/2x1 MHz for all bands except 3.6-3.8 GHz where a value of £383/2x1 MHz
- The band factor is:

Frequency band range	Proposed Band Factor
1.35 ≤ fb < 3.60	4.0
3.60 ≤ fb < 3.80	3.0
3.80 ≤ fb < 5	3.0
5 ≤ fb < 10	1.8
10 ≤ fb < 16	1.0
16 ≤ fb < 20	0.7
20 ≤ fb < 24	0.4
24 ≤ fb < 40	0.3
40 ≤ fb < 57.0	0.2
57.0 ≤ fb < 100.0	0.1

- The location factor would be 1 in areas where there is excess demand and a discount applied in other areas. The level of discount is for Ofcom to determine but we have indicated it could be similar to that for business radio use in low demand areas (i.e. 30% - 90%) though fees should always set above cost recovery levels.

TES and RSA fees can be calculated directly from the proposed PES reference fees and band factors. The new TES fees are as in Table 8-3. As with PES fees the values increase for bands below 20GHz and decrease in bands above 20 GHz.

Table 8-3: Fees schedule for TES – proposed fees per TES (current fees)

Range of p (defined below)	5.925 – 7.075 GHz	13.78 – 14.5 GHz	27.5 – 27.8185 GHz 28.4545 – 28.8265 GHz 29.4625 – 30 GHz
0 < p ≤ 100	£822 (500)	£471 (300)	£157 (200)
100 < p ≤ 2,500	£3947 (2400)	£2200 (1400)	£629 (800)
p > 2,500	£12169 (7400)	£6757 (4300)	£2043 (2600)

Notes: "p" is the product of *OMP* and *WBW*, where *OMP* is the Operational Maximum Power in Watts declared by the licensee *WBW* is the Widest Bandwidth in MHz declared by the licensee

RSA currently applies to receive only stations in the 1690-1710 MHz, 3600-4200 MHz and 7750-7850 MHz bands. The proposed new fees depend on the part of C band in which the earth station operates:

- If the earth station operates at 3.6-3.8 GHz then the fee increases from £17/MHz to £287/MHz.
- If the earth station operates at 3.8-4.2 GHz then the fee increases from £17/MHz to £33/MHz.

These values are multiplied by the bandwidth of the receive signal to give the AIP fee. There is clearly a strong financial incentive to use frequencies in the upper part of C band.

In the case of PES the fees are not linearly related to bandwidth and depend on the extent of co-location of earth stations. To give an indication of the changes in fees we have calculated fees under our proposals and compared them with current fees for the examples of earth station deployments shown in Table 8-4.

Table 8-4: PES examples for fee calculations

Example	PES per site (band)	Satellite	Carrier per path	Peak transmit power (W) x Bandwidth (MHz)	Flexible bandwidth access
1a	1 (C-band)	1	1	200 x 36	No
1b	1 (Ku-band)	1	1	200 x 36	No
1c	1 (Ka-band)	1	1	200 x 36	No
2	2 (Ku-band)	2	2	200 x 36 150 x 18 120 x 9 70 x 6 50 x 4.5 10 x 1 1 x 0.5 0.2 x 0.064	No
3	6 (2 C-band, 3 Ku-band, 1 Ka-band)	6	2	200 x 500 (C-band) 200 x 500 (C-band) 200 x 100 (C-band) 200 x 100 (C-band) 150 x 250 (Ku-band) 150 x 250 (Ku-band) 120 x 150 (Ku-band) 120 x 150 (Ku-band) 72 x 300 (Ku-band) 72 x 300 (Ku-band) 120 x 100 (Ka-band) 120 x 100 (Ka-band)	Yes

Notes: In example 2, the two PESs have flexibility to operate to the 2 satellites; hence there are four separate physical paths and eight P x B combinations. In example 3, each PES operates to one satellite; hence there are six physical paths and twelve P x B combinations.

The implied AIP fees for earth stations located in congested areas are shown in Table 8-5. As expected fees rise in the lower bands (C and Ku band) and fall at Ka band.

Table 8-5: AIP fees for PES examples (£)

Example	Current fee	Proposed fee	Percentage change
1a	4,087	6,720	64%
1b	2,376	3,734	57%
1c	1,426	1,120	-21%
2	3,020	4,746	57%
3	37,191	58,123	56%

Source: Plum and Aegis analysis

8.4 Concluding comments

There are several areas of work that are beyond the scope of this study and that Ofcom could consider undertaking, namely:

- Consider the introduction of factors into the fixed link algorithm related to the use of high performance antennas and transmit power control , as these can affect the area over which spectrum use is denied. Further, detailed modelling using representative deployments (based on Ofcom licence data) is required to determine appropriate parameter values.
- Reconsider the approach to setting RSA and PES fees so that the resulting fees are consistent, In particular, receive-only deployments should not pay a higher fee than a receive/transmit PES deployment that uses the same receive band as the receive only system. .
- Undertake user surveys to collect data on the actual choices facing users should they be denied access to spectrum in a given band and in particular collect data on the costs of those choices (e.g. site and equipment costs for use of alternative bands).
- Monitor the impact of changes in fees on use of bands each year to provide data that could be used to underpin future reviews.

Appendix A: Fixed link frequency bands

Frequency band		Amount of spectrum available for fixed service	Method of assignment
1.4 GHz	1350-1374.5 MHz paired with 1492.5 -1517MHz	2 x 24.5 MHz	Technically coordinated and assigned on a first come first served basis
1.7 GHz	1690-1710MHz	30MHz	Authorised under RSA
4 GHz	3600-3875 MHz paired with 3925-4200 MHz	2 x 275 MHz	Technically coordinated and assigned on a first come first served basis 3605-3689 MHz and 3925-4009 MHz is block assigned on a technology neutral basis
5.8 GHz	5725-5850 MHz	125 MHz	Light licensed
Lower 6 GHz	5925-6167.8 MHz paired with 6182.42-6425 MHz	2 x 242 MHz	Technically coordinated and assigned on a first come first served basis
Upper 6 GHz	6425-6760 MHz paired with 6780-7125 MHz	2 x 335 MHz	Technically coordinated and assigned on a first come first served basis
7.5 GHz	7425-7652 MHz paired with 7673-7900 MHz	2 x 227 MHz	Technically coordinated and assigned on a first come first served basis
10 GHz	10.125-10.225 GHz paired with 10.475-10.575 GHz	2 x 100 MHz	Auctioned
13 GHz	12.75-12.975 GHz paired with 13.017-13.25 GHz	2 x 224 GHz	Technically coordinated and assigned on a first come first served basis
15 GHz	14.5-14.613 GHz paired with 15.229-15.35 GHz	2 x 112 MHz	Technically coordinated and assigned on a first come first served basis
18 GHz	17.7-19.7 GHz (variable centre gap)	2000 MHz	Technically coordinated and assigned on a first come first served basis
23 GHz	22-22.6 GHz paired with 23-23.6 GHz	2 x 600 MHz	Technically coordinated and assigned on a first come first served basis
26 GHz	24.5-25.445 paired with 25.557-26.5 GHz	2 x 943 MHz	Technically coordinated and assigned on a first come first served basis
28 GHz	28.0525-28444.5 GHz paired with 29.0605-29452.5 GHz	2 x 336 MHz	Auctioned

Frequency band		Amount of spectrum available for fixed service	Method of assignment
31 GHz	31.0-31.3 GHz paired with 31.5-31.8 GHz	2x300 MHz	Technically coordinated and assigned on a first come first served basis
32 GHz	31.815-32.571 GHz paired with 32.627-33.383 GHz	2 x 756 MHz	Auctioned
38 GHz	37-38.178 GHz paired with 38.438-39.5 GHz	2 x 1178 MHz	Technically coordinated and assigned on a first come first served basis
40 GHz	40.5-42 GHz paired with 42-43.5 GHz	2 x 1500 MHz	Auctioned
52 GHz	51.4-51.944 GHz paired with 52.056-52.6 GHz	2 x 540 MHz	Technically coordinated and assigned on a first come first served basis
60 GHz	57-64 GHz	7000 MHz	Licence-exempt
65 GHz	64-66 GHz	2000 MHz	Light-licensed on a self-coordinated basis
70 GHz	71-76 GHz	5000 MHz	Part technically coordinated and part light-licensed on a self-coordinated basis
80 GHz	81-86 GHz	5000 MHz	Part technically coordinated and part light-licensed on a self-coordinated basis

Note: The amount of spectrum is indicative as in some bands the size of the paired sub-bands are not equal and also includes guard bands at the band edges.
Source: Ofcom

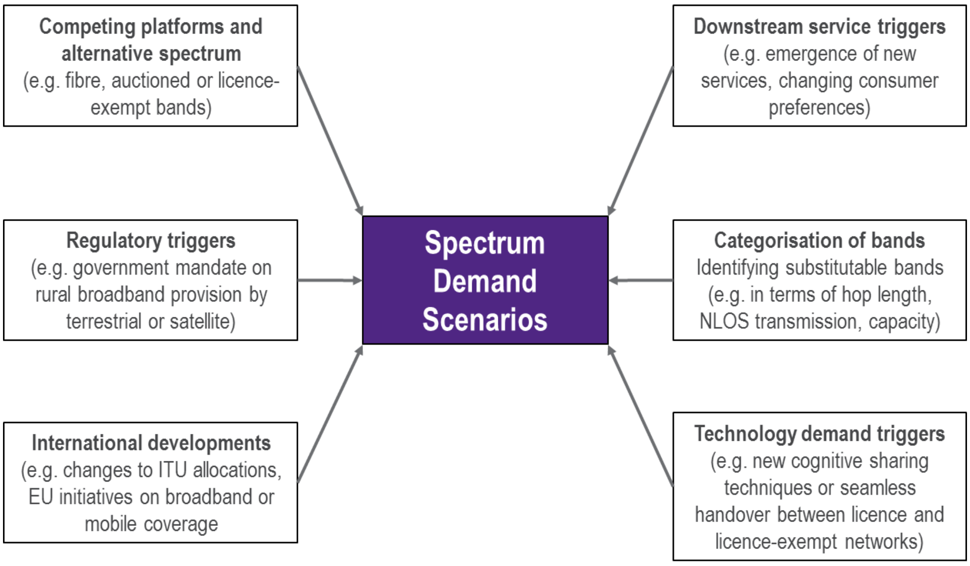
Appendix B: Summary of results from Aegis et al. (2011)

In the 2011 study on the future demand of fixed link spectrum, Aegis et al. considered the future demand taking into account the following macro factors:

- Strength of the economy
- Policy and regulation, in particular interventions in relation to broadband coverage
- Extent of fibre availability
- Fixed and mobile broadband service demand
- Public sector demand to support wireless CCTV and a possible new public safety mobile broadband network
- Utility demand in particular to support smart grids and pollution control
- Satellite service demand, in particular provision of rural fixed broadband
- Demand from other fixed link applications.

Figure B-1 provides an overview of the approach taken to develop the spectrum demand scenarios.

Figure B-1: Approach to spectrum demand scenario development



Four scenarios for the next 10 years (2011-2021) were developed based on different economic, policy and regulatory factors and the resulting demand assumptions for each of the above downstream service. The four scenarios are:

- **Scenario A – Fibred Nation** (weak economy, high regulatory intervention) – characterised by strong fibre deployment which displaces fixed link demand for mobile network backhaul; low consumer spending means low to moderate growth in mobile services

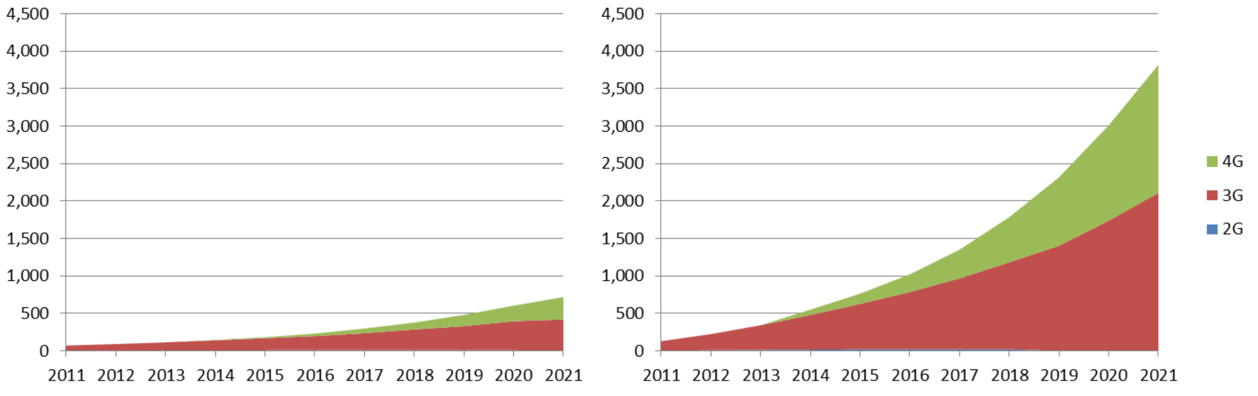
- **Scenario B – Green Agenda** (strong economy, moderate regulatory intervention) – characterised by a focus on green policies, growth in mobile demand (to facilitate teleworking and reduced travel) and increased mobile site sharing; high fibre deployment
- **Scenario C – Economy constraints** (weak economy, low regulatory intervention) – most pessimistic scenario characterised by reduced consumer expenditure on mobile, constraints on enterprise and utility spending and lower fibre availability due to limited government intervention
- **Scenario D – We want it now** (strong economy, low regulatory intervention) – characterised by strong economic recovery after recession, and strong demand for services and infrastructure investment; mobile networks move to LTE in urban, suburban and rural areas but limited competition in fibre means greater reliance on fixed links for backhaul

B.1 Mobile data and backhauling

The development of downstream services over the 2011-2021 period is the main differentiating factor between the four scenarios and this depends on various technology, user demand, policy, regulatory and economic factors. Mobile networks are currently the main user of fixed links for backhauling purposes and the future demand for fixed link spectrum depends crucially on mobile traffic growth and the extent of migration to fibre backhaul.

Figure B-2 shows total assumed mobile busy hour traffic demand per year (including offloaded traffic) for the low growth scenarios (A and C) and high growth scenarios (B and D).

Figure B-2: Total busy hour mobile data traffic including offload – national: Scenarios A and C on the left hand side and Scenarios B and D on the right hand side



Source: Aegis et al. (2011)

There are also variations in the extent of fibre deployment over the 2011-2021 period across the four scenarios as shown in Table B-1.[100]

[100] See Aegis et al. (2011), p.77 for a more granular distribution of fibre availability assumptions by scenario.

