The economic benefits from the use of C-band (3600-4200 MHz) for mobile broadband in the UK

A report for Huawei

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This study considers the economic benefit of bringing forward the availability of 3600-3800 MHz and 3800-4200 MHz for mobile data services in the UK. To derive the economic benefit results the study performed an evaluation of the protection required for C-Band satellite installations under several scenarios. The parameters used for each scenario are based on a combination of the existing ITU-R criteria, JTG contributions and sharing studies undertaken by Huawei. Huawei has performed simulations for C-Band fixed satellite service earth stations in the UK and the result of these studies have been used to cross check the output of calculated data used in this report.

This report makes use of data on C-Band satellite installations in the UK obtained from Ofcom. All of the calculations utilising this data are Plum's and it should be noted that while Ofcom has provided the data it does not endorse the results or conclusions.

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Executive summary

This study commissioned by Huawei provides an independent assessment of the economic benefits that would arise through use of C-Band spectrum (3600-4200 MHz) for mobile broadband services in the UK.

Mobile broadband traffic in the UK is forecast to grow rapidly over the next 10-15 years. It is possible that the UK may face a spectrum shortfall unless sufficient spectrum is made available to avoid operators having to make costly investments in infrastructure to support this traffic growth. The 3600-4200 MHz frequency range could be used to provide additional capacity to address this shortfall. It will reduce the costs of service provision and improve quality of service.

3600-4200 MHz is currently used by several services including fixed satellite service earth stations (FSS-ES). This report considers the economic benefit arising from the early release of spectrum in the 3600-4200 MHz range, use of a link performance aware frequency sharing scenario (determines an appropriate margin to mitigate interference from IMT services) and an advanced frequency sharing scenario (which makes more efficient use of the accessible bandwidth for the FSS ES). The baseline scenario for the study is the illustration of spectrum availability shown in Ofcom's Mobile Data Strategy Statement.

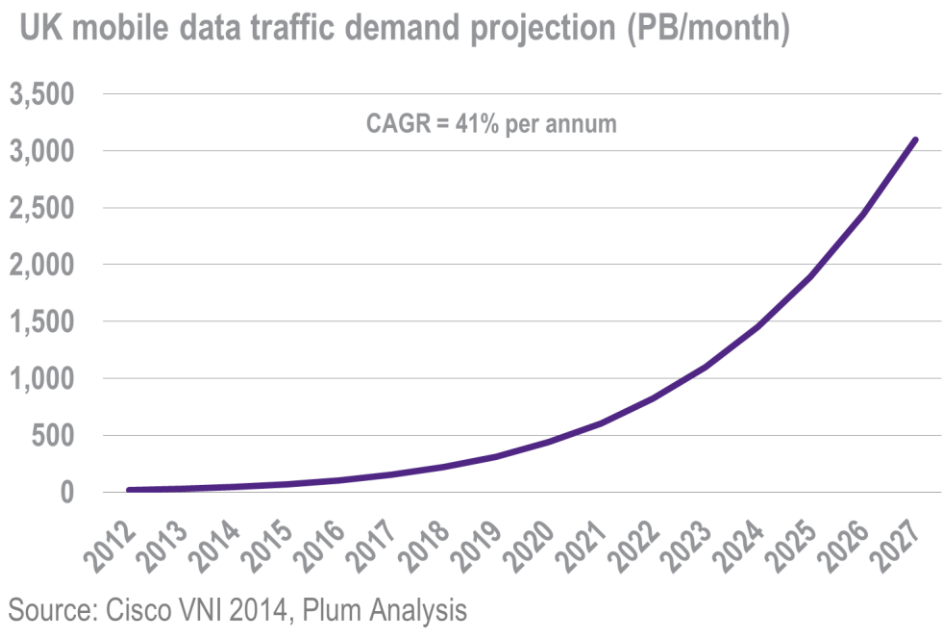
Demand for mobile broadband

In a world powered by demand for information, access to the internet has become increasingly important. Advances in access technology have made accessing the internet over a mobile device a reality, resulting in a rapid growth in mobile data traffic. Coverage has been the focus of much network deployment to date but as demand for data increases and user expectations of performance increase there is a need to focus more on capacity provision and quality of service to provide a more consistent user experience.

The traffic demand forecast we used for the UK is shown in Figure 1. The traffic demand forecast was derived by extrapolating the Cisco VNI 2014 short-term (2012-2018) projection for the UK to 2028. It was then calibrated using mid-year historical monthly mobile data volumes published in Ofcom's 2013 Infrastructure Report. This results in a Cisco-extrapolated forecast adjusted by a factor of 0.5.

We are of the view that the traffic demand forecast used in this report is reasonable and could actually turn out to be conservative. It amounts by 2027 to a usage level of 36GB per active SIM per month, assuming that the number of active SIMs remain at 84.7million. This is the equivalent of just over 1GB per day, which can be used up by 1-2 hours of HD streaming over the mobile network.

Figure 1: UK traffic demand projection



Source: Cisco VNI 2014, Plum Analysis

Using the traffic projection shown above, the earliest that operators need to roll out new sites in the absence of the 3600-4200 MHz spectrum is 2023.

Benefits of use of 3600-4200 MHz for mobile broadband in the UK

We have quantified the avoided cost benefit of using 3600-4200 MHz spectrum for mobile broadband in the UK. The benefit from avoided costs is computed as the difference in NPV of total radio access network cost between a base case and an alternative case with greater spectrum availability. Our estimates show that **use of 3600-4200 MHz for mobile broadband could generate benefits of as much as £1.4 billion in the UK**. This is comprised of benefits arising from the early release of the spectrum plus the use of the two frequency sharing scenarios (link performance aware and advanced frequency sharing, which are described in the body of the report). **The benefit arising from only the early release of the 3600-4200 MHz is £920m**.

The assumptions used to estimate the benefits are inherently conservative. For example our mobile data traffic forecast is calibrated to real UK data at the start of the period, we have assumed that the number of FSS ES remains constant throughout the period whereas in practice we would expect it to decrease, we have excluded benefits from indoor use of the spectrum and assumed a limit of carrier aggregation of three component carriers in the downlink. Benefits derived from technology innovation (i.e. evolution of LTE-A and 5G) that could be triggered by such a large availability of contiguous spectrum have not been taken into account; neither have the benefits from enhanced Quality of Service.

Regulatory action required

CEPT is currently considering commencing work in this field (based on contributions received from various member states and industry). This work could be supported by an industry working group in the UK that would develop proposals that could be the basis for developments more widely in Europe

1 Introduction

1.1 Reason for the study

In a world powered by demand for information, access to the internet has become increasingly important. Advances in access technology have made accessing the internet over a mobile device a reality, resulting in a rapid growth in mobile data traffic. Coverage has been the focus of much network deployment to date but as demand for data increases and user expectations of performance increase there is a need to focus more on capacity provision and quality of service to provide a more consistent user experience. This triggers a burgeoning need for investments in network infrastructure as well as a need for an increased amount of spectrum.

The need for more spectrum is recognised, and the European Commission Radio Spectrum Policy Programme (RSPP)[1] has identified a concrete action – "ensuring that at least 1200 MHz spectrum are identified to address increasing demand for wireless data traffic; and assessing the need for additional harmonised spectrum bands". In the UK there is also recognition of the requirement for additional spectrum and the Government's Public Sector Spectrum Release Programme[2] identifies the need to make 500 MHz of additional spectrum available by 2020. The June 2013 RSPG Opinion on "strategic challenges facing Europe in addressing the growing spectrum demand for wireless broadband" identifies the potential of 3800-4200 MHz for electronic communication services and that further studies should be carried out into the possibility of sharing in this band between IMT and the FSS.

This study focuses on the economic benefits of releasing spectrum in the 3600-4200 MHz frequency range in the UK. This range provides the opportunity to access the potentially large amounts of contiguous spectrum necessary for handling the greater volumes of data traffic envisaged in the period between now and the late 2020s. In the UK the band immediately below (i.e. 3400-3600 MHz) is being released for wireless broadband and it is expected to be awarded in 2015[3]. The 3400-3800 MHz band is also the subject of a European Commission Decision harmonising the band for mobile use[4].

This study, as part of its estimation of the avoided costs that accrue from 3600-4200 MHz, will take account of macro cell and outdoor small cell deployments. It is becoming increasingly apparent that networks based on macro cell sites may require additional coverage layers based on small cells in order to allow operators to provide mobile broadband capacity at the right level and in the right locations. To meet traffic demand, macro cell networks will increasingly be supported by many focused small cell deployments to create sufficient capacity in the right places. This type of network comprising coordinated resources in the macro and small cell coverage layers is also known as a heterogeneous network.

[1] http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32012D0243

[2] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/287992/PSSRP_update_5_March_2014_Final.pdf

[3] http://stakeholders.ofcom.org.uk/binaries/consultations/2.3-3.4-ghz/summary/2.3-3.4-ghz.pdf

[4] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:144:0077:0081:EN:PDF

1.2 Current and future use of 3400-3600 MHz and 3600-4200 MHz in UK

There are several allocated/assigned uses of this spectrum in the UK:

- 3400-3600 MHz –150 MHz is being released and it is expected that it will be used for wireless broadband. 40 MHz of the band is already assigned to UK Broadband (3480-3500 MHz and 3580-3600 MHz) and the licence for this assignment has recently been the matter of an Ofcom consultation[5]
- 3600-3800 MHz – 84 MHz is assigned to UK Broadband (3605-3689 MHz) with the remainder allocated to satellite (Fixed Satellite Service)[6] and fixed link use. It is believed that 3700-3800 MHz is not heavily utilised in the UK and this study assumes that 100 MHz of spectrum will be available for use in this part of the band
- 3800-4200 MHz – The range is currently allocated to satellite and fixed link services. There are 27 licensed/registered C-Band satellite sites and around 40 fixed links[7] known to be operating in the range.

In this study we assume that IMT will share with other services in this part of the band.

1.2.1 Ofcom: 3400-3600 MHz award

Ofcom has been developing the parameters of the award over the past year. The spectrum is being released by the UK Ministry of Defence as part of the Public Sector Spectrum Release Programme. The award of 150 MHz of 3400-3600 MHz is to be combined with the award of 40 MHz of spectrum at 2350-2390 MHz. The spectrum will be awarded by Ofcom using a market led process. Ofcom anticipates the spectrum will attract interest from mobile operators wishing to use it to deploy LTE services. Ofcom has stated that it intends to award the spectrum in a way that is consistent with the use of an unpaired TDD band plan[8]. Figure 1-1 shows the anticipated use of the band.

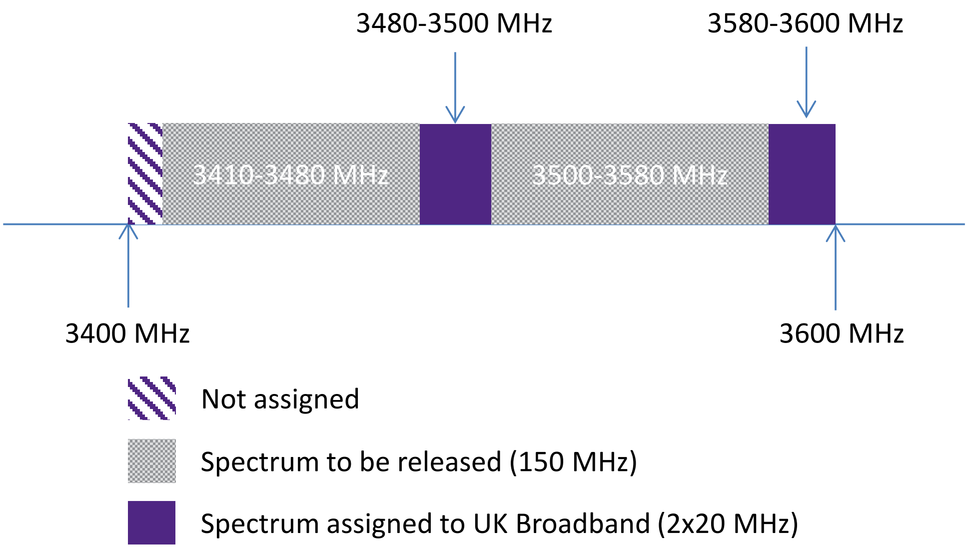
[5] http://stakeholders.ofcom.org.uk/binaries/consultations/uk-broadband-licence/statement/UK_Broadband_Statement.pdf

[6] C-Band – satellite to ground 3600-4200 MHz

[7] This study considers coexistence with satellite services. The analysis of co-existence with fixed links was not considered in this study