Table B-1: Fibre availability under Scenarios A and C

% of sites fibred	Scenario A		Scenario B		Scenario C		Scenario D	
	2011	2021	2011	2021	2011	2021	2011	2021
Sparse rural	0%	15%	0%	15%	0%	2%	0%	2%
Medium sub-urban	20%	85%	20%	75%	20%	30%	20%	35%
Dense urban	70%	98%	70%	98%	70%	75%	70%	80%

Source: Aegis et al. (2011)

In terms of fixed link spectrum requirements, there is higher demand under Scenarios B and D compared to Scenarios A and C respectively due to higher adoption of 4G services – 70% compared to 50%. In Scenario A, the migration of mobile backhaul to fibre leads to significant reduction in demand for fixed links across all bands. In Scenario C, the demand for fixed link spectrum for mobile backhaul remains steady as there is less fibre migration compared to Scenario A – some links above 30 GHz are still required while links below 10 GHz are needed for rural mobile backhaul

For Scenario B, the wider availability of fibre reduces demand for fixed links relative to Scenario D where less fibre is deployed. In Scenario B, links above 30 GHz are replaced by fibre in urban areas while some of these links are still required in Scenario D. Also in rural areas under Scenario D there is stronger demand for links below 20 GHz to support the upgrade from 2G to 3G and 4G. Table B-2 summarises the impact of mobile networks and the corresponding backhaul requirements on fixed link spectrum demand across different frequency bands.

Table B-2: Impact of mobile networks on fixed link spectrum demand (Aegis 2011)

Frequency range	Scenario A	Scenario B	Scenario C	Scenario D
Below 10 GHz	▼▼	▼	◄►	▲
10 – 20 GHz	▼▼	▼	◄►	▲
20 – 30 GHz	▼▼	▼	◄►	▲
Above 30 GHz	▼▼	▼▼	▼	▼

Key:
- ▼▼ – large decline in spectrum demand
- ▼ – small decline in spectrum demand
- ◄► – little change or no decline in spectrum demand
- ▲ – small increase in spectrum demand
- ▲▲ – large increase in spectrum demand

Source: Aegis et al. (2011)

B.2 Fixed wireless access (FWA)

Another application which has an important impact on fixed link spectrum demand is FWA services. There is likely to be demand for FWA in areas outside the reach of high speed wireline connections (i.e. mainly rural areas). Fixed links are important for backhaul in these areas given the lack of fibre for backhauling. FWA services are independent of access medium and the required capacity is a function of the assumed number of users and busy hour traffic per user. Thus the demand cases are generally in line with economic conditions and regulatory intervention.

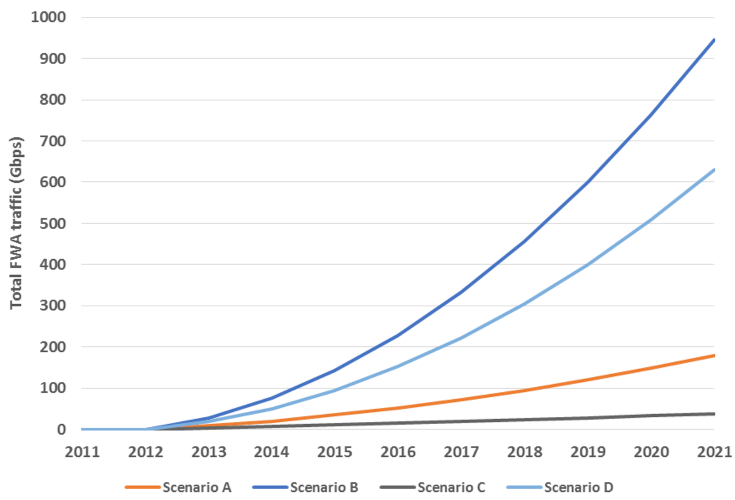
It was assumed that there are some 3 million non-DSL households in the UK and that FWA take-up and average traffic are expected to be higher under Scenarios B and D as shown in Table B-3 and Figure B-3 respectively.

Table B-3: Projected take up of FWA in areas beyond high speed DSL connectivity (Aegis 2011)

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

Source: Aegis et al. (2011)

Figure B-3: Total FWA traffic requirements



Source: Aegis et al. (2011)

The impact of FWA deployment on demand for fixed link spectrum is mainly limited to rural areas which require medium to long backhaul links in the 10 – 30 GHz range. Demand is higher under Scenarios B and D due to higher take-up and user data rates. Table B-4 summarises the impact of FWA backhaul requirements on fixed link spectrum demand across different frequency bands.

Table B-4: Impact of FWA on fixed link spectrum demand (Aegis 2011)

Frequency range	Scenario A	Scenario B	Scenario C	Scenario D
Below 10 GHz	◀▶	◀▶	◀▶	◀▶
10 – 20 GHz	▲	▲▲	▲	▲▲
20 – 30 GHz	▲	▲▲	▲	▲▲
Above 30 GHz	◀▶	◀▶	◀▶	◀▶

Source: Aegis et al. (2011)

B.3 Public safety requirements

The primary source of demand for fixed links by the public safety community is for the support of mobile broadband communications (e.g. video surveillance), although narrow band links are also extensively used to provide TETRA backhaul. The key assumption is the deployment of a national public safety mobile broadband network within the 10-year timeframe. Three of the scenarios (A, C and D) envisage the deployment of a dedicated network either in the UHF spectrum or in the 1.4 GHz band. Scenario B assumes that public safety communications evolve on a localised basis with national coverage being provided through commercial broadband networks.

Table B-5 summarises the impact of on fixed link spectrum demand across different frequency bands. For the UHF band public safety network in Scenarios A and C there would be demand for links below 10 GHz in rural areas, 10-20 GHz in suburban areas and 20-30 GHz in urban areas. In Scenario D links below 10 GHz fall due to decommissioning of existing regional deployments. In Scenario B regional deployments continue to use links between 10-30 GHz with the rise in demand due increasing use of video applications.

Table B-5: Impact of public safety requirements on fixed link spectrum demand (Aegis 2011)

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

Source: Aegis et al. (2011)

B.4 Broadcasting, local authorities, utilities

Compared to the other services discussed above the impacts of the broadcast, local authority and utility sectors on demand for fixed links are relatively small.

In terms of broadcasting there are no significant changes expected in the 2011-2021 timeframe as backhaul links for DTT are largely completed. The expansion of DAB into rural areas might increase demand for 1.4 GHz but will have little impact on higher frequency bands.

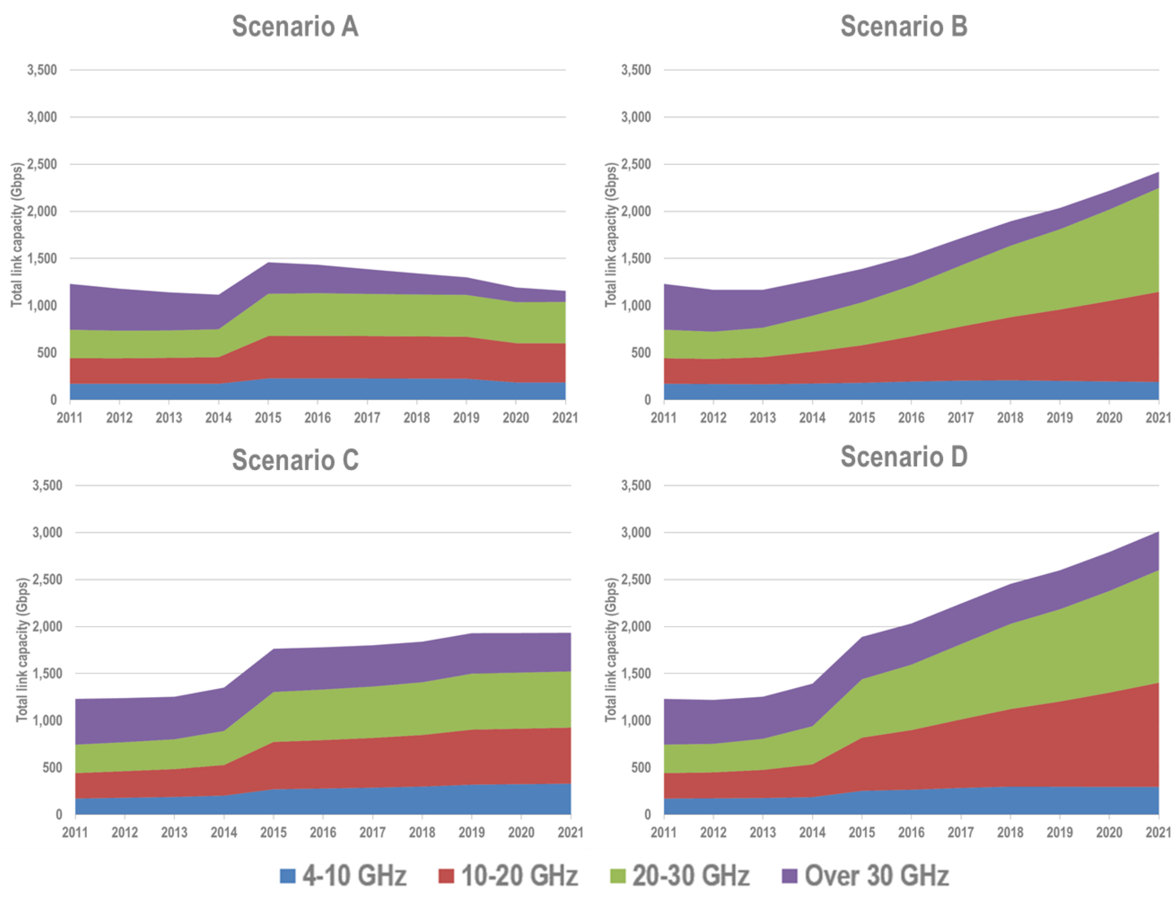
For local authorities, the deployment of wireless CCTV and data networks will increase demand. However under Scenarios A, B and D the effect on the whole will be small across all frequency bands compared to the demand by mobile, FWA and public safety. In Scenario C, higher crime and security concerns, coupled with limited fibre availability and coverage by commercial mobile networks, means there is higher demand for fixed links by local authorities.

In terms of utilities there will also be an increase under all four scenarios across all frequency ranges reflecting the mix of link lengths required in urban, suburban and rural areas. The deployment of smart grids to support energy efficiency improvement is fastest under Scenario B with rapid rollout in 2014-15 reflecting the emphasis on the green agenda.

B.5 Fixed link capacity demand and spectrum requirements

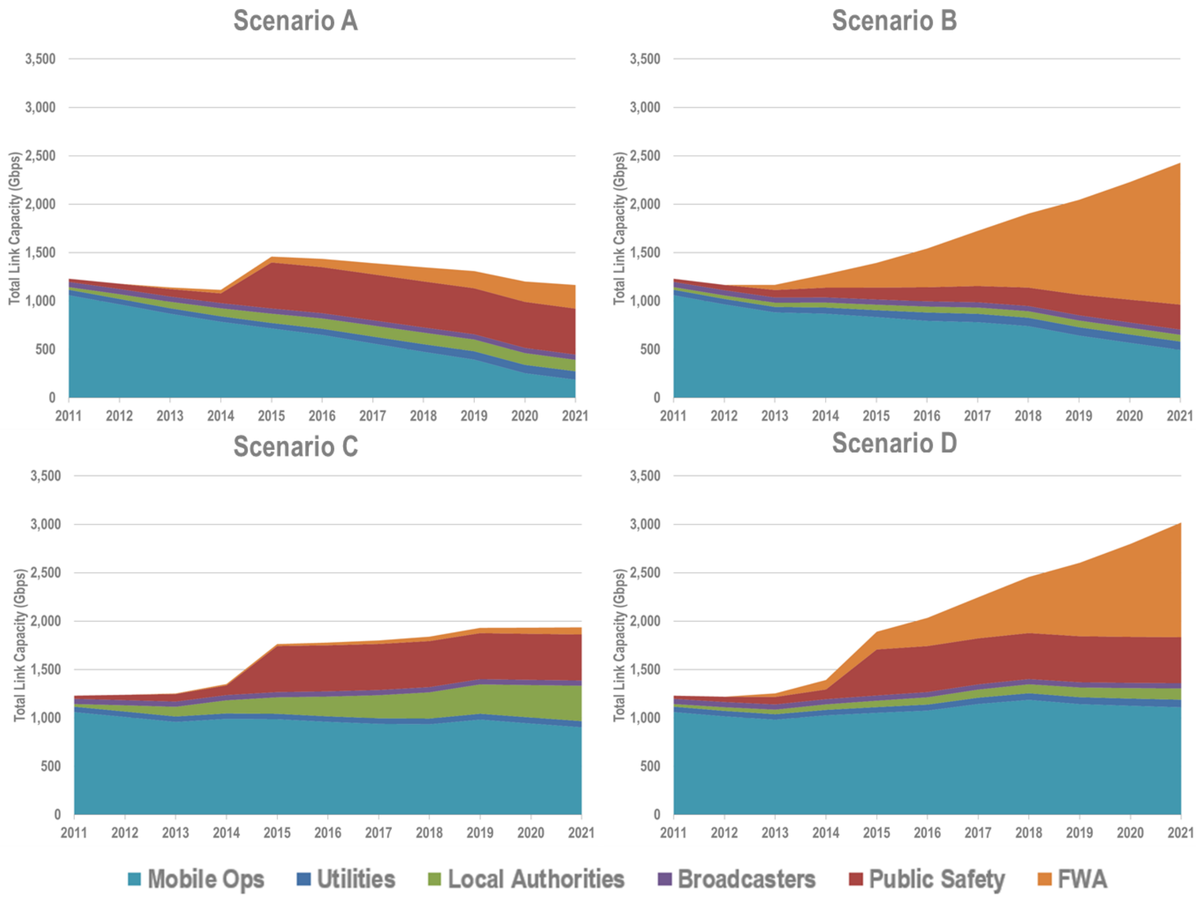
Figure B-4 and Figure B-5 shows the projected fixed link capacity demand by frequency band and by user type. The main demand is expected to be in the 10-20 GHz and 20-30 GHz bands with mobile, public safety and FWA having the biggest requirements albeit in different proportions across the scenarios. Scenario D is the most aggressive in terms of overall demand for fixed link spectrum followed by Scenarios B, C and A. The geographic distribution of demand also varies significantly between the scenarios.

Figure B-4: Fixed link capacity demand by frequency band nationally (Gbps)



Source: Aegis et al. (2011)

Figure B-5: Fixed link capacity demand by user type nationally (Gbps)



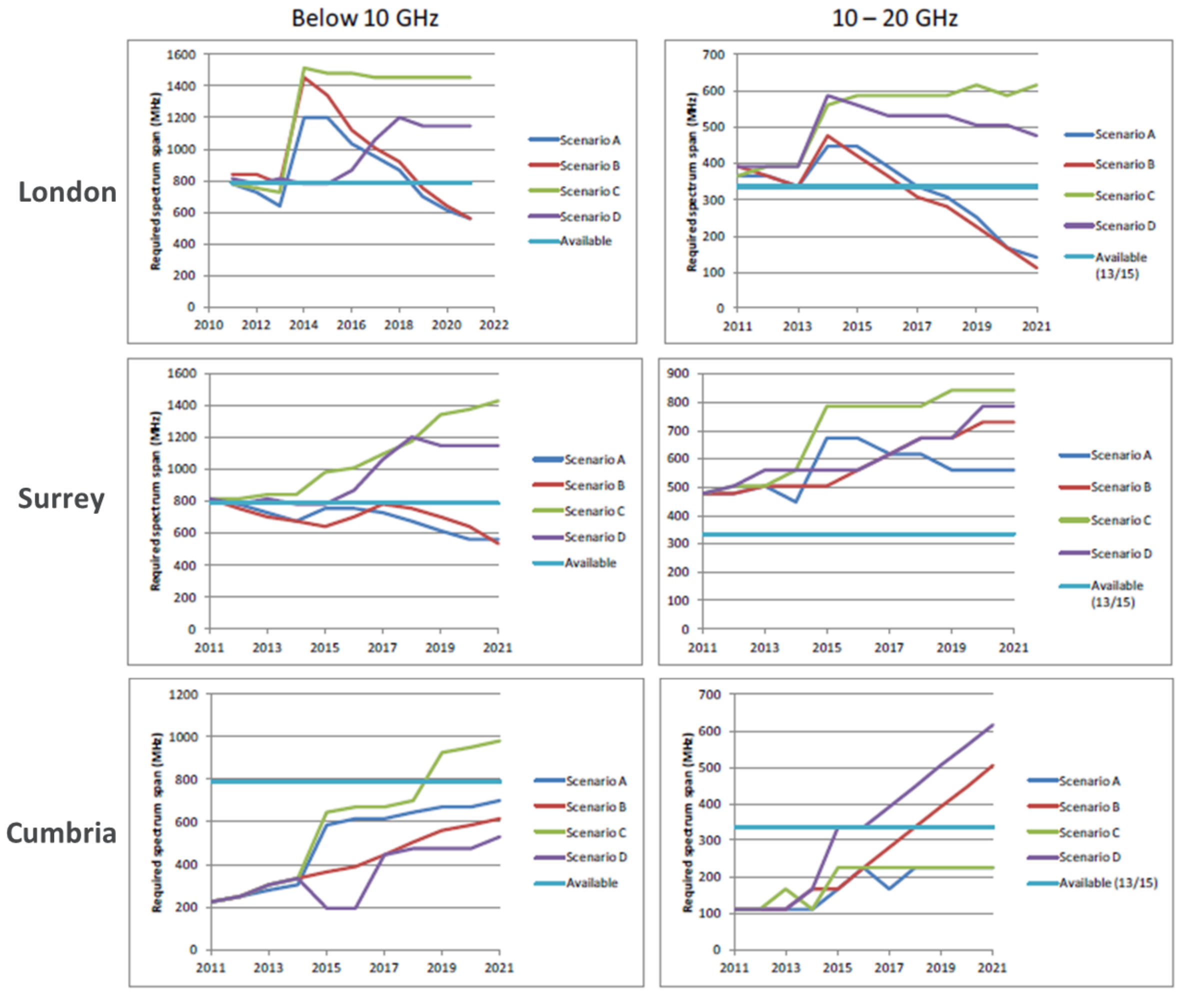
Source: Aegis et al. (2011)

The spectrum span[101] requirements for the four frequency range groupings are estimated based on projected traffic levels in the busiest 10km sq of each area. The results indicate that there is ample spectrum above 20 GHz to address the increase in demand for all four scenarios due to the short path lengths involved and the frequency re-use factor for these higher frequency links.

As shown in Figure B-6, there is likely to be short term congestion in London (dense urban areas) under Scenario B but this will be alleviated with the migration to fibre backhaul. In Surrey (suburban) and Cumbria (rural) it is anticipated that significant congestion will arise in the 13 and 15 GHz bands under Scenario B due to mobile and FWA backhaul requirements. However assuming at least part of the 18 GHz band is available for fixed links then the congestion at 13 and 15 GHz is not likely to be an issue.

[101] This refers to the total bandwidth required to meet capacity demand in a given area in a single direction, assuming all links in that areas are uniformly distributed and assigned in an optimum fashion.

Figure B-6: Spectrum span requirements for below 10 GHz and 10-20 GHz by area



Source: Aegis et al. (2011)

Appendix C: Technology developments

C.1 Overview

Current practice as implemented by Ofcom when making frequency assignments is to determine a frequency channel and maximum transmit power level that will meet a given availability requirement and at the same time avoid interfering with other existing fixed links. In undertaking this planning it is assumed that the characteristics of the transmission (e.g. power level and modulation used) are static and that variations in the received signal level are solely due to propagation variations.

A number of technologies / implementations can be considered with a view to making wider and/or more efficient use of the spectrum. In this Appendix we consider the pros and cons and practicality of providing incentives through the AIP algorithm to adopt the following technologies:

- Higher modulation states
- Variable bit rate
- Power control
- High performance antennas
- MIMO
- Non-line of sight links (NLOS)
- Mesh networks.

In summary we find that increased spectral efficiency could result from users adopting higher modulation states, MIMO, variable bit rates or power control and higher gain antennas. Some but not all of these innovations will come at an increased equipment cost to the user and in some cases the efficiency enhancement will be significantly less than the headline gain because of the increased sensitivity of transmissions to interference.

In the case of the use of higher modulation states in a static configuration it is now that case that there is little or no additional cost so it is anticipated that users will make use of higher modulation states without the need for encouragement beyond the bandwidth factor in the existing fee algorithm. Similarly, the use of variable bit rates over a link on a dynamic basis will also be deployed by users if needed with those users[102] making full use of the power available and their licensed spectrum.

Ideally, links with a static bit rate should be encouraged through fees to use transmit power control in order to increase overall spectrum efficiency. Similarly, use of high performance antennas should be encouraged. However, in both cases the degree of fee reduction is difficult to quantify without a significant amount of modelling work that is beyond the scope of this study.

In respect of the relevance of the remaining technological developments for AIP we observe that:

- In the case of MIMO it is possible to increase the link capacity without requiring further bandwidth but there could be increased interference to other links. Lack of experience with MIMO means it is too soon to know the scale of these impacts with any certainty.

[102] This depends on whether the user has highly variable traffic or not.

- Mesh networks may improve system and spectrum efficiency by statistically multiplexing traffic from multiple transmitter sites so that the traffic peaks from one site may cancel out the troughs from another. Overall the data throughput requirements are reduced as it is not necessary to cater for the maximum data requirements on each individual link and this could lead to less bandwidth being required to connect the same transmitter sites. However, deployment of mesh networks will require users to have flexibility to add and remove nodes as required and this will be most easily implemented by users in self-managed blocks of spectrum. Hence mesh networks are not likely to be deployed on a per link basis in bands managed by Ofcom in which case the fees algorithm will not apply.
- Similarly NLOS links are likely to be deployed in self-managed blocks of spectrum because of the need to change their deployment in response to changes in clutter. Again the Ofcom fixed link fees algorithm is not applicable.

In summary, we find that:

- The use of higher modulation states on a static basis does not need additional encouragement through pricing and neither does the use of variable bit rates – these techniques will be implemented by the user where it is efficient to do so.
- Ideally, the use of transmit power control and high performance antennas should be encouraged[103] but the overall benefit obtained by the use of these techniques is difficult to quantify and beyond the scope of this study.
- The use of MIMO, mesh networks and NLOS links are either not well enough established or are not applicable to the case of links assigned by Ofcom because they would be deployed in self-managed blocks of spectrum.

C.2 Higher modulation states

The highest modulation state accommodated by current Ofcom planning[104] is 512 QAM. Higher modulation states (1024[105] / 2048[106]) are being proposed. Figure C-1 shows the increase in bit rate with modulation for a channel spacing of 28 MHz[107].

The E_b/N_0 target for higher rate modulations is greater than for lower rate modulations as it is harder to distinguish between the different states, each of which represents more bits, in the presence of noise since they are closer together in the constellation of signal states. This requirement for a higher E_b/N_0 (or equivalently C/N) leads to shorter links for the same EIRP or a higher EIRP requirement to maintain the same link length. Similar to the need for a higher E_b/N_0 target, the wanted to unwanted ratio that has to be met when planning a new link with respect to existing links, is also higher.

[103] This would require that Ofcom's planning tool could incoprorate these aspects of fixed link deployment. This is not the case at present.

[104] OfW 446 – Technical Frequency Assignment Criteria for Fixed Point-to-Point Radio Services with Digital Modulation. Version 6.0 December 2013.

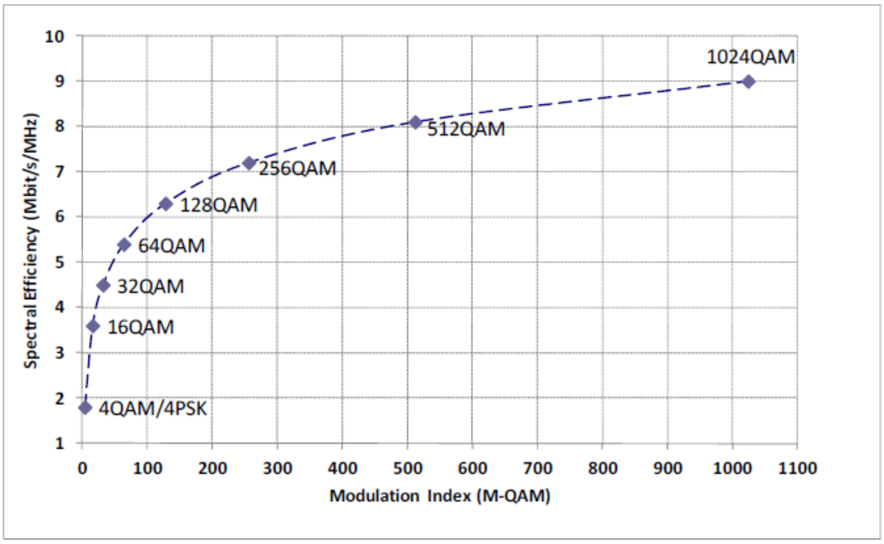
[105] ECC Report 173

[106] Vendors such as Aviat Networks, Alcatel Lucent and Ceragon

[107] ECC Report 173. It is noted in the report that there may be little benefit in extending above 1028 QAM to increase capacity because of the cost of investment.

While the spectral efficiency of the link in question is greater, the benefit of this to overall spectrum efficiency is somewhat diluted by the need for higher power levels and the greater susceptibility to interference.

Figure C-1: Relationship between spectral efficiency and modulation



Implications

There is now negligible additional equipment cost involved in implementing higher modulation states. From the user's point of view employing higher modulation states is potentially a zero equipment cost option if a higher data rate is the objective. The cost to the user is either an acceptance of greater susceptibility to interference or a requirement for higher power levels[108] which will limit spectrum access for other users. We do not have information on the value of a loss of availability to users or the additional power costs.

Overall, we consider that the use of higher modulation states on a static basis does not need additional encouragement through pricing.

C.3 Variable bit rate

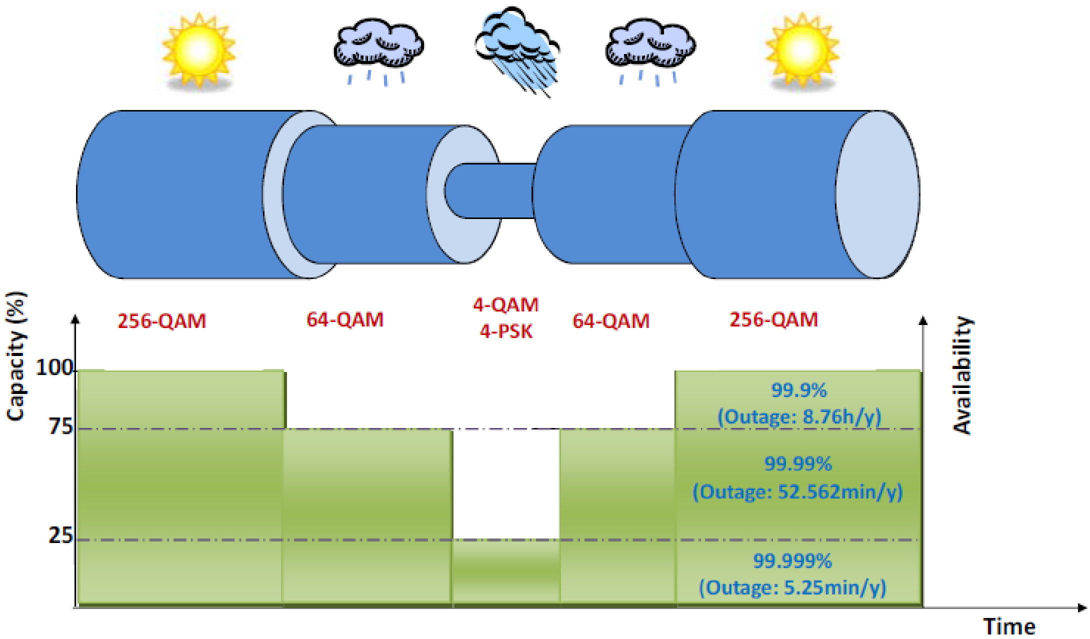
Traditional fixed link planning provides for a margin in the link such that a constant throughput can be maintained for most of the time (e.g. 99.99% of the time) even in the presence of multipath fades or rain attenuation on the link. Only the most severe fades or rain cause an outage when the margin is exceeded by the fade/attenuation.

For most of the time therefore a higher than necessary Carrier to Noise ratio (C/N) is available but it is not exploited. It should however be noted that the margin available also absorbs elevated levels of interference due to short term propagation enhancements on interfering paths.

[108] To achieve the increased E_b/N_0 target but also to provide a greater margin in order to cater for the link's increased susceptibility to interference.

Adaptive modulation makes use of the margin available to increase throughput (higher order modulations in the same bandwidth). This increased throughput is possible when the margin is available falling back to a core throughput (lower order modulation) when the margin is taken up by a fade / rain event as shown in the diagram below. The link will have been planned on the basis of 99.999% availability but for a significant time (99.9% for example) it is likely that the capacity over the link can be increased to four times its planned data rate by using a higher modulation state as shown in the following diagram.

Figure C-2: Example of adaptive modulation with indicative values



Source: ECC Report 173

It is expected that slightly less than full advantage can be taken of this technique since the use of higher modulations states are more susceptible to interference.

Implications

The exploitation of available margins by a fixed link operator to support higher throughput, albeit not on a guaranteed basis, clearly improves spectrum efficiency since power levels are no greater and additional protection is not sought. However, the user may do this if it is advantageous and the implementation of variable bit rates (or not) is not controlled by Ofcom.

Overall we consider that the use of variable bit rates on a dynamic basis does not need additional encouragement through pricing.

C.4 Power control

As noted above under the “Variable bit rate” option, traditional fixed link planning provides for a margin in the link such that a constant throughput can be maintained for most of the time (e.g. 99.99% of the time) even in the presence of fades or rain attenuation on the link. Only the most severe fades or rain cause an outage.

The variable bit rate option uses the margin available from a constant EIRP level to achieve higher modulation states and consequently higher throughputs for most of the time. Alternatively power control can be used to reduce the EIRP used most of the time and only increase the EIRP level when fades occur.