[8] http://stakeholders.ofcom.org.uk/binaries/consultations/uk-broadband-licence/summary/condoc.pdf

Figure 1-1: 3400-3600 MHz

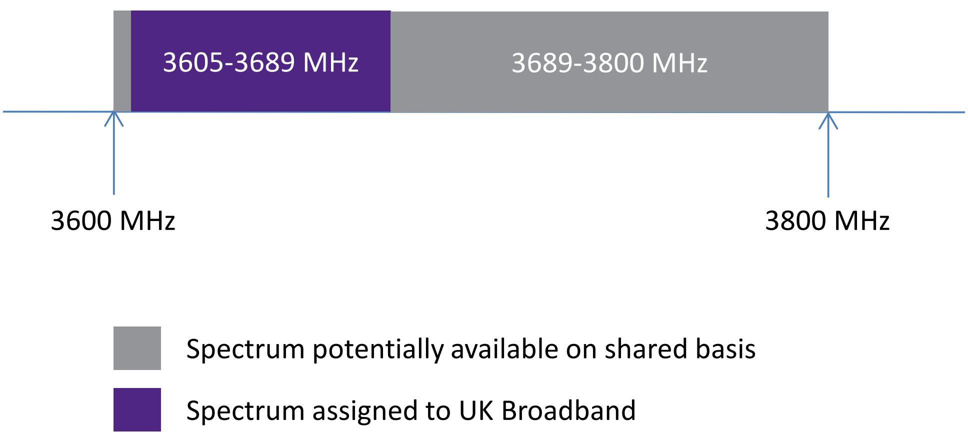


1.2.2 EC Decision of 3400-3800 MHz

Decision 2008/411/EC as amended by Decision 2014/276/EC harmonises the technical conditions for 3400-3800 MHz for fixed, nomadic and mobile electronic communication services in the European Union. ECC Decision (11)06 as amended on 14th March 2014[9] sets out harmonised frequency arrangements for mobile/fixed communications networks (MFCN) operating in the bands 3400-3600 MHz and 3600-3800 MHz. Decision 243/2012/EU requires Member States to make available the 3400-3800 MHz frequency band under the terms and conditions of Decision 2008/411/EC subject to market demand and without prejudice to existing service deployments. The Decision indicates a preference for a TDD mode of operation.

Figure 1-2 shows the current use of spectrum in 3600-3800 MHz in the UK.

Figure 1-2: 3600-3800 MHz



[9] http://www.erodocdb.dk/docs/doc98/official/pdf/ECCDec1106.pdf

1.2.3 Ofcom mobile data strategy

Ofcom published its Mobile Data Strategy Statement in May 2014[10]. The document sets out Ofcom's long term strategy to address the increasing use of data by mobile devices, identifies additional spectrum bands for potential mobile use and indicates likely priorities. Table 1-1 shows that 3600-4200 MHz spectrum is identified in the high or medium high categories according to Ofcom's published view on bands and priorities. Ofcom defines:

- "Current" as existing work to enable mobile use
- "High" as enable cleared bands to be brought into use as demand emerges
- "Medium High" as establish viability of access and promote international support.

Table 1-1: Ofcom bands and priorities

Ofcom priority	Band	Ofcom's illustrative timing
Current	700 MHz	2022
	2350-2390 MHz and 3410-3480 MHz/3500-3580 MHz (190 MHz in total)	2016
	UHF white space (shared)	
High	1452-1492 MHz	2016
	2 GHz MSS	2022[11]
	3600-3800 MHz (shared)	2022
	5.6 GHz Wi-Fi (shared)	
Medium High	1427-1452 MHz (shared)	2022
	3800-4200 MHz (shared)	2028

Source: Ofcom

Ofcom acknowledge that spectrum in the 3600-3800 MHz and 3800-4200 MHz bands potentially enables large contiguous blocks. However Ofcom also identifies that its current view on 3800-4200 (i.e. only medium high) is because the band is not harmonised for mobile use and the opposition from a number of countries for a co-primary allocation. Ofcom also notes in its statement the issues arising from satellite links operating in the band. This report addresses some of the issues raised by Ofcom regarding co-existence of mobile and satellite services in 3800-4200 MHz.

Ofcom identify actions in respect of 3600-4200 MHz as follows:

- Analyse feasibility and costs of mobile broadband sharing with earth stations across 3600-4200 MHz

[10] http://stakeholders.ofcom.org.uk/binaries/consultations/mobile-data-strategy/statement/statement.pdf

[11] This band is identified as high priority for Ofcom but it is currently allocated on a pan European basis for providing mobile satellite services (MSS). If services are not provided by the current licensees then this spectrum might in the future become available for terrestrial mobile. As the future of this band is uncertain we have excluded it from the analysis performed for this report

- Continue to support further harmonisation of 3600-3800 MHz in CEPT/EU and continue to support as a potential candidate band for WRC-15
- Support longer term consideration for potential mobile broadband use of 3800-4200 MHz in CEPT/EU (e.g. sometime after WRC-15).

1.2.4 Ofcom: Preparations for WRC15

Ofcom published its consultation on the UK preparations for the World Radiocommunication Conference 2015 (WRC-15) in June 2014. This consultation sets out the key issues for the UK at WRC15 and in it Ofcom states that:

- It supports the use of the 3400-3800 MHz band for mobile broadband
- It supports the longer term consideration of 3800-4200 MHz for potential mobile broadband use in CEPT/EU. However, Ofcom qualifies its support by mentioning the sensitivities that would be raised if a mobile allocation up to 4200 MHz were brought up directly at WRC-15. More specifically Ofcom have stated: "As we have indicated in the Mobile Data Strategy statement, we will be taking action to analyse the feasibility and costs of mobile broadband sharing with earth stations across 3.6 - 4.2 GHz at a national level, while internationally we support the longer term consideration of this band for potential mobile broadband use in CEPT/EU. Taking account of the position of other countries, the line we have adopted in CEPT is that the band is not suitable for inclusion in the list of supported bands for WRC-15, but equally a firm European Common Proposal for "no change" in this band would send the wrong signal about our views on actions after WRC-15. Consequently, we believe that it should be placed in the "under study" category."

Ofcom's proposed approach seems to be consistent with the June 2013 RSPG Opinion on "strategic challenges facing Europe in addressing the growing spectrum demand for wireless broadband" which states that:

> "… nevertheless, the frequency range 3800-4200 MHz has the potential to play a role in the provision of electronic communications services to ensure that the future capacity needs especially in urban areas, are met. Therefore, studies should be carried out into the possibility of sharing in Europe between the FSS and terrestrial wireless broadband services." [12]., "
>
> "… The Commission should study the possible application of new sharing techniques in Europe between the FSS and terrestrial wireless broadband in this frequency range, while recognizing that the situation within and outside Europe may differ"[13]
>
> , "…Studies should be carried out into the possibility of sharing in Europe between the FSS and terrestrial wireless broadband services including LSA"[14]

[12] RSPG13-521 rev 1, Section 9.6 page 22

[13] RSPG13-521 rev 1, Section 11, page 29

[14] RSPG13-521 rev 1, Annex 2 page A2_6

1.3 Use of Licensed Shared Access (LSA)

It is envisaged that mobile services operating in 3600-4200 MHz will share with existing services operating in the band. In this study we consider two approaches to maximise the extent of co-existence of mobile services with the existing C-Band satellite services. The two approaches are:

- "Link performance aware" – considers specific satellite to ground link performance and how it could be affected by the introduction of certain types of IMT network (beyond the I/N thresholds defined by ITU-R for international satellite coordination)
- "Advanced frequency sharing" – in addition to the above approach, explores the benefits from making use of the spectrum not used by emissions in the accessible bandwidth at an earth station.

Section 2.1 describes the two approaches in more detail.

Licensed Shared Access (LSA) is seen as a suitable enabler for the "advanced frequency sharing" approach. LSA is a regulatory framework for licensed sharing of bands that are already assigned to a user(s) where the additional user is granted access through an individual authorisation scheme following the terms and conditions set out in the Authorisation Directive[15]. Some of the key features of LSA applicable to sharing in 3600-4200 MHz are:

- Voluntary: The terms and conditions of any access to a band by new user(s) would be agreed between the incumbent user, the new user(s) and the regulator on a voluntary basis
- Mutually beneficial: Both the incumbent and the new user need to have incentives to engage in a sharing arrangement
- Legal certainty and quality of service: the new user(s) in the band has exclusive access to the spectrum on the terms and conditions specified in its licence. Incumbent and new user systems will receive protection from harmful emissions. The new licensee would be of equivalent status to the incumbent
- Harmonised bands: To create and take advantage of scale economies the bands in question are likely to be harmonised for uses requiring significant additional spectrum access (e.g. for mobile broadband)
- Compatible with European regulation: The involvement of the regulator is required to ensure the terms and conditions of access are compatible with the Authorisation Directive.

The CEPT is now looking at the possibility to trigger specific work to address the approaches above with specific reference to C-Band spectrum.[16]

1.4 Study Approach

The key questions addressed by the study are:

- to assess the economic benefit of bringing forward the availability of spectrum at 3600-3800 MHz and 3800-4200 MHz

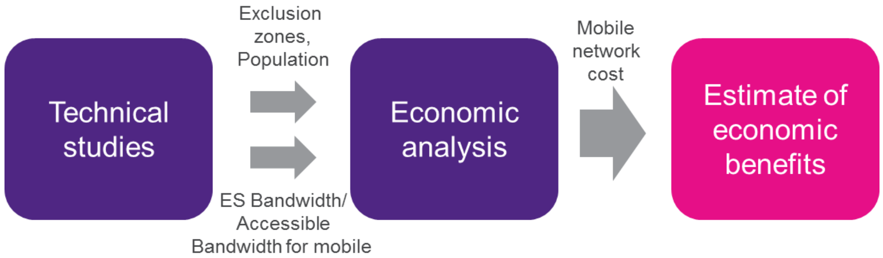
[15] Directive 2002/20/EC

[16] ECC PT1(14)115 Draft Minutes 16th September 2014

- To assess the economic benefit arising from the application of the link performance aware and advanced frequency sharing approaches.

Figure 1-3 summarises our approach to this analysis.

Figure 1-3: Overview of the approach to economic benefit estimation



Our approach involves the following steps:

- Technical studies – deriving, for each identified sharing scenario, the size of the areas where potential interference between mobile base stations and satellite earth stations (FSS ES) could occur. Within each of these areas, the study determines the actual amount of spectrum that could be available for IMT based on the spectrum required by satellite users. The frequency sharing scenarios are modelled in Section 2.
- Economic analysis – this takes the output of the technical studies and uses it as the basis for determining the total available spectrum for IMT across the UK. This then enables estimation of the total available capacity under the identified sharing scenarios. Cases for the analysis are defined, which are characterised by sharing scenarios and timing of the C-Band spectrum release. The cost associated with the capacity requirement in each case is then computed.
- Economic benefit estimation – the benefit is computed as the cost that mobile operators could avoid as a result of having access to amounts of spectrum in the C-Band. It is computed as the difference in total radio access network cost between a base case (least spectrum/highest cost) and an alternate case (more spectrum/lower cost) and expressed in 2018 NPV terms. Detailed descriptions of the cases can be found in Section 3.

2 Technical studies

Prior to undertaking the economic analysis detailed in Section 3 of this report it is necessary to determine the amount of spectrum that is available for mobile services in any geographic area along with the number of people for which that spectrum is available. The presence of FSS ES using some portion of the frequency band prevents mobile use of that portion of the frequency band in certain areas. It is therefore necessary to combine a model of frequency and geographic areas around UK FSS ES receiving C-band signals with a model of UK population by area obtained from UK 2011 census data.

The area around a certain FSS receiving earth station can be viewed as a coordination area when considering ITU-R I/N based criteria, tending towards an exclusion area (with reference to the frequencies used by the FSS Earth station) when full account is taken of FSS link performance in terms of C/(N+I). It will be seen later that representative satellite link performance has been taken into account but since this is representative rather than definitive, we have used the term coordination area rather than using a mixture of coordination area and exclusion area. Regardless of nomenclature the following considerations ensure the satellite spectrum being used is protected.

2.1 Description of the frequency sharing scenarios

There are three distinct scenarios that describe different frequency and geographic sharing situations. These three scenarios depend on:

- The FSS ES interference protection level. The two options are to maintain the very conservative ITU-R criteria which relate to the noise floor or to take account of received signal levels which suggest that margins can accommodate higher levels of interference (i.e. link performance aware approach)
- The amount of spectrum that is actually used by the FSS ES. An FSS ES is licensed by Ofcom to operate over a specified bandwidth, which can be considered the accessible bandwidth, and to use certain emission bandwidths. At one extreme it can be considered that an earth station operator uses the whole of the accessible bandwidth and at the other extreme a single emission bandwidth somewhere within the accessible bandwidth. In this regard the two options below labelled “Link performance aware” and “Advanced frequency sharing” provide a range within which the actual situation must reside.