Implications

The implications of power control for spectrum efficiency were examined in a 2006 Ofcom research project[109]. From analysis of the implementation of automatic transmit power control (ATPC) in the 38 GHz band, it was concluded that:

- Significant improvements in spectrum efficiency can be obtained as measured by the increase in the number of links assigned to channel 1 (from ~50% to ~70%) and the decrease in the maximum bandwidth used by the totality of links (from ~300 MHz to ~180 MHz). The introduction of ATPC does give rise to a number of additional outages in the presence of intense rain (~10% increase in the presence of frontal rain). These additional outages can be mitigated to some extent by band-wide changes to the planning process and by matching the ATPC range with the remote fade margin; however, the outages cannot be wholly eliminated by the methods examined.
- Adjusting the wanted to unwanted signal ratio (W/U) in the planning process is a more effective technique for reducing ATPC-induced outages than adjusting the fade margins or interference margin. However, it is evident that none of these band-wide mitigation techniques targets the ATPC-induced outages very effectively.
- Based on the similarity of average fade margins between the 38 GHz band and other high frequency fixed link bands, gains in spectrum efficiency should equally be possible in other high frequency bands.

We conclude the use of transmit power control should be encouraged but the overall benefit obtained by the use of this technique is difficult to quantify and such quantification is beyond the scope of this study.

C.5 Higher performance antennas

Two standards define the performance for a number of classes of fixed link antenna operating in the range 1 to 86 GHz[110] as follows:

- Antenna patterns are defined for 4 classes of antenna in different frequency ranges. Because of the varying shape of the masks it is only possible to generalise about the benefits:
- The difference between Class 2 and 3 antennas lies in the range 2 to 15 dB depending on off-beam angle
- The difference between Class 3 and 4 is similar (2 to 15 dB)

[109] Impact of introducing Automatic Transmit Power Control in P-P Fixed Service systems operating in bands above 13 GHz - CCLRC Rutherford Appleton Laboratory and Aegis Systems Limited, 28 February 2006

[110] See, Essential and system dependent requirements, EN 302 217-4 from 2010-01.

However the maximum difference encompassing the classes (2, 3 and 4) is 25 dB rather than the 30 dB that might be implied

Implications

With increased discrimination available from higher class antennas there will benefits for fixed link planning in terms of allowing for a higher density of links. However, the extra discrimination available depends on the exact geometry involved and, as noted above, can fall within a range 2 to 15 dB between classes. It can be seen therefore that the benefit ranges from insignificant to significant.

The use of high performance antennas should be encouraged but the overall benefit obtained by their use is difficult to quantify and such quantification is beyond the scope of this study.

C.6 MIMO

Conventional links are generally designed using single antennas at both ends of the link and supporting a single data stream. Diversity paths and antennas have been employed to overcome reflections or fading (e.g. ducting). MIMO is being considered as a potential option to increase the capacity of point to point links by providing multiple paths established through multiple antennas provided there is sufficient space on the towers, especially for lower frequency band links.

According to a recent input into CEPT PT SE19[111] the ECC has previously issued the guidance that the total transmitted power (e.i.r.p) from a MIMO enabled link should not exceed the total transmitted power level (e.i.r.p) from a single antenna link but such an approach "overlooks the fact that "turning down" the power to each antenna in a MIMO configuration will negate many of the advantages of installing the MIMO technology".

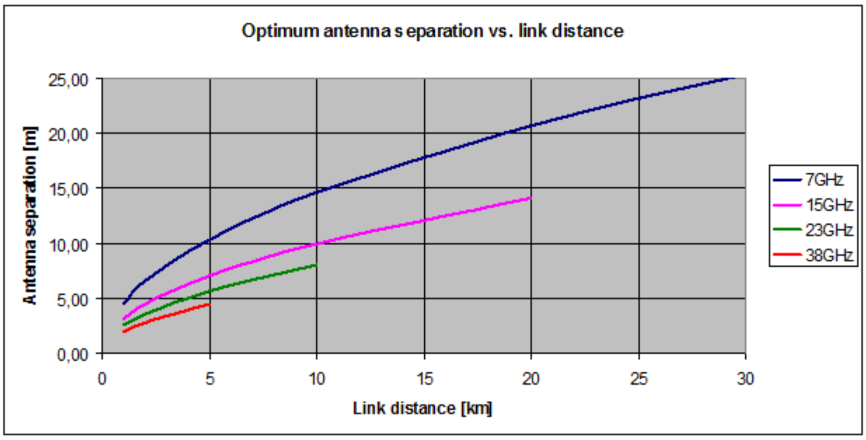
Implications

The greater spectral efficiency of implementing MIMO may be reduced by the need to increase the power to each antenna and therefore the potential increase in interference to other links. There is no reliable cost information on which to base a spectrum value calculation for MIMO. Lack of experience with MIMO means it is too early to determine the efficiencies that might be gained and it is possible that these may only apply in the higher less congested frequency bands, as the required antenna separation distances on a mast are significant for lower frequency bands, for example at 7 GHz for hop links greater than 5 km antenna separations of 10 metres and more are required (see Figure C-3).

We consider that the use of MIMO is not well enough established to link it to current assignment methods or to quantify the benefits.

[111] SE19(13)112_Annex 1-Use of MIMO-BNetzA

Figure C-3: Antenna separation requirements for different frequency bands and link lengths



Source: Annex 1 to Minutes of 65th PT SE19 Meeting, October 2013

C.7 NLOS

Except for the lowest frequency bands fixed links are planned by Ofcom on the basis of line-of-sight paths[112]. However, EIRP uplifts of up to 6 dB are allowed by Ofcom on a case-by-case basis where obstacles are present on the wanted path. This is not encouraged by Ofcom and operators are encouraged to use alternative routes or deploy antennas at increased heights.

There is however a demand for a regime that would allow for the operation of fixed links in environments that have significant obstructions. Such non-line of sight operation relies on reflected and diffracted signals[113].

Implications

While enabling links to be established in the presence of obstacles it is inevitable that such links will require higher transmitter powers and also may increase the interference environment. There needs also to be access to a suitable planning tool that can take into account the interference paths when calculating interference into existing links and identifying suitable frequencies. Furthermore NLOS links are likely to be deployed in self-managed blocks of spectrum because of the need to change their deployment in response to changes in clutter.

The use of NLOS links does not fit well with current assignment methods and if deployed in self-managed spectrum blocks the Ofcom fixed link fees algorithm is not applicable..

[112] These are defined by set values for k (4/3) and Fresnel zone clearance (0.67). The value for k represents typical atmospheric refraction in the UK and the Fresnel zone clearance value ensures that the path is unobstructed.

[113] ECC Report 173. Fixed service in Europe: current use and future trends post 2011. March 2012

C.8 Mesh networks

Fixed links are currently planned on a link by link basis taking account of the High v. Low site protocol. Operators of the links may plan their network to have diverse routes and this is generally done at a macro level.

Mesh networks are based on multiple connections between nodes and traffic routing can be dynamic thereby providing great flexibility and resilience. Such systems are best viewed as a collection of interconnected nodes within an area[114].

Implications

The operators require the flexibility to be able to add or remove nodes in their networks and this may impact on the frequency planning. To implement such networks the operators ideally require access to blocks of spectrum which they can self-manage.

The use of mesh networks does not fit well with current assignment methods.

[114] ECC Report173

Appendix D: Supporting material least cost alternative calculations

Below we provide the calculations of least cost alternative values of spectrum for the situation in which a user of spectrum is denied access to its preferred band and considers the following two alternatives:

- Use of a higher less congested frequency band that involves deployment of an additional hop as compared with the preferred band (Section D.1 below)[115]
- Use of a wired connection purchased from a fixed network supplier rather than deployment of a wireless link in the preferred band (Section D.2 below).

The user in question is assumed to be wishing to deploy a fixed link with of a "typical" bandwidth for the frequency range under consideration. This could be a user wanting a new link either because of a new demand or because an old link is being replaced.

Our analysis of Ofcom data given in Section 3 of this report suggests that a typical bandwidth would be 2x28 MHz (which could accommodate typical data rates of 155-311 Mb/s). In the case of the wired connection BT's wholesale services support either 100Mb/s or 300-1 Gbps which does not match well to the fixed link data rates. For the lower 100Mbps data rate a 2x28 GHz link could support the service, however, this is not necessarily the case for bit rates towards the top end of the 300-1 Gbps range and so we show results assuming a 2x56 MHz bandwidth.

Throughout this Appendix we use the term **site occupant** to refer to a radio transmitter/receiver at a mast site.

D.1 Calculations for use of a higher frequency band requiring an additional hop

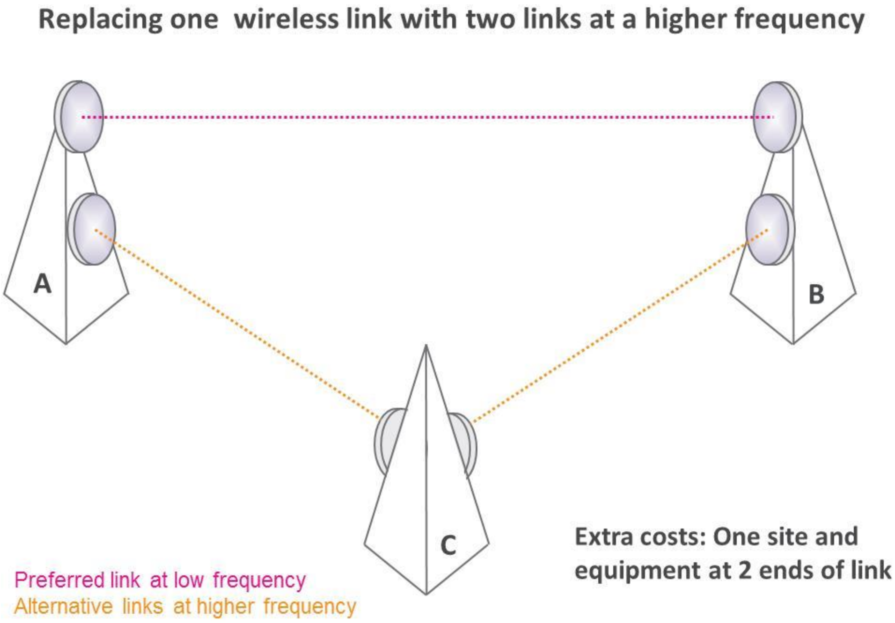
The situation we are considering here is where a potential fixed link user would ideally deploy a link at a low frequency band because this is the least cost option facing the user i.e. a situation where there are additional costs to using higher frequency bands that arise from the need for additional infrastructure. However, the user is denied access to this low frequency band because it is congested. The user must then opt for a higher frequency and deploy an additional hop. As can be seen from Figure D-1, the user will incur additional site and equipment costs at site C. The user may however, save some costs (at the original sites) if higher frequency equipment costs less and/or incurs lower site costs (because it is smaller) than lower frequency equipment.

We quantify the potential cost savings for two situations:

- a user denied access to frequencies below 10GHz and instead uses frequencies in the 10-20 GHz range
- a user denied access to 10-20 GHz and instead uses frequencies in the above 20 GHz range.

[115] In 2004 the LCA value was derived based on the additional cost of higher modulation fixed link equipment. This can approach can no longer be used because there is no additional cost for higher modulation equipment. So when a user implemented a new link it will logically deploy highest modulation state.

Figure D-1: Situation with an additional link



In the sections below we present estimates of the costs incurred in deploying fixed links (Section D.1.1) and then calculate the implied increase in costs and costs/2x1 MHz to a user from having to use a higher frequency band (Section D.1.2). To derive spectrum values we need to divide these costs by the bandwidth of the link in the lower preferred band. Sensitivity tests are undertaken in Section D.1.3 as we do not have reliable information on a number of the input parameters, in particular site costs per user. A summary of the implied spectrum values per 2x1 MHz for each band (under 10 GHz, 10-20 GHz and above 20 GHz) are given in Section D.1.4.

D.1.1 Fixed link costs

In this section we provide information on the following cost elements associated with the deployment of a fixed link and an additional hop:

- Fixed link equipment costs (transceivers and antennas)
- Site construction costs
- Site rental
- One-off installation and commissioning costs for radio equipment
- One-off infrastructure costs for equipment accommodation and a power supply
- On-going maintenance costs

We obtained fixed link equipment costs from suppliers and consider these are reasonably representative of the costs facing a user seeking to deploy a new link. We have not found a source of reliable data on the costs to a fixed link user of renting space, cabinets and mast capacity at different locations. Rather we have had to estimate these costs based on land/space rental costs and mast build costs and using industry rules of thumb concerning the relationship between equipment costs and the costs of installation, commissioning, site infrastructure and maintenance. In all cases capital costs are annualised using a 9% nominal discount rate[116].

Next, to compute the site related costs incurred by a user, we need to make assumptions about the number of occupants per site and to compute an average cost per occupant. We do not have data on the number of occupants per site and so make assumptions based on our experience. We use a Base Case and three variations from this base case which are described as follows.

Site Sharing Cases

Base Case: In this case we assume a **rural site has 3 site occupants** and an **urban site has 1 site occupant**, noting than urban sites tend to be much smaller than rural sites.

Increased site sharing: In this case it is assumed that a **rural site has 6 site occupants** and an **urban site has 3 site occupants**

No site costs: In this case it is assumed that fixed link users do not incur any incremental site costs, for example, because they own the mast and are already covering the costs with other services operating from the site.

Single rural site occupant: In this case we assume that there is **one occupant** on a rural site.

Radio equipment

The range of prices for point-to-point fixed link equipment is large. For frequency bands at 10GHz and above the price for two transceivers / antennas ranges from £2,250 to £42,000 across a range of manufacturers and suppliers we contacted[117]. Ignoring the outliers, most prices fall in the range £5,000 to £12,000 with most values we obtained towards the lower end of the range so we will **take £7,000 as representative**. These prices are for small quantities and it can be expected that purchasers of large quantities of equipment (e.g. mobile and fixed network operators) would achieve significant discounts (e.g. 50%) on the prices quoted. It is understood that antennas used by this equipment are of a standard level of performance and are included in this equipment price.

Whilst in the past there was a difference in prices for equipment operating in the lower frequency bands and for different modulation / bit rate equipment, that is no longer the case as equipment is modular and configured through software. In fact adaptive modulation equipment is the norm for Ethernet equipment and vendors might even charge an excess for equipment with fixed modulation.

For frequency bands below 10 GHz (excluding the 1.4 GHz band) standard relatively large dish antennas (excluding 1.4 GHz which uses lightweight Yagi antennas) cost £2,500 each i.e. **the total equipment cost for a link below 10 GHz is assumed to be £12,000** (=£7,000 +2 x £2,500). The further implication for these lower frequency bands (excluding the 1.4 GHz band) is the need for more robust structures to support the antennas and this potentially implies higher site rental costs (addressed below) and/or the need to erect an appropriate mast.

Site construction costs

We have not been able to obtain data on the costs of mast rental. Hence in all cases we have had to calculate such costs assuming that a new site is developed and a mast is constructed and then

[116] This is based on the pre-tax nominal weighted average cost of capital derived by Ofcom for a mobile operator of 8.9%. See Appendix E.

[117] Aegis investigation of manufacturers price lists and discussions with manufacturers in the course of this study.

assume these costs are shared on an annualised basis between an assumed number of site occupants. The construction costs of a mast supporting antennas for equipment using frequencies below 20 GHz in a rural area would fall in the range £150,000 to £250,000 (which spread over a 20 year life at 9% discount rate[118] equates to almost £15,000 to £25,000 per annum and has been reduced pro rata for multiple occupancy)[119]. **A mid-range rural construction cost of £200,000 is used in subsequent calculations.**

For those cases where a roof-top site is used for the installation, the mast construction costs are significantly less, although for lower frequency bands there still has to be a sufficient structure to accommodate the antennas[120]. **It is estimated that such costs for roof-top sites in urban and suburban areas would be £25,000**[121].

For frequencies **above 20 GHz** where equipment tends to be smaller it is estimated that mast constructions costs are **£100,000 in rural areas and £10,000 for roof-top sites in urban and suburban areas.**

Site rental[122]

Non-roof top site rental is of the order £5,250 per annum but can be less than £1,000 per annum in rural areas. Roof top site rental is of the order £16,000 per annum within the M25 and £11,000 per annum outside the M25 although some urban sites can be less than £2,000 per annum. These prices do not include anything beyond making space available. Costs for any cabins, masts, power, etc, are all additional to these costs.

It has been assumed that site rental is **£1,000 per annum in rural areas** and **£11,000 per annum for roof top sites in urban and suburban areas**, the latter decreasing to **£5,000 per annum for frequencies above 20 GHz** due to the smaller structures required.

Installation and commissioning

A one-off labour cost will be incurred for the installation and commissioning of the radio equipment. In the past[123] this has been taken to be 50 % of the capital cost but since equipment costs have fallen significantly (and labour costs are likely to have risen) this is now more likely to be **100% of the annualised capital cost for the lower frequency bands (i.e. below 20 GHz)**. A value of **50% has been used for frequencies above 20 GHz** as equipment tends to be more manageable i.e it is smaller and more self-contained**.**

Infrastructure – equipment accommodation and power supply

Since this is not generally included as part of the site rental, provision will have to be made for equipment accommodation and a power supply. Based on our industry knowledge we consider this

118 This is based on the pre-tax nominal weighted average cost of capital derived by Ofcom for a mobile operator of 8.9%. See Appendix E.

119 Based on a web review of costs. Main sources used were from the US http://www.statisticbrain.com/cell-phone-tower-statistics/, http://www.quora.com/Telecommunications/How-much-money-would-it-cost-to-build-a-cell-towerTelecommunications, http://www.nasdaq.com/article/celltower-firms-stand-tall-in-infrastructure-field-cm192574#ixzz2vpZerDa8

120 It should be noted that many roof top installations are unlikely to be suitable for lower frequency bands where there is a need to accommodate larger antennas and for greater pointing accuracy.

121 Aegis estimate

122 Source: Batcheller Monkhouse's survey 2013 on rental trends (chartered surveyors specialising in telecoms work). It is based on analysis of 5,500 site transactions out of a total of ~30,000 sites.

123 Estimating the commercial trading value of spectrum. Plum report for Ofcom. July 2009.

should also be taken to be **100 % of the annualised capital cost of the radio equipment below 20 GHz**. As above and for the same reasons, a value of **50% has been used for frequencies above 20 GHz.**

Maintenance

Ongoing maintenance will be an **annual** cost and our experience suggests this amounts to **12% of the total capital cost of the radio equipment**.

D.1.2 Base Case analysis

In Table D-1 we show the costs for a link for the three frequency ranges under 10 GHz, 10-20 GHz and above 20 GHz and for a rural and an urban deployment for the Base Case. Table D-2 shows the costs of an additional hop at each frequency range and for a rural and an urban deployment for the Base Case.

Table D-1: Cost estimates for complete link (two sites and equipment pair) at different frequencies and in rural and urban situations (£) – Base Case

	Site cost - Construction (Note 1)	Site cost - Rental (Note 1)	Equipment cost - Capital	Equipment cost - Install, infrastructure and maintenance (annual) (Note 2)	Total annualised cost (Note 4)
Costs for complete link below 10 GHz					
Rural	400,000 13,400 p.a.	667 p.a.	12,000 (Note 3) 2,187 p.a.	5,815 p.a.	22,069
Urban or suburban	50,000 5,025 p.a.	22,000 p.a.	12,000 (Note 3) 2,187p.a.	5,815 p.a.	35,027
Costs for complete link 10-20 GHz					
Rural	400,000 13,400 p.a.	667 p.a.	7,000 1,276 p.a.	3,392 p.a.	18,735
Urban or suburban	50,000 5,025 p.a.	22,000 p.a.	7,000 1,276 p.a.	3,392 p.a.	31,693
Costs for complete link above 20 GHz					
Rural	200,000 6,700 p.a.	667 p.a.	7,000 1,276 p.a.	2,116 p.a.	10,759
Urban or suburban	20,000 2,010 p.a.	10,000 p.a.	7,000 1,276 p.a.	2,116 p.a.	15,402

Note 1 – The Base Case assumes 3 site occupiers in rural areas and one site occupier in urban areas.
Note 2 - For the below 10 GHz and 10-20 GHz cases installation costs are 100% of the annualised equipment capital cost and infrastructure costs are also 100% of the annualised equipment costs. Above 20 GHz installation costs are 50% of the annualised equipment capital cost and infrastructure costs are also 50%.
Annual maintenance is taken to be 12% of the total equipment capital costs.
Note 3 – Equipment costs below 10 GHz include larger antennas. Hence the equipment cost is £5k more than at higher frequencies.
Note 4 – All calculations assume a nominal discount rate = 9% and lifetime of new equipment = 7 years, Lifetime of structures = 20 years

Table D-2: Cost estimates for additional hop (one site and equipment pair[124]) at different frequencies and in rural and urban situations (£) – Base Case

	Site cost - Construction (Note 1)	Site cost - Rental of land/roof space (Note 1)	Equipment cost - Capital	Equipment cost - Install, infrastructure and maintenance (annual) (Note 2)	Total annualised cost (Note 4)
Costs for additional hop below 10 GHz					
Rural	200,000 6,700 p.a.	333 p.a.	12,000 (Note 3) 2,187 p.a.	5,815 p.a.	15,035
Urban or suburban	25,000 2,513 p.a.	11,000 p.a.	12,000 (Note 3) 2,187 p.a.	5,815 p.a.	21,515
Costs for additional hop 10-20 GHz					
Rural	200,000 6,700 p.a.	333 p.a.	7,000 1,276 p.a.	3,392 p.a.	11,701
Urban or suburban	25,000 2,513 p.a.	11,000 p.a.	7,000 1,276 p.a.	3,392 p.a.	18,181
Costs for additional hop above 20 GHz					
Rural	100,000 3,350 p.a.	333 p.a.	7,000 1,276 p.a.	2,116 p.a.	7,075
Urban or suburban	10,000 1,005 p.a.	5,000 p.a.	7,000 1,276 p.a.	2,116 p.a.	9,397

Note 1 – The Base Case assumes 3 site occupiers in rural areas and one site occupier in urban areas.
Note 2 – For the below 10 GHz and 10-20 GHz cases installation costs are 100% of the annualised equipment capital cost and infrastructure costs are also 100% of the annualised equipment costs. Above 20 GHz installation costs are 50% of the annualised equipment capital cost and infrastructure costs are also 50%.
Annual maintenance is taken to be 12% of the total equipment capital costs.
Note 3 – Equipment costs below 10 GHz include larger antennas. Hence the equipment cost is £5k more than at higher frequencies.
Note 4 – All calculations assume a nominal discount rate = 9% and lifetime of new radio equipment = 7 years, Lifetime of structures = 20 years

To estimate the marginal value of a lower (more congested) band we add the additional cost of using a higher band divided by the bandwidth of the desired link in the preferred band and the price of spectrum in the higher band as follows:

$MV_L = C_H/BW + P_H$

Where:

[124] The equipment pair for an additional hop is treated as a single occupant for the purposes of calculating the site costs associated with an additional hop.

MV_L = marginal value of 2x1 MHz in the lower (more congested) band

C_H = additional equipment and other costs of using the higher (less congested) band

BW = bandwidth of the link in the preferred band

P_H = price of 2x1 MHz in the higher (less congested) band

We start the calculations with the situation in which P_H is zero, namely bands above 20 GHz where spectrum is plentiful, and estimate the marginal value for 10-20 GHz. Next we estimate the value for below 10 GHz using the marginal value for 10-20 GHz just calculated.

D.1.2.1 Moving from 10-20 GHz to >20 GHz

The additional cost in moving from the lower frequency band to the higher frequency band includes not only the cost of an additional hop in the higher frequency band (costs for one site and two sets of equipment – i.e. Site C in Figure D-1) but also any difference in site / equipment costs between the two frequency bands for the two original sites (i.e. Sites A and B in Figure D-1). In the case of the latter element there is a cost saving (negative additional cost) in using the higher band as site costs are lower for higher frequency equipment but equipment costs are the same.

Table D-3: Costs of 2 hops at above 20 GHz versus one hop at 10-20 GHz

Situation	Costing (p.a.) [cost of additional hop + cost difference for original sites]	Net cost of move to 20GHz – one additional hop
Rural	7,075 + (10,759 – 18,735)	-901 p.a.
Urban or suburban	9,397 + (15,402 – 31,693)	-6,894 p.a.

The values are negative which means that the cost saving for a complete hop when moving from the lower frequency band (10-20 GHz) to the higher frequency band (>20 GHz) is greater than the cost of an additional hop in the higher frequency band. In other words it is cheaper for the user to opt for frequencies above 20 GHz wherever this can be achieved with at most one hop. Hence this is not a realistic situation as the user would opt for a link above 20 GHz because of the lower costs involved.

Hence we next consider the situation where two additional hops are required. The additional costs are shown in Table D-4.

Table D-4: Costs of 3 hops at above 20 GHz versus one hop at 10-20 GHz (£) – Base Case

Situation	Costing (p.a.) [cost of additional hops + cost difference for original sites]	Net cost of move to 20 GHz – two additional hops	Cost per 2x1 MHz for a 2x28 MHz link
Rural	2*7,075 + (10,759 – 18,735)	6,174 p.a.	221
Urban or suburban	2*9,397 + (15,402 – 31,693)	2,503 p.a.	89

D.1.2.2 Moving from <10 GHz to 10-20 GHz

Applying the same principle as for the higher frequency move outlined above, the additional cost in moving operations from below 10 GHz to the 10-20 GHz frequency range is obtained as shown in Table D-5 below. In this case site costs are the same between frequency bands but equipment costs differ as larger antennas are generally required below 10 GHz.

Table D-5: Costs of 2 hops at 10-20 GHz versus one hop at 10 GHz (£) – Base Case

Situation	Costing (p.a.) [cost of additional hop + cost difference for original sites]	Net additional cost of using 10-20 GHz vs <10 GHz	Cost per 2x1 MHz for a 2x28 MHz link
Rural	11,701 + (18,735 – 22,069)	8,367 p.a.	299
Urban or suburban	18,181 + (31,693 – 35,027)	14,847 p.a.	530

The additional cost per 2x1 MHz from being required to use the 10-20 GHz frequency range rather than the preferred frequencies below 10 GHz falls in the range £299-530, as shown in the final column of Table D-5.

D.1.2.3 Implied spectrum values[125]

The preceding sections have provided costs of being denied a link at 10 – 20 GHz and having to use links above 20 GHz which when divided by the desired bandwidth at 10-20 GHz gives the value of 10 – 20 GHz spectrum. In order to obtain the value of spectrum below 10 GHz it is necessary to add the

[125] Note these are not AIP values.

value of 10 – 20 GHz spectrum to that calculated for spectrum below 10 GHz. The resulting values of spectrum are shown in Table D-6 below.

Table D-6: Value of spectrum below 10 GHz and 10-20 GHz (£/2x1 MHz) – Base Case

	3 rural site occupiers & 1 sub/urban site occupier
Value of <10 GHz	
Rural	520 (= 221 + 299)
Urban or suburban	619 (= 89 + 530)
Value of 10-20 GHz	
Rural location	221
Urban or suburban	89

Source: Plum and Aegis analysis

D.1.3 Sensitivity tests

For the situations assessed so far it has been assumed that a rural site will attract 3 site occupants and for a mast on top of a building in urban and suburban areas, it has been assumed that the smaller structure has one site occupant.

It is possible that where sites and infrastructure already exist they will be shared by a greater number of site occupants than assumed in the Base Case. For the rural tower case we have assumed that the Base Case number of site occupants is doubled from 3 to 6 and for the urban/suburban rooftop case we have assumed that a single site occupant becomes a three way share. Based on corresponding reductions in structure costs and rental as attributed to each user, the annualised cost changes are as shown in Table D-7 below.

In the case where masts already exist and are owned by an operator, it can be envisaged that no mast or site rental costs are attributed to the fixed link. For example, there is no explicit attribution of site costs to backhaul links in the Ofcom Mobile Termination Rate model. This case is also shown in Table D-7 and Table D-8 below. The costs associated with the Base Case site occupant assumptions are the same as those in Table D-1 and Table D-2.

Finally we consider a case of higher costs, with a rural site having only one occupant.

Table D-7: Complete link costs (two sites and equipment pair) under different site occupancy assumptions (£)

	Rural			Sub/urban		
	< 10 GHz	10 – 20 GHz	> 20 GHz	< 10 GHz	10 – 20 GHz	> 20 GHz
Base case	**3 rural site occupants**			**1 sub/urban site occupants**		
Two sites cost p.a.	14,067	14,067	7,367	27,025	27,025	12,010
Equipment cost p.a.	8,002	4,668	3,392	8,002	4,668	3,392
Total p.a. (Note 1)	22,069	18,735	10,759	35,027	31,693	15,402
Increased sharing case	**6 rural site occupants**			**3 sub/urban site occupants**		
Two sites cost p.a.	7,033	7,033	3,683	9,008	9,008	4,003
Equipment cost p.a.	8,002	4,668	3,392	8,002	4,668	3,392
Total p.a.	15,035	11,701	7,075	17,010	13,676	7,395
No site costs						
Two sites cost p.a.	0	0	0	0	0	0
Equipment cost p.a.	8,002	4,668	3,392	8,002	4,668	3,392
Total p.a.	8,002	4,668	3,392	8,002	4,668	3,392
Single rural site occupant						
Two sites cost p.a.	42,201	42,201	22,100	n.a.	n.a.	n.a.
Equipment cost p.a.	8,002	4,668	3,392	n.a.	n.a.	n.a.
Total p.a.	50,203	46,869	25,492	n.a.	n.a.	n.a.