2.1.1 “ITU-R criteria” frequency sharing scenario

This scenario assumes that the ITU-R criteria determine the level of interference that can be tolerated by the FSS ES and that the amount of spectrum used by the FSS ES is defined by the accessible bandwidth.

The ITU-R criteria is a safety first method that is suited to identifying ‘potential’ interference cases and works against the goal of spectrum sharing and spectral efficiency. It takes a universal I/N threshold and applies this to all satellite services currently offered in C-band (including TV reception as well as FSS). As the I/N threshold has to cover all services and all deployments it means that if there is only one case where sharing is not possible, all options are closed.

In satellite coordination it has long been acknowledged that I/N thresholds – universally applied – is not an efficient way to manage the regulatory environment for spectrum sharing.

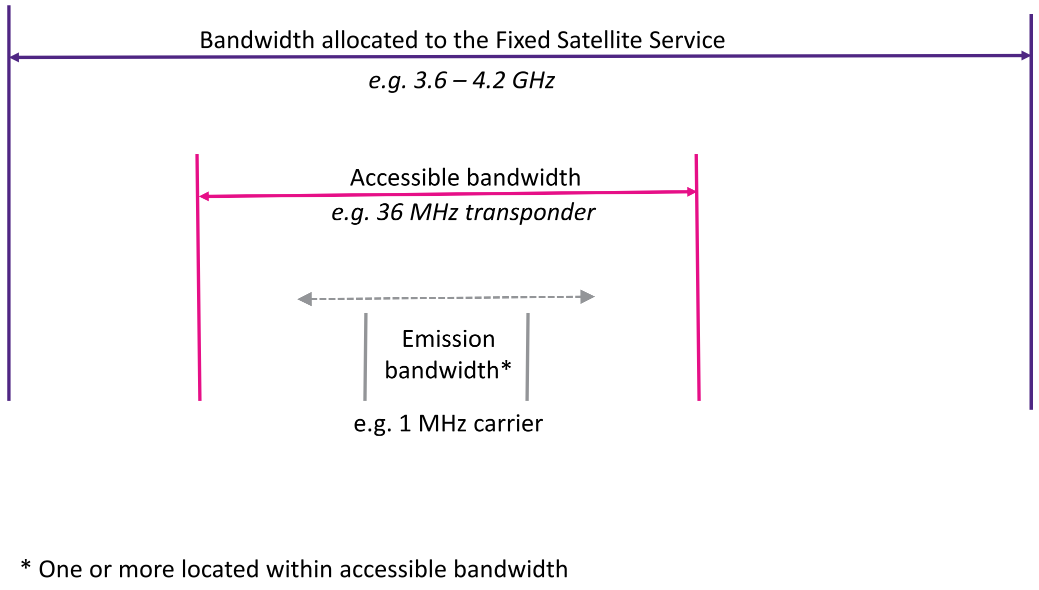
2.1.2 "Link performance aware" frequency sharing scenario

This scenario considers a range of satellite and earth station operating characteristics with a view to determining possible margins that might be available to mitigate interference. As for the ITU-R criteria case above, the amount of spectrum used by the FSS ES is defined by the accessible bandwidth.

2.1.3 "Advanced" frequency sharing scenario

This scenario, as for the link performance aware case above, considers a range of satellite and earth station operating characteristics with a view to determining possible margins that might be available to mitigate interference. In this case the amount of spectrum used by the FSS ES is defined by the emission bandwidth. The relationship between different types of bandwidth is summarised in Figure 2-1.

Figure 2-1: Relationship between different types of bandwidth



2.2 Technical modelling results

The technical modelling is a two-step process:

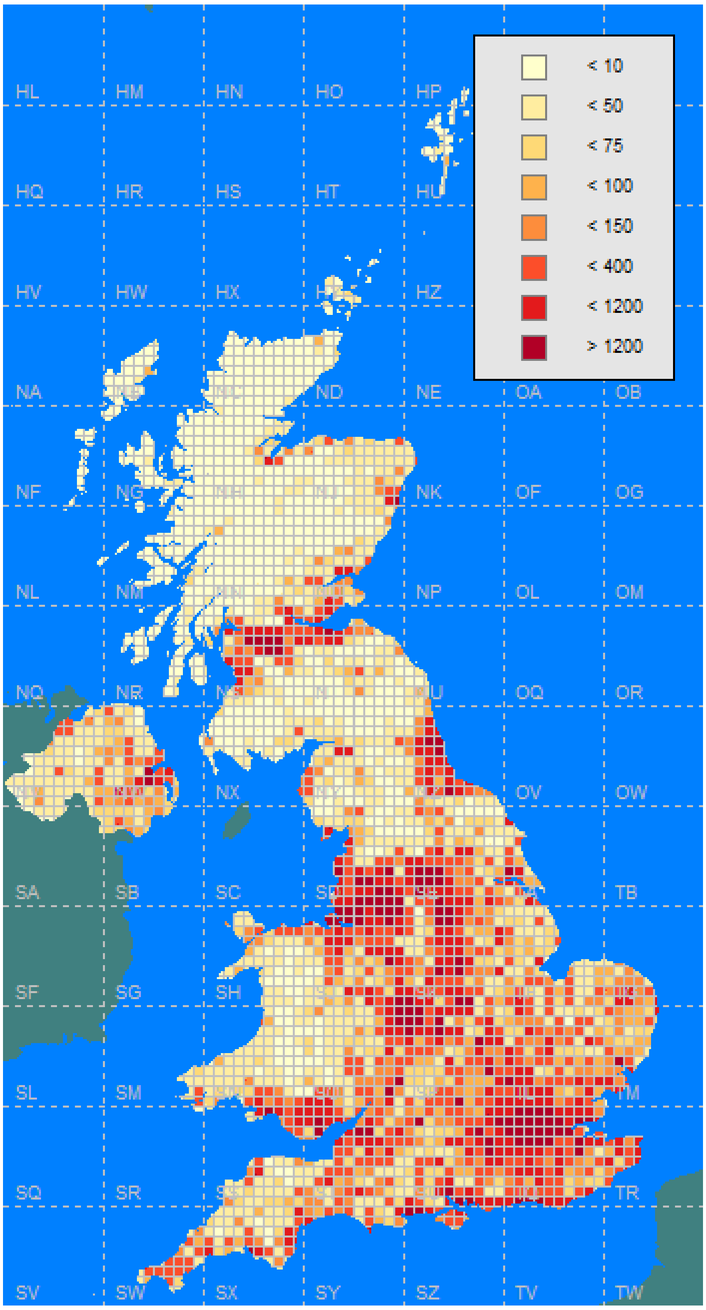
1. The first step determines the amount of spectrum that is precluded from mobile use and over what area
2. The second step maps the precluded spectrum/areas to census data

The output from this modelling, namely the areas where differing amounts of spectrum are not available to a certain number of people for mobile use, is then subtracted from the whole frequency band to give the spectrum that is available by area and number of people. The amount of spectrum available (i.e. the amount that is not used by the Satellite Earth Stations) for the three scenarios is shown in Figure 2-3 to Figure 2-6.

The granularity with which the analysis has been undertaken involves mapping the location of census centroids to 2 km x 2 km squares across the whole UK. In the case of small cells under some scenarios the coordination area is defined by a radius of 300 m which is small compared to the grid size and therefore has a tendency to give nil results because the small coordination area does not often overlap the grid square centre point. A worst case assumption has therefore been implemented ("snap to grid") whereby the small cell is assumed to be coincident with the grid square centre.

Figure 2-2 shows a map of population density for the UK in 10km by 10km grid-square format. The map can be compared to the maps of coordination areas to obtain an idea of the population density in areas where the coordination areas fall.

Figure 2-2: UK population density map (10km x 10 km grid squares)



2.2.1 Results for "Macro cell" IMT rollout scenario

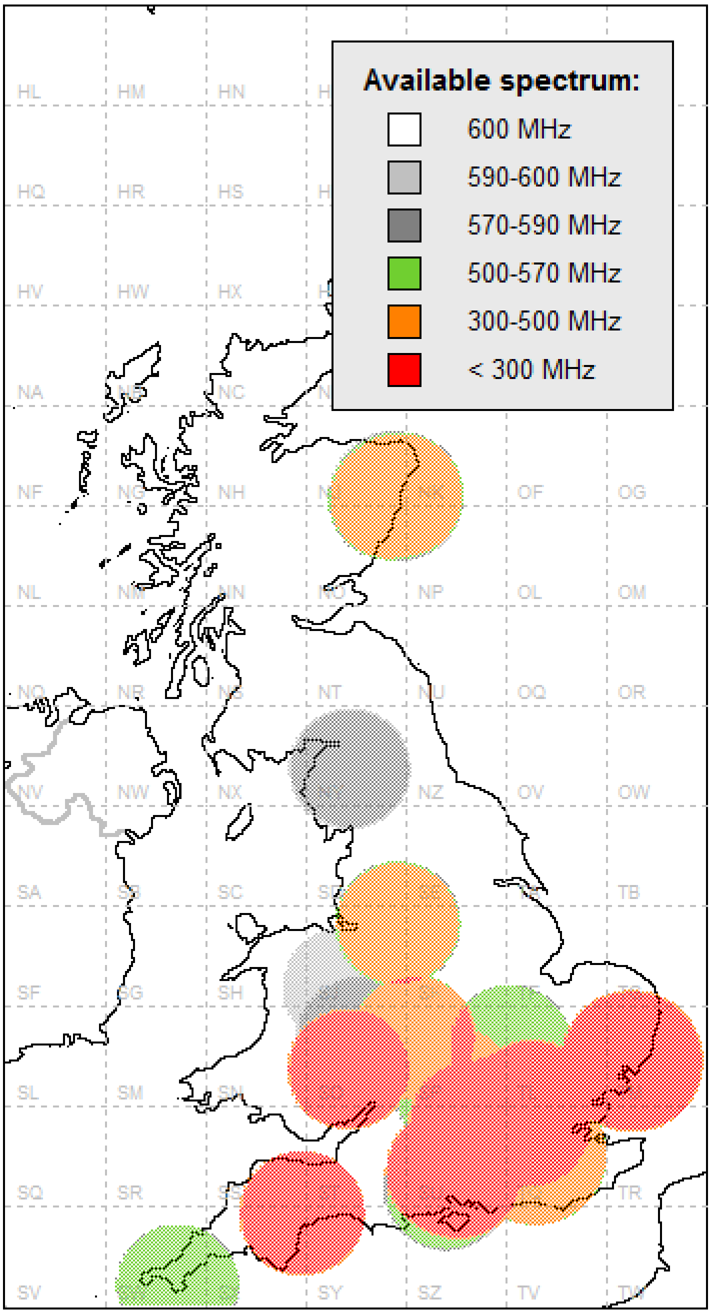
As noted at the beginning of Section 2, the maps that follow are derived on the basis of protecting FSS receive earth station usage. Such protection is afforded through consideration of coordination and exclusion requirements, represented by an area around an earth station. For the purposes of the work reported here, protection has been afforded to earth stations on the basis of both types of criterion:

- Figure 2-3 is based on the ITU-R criteria frequency sharing scenario, highlighting the coordination areas around each FSS ES with reference to the FSS ES accessible bandwidth

- Figure 2-4 is based on the link performance aware frequency sharing scenario, highlighting the exclusion zones around each FSS ES with reference to the FSS ES accessible bandwidth
- Figure 2-5 is based on the advanced frequency sharing scenario, highlighting the exclusion zones around each FSS ES as in the case of Figure 2-4 but with reference to the FSS ES emission bandwidth (smaller than the accessible bandwidth) due to the adoption of LSA.

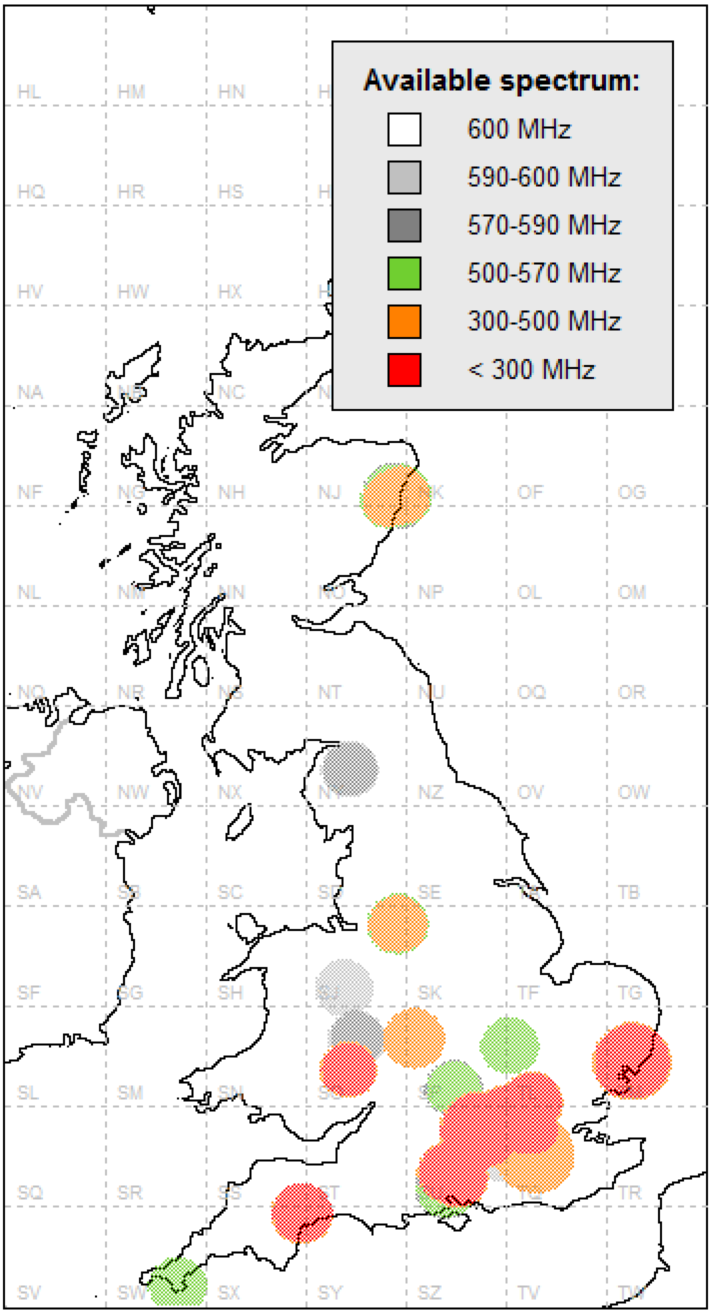
The amount of spectrum available to IMT has therefore been derived by subtracting the protected spectrum being used by the earth station (accessible bandwidth / emission bandwidth) in its coordination / exclusion area from the total amount of spectrum available i.e. 600 MHz (3600 - 4200 MHz range).

Figure 2-3: Amount of spectrum (within the 3600-4200 MHz range) that could be available for IMT macro-cell use within the identified coordination areas around the FSS ES - based on ITU-R criteria and accessible bandwidth (ITU-R criteria scenario)



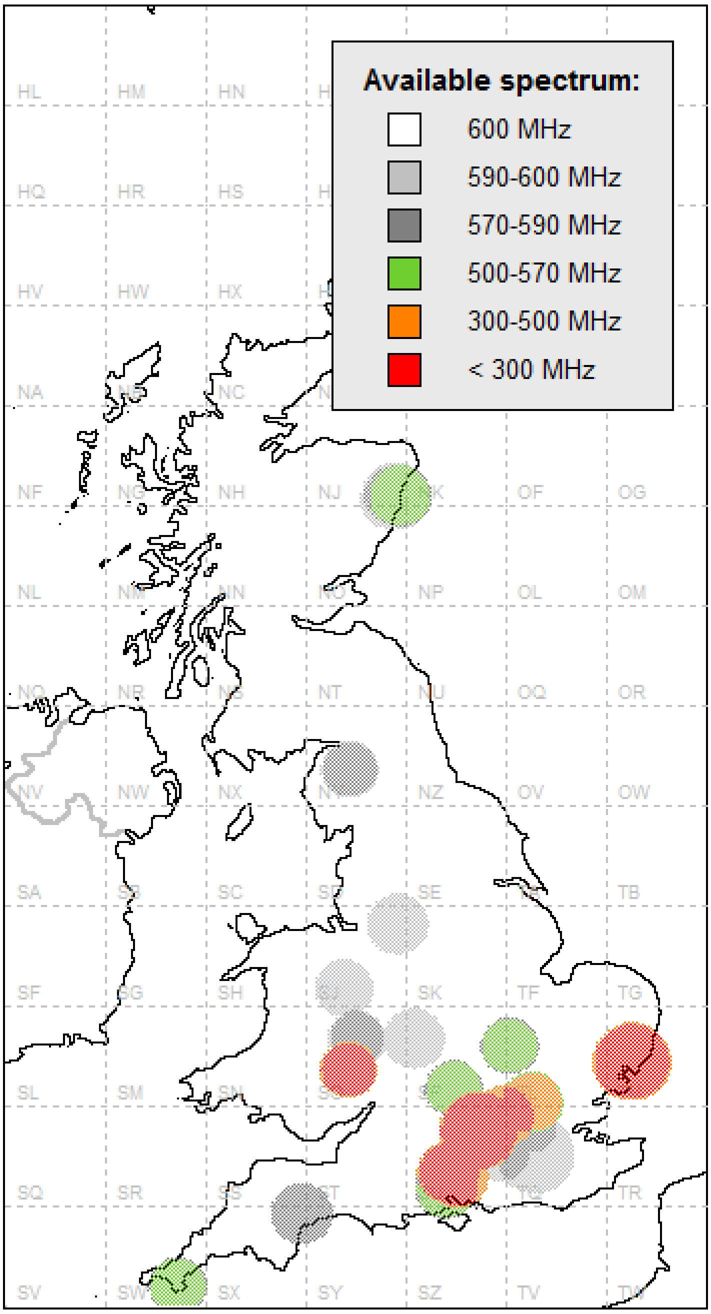
The unshaded areas represent land masses where no FSS ES is present, so that all of the C-Band is available for IMT. These are areas outside of the coordination zones for macro cells.

Figure 2-4: Amount of spectrum (within the 3600-4200 MHz range) that could be available for IMT macro-cell use within the identified coordination areas around the FSS ES - based on FSS ES margin available and accessible bandwidth (Link performance aware scenario)



The unshaded areas represent land masses where no FSS ES is present, so that all of the C-Band is available for IMT. These are areas outside of the coordination areas for macro cells.

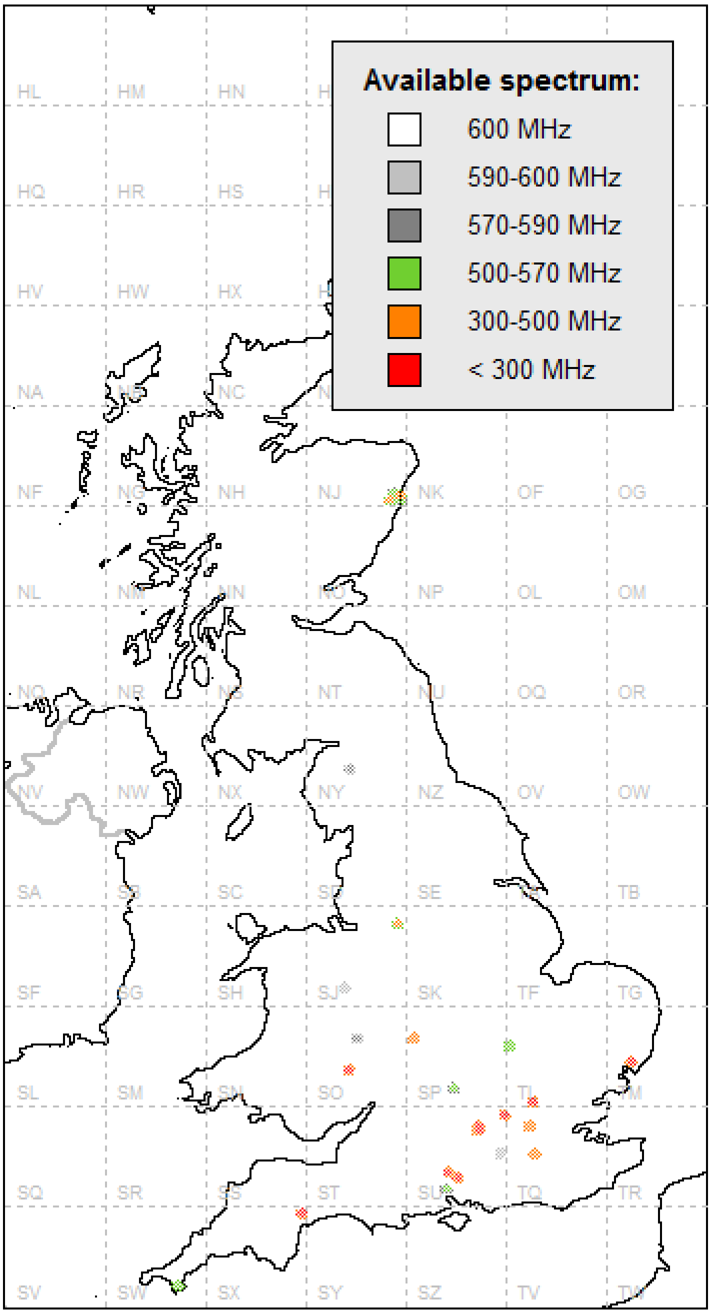
Figure 2-5: Amount of spectrum (within the 3600-4200 MHz range) that could be available for IMT macro-cell use within the identified coordination areas around the FSS ES - based on earth station margin available and emission bandwidth (Advanced frequency sharing scenario)



The unshaded areas represent land masses where no FSS ES is present, so that all of the C-Band is available for IMT. These are areas outside of the coordination areas for macro cells.

2.2.2 Results for "Outdoor small cell" IMT rollout scenario

Figure 2-6: Amount of spectrum (within the 3600-4200 MHz range) that could be available for IMT small cell use outdoors within the identified coordination areas around the FSS ES - based on ITU-R criteria and accessible bandwidth (ITU-R criteria scenario)



The unshaded areas represent land masses where no FSS ES is present, so that all of the C-Band is available for IMT. These are areas outside of the coordination areas for outdoor small cells.

For the other two small cell scenarios, namely “Link performance aware” and “Advanced frequency sharing”, the coordination areas around FSS ES sites have a radius of 300 m and therefore do not show well on maps of this scale. The areas have however been taken into account by analysis described subsequently.

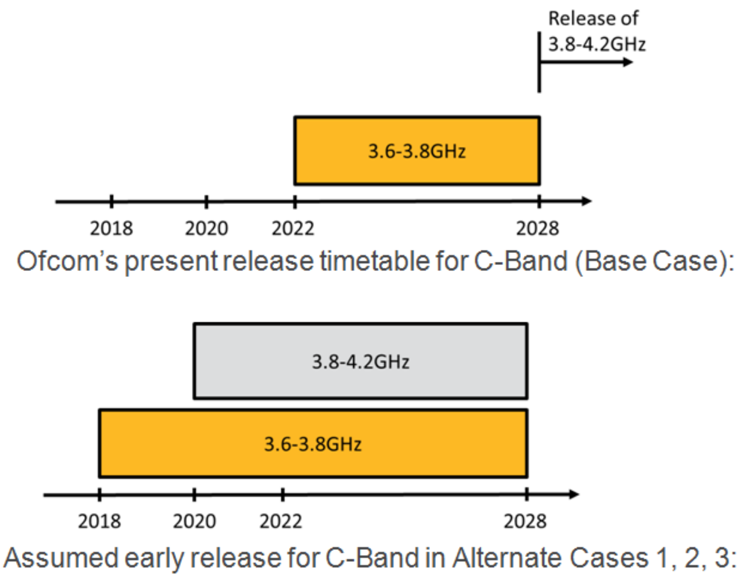
3 Deriving the economic benefits

3.1 Economic modelling

In this analysis, the economic benefit is estimated as the potential change in cost that operators could experience from having access to larger amounts of spectrum compared to a base case. In the base case, it is assumed that the frequencies in the spectrum range 3600-3800 MHz and the spectrum range 3800-4200 MHz will be released in 2022 and 2028 respectively. The sharing scenario required for the use of these ranges in this base case is assumed to be one based on the ITU-R criteria.

The timing of spectrum availability between the base case and the three alternate cases is shown in Figure 3-1.