Note 1 – The totals in this row correspond to the totals in the right hand column of Table D-1 where a more detailed breakdown of costs is given.

n.a. = not applicable

Table D-8: Additional hop costs (one site and equipment pair) under different site occupancy assumptions (£)

	Rural			Sub/urban		
	< 10 GHz	10 – 20 GHz	> 20 GHz	< 10 GHz	10 – 20 GHz	> 20 GHz
Base case	**3 rural site occupants**			**1 sub/urban site occupant**		
Single site cost p.a.	7,033	7,033	3,683	13,513	13,513	6,005
Equipment cost p.a.	8,002	4,668	3,392	8,002	4,668	3,392
Total p.a. (Note 1)	15,035	11,701	7,075	21,515	18,181	9,397
Increased sharing case	**6 rural site occupants**			**3 sub/urban site occupants**		
Single site cost p.a.	3,517	3,517	1,842	4,504	4,504	2,002
Equipment cost p.a.	8,002	4,668	3,392	8,002	4,668	3,392
Total p.a.	11,519	8,185	5,234	12,506	9,172	5,394
No site costs						
Single site cost p.a.	0	0	0	0	0	0
Equipment cost p.a.	8,002	4,668	3,392	8,002	4,668	3,392
Total p.a.	8,002	4,668	3,392	8,002	4,668	3,392
Single rural site occupant						
Single site cost p.a.	21,100	21,100	11,050	n.a.	n.a.	n.a.
Equipment cost p.a.	8,002	4,668	3,392	n.a.	n.a.	n.a.
Total p.a.	29,102	25,768	14,442	n.a.	n.a.	n.a.

Note 1 – The totals in this row correspond to the totals in the right hand column of Table D-2 where a more detailed breakdown of costs is given.
n.a. = not applicable

The values given above are then used to derive the annualised costs of an additional hop where this is the cost of an additional hop in the higher frequency band (costs for one site and two sets of equipment as shown in

Table D-8) and also any difference in site / equipment costs between the two frequency bands for the two original sites (obtained from Table D-7). For example, in an urban or suburban environment moving from below 10 GHz to 10-20 GHz under an increased site occupancy assumption (3 rather than 1), the annualised cost in Table D-9 of £5,838, is obtained as follows:

Cost of additional hop in higher frequency band (10-20 GHz) = 9,172 p.a.

Cost of complete link in lower frequency band (below 10 GHz) = 17,010 p.a.

Cost of complete link in higher frequency band (10-20 GHz) = 13,676 p.a.

Total annualised cost = 9,172 + (13,676 – 17,010) = 5,838

Table D-9: Annualised costs of an 2x28 MHz additional hop under different site occupancy assumptions and the implied costs per 2x1 MHz in brackets (£)

Situation	Base case 3 rural site occupants 1 sub/urban site occupants	Increased sharing case 6 rural site occupants 3 sub/urban site occupants	No site costs Independent of site occupancy numbers
Case 1: Moving from below 10 GHz to 10-20 GHz			
Rural	11,701 + (18,735 – 22,069) = 8,367 (299 per 2 x 1 MHz)	8,185 + (11,701 – 15,035) = 4,851 (173 per 2 x 1 MHz)	4,668 + (4,668 – 8,002) =1,334 (48 per 2 x 1 MHz)
Urban or suburban	18,181 + (31,693 – 35,027) = 14,847 (530 per 2 x 1 MHz)	9,172 + (13,676 – 17,010) = 5,838 (209 per 2 x 1 MHz)	4,668 + (4,668 – 8,002) =1,334 (48 per 2 x 1 MHz)
Case 2: Moving from 10-20 GHz to above 20 GHz			
Rural	2*7,075 + (10,759 – 18,735) = 6,174 (221 per 2 x 1 MHz) (Note 1)	5,234 + (7,075 – 11,701) = 608 (22 per 2 x 1 MHz)	3,392 + (3,392 – 4,668) = 2,116 (76 per 2 x 1 MHz)
Urban or suburban	2*9,397 + (15,402 – 31,693) = 2,503 (89 per 2 x 1 MHz) (Note 1)	2*5,394 + (7,395 – 13,676) = 4,507 (161 per 2 x 1 MHz) (Note 1)	3,392 + (3,392 – 4,668) = 2,116 (76 per 2 x 1 MHz)

Note 1 – In these instances the implied value is based on two additional hops being required when moving from the lower to the higher frequency band.

For the rural case where there is a single tenant the annualised costs for an additional hop and the implied costs per 2x1 MHz are given by:

Case 1 (Moving from below 10 GHz to 10-20 GHz)

25,768 + (46,869 – 50,203) = 22,434 p.a. or 801 p.a. per 2 x 1 MHz

Case 2 (Moving from 10-20 GHz to above 20 GHz) – 2 additional hops required

2 * 14,442 + (25,492 – 46,869) = 7,507 p.a. or 268 p.a. per 2 x 1 MHz

D.1.4 Values of spectrum by band - summary

To obtain the value of spectrum below 10 GHz it is necessary to add the value of 10 – 20 GHz spectrum to that calculated for spectrum below 10 GHz. This is shown in Table D-10.

Table D-10: Value of spectrum below 10 GHz and 10-20 GHz (£)

Situation (user/site)	Base case 3 rural site occupants 1 sub/urban site occupant 2 x 1 MHz	Increased sharing case 6 rural site occupants 3 sub/urban site occupants 2 x 1 MHz	No site costs Independent of the number of site occupants 2 x 1 MHz
Case 1 – Value of <10 GHz			
Rural	520 (= 221 + 299)	195 (= 22 + 173)	124 (= 76 + 48)
Urban or suburban	619 (= 89 + 530)	370 (= 161 + 209)	124 (= 76 + 48)
Case 2 – value of 10-20 GHz			
Rural location	221	22	76
Urban or suburban	89	161	76

For the rural case where there is a single site occupant:

The value of spectrum in the range 10 – 20 GHz is £268 p.a. per 2 x 1 MHz

The value of spectrum < 10 GHz is £1,069 p.a. per 2 x 1 MHz (given by 268 + 801)

D.2 Wired technology

In this case we compare the cost of a wireless link with that of a wired connection, as we are considering a situation where a user is potentially denied access to spectrum and choses a wired alternative from BT Openreach – this could be a leased line or an Ethernet product. Three possible situations arise for the deployment of the wired connection as follows:

- Situation A: No additional cost of connecting to the fixed network access points (Figure D-2)
- Situation B: One new wired connection required to connect to the fixed network access points (Figure D-3)
- Situation C: Two new wired connections required to connect to the fixed network access points (Figure D-4).

We do not have data on the distribution of fixed links across these cases and so we compute values for the range of cases. We assume that for the majority of users, such as utilities, mobile and fixed network operators and broadcasters the wireless link is deployed on an existing site (which has connectivity) or close to such a site.

Figure D-2: Situation A – no new connections to the fixed telecoms network

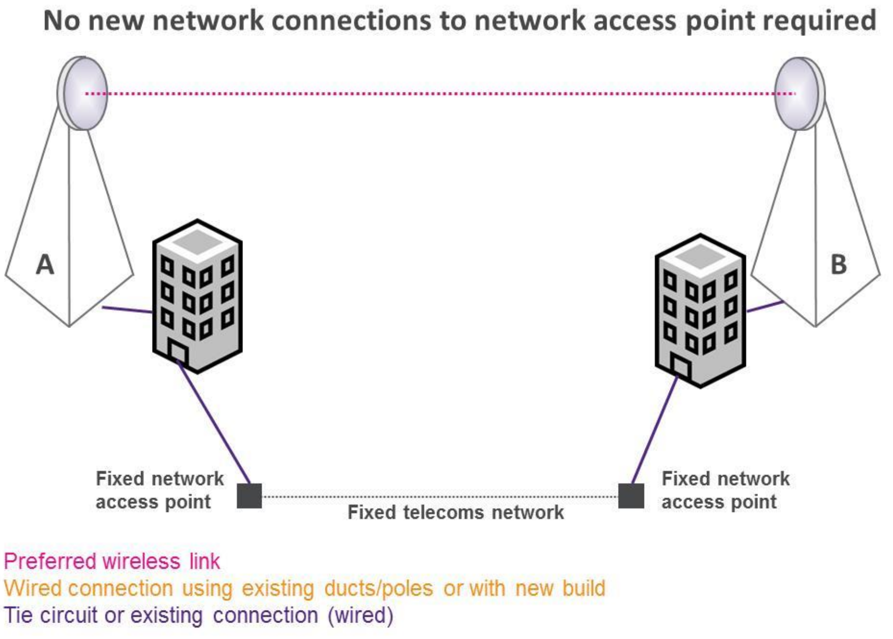


Figure D-3: Situation B- One new connection to the fixed telecoms network

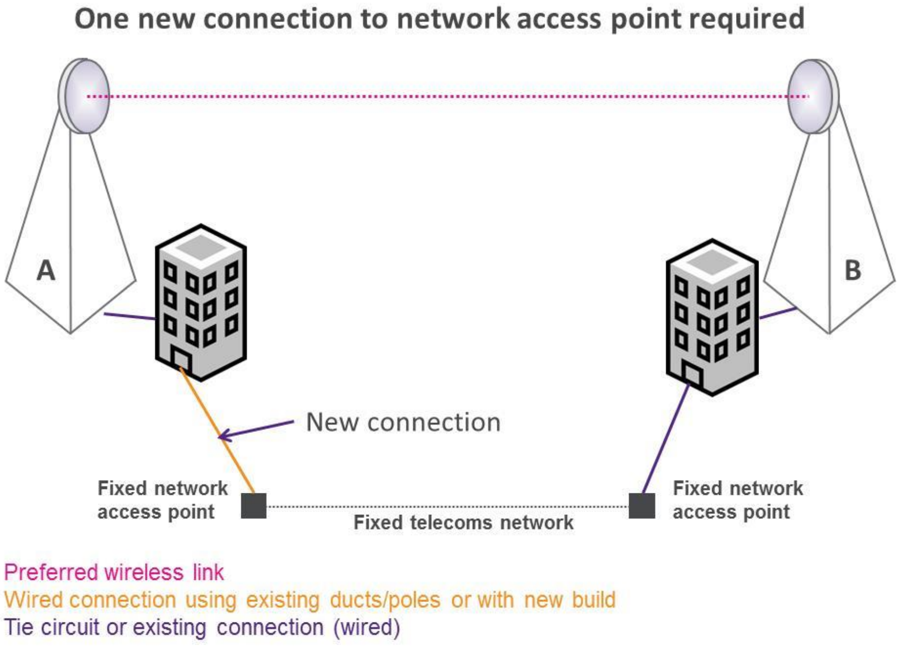
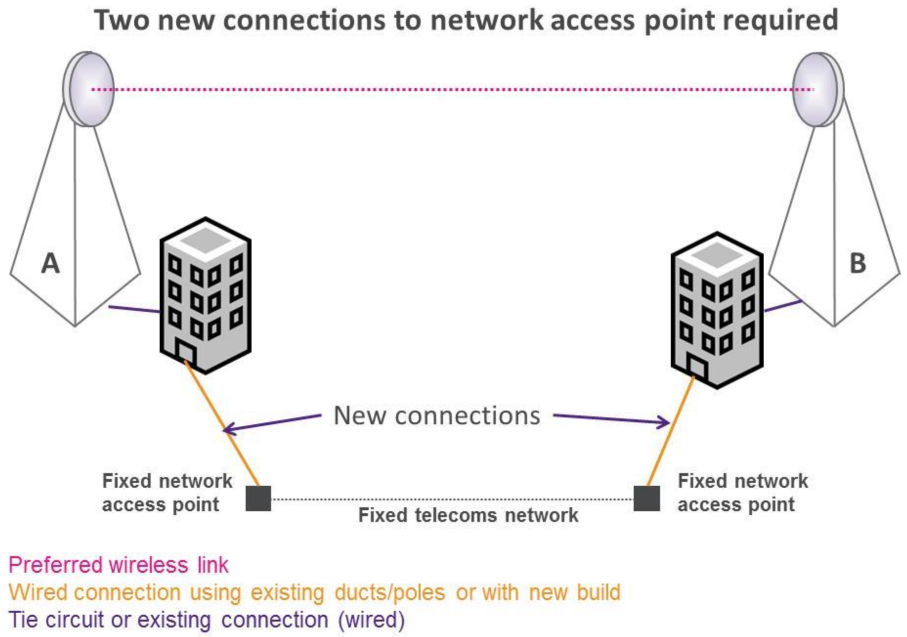


Figure D-4: Situation C – Two new connections to the fixed telecoms network



The wireless costs for the analysis are given in Section D.1.1. In Section D.2.1 we report information on the costs of wired connections for a 100Mbps and a 300Mbps-1 Gbps link – the bandwidths of corresponding fixed links are assumed to be 2x28MHz and 2x56 MHz respectively. In Section D.2.2 these costs are compared to those for fixed links at different frequency ranges and cost differences/2x1 MHz calculated. Sensitivity tests are given in Section D.2.3.

D.2.1 Wired services costs

The (retail) rental price of a 100 Mbps leased line (shared bearer rather than dedicated physical link) within urban areas falls in the range £450 to £650 per calendar month (pcm) (£5,400 to £7,800 per annum) depending on the installation work that has to be undertaken at each end. For links over 25 km there is no variation with distance. For links shorter than 25km a reduction in the amounts quoted would be expected as implied by the wholesale prices indicated below. The average cost per annum can be taken to be £6,600 for a 100 Mbps link (25 km or greater).

The comparable cost for a 1 Gbps link is between £2,000 and £4,000 pcm so the average cost per annum is £36,000. The wider range here, compared to the 100 Mbps case, is due to the greater uncertainty in existing infrastructure at each end. Note that these prices, and for those the 100 Mbps connection above, may fall in light of the upcoming wholesale price reductions noted below.

The retail prices above are from a commercial provider accessing the communications infrastructure market generally. Wholesale prices of equivalent products from BT Openreach for extended reach (i.e. over 25 kms) are currently:

- £5,000 per annum for a 100 Mbps link and a one-off connection fee of £2,500 (annualised £251 per annum[126]).
- In the range between £11,000 and £15,000 per annum for a 1 Gbps link. There is also a one-off connection fee of £3,500 (annualised £352 per annum).

The wholesale prices of equivalent products from BT for non-extended reach (less than 25 kms) are:

- £2,400 per annum for a 100 Mbps link and one off connection fee of £2,000 (annualised £201 per annum).
- In the range £5,500 to £9,500 per annum for a 1 Gbps link. There is also a one-off connection fee of £3,500 (annualised £352 per annum).

In both cases there may be other charges, which could be significant in comparison, if any civil work needs to be undertaken to connect to an appropriate access point. We first consider the case where these costs are not incurred.

To derive a per MHz cost per annum it is assumed that the comparable bandwidth for the 100 Mbps link is 28 MHz and for the 1 Gbps link is 56 MHz[127]. This bandwidth conversion is consistent with the approach adopted in the previous section for comparing the radio equipment alternatives.

For the purposes of the analysis that follows the wired costs are as shown in Table D-11.

Table D-11: Costs of wired connections (without any civil work)

	Rental p.a.	Connection fee	Annual cost
100 Mbps link from BT (wholesale) > 25 kms	5,000	2,500 = 251 p.a.	5,251
100 Mbps link from BT (wholesale) < 25 kms	2,400	2,000 = 201 p.a.	2,601
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms	15,000	3,500 = 352 p.a.	15,352
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms	9,500	3,500 = 352 p.a.	9,852

D.2.2 Base Case values with and without civil work for the wired connection

D.2.2.1 No civil work case

Table D-12 and Table D-13 give the wired link cost less the wireless link cost for the Base Case assuming no civil work is required for the wired connection. In all cases the costs of the wired

[126] This assumes a lifetime of 20 years which would be reasonable when considering wired solutions.