Figure 3-1: Timing of C-Band spectrum release for the base case and the three alternate cases



Having more spectrum at any given point in time will in general allow operators to roll out fewer sites to support the same volume of mobile data. This leads to a lower network cost. Therefore, the total benefits in the modelled scenarios come from the operators having:

- The same amount of spectrum as in the base case but at an earlier point in time and/or
- A larger amount of spectrum in the C-Band compared to the base case (as a result of less stringent frequency sharing criteria than the ITU-R criterion)

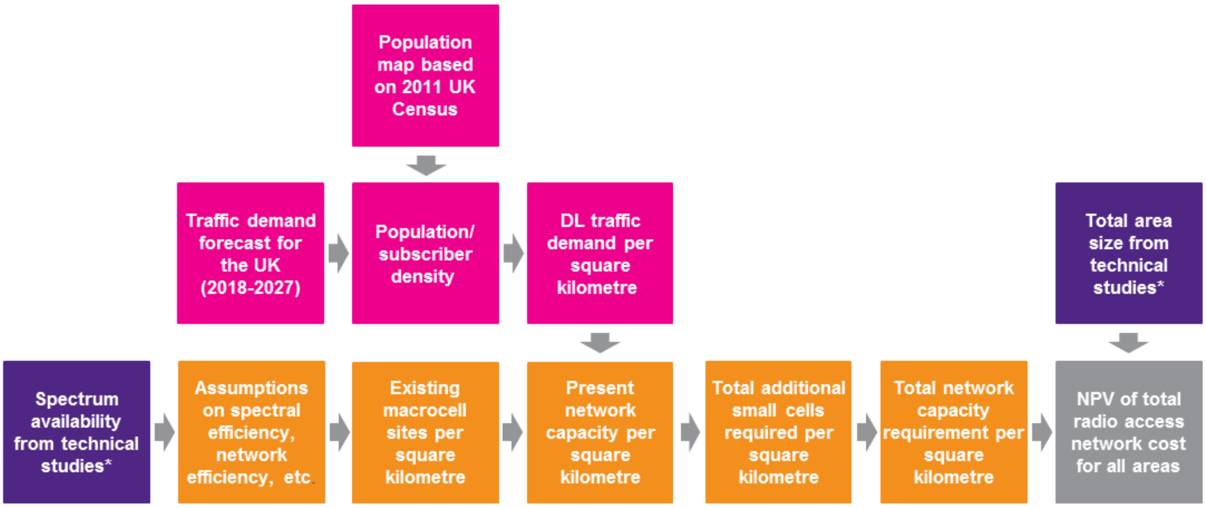
The type of benefit as outlined above is known as avoided cost. We restrict our estimation of benefit to the avoided cost from the use of C-Band spectrum for macro and small cells in the outdoor environment. This means that IMT rollout scenarios in this analysis comprise outdoor macro and outdoor small cells.

We do not consider indoor small cells in our analysis

Today indoor mobile data traffic is being overwhelmingly carried over Wi-Fi at very low cost. This means that the bulk of the benefit from indoor use of the 3600-4200 MHz band will not come from avoided cost. Rather the bulk of the benefit of deployment of the band indoors is likely to come from an increase in consumer surplus due to the improvement in quality of service (should there be a viable business model to support such deployment). Consideration of this type of benefit is outside of the estimation of benefits performed for this report. The exclusion of the indoor benefit of C-Band deployment in our analysis will lead to our estimate of the benefit from 3600-4200 MHz being a conservative one.

Figure 3-2 provides an overview of the steps used to derive the costs that form the input to the calculation of the avoided costs. The process for deriving the benefit is described in detail in Appendix B. The appendix also contains a discussion of the key assumptions that are implicit in the network costing function of the model.

Figure 3-2: Overview of the steps to calculate radio access network cost for all areas and for all bands including C-Band (in the 2018-2027 time frame)



*There are 3 frequency sharing scenarios and for each scenario 3 types of areas – i.e. macro cell and small cell coordination zones plus the area outside of these coordination zones. This means in total there are 9 combinations of spectrum availability and total area size to consider before change in the timing of C-Band release is accounted for.

The benefit from avoided costs is computed as the difference in NPV of total radio access network cost between a base case and an alternative case with greater spectrum availability– i.e. Benefit equals (Base Case's cost NPV) minus (Alternative Case cost NPV). Table 3-1, summarises the key characteristics of the base case and the 3 alternate cases that are modelled. These characteristics are the timing of the release of the 3600-3800 MHz and 3800-4200 MHz ranges and the sharing criteria that are assumed for each case.

Table 3-1: Definition of Base Case and Alternate Cases by C-Band release dates, frequency sharing scenario and IMT rollout scenario

Modelling scenario	Release date of 3600-3800 MHz	Release date of 3800-4200 MHz	Frequency sharing scenario	IMT rollout scenario
Base Case	2022	After 2028	ITU-R criterion	Macro Cell + outdoor Small Cell
Alternate Case 1	2018	2022	ITU-R criterion	Macro Cell + Outdoor Small Cell
Alternate Case 2	2018	2022	Link performance aware	Macro Cell + Outdoor Small Cell
Alternate Case 3	2018	2022	Advanced frequency sharing	Macro Cell + Outdoor Small Cell

The sharing criteria assumed for the base case and the 3 alternate cases are summarised in Section 2.1.1, Section 2.1.2 and Section 2.1.3

ITU-R sharing assumes that the ITU-R criteria determines the level of interference that can be tolerated by the FSS ES and that the amount of spectrum used by the FSS ES is defined by the accessible bandwidth.

Moving from ITU-R to link performance aware decreases the minimum separation distance required between FSS ES and IMT base stations while still avoiding any interference that could otherwise undermine the proper operation of the satellite downlinks.

Moving from link performance aware to advanced frequency sharing decreases the total amount of spectrum that is assumed to be required for FSS ES operations. As a consequence, the total amount of spectrum available to IMT in the coordination zones as shown in Section 2.2.1 and Section 2.2.2 increases.

Geotypes are used to ensure that the variation in subscribers and site density in different areas across the UK is captured. There are 5 geotypes, which are defined by population density thresholds: hot spot, dense urban, urban, suburban and rural areas. The definitions of the geotypes as well as the population/subscriber and network parameters associated with them can be found in Appendix B.

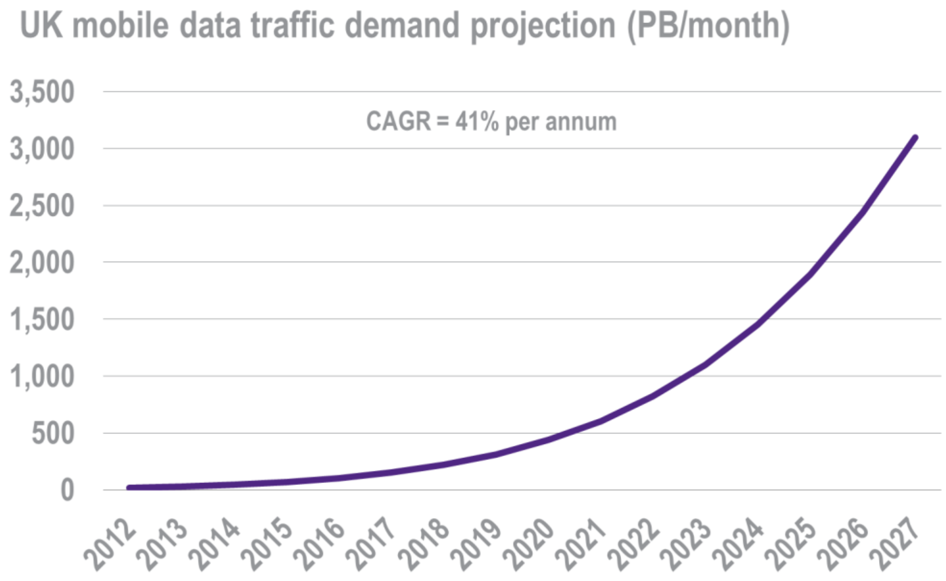
The concept of heterogeneous networks is incorporated into this analysis by making the assumption that all new cells will be small cells subsequent to 2014. However, small cells will only be rolled out when all available bands (including C-band when available) have been deployed on existing macro-cell sites and there is still capacity shortfall[17]. This means that operators are assumed to prefer adding new bands to macro-cells as opposed to installing new small cells straight away. When small cells are rolled out, it is assumed that only bands above 2600MHz will be used on them.

[17] It should be noted here that not all macro cell sites will be suitable for C-band deployment due to their location. We assume that only a certain proportion of macro cell sites in each geotype will be upgraded with C-band frequencies. These percentages can be found in Appendix CTable C-4.

3.1.1 Traffic demand forecast

The key demand-side input is the amount of traffic that operators will need to support. The traffic demand forecast is derived by first extrapolating the Cisco VNI 2014 short-term (2012-2018) projection for the UK[18] to 2028 using a Gompertz curve. Mid-year historical monthly mobile data volumes published in Ofcom's 2013 Infrastructure Report are then used as the reference for scaling the Cisco-extrapolated forecast. The Ofcom numbers for June 2012 and June 2013 are roughly half of what Cisco reported. Therefore, the Cisco-extrapolated forecast is adjusted by a factor of 0.5. The resulting traffic demand projection that is used as the input into the economic model is shown in Figure 3-3.

Figure 3-3: Traffic demand



Source: Cisco VNI 2014, Plum Analysis

Table 3-2 shows the annual growth rate of traffic demand implicit in the forecast. Although the curve does not have an obvious inflexion point, the tabulated growth rates show that traffic growth declines reasonably quickly. The rate drops from 61% in 2013 to 27% in 2027.

Table 3-2: Annual growth rate for traffic projection

Year	Annual growth rate (%)
2013	61%
2014	57%
2015	54%
2016	51%
2017	48%

[18] http://ciscovni.com/forecast-widget/advanced.html

Year	Annual growth rate (%)
2018	45%
2019	43%
2020	40%
2021	38%
2022	36%
2023	34%
2024	32%
2025	30%
2026	29%
2027	27%

Long-term projections of mobile data traffic demand are inherently uncertain. Usage behaviour beyond the next few years will depend on both the availability of devices and applications, the quality of the service that can be delivered and the associated supply side cost. The latter will also determine the extent of mobile device data offload to WiFi and residential indoors small-cells.

Ofcom has published a cost-benefit study conducted by Analysys Mason[19] for its consultation on the release of the 700MHz spectrum. This analysis takes as one of its key inputs mobile data traffic forecast to 2040. Their projection shows that by 2028, post-offload[20] traffic for a generic operator with 25% of the market is in the range 2,700PB to 3,500PB per annum. This is equivalent to around 1,000PB per month for the entire market, which is lower than the forecast used for the analysis for this report.

We are of the view that the traffic forecast used for this report is reasonable and could actually turn out to be conservative. It amounts by 2027 to a usage level of 36GB per active SIM per month, assuming that the number of active SIMs remain at 84.7million (what is reported for mid-year 2013 in Ofcom's Infrastructure Report 2013[21]). This is the equivalent of just over 1GB per day, which can be used up by 1-2 hours of HD streaming over the mobile network. Using this traffic projection, the earliest that operators need to roll out new sites in the absence of the 3400-4200 MHz band is 2023. This result is based on the site and technical network assumptions that are detailed in Appendix B.

3.1.2 In-band backhaul use

The analysis also considers the use of C-Band for in-band backhaul. The use of C-band or 2600MHz TDD spectrum for backhaul is assumed to apply only for outdoor small cells. We assume that microwave and fixed connections will continue to be used for backhaul on macro cell sites. The use of in-band backhaul for small cells means that not all of the spectrum available can be used for radio access – i.e. to serve mobile users' traffic. To ensure that backhaul capacity is guaranteed for small

[19] http://stakeholders.ofcom.org.uk/binaries/consultations/700MHz/annexes/benefits_700MHz.pdf

[20] This is traffic excluding traffic offloaded to WiFi and femtocells.

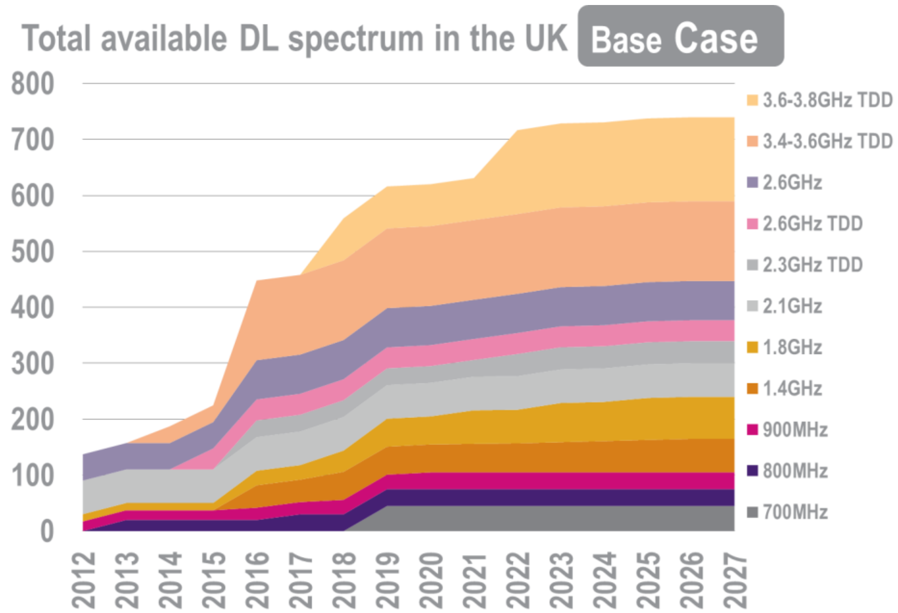
[21] http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/infrastructure-report/IRU_2013.pdf

cells, half of all available spectrum for IMT in the C-Band is assumed to be reserved for backhaul. Implicit in this assumption is that operators do not incur annual spectrum fees on backhaul for small cells.

3.1.3 Spectrum supply in the Base Case

Spectrum supply is an important supply-side input. It determines the level of existing capacity for comparison with demand. Figure 3-4 shows the base case portfolio of downlink spectrum assumed to be available to operators outside of coordination areas during the modelling period. Note that the profile of available downlink spectrum will change moving from the Base Case to Alternate Case 3.

Figure 3-4: Downlink spectrum availability – Base Case



Source: Ofcom publications, Plum Analysis

In particular, in line with the illustration of spectrum availability in Ofcom's mobile data strategy statement, the following amount of the C-Band is assumed to be available for the base case as follows:

Table 3-3: Total C-band spectrum assumed to be available in the base case

Range in C-Band	Total amount available from 2016 (MHz)	Total amount available from 2018 (MHz)	Total amount available from 2022 (MHz)	Total amount available from 2028 (MHz)
3400-3600 MHz	190	190	190	190
3600-3800 MHz	0	100	200	200
3800-4200 MHz	0	0	0	400

3.1.4 Other key considerations

Another key supply-side input is the number existing sites per square kilometre. Ofcom's Sitefinder database and the map on the Ofcom website[22] have been used to estimate the number of operators' existing sites per square kilometre. This data was cross checked against data received from Qualcomm used in another economic study. It is believed that the Sitefinder tool may not contain the most up-to-date information. Nevertheless, given the trend towards consolidation and infrastructure sharing, it is likely that historical numbers from 2012 or earlier will yield a site count higher than the actual number of sites in use today. A lower site count means that existing capacity will be exhausted more quickly, therefore the use of the site finder data may mean that the benefit estimate is conservative.

For the purpose of determining the total radio network infrastructure requirement, it is assumed that outdoor small cells can support a total of 60MHz during the modelling period (i.e. an outdoor small cell will have capacity to transmit on three 20MHz carriers, which could be in the same or different bands)[23]. Given the fact that 3GPP is specifying the aggregation of three component carriers in the downlink in Release 12, this assumption may be a conservative one.

Further evolution of LTE-Advanced technology that will support more advanced carrier aggregation schemes (beyond 5 component carriers) as well as wider channel bandwidths (beyond 20 MHz) is being actively discussed for future 3GPP Releases.

5G mobile networks will be deployed from 2020, starting with some leading markets of the world (e.g. Japan and Korea). It is understood they will support 1000-fold mobile traffic increase, connections for at least 100 billion devices, and multi-Giga-bps individual user data rate, extremely low latency and low energy consumption. The availability of the 3800-4200 in the 2020 timeframe will represent an important candidate frequency to support the introduction of 5G.

The benefits associated with the contribution that the 3600-4200 MHz range would give to the innovation of mobile broadband networks and in particular to the establishment of 5G have not been quantified within the avoided cost model of this report.

3.2 Results of economic modelling

The move from Alternate Case 1 to Case 2 to Case 3 generates a cumulative benefit. This is because Case 2 and Case 3 are a variant of Case 1. The only difference between Case 1 and the other cases – albeit an important one – is that there is greater spectrum availability for IMT due to revised frequency sharing criteria in both Case 2 and Case 3:

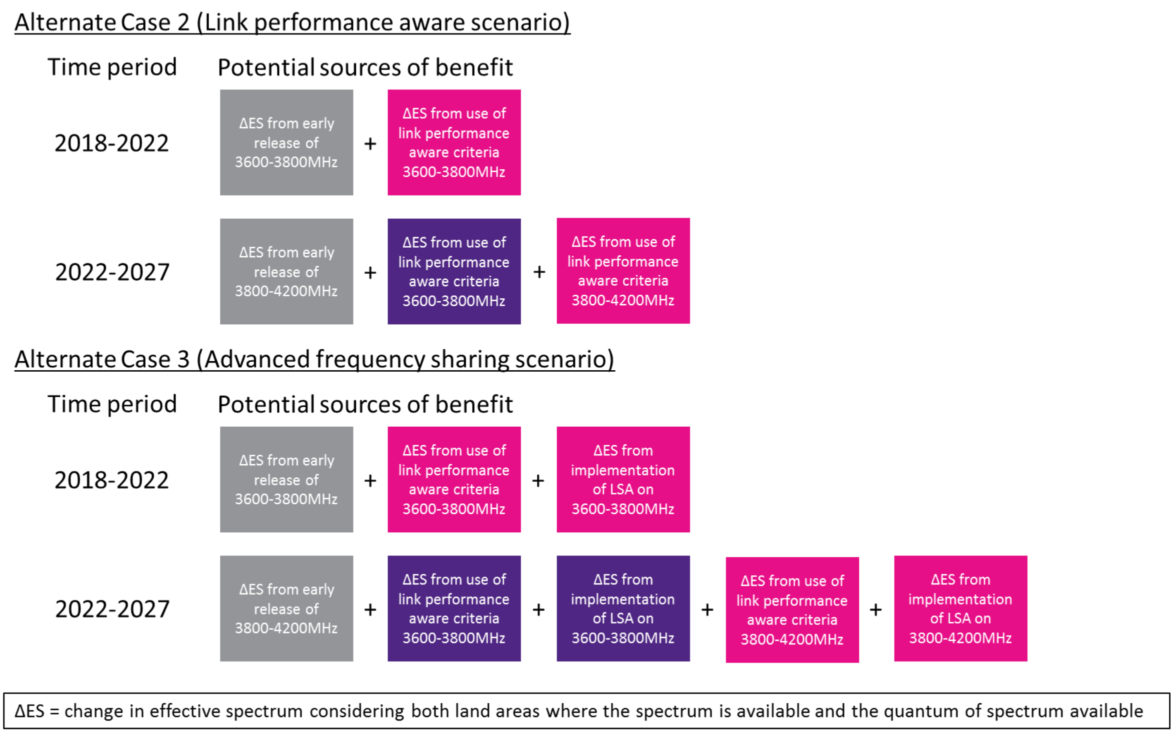
- Case 1 has the same amount of spectrum in the long run as the base case
- Case 2 and Case 3 have all the benefits associated with Case 1 (given that there is at least as much spectrum as in Case 1) plus additional benefits that arise from being able to use the spectrum available in addition to Case 1 due to more advanced frequency sharing.

[22] http://sitefinder.ofcom.org.uk/

[23] Based on discussion with industry stakeholders and vendors on the evolution of carrier aggregation in small cells and the current specifications of microcells. At present, an outdoor microcell can only support a maximum of 2 bands and 1 carrier in each band. Longer term small cells will support up to five 20 MHz carriers

Figure 3-5 illustrates the potential sources of benefit of Alternate Case 2 and Alternate Case 3. Each potential source of benefit relates to an increase in spectrum. As mentioned, more spectrum could allow operators to reduce infrastructure costs and thus generate avoided-cost benefit.

Figure 3-5: Illustration of potential sources of benefit for Alternate Case 2 and Alternate Case 3



In both Case 2 and Case 3, there is a change in the amount of effective spectrum available from 2018 on account of the early release of spectrum in the range 3600-3800MHz. Then, between 2022 and 2027, operators also have additional spectrum in the 3800-4200 MHz range. In the base case, frequencies in the range 3600-3800MHz only become available to operators in 2022, while frequencies in the range 3800-4200MHz are only released in 2028. Therefore, the early release of these two parts of the C-band lead to an increase in effective spectrum, which is a potential source of the derived benefit in Section 3.2.1.

The other sources of benefit take the form of the increase in effective spectrum from the use of revised frequency sharing criteria. In Alternate Case 2, between 2018 and 2022 there is a further increase in effective spectrum in the 3600-3800MHz range which is released early, since more spectrum can be used when link performance aware sharing criteria are adopted. Similarly, there is an increase in the total amount of 3800-4200MHz spectrum which is released early in 2022 due to the use of link performance aware sharing criteria. In Alternate Case 3, even more spectrum is available in each frequency range during each time period. This is because advanced frequency sharing is now implemented on the total spectrum in each sub-band that is available through early release and the adoption of link performance aware criteria. This increment in spectrum from the implementation of advanced frequency sharing constitutes another potential source of benefit.

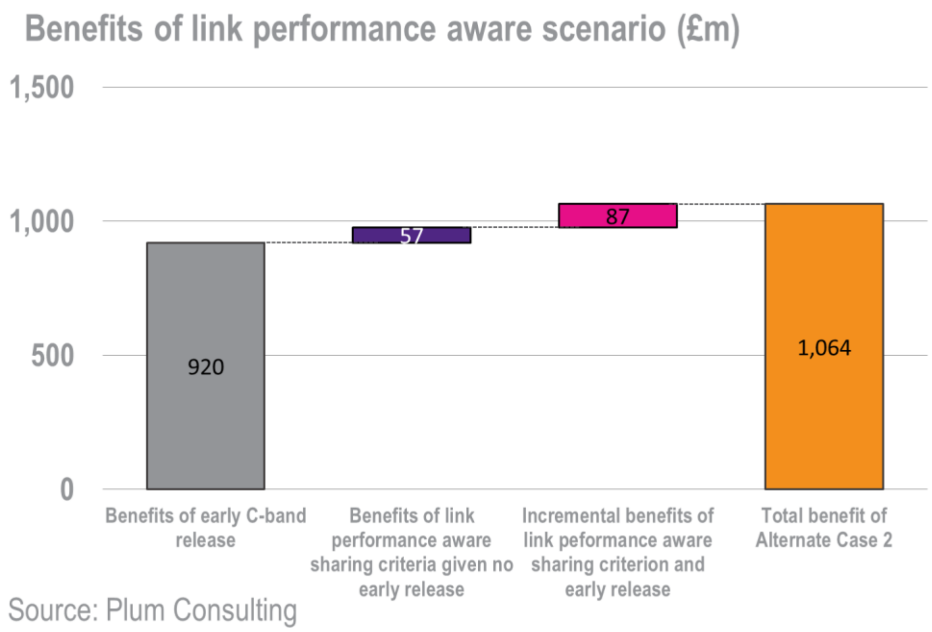
3.2.1 Alternate Case 1 benefit

The benefit in Case 1 comes solely from the early availability of C-Band spectrum. As with the Base Case, the ITU-R criteria is assumed, and all of FSS ES's accessible bandwidth is excluded for IMT within the coordination area. As discussed, the only difference is in the timing of the release of the 3600-3800 MHz and 3800-4200 MHz bands. The calculation shows that the avoided cost associated with Case 1 is £920m, expressed as 2018 NPV.

3.2.2 Alternate Case 2 benefit

Figure 3-6 shows the composition of the total benefit for Case 2. In this case, the satellite accessible bandwidth is excluded but the margin is improved leading to more spectrum being available for IMT.