[127] This might be on the low size but is intended to cover links between 155 Mbps and 1 Gbps

connection are significantly less than those of wireless link and so negative values of spectrum are obtained. In this instance a user would simply opt for the wired connection.

In the tables that follow the range in fixed link values represents the types of location i.e. rural and urban / suburban.

Table D-12: Costs of wired connection vs a fixed link (100Mbps) – Base Case assumptions for site sharing and no civil work

Type of wired connection (alternative)	Total annualised cost Wired connection	Total annualised cost Fixed link	MHz	Value per 2x1 MHz
100 Mbps link from BT (wholesale) > 25 kms	5,251	22,069 to 35,027 (below 10 GHz)	28	-601 to -1063
100 Mbps link from BT (wholesale) < 25 kms	2,601	18,735 to 31,693 (above 10 GHz)	28	-576 to -1039

Table D-13: Costs of wired connection vs a fixed link (300 Mbps – 1 Gbps) – Base Case assumptions for site sharing

Type of wired connection	Total annualised cost Wired connection	Total annualised cost Fixed link	MHz	Value per 2x1 MHz
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms	15,352	22,069 to 35,027 (below 10 GHz)	56	-120 to -351
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms	9,852	18,735 to 31,693 (above 10 GHz)	56	-159 to -390

D.2.2.2 Civil work required

Here we focus on the situation for a potential licensee where significant civil work is required to connect the user's site to a network access point. This additional civil work increases costs and therefore makes a wireless connection more attractive as compared with a wired connection.

We use BT Openreach prices for civil works[128] and Ethernet products. The published BT Openreach prices of a 1 km connection to existing infrastructure are:

- Cable laid by mole plough at £25 per metre = £25,000
- Installation of small footway box = £705

[128] Openreach Ethernet backhaul direct
http://www.openreach.co.uk/orpg/home/products/pricing/loadProductPriceDetails.do?data=F6GFzqfhDSmh7Oyv8Xw%2Bt6ZkEknUEHFW9O1w%2FCiltaVZ6rNZujnCs99NbIKJZPD9hXYmiijxH6wrCQm97GZMyQ%3D%3D
Openreach Ethernet access direct
http://www.openreach.co.uk/orpg/home/products/pricing/loadProductPriceDetails.do?data=5uW5cDedIGJkun%2FLo2I67PEgpNm%2BtShF6YESRcCqrDFZ6rNZujnCs99NbIKJZPD9hXYmiijxH6wrCQm97GZMyQ%3D%3D

- Survey fee = £255
- TOTAL = £25,960 (equivalent to £2,609 p.a. when annualised over 20 years at 9%).

The cost of additional civil works to connect to an access point is nearly proportional to distance. The costs used in subsequent tables are as follows:

Table D-14: Costs of civil works for 1km, 5 km and 15 km connections to a network access point

Distance (km)	Cost (£)	Annualised cost (£ p.a.) 9% / 20 years
1	(1 x 1,000 x 25) + 705 + 255 = 25,960	2,609
5	(5 x 1,000 x 25) + 705 + 255 = 125,960	12,659
15	(15 x 1,000 x 25) + 705 + 255 = 375,960	37,784

In Table D-15 and Table D-16 we report the costs of providing a 100Mbps link and a 300Mbps - 1Gbps link using wired[129] and wireless technology, and take the cost difference divided by the spectrum required on the wireless link to derive a spectrum value. The values depend on whether the transmission distance is more or less than 25km[130] and the length of connection from the user's site to existing wired network infrastructure – we test the impact of 1km, 5km and 15km connection distances. Because costs are roughly proportional to distance, these distances could be assumed to be the length of a connection from the user's site to the wired network at one end of the link or the sum of connections at both ends of the link.

As can be seen in Table D-15 the wireless fixed link option is only attractive (i.e. there is a positive spectrum value) for a 100Mbps link if the user's site is distant from a network connection point (i.e. 15 km or more). This is only likely to occur in rural areas, although as mentioned above the fact that we do not have an estimate of the value of any qualitative advantages of fixed links (e.g. possibly more flexible and timely deployment) means the values are likely to be underestimates.

In the case of a 300Mbps – 1Gbps link (Table D-16) the wireless fixed link option becomes attractive for shorter distances to a network connection point i.e. at 5km as well as 15km.

The implied spectrum values are much the same for the above and below 10 GHz cases.

[129] BT Openreach does not offer products for bandwidths between 100Mbps and 1Gbps.

[130] The price of a BT Openreach Ethernet service depends on whether the transmission distance is more or less than 25km.

Table D-15: Value of spectrum – 100Mbps wired link plus connection to network access point versus 2x28 GHz wireless link

Type of wired connection	Total annualised cost (Note 1)				Value per 2x1 MHz		
	Wired link + 1 km	Wired link + 5 km	Wired link + 15 km	Wireless fixed link (28 MHz) (Note 2)	+1 km	+5 km	+15 km
100 Mbps link from BT (wholesale) < 25 kms	2,601 + 2,609 = 5,210	2,601 + 12,659 = 15,260	2,601 + 37,784 = 40,385	18,735 to 31,693 (>10 GHz)	-483 to -946	-124 to -587	310 to 773
100 Mbps link from BT (wholesale) > 25 kms	5,251 + 2,609 = 7,860	5,251 + 12,659 = 17,910	5,251 + 37,784 = 43,035	22,069 to 35,027 (<10 GHz)	-507 to -970	-149 to -611	286 to 749

Source: Plum and Aegis analysis.

Note 1: The base wired connection costs without additional civil works as identified earlier are 2,601 (< 25 km) and 5,251 (> 25 km)

Note 2: Transmission distances above 25km typically require frequencies below 10 GHz.[131] At shorter distances high frequencies can be used and this results in lower equipment costs and site costs.

Table D-16: Value of spectrum – 300Mbps-1 Gbps wired link plus connection to network access point versus 2x56 GHz wireless link

Type of wired connection	Total annualised cost (Note 1)				Value per 2x1 MHz		
	Wired link + 1km	Wired + 5 km	Wired + 15 km	Wireless Fixed link (56 MHz)	+1 km	+5 km	+15 km
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms	9,852 + 2,609 = 12,461	9,852 + 12,659 = 22,511	9,852 + 37,784 = 47,636	18,735 to 31,693 (>10 GHz)	-112 to -343	-163 to 67	285 to 516
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms	15,352 + 2,609 = 17,961	15,352 + 12,659 = 28,011	15,352 + 37,784 = 53,136	22,069 to 35,027 (<10 GHz)	-73 to -305	-125 to 106	323 to 555

Source: Plum and Aegis analysis

Note 1: The base wired connection costs without additional civil works as identified earlier are 9,852 (< 25 km) and 15,352 (> 25 km)

[131] See Table 6.2, Aegis et al (2011)

D.2.3 Sensitivity Analysis – no civil work assumed

Table D-17 and Table D-18 give the wired link cost less the wireless link cost for the Increased Sharing Case with no civil work. In almost all the situations shown the costs of the wired connection are significantly less than those of wireless link and so negative values of spectrum are obtained. In this instance a user would simply opt for the wired connection.

Table D-17: Costs of wired connection vs a fixed link (100Mbps) – Increased sharing case and no civil work

Type of wired connection (alternative)	Total annualised cost Wired connection	Total annualised cost Fixed link	MHz	Value per 2x1 MHz
100 Mbps link from BT (wholesale) > 25 kms	5,251	15,035 to 17,010 (below 10 GHz)	28	-349 to -420
100 Mbps link from BT (wholesale) < 25 kms	2,601	11,701 to 13,676 (above 10 GHz)	28	-325 to -396

Table D-18: Costs of wired connection vs a fixed link (300 Mbps – 1 Gbps) – Increased sharing case and no civil work

Type of wired connection	Total annualised cost Wired connection	Total annualised cost Fixed link	MHz	Value per 2x1 MHz
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms	15,352	15,035 to 17,010 (below 10 GHz)	56	6 to -30
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms	9,852	11,701 to 13,676 (above 10 GHz)	56	-33 to -68

Table D-19 and Table D-20 give the wired link cost less the wireless link cost for the No site costs case with no civil work. Here the wired option is more attractive for low speed (100Mbps) links. Conversely, the wireless option is more attractive for the high speed links (300-1 Gbps).

Table D-19: Costs of wired connection vs a fixed link (100Mbps) – No site costs case and no civil work

Type of wired connection (alternative)	Total annualised cost Wired connection	Total annualised cost Fixed link	MHz	Value per 2x1 MHz
100 Mbps link from BT (wholesale) > 25 kms	5,251	8,002 (below 10 GHz)	28	-98
100 Mbps link from BT (wholesale) < 25 kms	2,601	4,668 (above 10 GHz)	28	-74

Table D-20: Costs of wired connection vs a fixed link (300 Mbps – 1 Gbps) – No site costs case and no civil work

Type of wired connection	Total annualised cost Wired connection	Total annualised cost Fixed link	MHz	Value per 2x1 MHz
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms	15,352	8,002 (below 10 GHz)	56	131
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms	9,852	4,668 (above 10 GHz)	56	93

The implied values of spectrum are summarised in Table D-21. In almost all cases the resulting values are negative indicating it is cheaper to use a wired technology assuming this is available with a low (or zero) cost of connection. In other words users in this situation would not apply for fixed link spectrum licences. However, if we assume increased site sharing (and so lower site costs then the fixed link alternative can be attractive for high capacity (1 Gbps) links.

Table D-21: Annualised costs per 2x1MHz under different site sharing assumptions – No Civil Work

Situation	Base case 2 x 1 MHz	Increased sharing case 2 x 1 MHz	No site costs 2 x 1 MHz
Wired v fixed link – 100 Mbps >25 km wholesale < 10 GHz	-601 to -1063	-349 to -420	-98
Wired v fixed link – 100 Mbps <25 km wholesale > 10 GHz	-576 to -1,039	-325 to -396	-74
Wired v fixed link – 300Mbps - 1 Gbps >25 km wholesale (2 hop) < 10 GHz	-120 to -351	6 to -30	131
Wired v fixed link – 300Mbps - 1 Gbps <25 km wholesale > 10 GHz	-159 to -390	-33 to -68	93

Note 2: Transmission distances above 25km typically require frequencies below 10 GHz. At shorter distances high frequencies can be used and this results in lower equipment costs and site costs

D.2.4 Sensitivity Analysis – Civil Work Assumed

Tables D-22 and Table D-23 give the wired link cost less the wireless link cost for the Increased Sharing Case where there is civil work. In almost all the situations shown the costs of the wired connection exceed those of the wireless link for connection distances of 5km or more in which case there is a positive value to spectrum.

Table D-22: Value of spectrum – 100Mbps wired link plus connection to network access point versus 2x28 GHz wireless link – Increased Sharing Case with civil work

Type of wired connection	Total annualised cost (Note 1)				Value per 2x1 MHz		
	Wired link + 1 km	Wired link + 5 km	Wired link + 15 km	Wireless fixed link (28 MHz) Note 2)	+1 km	+5 km	+15 km
100 Mbps link from BT (wholesale) < 25 kms	2,601 + 2,609 = 5,210	2,601 + 12,659 = 15,260	2,601 + 37,784 = 40,385	11,701 to 13,676 (>10 GHz)	-232 to -302	57 to 127	954 to 1024
100 Mbps link from BT (wholesale) > 25 kms	5,251 + 2,609 = 7,860	5,251 + 12,659 = 17,910	5,251 + 37,784 = 43,035	15,035 to 17,010 (<10 GHz)	-256 to -327	32 to 103	929 to 1000

Source: Plum and Aegis analysis.

Note 1: The base wired connection costs without additional civil works as identified earlier are 2,601 (< 25 km) and 5,251 (> 25 km)Note 2: Transmission distances above 25km typically require frequencies below 10 GHz.[132] At shorter distances high frequencies can be used and this results in lower equipment costs and site costs.

Table D-23: Value of spectrum – 300Mbps-1 Gbps wired link plus connection to network access point versus 2x56 GHz wireless link – Increased Sharing Case with civil work

Type of wired connection	Total annualised cost (Note 1)				Value per 2x1 MHz		
	Wired link + 1km	Wired + 5 km	Wired + 15 km	Wireless Fixed link (56 MHz)	+1 km	+5 km	+15 km
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms	9,852 + 2,609 = 12,461	9,852 + 12,659 = 22,511	9,852 + 37,784 = 47,636	11,701 to 13,676 (>10 GHz)	-22 to 14	158 to 193	606 to 642
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms	15,352 + 2,609 = 17,961	15,352 + 12,659 = 28,011	15,352 + 37,784 = 53,136	15,035 to 17,010 (<10 GHz)	17 to 52	196 to 232	645 to 680

Source: Plum and Aegis analysis

Note 1: The base wired connection costs without additional civil works as identified earlier are 9,852 (< 25 km) and 15,352 (> 25 km)

Table D-24 and Table D-25 give the wired link cost (with Civil work) less the wireless link cost for the No Site Costs Case. In almost all the situations shown the costs of the wired connection exceed those of the wireless link for connection distances. Therefore there is a positive value to spectrum.

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[132] See Table 6.2, Aegis et al (2011)

Table D-24: Value of spectrum – 100Mbps wired link plus connection to network access point versus 2x28 GHz wireless link – No Site Costs Case with civil work

Type of wired connection	Total annualised cost (Note 1)				Value per 2x1 MHz		
	Wired link + 1 km	Wired link + 5 km	Wired link + 15 km	Wireless fixed link (28 MHz) (Note 2)	+1 km	+5 km	+15 km
100 Mbps link from BT (wholesale) < 25 kms	2,601 + 2,609 = 5,210	2,601 + 12,659 = 15,260	2,601 + 37,784 = 40,385	4,668 (>10 GHz)	19	378	1276
100 Mbps link from BT (wholesale) > 25 kms	5,251 + 2,609 = 7,860	5,251 + 12,659 = 17,910	5,251 + 37,784 = 43,035	8,002 (<10 GHz)	-5	354	1251

Source: Plum and Aegis analysis.

Note 1: The base wired connection costs without additional civil works as identified earlier are 2,601 (< 25 km) and 5,251 (> 25 km)Note 2: Transmission distances above 25km typically require frequencies below 10 GHz.[133] At shorter distances high frequencies can be used and this results in lower equipment costs and site costs.

Table D-25: Value of spectrum – 300Mbps-1 Gbps wired link plus connection to network access point versus 2x56 GHz wireless link – No site Costs Case with civil work

Type of wired connection	Total annualised cost (Note 1)				Value per 2x1 MHz		
	Wired link + 1km	Wired + 5 km	Wired + 15 km	Wireless Fixed link (56 MHz)	+1 km	+5 km	+15 km
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms	9,852 + 2,609 = 12,461	9,852 + 12,659 = 22,511	9,852 + 37,784 = 47,636	4,668 (>10 GHz)	139	319	767
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms	15,352 + 2,609 = 17,961	15,352 + 12,659 = 28,011	15,352 + 37,784 = 53,136	8,002 (<10 GHz)	178	357	806

Source: Plum and Aegis analysis

Note 1: The base wired connection costs without additional civil works as identified earlier are 9,852 (< 25 km) and 15,352 (> 25 km)

Finally, we report results for the situation in which there is one site occupier for rural locations. As can be seen this usually results in negative values, meaning that the user would opt for the wired alternative.