Figure 3-6: Alternate Case 2 benefit (early release + link performance aware frequency sharing scenario)



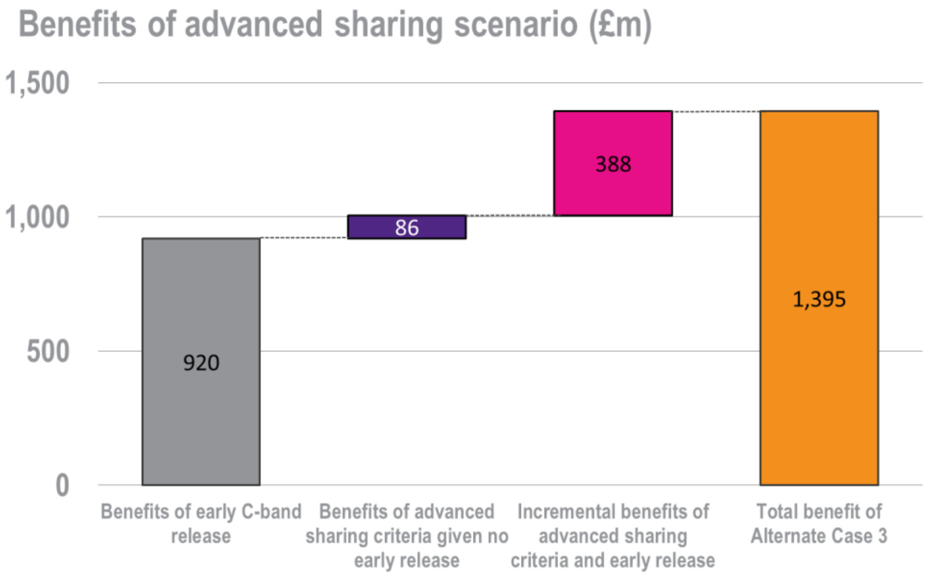
The colours of the benefit bars correspond to the colours of the potential source of benefit shown in Figure 3-5.

In addition to the early benefit of having the spectrum under the ITU-R criteria (from 2018), which amounts to £920m in 2018 NPV (Alternate Case 1 benefit), there is an additional benefit of having more spectrum (3600-3800MHz and 3800-4200MHz) through the use of link performance aware criteria from 2022 (£57m in 2018 NPV) and the extra benefit of having more spectrum (3600-3800 MHz) through using link performance aware criteria from 2018 (£87m in 2018 NPV).

3.2.3 Alternate Case 3 benefit

Figure 3-7 shows the composition of the benefit for Case 3. In this case, only the satellite emission bandwidth is excluded when calculating the benefit (as opposed to the accessible bandwidth). Consequently, the total excluded spectrum is less than in Case 2, providing the greatest amount of spectrum for IMT of the three cases considered.

Figure 3-7: Alternate Case 3 benefit (early release + advanced frequency sharing scenario)



Source: Plum Consulting

The colours of the benefit bars correspond to the colours of the potential source of benefit shown in Figure 3-5.

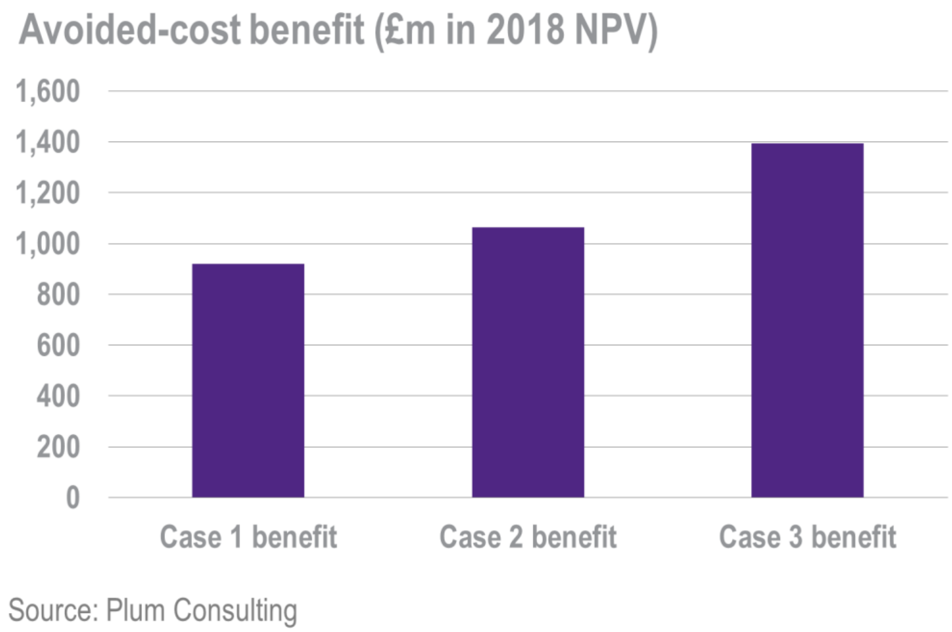
In line with Case 2, in addition to the benefit of having the spectrum under the ITU-R criteria early (from 2018), which amounts to £920m in 2018 NPV (Case 1 benefit), there is also the additional benefit of having more spectrum (3600-3800MHz and 3800-4200MHz) through the use of advanced frequency sharing criteria from 2022 (£86m in 2018 NPV) and the extra benefit of having more spectrum (3600-3800MHz) through using advanced frequency sharing criteria from 2018 (£388m in 2018 NPV).

In total, implementing advanced frequency sharing increases the total benefit by £330m in 2018 NPV relative to Case 2. The total incremental benefit of revised sharing criteria in Case 2 is £144m in 2018 NPV in total, while the total incremental benefit of revised sharing criteria in Case 3 is £474m. The bulk of the increase in benefit in Case 3 comes from having access to a significantly higher amount of 3800-4200MHz spectrum from 2022 compared to Case 2.

3.3 Discussion of results

Figure 3-8 summarises the benefits of the 3 cases considered in this analysis. In each case, the benefit is the potential reduction to mobile operators in cost as a result of an early release of spectrum and/or revised frequency sharing criterion compared to the Base Case.

Figure 3-8: Comparison of avoided cost



3.3.1 Interpretation of Case 2 and Case 3 results

The benefits of Case 2 and Case 3 could be thought as the lower and upper bound of the total benefit that could accrue to the use of updated frequency sharing scenarios. As discussed in Section 2, the link performance aware scenario (Case 2) is based on a consideration of the earth station margin available and accessible bandwidth. The advanced frequency sharing scenario (Case 3) is based on a consideration of earth station margin available and emission bandwidth, with one emission channel. In reality, there could be multiple emission channels used by satellite operators. Therefore, the most that will be unavailable for IMT is the accessible bandwidth and the least is the emission bandwidth for one channel, making the benefits of Case 2 and Case 3 the minimum and maximum level of benefit for revised sharing criteria.

3.3.2 Use of conservative assumptions

In the analysis, a number of assumptions were made, which could have the effect of making the benefit calculated conservative. They are as follows:

- The number of FSS ES stays constant throughout the modelling period whereas in practice it is expected to decrease by 2027. If the number of FSS ES declines over time there will be fewer coordination areas and more of the UK (by area) will have all of the C-Band available for use for IMT. This will increase the benefit.

- For coordination areas whose size is smaller than the 2 km x 2 km grid used, it is assumed that the entire 2 km x 2 km grid is affected. Hence more people are assumed to be affected than might be the case in reality. This means that spectrum usage is restricted in a larger area than needs to be the case.
- Potential benefits from indoor use of the spectrum are excluded as these would not be modelled as an avoided cost but would instead generate consumer surplus due to improvement in quality of service. By not taking this benefit into account, it is likely benefits in terms of consumer surplus that arise from improved mobile users' experience are ignored, which could be large.
- A total of 60MHz per small cell is assumed. (including contributions from all possible other bands supported by the same macro base station / small cell). Given the fact that 3GPP Rel. 12 is specifying the aggregation of three component carriers in the downlink (two CC in 3GPP band 42 and one CC in 3GPP band 41), this assumption may be a conservative one.
- We assume that the FSS ES elevation angle is 5 degrees. In reality, there is a variety of elevation angles, with 5 degrees being low for the UK. The lower the elevation angle the larger the coordination area needs to be. Therefore, by assuming a uniform elevation angle of 5 degrees, it is likely that the size of the coordination areas is over estimated, which will have the effect of making the benefits calculated too low.
- The benefits associated with the contribution that the 3600-4200MHz range would give to the innovation of mobile broadband networks and in particular to the establishment of 5G have not been quantified within the avoided cost model.
- Benefits from enhanced QoS to provide consistent performance across the whole coverage area were not taken into account.

4 Conclusion

The early availability in the UK of 3600-3800 MHz and 3800-4200 MHz spectrum for IMT is expected to yield significant net benefit. This spectrum potentially offers the large contiguous blocks that will be required for mobile broadband use as mobile data traffic grows.

The benefit of bringing forward the availability of this spectrum could amount to £920m of avoided cost over the period 2018 to the end of 2027 in 2018 NPV terms. The benefit could be further enhanced through the use of link performance aware and advanced frequency sharing techniques by more than another £400m in 2018 NPV terms[24]. This additional benefit could be facilitated through the use of LSA which would allow voluntary agreements to be concluded between FSS ES operators and mobile operators[25].

The additional spectrum at 3600-4200 MHz is required to provide capacity to meet mobile data traffic demand as mobile data traffic grows. The analysis suggests that a spectrum crunch occurs in 2023 in the absence of the earlier availability of this spectrum (i.e. if the spectrum is assumed to become available in line with the illustration of spectrum availability in Ofcom's mobile data strategy statement). This result is based on the relatively conservative mobile data traffic demand forecast used for modelling the avoided costs. If mobile traffic demand were to grow more aggressively the spectrum crunch would occur before 2023.

It should be noted that some of the other assumptions used to model the benefit are conservative and as a result the avoided cost is likely to be underestimated. Also, only outdoor deployments have been considered in the model and no benefits are included from use of the spectrum for indoor cells.

The results of study suggest that consideration should be given to the early release of spectrum at 3600-3800 MHz (which is supported by Ofcom as a candidate band for WRC15 and is the subject of a European Commission Decision). Also, early release of spectrum at 3800-4200 MHz should be considered. The latter range is supported by Ofcom for longer term consideration for IMT but the likelihood of a spectrum crunch as early as 2023 indicates that action is required in the short term to deliver sufficient predictability and regulatory certainty for potential users of the band.

The study results also suggest that there should be further examination of the use of LSA to facilitate sharing arrangements between FSS ES operators and IMT.

While CEPT is currently considering commencing work in this field (based on contributions received from various member states and industry)[26] an industry working group could be created in the UK to develop proposals which could be the basis for developments more widely in Europe.

[24] Depending on the actual relationship between accessible bandwidth and emission bandwidth signals at FSS ESs

[25] With oversight from the regulator. This oversight will ensure that agreements are consistent with the requirements of the Authorisation Directive.

[26] ECC PT1(14)115 draft minutes 16 September 2014

Appendix A: Technical modelling assumptions

The area around a Fixed Satellite Service Earth Station within which a particular piece of spectrum would not be available to mobile services is determined by a large number of factors including the surrounding terrain and the earth station antenna pattern in the horizontal plane which in turn is determined by the elevation angle at which the antenna is operated. For simplicity it has been assumed that the area around the earth station is described by a circle of a particular radius. That radius has been determined by an extensive Huawei study (reported in JTG contributions[27] and further developed since then) which takes account of:

- The types of location in which the Satellite Earth Station and the macro and small cells are located
- The aggregation of potential interference from multiple macro / small cell transmitters
- A propagation model (based on long term interference because aggregation effects are being considered) with a small obstacle mid-path. Note that this approach gives rise to similar separation distances to those that are obtained through the specific modelling of actual earth station sites (i.e. taking account of actual terrain)
- An earth station elevation angle of 5 degrees. This is a very conservative assumption as many of the earth station antennas are known to operate at elevation angles greater than 5 degrees. Operation at higher elevation angles gives rise to a reduced earth station antenna gain in the horizontal plane and consequently smaller coordination areas

The coordination area radius is also determined by the criterion defining an acceptable level of interference at the Satellite Earth Station. The starting position is the traditional ITU-R criteria which is defined relative to the noise floor of the FSS ES receiver (I/N = -13 dB). However, consideration is also given to the situation where a margin exists on the satellite link such that a higher level of interference can be tolerated. Examination of satellite and earth station characteristics suggests that such margins might support an I/N of 10 dB or more. It is noted that a detailed end-to-end link performance (i.e. uplink and downlink combined) would determine the actual margins available. However, such information is not generally available in the public domain so the downlink characteristics have been considered in isolation.