[133] See Table 6.2, Aegis et al (2011)

Table D-26: Value of spectrum – 100Mbps wired link plus connection to network access point versus 2x28 GHz wireless link – Single Rural Site Occupier with civil work

Type of wired connection	Total annualised cost (Note 1)				Value per 2x1 MHz		
	Wired link + 1 km	Wired link + 5 km	Wired link + 15 km	Wireless fixed link (28 MHz) (Note 2)	+1 km	+5 km	+15 km
100 Mbps link from BT (wholesale) < 25 kms	2,601 + 2,609 = 5,210	2,601 + 12,659 = 15,260	2,601 + 37,784 = 40,385	46,869 (>10 GHz)	-1,488	-1,129	-232
100 Mbps link from BT (wholesale) > 25 kms	5,251 + 2,609 = 7,860	5,251 + 12,659 = 17,910	5,251 + 37,784 = 43,035	50,203 (<10 GHz)	-1,512	-1,153	-256

Source: Plum and Aegis analysis.

Note 1: The base wired connection costs without additional civil works as identified earlier are 2,601 (< 25 km) and 5,251 (> 25 km)

Note 2: Transmission distances above 25km typically require frequencies below 10 GHz.[134] At shorter distances high frequencies can be used and this results in lower equipment costs and site costs.

Table D-27: Value of spectrum – 300Mbps-1 Gbps wired link plus connection to network access point versus 2x56 GHz wireless link – Single Rural Site Occupier with civil work

Type of wired connection	Total annualised cost (Note 1)				Value per 2x1 MHz		
	Wired link + 1km	Wired + 5 km	Wired + 15 km	Wireless Fixed link (56 MHz)	+1 km	+5 km	+15 km
300 Mbps – 1 Gbps link from BT (wholesale) < 25 kms	9,852 + 2,609 = 12,461	9,852 + 12,659 = 22,511	9,852 + 37,784 = 47,636	46,869 (>10 GHz)	-614	-435	14
300 Mbps – 1 Gbps link from BT (wholesale) > 25 kms	15,352 + 2,609 = 17,961	15,352 + 12,659 = 28,011	15,352 + 37,784 = 53,136	50,203 (<10 GHz)	-576	-396	52

Source: Plum and Aegis analysis

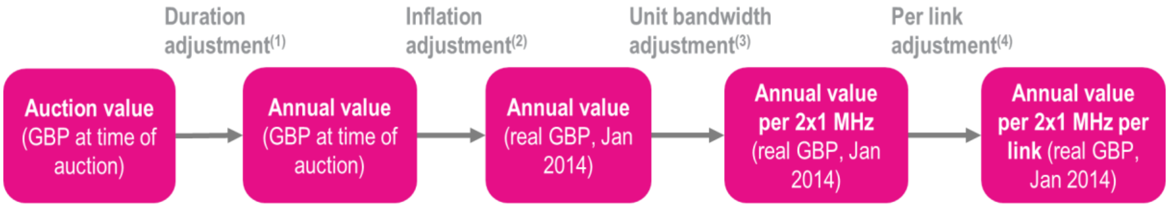
Note 1: The base wired connection costs without additional civil works as identified earlier are 9,852 (< 25 km) and 15,352 (> 25 km)

[134] See Table 6.2, Aegis et al (2011)

Appendix E: Converting auction data to annual values

Figure E-1 shows the method we have used to convert the lump sum auction amounts into annual values in January 2014 pounds. These are then expressed in a value per 2x1 MHz per link for comparison with the current fees. The approach adopted here is similar to that used in the past by Ofcom to determine AIP fees, namely it involves use of an industry WACC as a discount rate.

Figure E-1: Converting from lump sum to annual values



Notes:
(1) Adjustment from lump sum to annual fee based on nominal pre-tax WACC (i.e. 8.9%)
(2) Inflation adjustment to constant prices using national RPI data
(3) Express annual value in 2x1 MHz
(4) Apply reuse factor to derive annual value per 2x1 MHz per link

E.1 Conversion into annual values

The first step involves adjusting a lump sum auction value to an annual value. Here we assume the lump sum fee paid by the winning bidder(s) represents the net present value (NPV) of the annual profit stream over the duration D years of the licence. We assume this annual profit stream is constant over time and denote its value as A.

Hence the

$$Lump\ sum\ value\ = \sum_{t=0}^{D-1} \frac{A}{(1 + discount\ rate)^t}$$

To derive the annual value of this annual amount, we apply the following formula:

$$A = Lump\ sum\ auction\ fee / \sum_{t=0}^{D-1} \frac{1}{(1 + discount\ rate)^t}$$

The discount rate we use is the nominal pre-tax WACC of 8.9% as the discount rate. This is the same WACC used by Ofcom in the wholesale mobile call termination (MCT) review and the recent consultation on annual licence fees for the 900 MHz and 1800 MHz mobile spectrum.[135]

[135] This is a value for the mobile sector which is the main user of fixed links. Ofcom. Wholesale mobile voice call termination statement, March 2011. http://stakeholders.ofcom.org.uk/consultations/mtr/statement; Ofcom. Annual licence fees for 900 MHz and 1800 MHz spectrum. Consultation, October 2013. http://stakeholders.ofcom.org.uk/consultations/900-1800-mhz-fees/

E.2 Inflation adjustment

This step involves adjusting current prices at the time of the auction to constant prices. Here we have to decide the appropriate inflation index to use. The consumer price index (CPI) is a measure of inflation based on all forms of household spending. The retail price index (RPI) is similar but uses a smaller base of households and includes housing costs (e.g. mortgage interest payments and council tax).[136] The RPI is used rather than consumer prices index (CPI) as RPI was adopted to derive the mobile industry WACC in the MCT review.

[136] One of the main differences between CPI and RPI is that CPI mostly uses geometric mean to aggregate prices while RPI uses arithmetic mean to do so. This means that for a similar change in price of a particular good or service, RPI is likely to fluctuate more than CPI. According to the ONS, the geometric mean better reflects changes in consumer spending patterns relative to changes in the price of goods and services. ONS (2013). Consumer Price Indices: a brief guide. http://www.ons.gov.uk/ons/guide-method/user-guidance/prices/cpi-and-rpi/consumer-price-indices--a-brief-guide.pdf ; ONS (2010). Differences between the RPI and CPI measures of inflation – information note. http://www.ons.gov.uk/ons/guide-method/user-guidance/prices/cpi-and-rpi/differences-between-the-rpi-and-cpi-measures-of-inflation.pdf

Appendix F: Glossary

Abbreviation/term	Definition
ADSL	An Asymmetric Digital Subscriber Line allows data to be transferred at higher speeds and is the most common type of broadband DSL technology. It is asymmetric because it delivers a higher downlink data rate than uplink data rate.
Antenna gain	The ratio of the power required at the input of a loss-free reference antenna to the power supplied to a given antenna to produce the same signal (direction, distance, strength). It describes how efficiently a transmitting antenna converts input power into radio waves, or how efficiently a receiving antenna converts radio waves into power.
Antenna pattern	A graphical representation of the radiation properties of an antenna as a function of direction.
AIP	Administered Incentive Pricing are fees charged to spectrum licensees (and holders of recognised spectrum access) that are set by Ofcom and are intended to reflect the opportunity cost of spectrum use and thereby provide effective incentives for efficient use of spectrum.
ATPC	Automatic Transmitter Power Control is an electronic process for controlling the transmission power depending on the power level received by the receiver.
Backhaul	Backhaul is the part of the mobile network infrastructure that connects the core network (or backbone) to base stations.
Bit rate	The rate at which bits are transferred from one location to another. Usually measured in megabits per second.
BSS	Broadcasting Satellite Service frequencies support services such as Direct To Home (DTH) TV.
BWA	Broadband Wireless Access technologies provide broadband data access by wireless means to consumer and business markets. For example, LTE or WiMAX.
C-band	Satellite frequency band with downlink at 3.7–4.2 GHz and uplink at 5.925–6.425 GHz.
CEPT	European Conference of Postal and Telecommunications Administrations is a regional body of regulators that coordinates telecommunications policy across Europe.
C/N	Carrier to Noise power ratio in the receive channel usually expressed in dB
Cost based fees	Fees charged to spectrum licensees that are set by Ofcom and are intended to reflect spectrum management and administrative costs. These fees apply in cases where spectrum is not scarce or in excess demand and therefore the use of AIP is not appropriate.
dB	Decibel is the (logarithmic) ratio of a unit e.g. signal strength.
dBi	Decibels Isotropic is a measurement of antennal gain relative to an isotrope, which is a transmitting/receiving antenna that radiates/receive a signal equally well in all directions.
dBm	Used to describe the power of a transmitter and the sensitivity of a receiver. It is the power of a signal referenced to a signal of one milliwatt.
dBW	The strength of a signal in decibels, relative to one watt.
DSL	Digital Subscriber Line technologies provide internet access by connecting end-users using telephone lines.

Abbreviation/term	Definition
E_b/N_0	Energy per bit to noise density ratio usually expressed in dB
EIRP	Equivalent Isotropically Radiated Power is the product of the power supplied to the transmitting antenna and the antenna gain in a given direction relative to an isotropic antenna radiator.
Fixed links	Fixed Terrestrial Links or Fixed Wireless Systems (FWS) refer to terrestrial based wireless systems, operating between two or more fixed points. Using mainly digital technologies, directional antennas and typically operating at very high levels of availability, fixed terrestrial links are used to provide network infrastructure and customer access applications across a wide range of frequency bands, currently ranging from 450MHz to 86GHz.
FSS (E-S and S-E)	Fixed Satellite Services are geostationary and non-geostationary satellites that facilitate Earth to Satellite and Satellite to Earth transmissions.
FWA	Fixed wireless access (FWA) systems refer to a means of making fixed connections between users' premises and telecommunication networks. These networks may deliver a range of services, including telephony, high speed data, television and multimedia services.
LTE	Long Term Evolution is the current generation of GSM as at 2014. Although operators worldwide have rolled out LTE networks under a '4G' marketing message, LTE is actually just short of the 3GPP original 4G specifications, and would be better described as '3.9G'.
Ka band	Satellite frequency band with downlink at 18.3-22.2 GHz and uplink at 27-31 GHz.
Ku band	Satellite frequency band with downlink at 10.7-13.25 GHz and uplink at 12.75-14.25 GHz.
ITU	The International Telecommunication Union is the international organisation for the harmonisation of frequency bands and technical standards across the world.
LCA	The least cost alternative method is an approach to estimating the opportunity cost of spectrum. It involves estimating the value of spectrum to an average user based on the least cost alternative technology or service to enable the same output to be produced. For example, for fixed links this could be achieved via an alternative technology such as fibre or moving to a less congested spectrum band.
Mesh network	Mesh networks are based on multiple connections between nodes and traffic routing can be dynamic thereby providing great flexibility and resilience. Such systems are best viewed as a collection of interconnected nodes within an area.
Metrocells	Compact mobile base stations used in densely populated areas. Usually discrete, often mounted on lampposts.
MetSat	Meteorological Satellites are used to monitor the weather and climate for forecasting purposes.
MIMO	Multiple-Input and Multiple-Output technologies are where both transmitter and receiver use multiple antennas to transmit/receive signals along different paths simultaneously. MIMO increase spectral efficiency.
MNO	Mobile Network Operators are telecom operators that deploy a transmission network and use radio spectrum to offer mobile services to the general public.
Modulation	Modulation is the means by which information is superimposed on radio waves. The form of modulation (AM, FM, digital) affects spectral efficiency.
MSS	Mobile Satellite Services provide mobile services using satellite links.

Abbreviation/term	Definition
NGSO	Satellites in a Non-Geostationary Satellite Orbit move relative to points on the Earth's surface, rather than appearing to be stationary as is the case for Geostationary Satellites.
NLOS	Non-line-of-sight is radio transmission across a path that is partially obstructed. That is, radio signal are not totally hindered by objects in the transmission path.
Opportunity cost	The opportunity cost of using spectrum for application A is the value of the spectrum to the highest value alternative forgone i.e. the best alternative denied access to the spectrum.
PES	A Permanent Earth Station (PES) is a satellite earth station operating from a permanent, specified location to a satellite, normally one which is in geostationary orbit. A PES is typically used to provide telephony and data backhaul, broadcast feeder links, private corporate networks or satellite telecommand and control.
PMSE	Programme Making and Special Events is the name given to radio frequency usage by wireless microphones and low-power two-way radios for events such as festivals or sporting events.
PMR	Private Mobile Radio is one term used to describe communication between mobile terminals and/or base stations owned and operated by private individuals or companies.
Receiver noise power density	The noise floor of a receiver expressed in terms of a power level per unit of bandwidth (e.g. dBm/MHz)
RSA	Recognised spectrum access (RSA) is a spectrum management instrument in which the holder of the grant is provided with the opportunity to identify frequency bands and geographic areas within which Ofcom will endeavour to ensure that agreed levels of interference are not exceeded. RSA provides receive-only earth stations, which are usually exempt from licensing, a means of avoiding harmful interference. Currently RSA is granted to receive only earth stations (ROES) in 1690-1710 MHz, 3600-4200 MHz, and 7750-7850 MHz and radio astronomy sites.
RSPG	The Radio Spectrum Policy Group is a high level advisory group to the EC on spectrum matters whose members are taken from national regulators.
SRSP	The Strategic Review of Spectrum Pricing was conducted by Ofcom in 2010.
STL	Studio to Transmitter Links are used in broadcasting to send data from the broadcasting studios to transmitters.
TETRA	Terrestrial Trunked Radio are two-way radio services (walkie-talkies) used by the military, the emergency services and transport services.
TES	A Transportable Earth Station (TES) is a satellite earth station operating from a specified location to a satellite in the fixed satellite service. TES operations are commonly associated with the broadcasting industry, where they are used to provide outside broadcast links either back to a studio or directly to a broadcasting satellite. Installations range from small fly-away terminals to large vehicles.
Transmitter Power Density	The power of a transmitter expressed in terms of a power level per unit of bandwidth (e.g. dBm/MHz)
UHF	The frequency range 300 MHz to 3 GHz is known as Ultra High Frequency.
VSAT	A Very Small Aperture Terminal is a two way satellite ground station. VSATs are commonly used to transmit broadband data.
WBB	Wireless broadband

Abbreviation/term	Definition
White space	These are radio frequencies that are allocated to broadcasting but which are not used in a specific geographic area. In theory they can be used by low power devices.
WRC	World Radiocommunication Conference is the general ITU congress where technical and allocation decisions are finalised. It occurs approximately every three years; the next one will be WRC-15.
W/U	Wanted signal to Unwanted signal ratio usually expressed in dB and using the power levels in the native bandwidth of each signal