On the basis of the above considerations, the radii of the coordination areas around the 27 FSS ES sites under different frequency sharing scenarios (e.g. ITU-R criteria, link performance aware, advanced frequency sharing), rollout scenarios (macro cell, outdoor small cell), and geotypes (urban, suburban, rural) are as follows:

[27] CPG-PTD(14)057_Report on sharing between terrestrial IMT and FSS systems operating in the 3800-4200 MHz frequency range

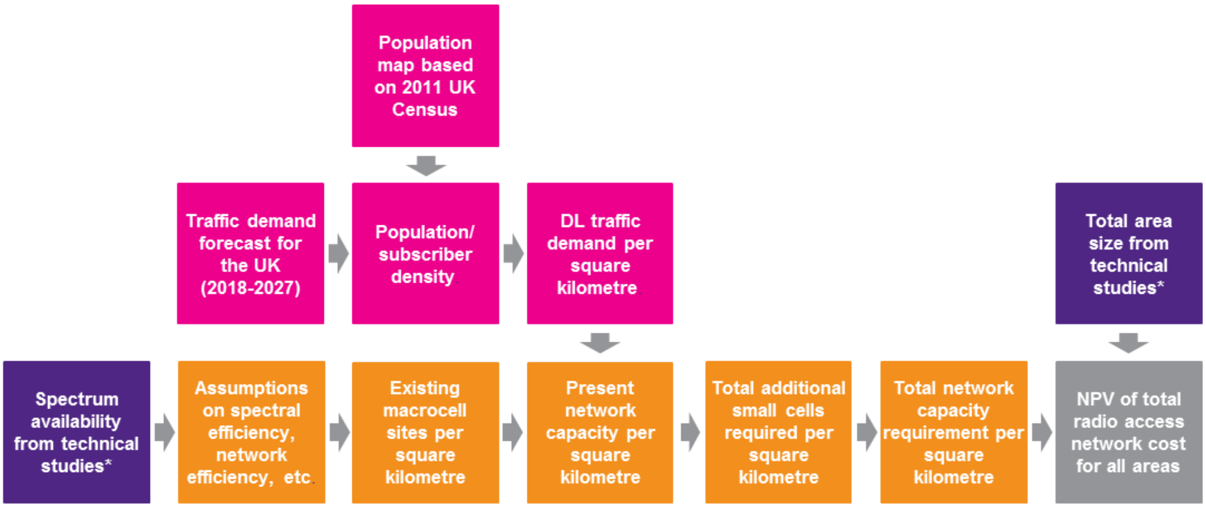
Table A-1:

Ref	Frequency sharing scenario	Sharing	Criterion	Cell type	Cell geotype	ES Rural (km)	ES Suburban (km)	ES Urban (km)	Figure in main body of report
1	ITU-R	No sharing within accessible bandwidth	ITU-R I/N = -13 dB	Macro	Urban/suburban mean	59.5	61.25	70	Figure 2-3
2	ITU-R	No sharing within accessible bandwidth	ITU-R I/N = -13 dB	Small cell (outdoor)	Urban	5	5	5	Figure 2-6
3	Link performance aware	No sharing within accessible bandwidth	Margin I/N = +10 dB	Macro	Urban/suburban mean	27.5	29.5	38.25	Figure 2-4
4	Link performance aware	No sharing within accessible bandwidth	Margin I/N = +10 dB	Small cell (outdoor)	Urban	0.3	0.3	0.3	Not shown – areas too small to be seen on map
5	Advanced frequency sharing	Sharing within accessible bandwidth (LSA)	Margin I/N = +10 dB	Macro	Urban/suburban mean	27.5	29.5	38.25	Figure 2-5
6	Advanced frequency sharing	Sharing within accessible bandwidth (LSA)	Margin I/N = +10 dB	Small cell (outdoor)	Urban	0.3	0.3	0.3	Not shown – areas too small to be seen on map

Appendix B: Economic model structure

The economic analysis is confined to traffic transmitted over macro cells and outdoor small cells. Network costing, which forms the basis for the avoided-cost benefit calculation, is summarised in the flow diagram in Figure B-1.

Figure B-1: Structure of the network costing process



*There are 3 frequency sharing scenarios and for each scenario 3 types of areas – i.e. macro cell and small cell coordination zones plus the area outside of these coordination zones. This means in total there are 9 combinations of spectrum availability and total area size to consider before change in the timing of C-Band release is accounted for.

The rest of this appendix discusses the steps undertaken and the key assumptions made in the processes of:

- Treating the technical study output for use in the economic analysis
- Mobile traffic demand determination
- Infrastructure and capacity supply determination
- Infrastructure costing and benefit calculation

B.1 Technical study output processing

The model determines the extent of the coordination areas, where the coexistence of FSS ES and IMT mean there is only partial spectrum availability for IMT.

- This is done for macro cells and outdoor small cells, where the radii of the coordination areas with the ES at their centres will be larger for macro cells than for small cells.
- Within the coordination areas for macro cells, the entire C-Band frequency range can be deployed on small cells except in the coordination areas for small cells (nested within the macro cells'

coordination areas). Within the small cells coordination areas, there is a restriction on spectrum usage due to potential interference with the FSS ES.

The coordination areas are superimposed on a gridded map of the UK population density (2km x 2km squares), which is in turn divided up into 5 geotypes based on population density. The geotypes are:

- Hotspots (13,910< persons per sqkm)
- Dense urban (between 10,910 and 13,910 persons per sqkm)
- Urban (between 4,290 and 10,910 persons per sqkm)
- Suburban (between 202 and 4,290 persons per sqkm)
- Rural (between 0 and 202 persons per sqkm)

The brackets contain the geotype's definition in terms of 2011 population density. This is calibrated from an earlier economic study conducted for Qualcomm in 2011. We have data on the area size of each of the 5 geotypes for London and the subscriber density associated with them from this previous study. By ordering individual unit squares for London from our gridded map in order of descending population density, we are able to define the upper and lower population density bounds for each geotype. These definitions are then applied to the whole of the UK to find the total areas of each geotype. The geotypes are then assigned subscriber densities in line with the earlier Qualcomm study.

The amount of spectrum needed for the FSS ES is then determined and hence the quantum available for IMT in each of the coordination areas for macro cells and small cells. The effective amount of spectrum can then be computed for the areas belonging to the 5 geotypes within these coordination areas. The effective amount of spectrum available is calculated as the average amount in MHz across each geotype in the coordination areas for macro cells and small cells.

B.2 Traffic demand forecast

The short-term mobile traffic projection from Cisco VNI 2014 is extrapolated to 2028 using a best-fit Gompertz curve. Historical mid-year numbers (2012 and 2013) from Ofcom's Infrastructure Report 2013 are used as points of reference. These numbers are roughly half of Cisco's 2012 and 2013 numbers. As a result Cisco's VNI-extrapolated projection is multiplied by a factor of 0.5 in our benefit calculation.

The subscriber distribution is used as the basis on which traffic is allocated across the geotypes and grids.

During the busy hour, the traffic volume transmitted is assumed to be 8%[28] of the total traffic during the day.

[28] http://dspace.mit.edu/bitstream/handle/1721.1/62579/MIT-CSAIL-TR-2011-028.pdf?sequence=1

B.3 Infrastructure and capacity supply

The number of sites per square kilometre for the 5 geotypes is estimated from Ofcom's Sitefinder database, which was most recently updated in May 2012. As a simplification, it is assumed that all sites are macro cell sites, on which up to 12 different spectrum bands can be deployed.

It is assumed that not all macro cell sites that have been built will be suitable for C-Band deployment due to their locations as well as the more limited propagation distance of the C-Band spectrum. The percentage of sites that are suitable for C-Band deployment in each geotype can be found in Appendix C.

The totality of sites erected up until 2014 gives operators an inherent capacity given the amount of spectrum available. Future capacity shortfall, when mobile traffic demand exceeds supply, will be supported by outdoor small cells. However, small cells will only be rolled out when all available bands (including C-band when available) have been deployed on existing macro-cells and there is still capacity shortfall. This means that where possible operators are assumed to prefer adding new bands to macro-cells to installing new small cells straight away. When small cells are rolled out, it is assumed that only bands above 2.6GHz will be used on them.

The total available amount of spectrum for different cell types depends on the cell types (i.e. macro and small) in the coordination areas. Outside of these zones, all spectrum is assumed to be available for IMT. The long-term availability of the C-Band for different geotypes in the coordination areas under different sharing criteria is summarised in Table B-1 to Table B-6 below.

A total of 60MHz per small cell is assumed based on discussion with Huawei and other industry stakeholders. This could mean the use of three 20MHz carriers in one band or the use of 3 bands, each supporting one carrier. At present, outdoor microcells support up to 2 bands and up to 1 carrier per band, giving a maximum of 40MHz of spectrum[29]. Given the fact that 3GPP is specifying the aggregation of three component carriers in the downlink in Release 12, this assumption is expected to be a conservative one

The use of C-band or 2.6GHz TDD spectrum for wireless backhaul is assumed to only be made for outdoor small cells. We assume that microwave and fixed connections continue to be used for traffic backhaul on macro cell sites.

The use of in-band backhaul for small cells means that not all of the spectrum available in the C-Band can be used for radio access – i.e. to serve mobile users' traffic. To ensure that backhaul capacity is guaranteed for small cells, half of all available spectrum for IMT in the C-Band is assumed to be reserved for backhaul.

[29] http://www.thedasforum.org/wp-content/uploads/2013/02/DAS-And-Small-Cell-Technologies-Distinguished-2_4_13.pdf

Table B-1: Spectrum availability for 3600-3800 MHz under ITU-R criteria frequency sharing scenario

Geotype	3600-3800 MHz availability (MHz) in Macro cell coordination areas[30]	3600-3800 MHz availability (MHz) in Small cell coordination areas
Hot spot	165	200
Dense urban	167	200
Urban	174	186
Suburban	177	172
Rural	168	185

Table B-2: Spectrum availability for 3800-4200 MHz under ITU-R criteria frequency sharing scenario

Geotype	3800-4200 MHz availability (MHz) In Macro cell coordination areas	3800-4200 MHz availability (MHz) In Small cell coordination areas
Hot spot	0	126
Dense urban	8	126
Urban	88	165
Suburban	130	170
Rural	149	215

Table B-3: Spectrum availability for 3600-3800 MHz under link performance aware frequency sharing scenario

Geotype	3600-3800 MHz availability (MHz) In Macro cell coordination areas	3600-3800 MHz availability (MHz) In Small cell coordination areas
Hot spot	185	200
Dense urban	185	200
Urban	184	200
Suburban	177	156
Rural	175	186

[30] The coordination zones are superimposed on maps with set geotypes. Each coordination zone may straddle across affects a different distribution of geotypes: this implies each geotype has a different amount of spectrum that is available for use. We then calculate an average amount of spectrum per unit area for each geotype by sharing scenario. This applies to both 3600-3800MHz and 3800-4200MHz ranges.

Table B-4: Spectrum availability for 3800-4200 MHz under link performance aware frequency sharing scenario

Geotype	3800-4200 MHz availability (MHz) In Macro cell coordination areas	3800-4200 MHz availability (MHz) In Small cell coordination areas
Hot spot	14	400
Dense urban	15	400
Urban	78	214
Suburban	133	130
Rural	183	186

Table B-5: Spectrum availability for 3600-3800 MHz under advanced frequency sharing scenario

Geotype	3600-3800 MHz availability (MHz) In Macro cell coordination areas	3600-380 MHz availability (MHz) In Small cell coordination areas
Hot spot	197	200
Dense urban	197	200
Urban	195	200
Suburban	188	192
Rural	190	186

Table B-6: Spectrum availability for 3800-4200 MHz under advanced frequency sharing criteria

Geotype	3800-4200 MHz availability (MHz) In Macro cell coordination areas	3800-4200 MHz availability (MHz) In Small cell coordination areas
Hot spot	233	400
Dense urban	265	400
Urban	269	399
Suburban	240	270
Rural	257	213

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B.4 Infrastructure costing and benefit calculation

A comparison is made of mobile data traffic demand with capacity supply between 2012 and 2027. Where demand exceeds supply, new infrastructure is required, operators will deploy additional bands on existing suitable macro cell sites until these bands are exhausted, at which point they will begin to roll out outdoor small cells to meet traffic demand. Bands that are used on outdoor small cells are

2.6GHz (both TDD and FDD), 3.4-3.6GHz, 3.6-3.8GHz and 3.8-4.2GHz. This determines the total infrastructure requirement under different frequency sharing and spectrum release scenarios

The annualised cost for each site type is calculated based on the CAPEX and OPEX parameters detailed in Appendix C.

The total annualised cost of radio network infrastructure for the different modelling scenarios is computed for each year up to 2027.

A 2018 NPV of the total radio network infrastructure cost is calculated based on a discount rate of 8% for each modelling scenario

The benefit is calculated as the avoided cost – i.e. the reduction in cost that operators can enjoy as a result of having more spectrum compared to a base case. Therefore, the benefit is calculated as the difference in NPV of the total network cost between a modelled scenario and the Base Case. This means that the benefit that accrues to an alternate Case 1 is:

Benefit of Case 1 = Cost NPV of Base Case – Cost NPV of Case 1

The key characteristics of the Base Case and the alternate modelling scenarios are summarised in Table B-7.

Table B-7: Definition of Cases by C-Band release and sharing scenario

Modelling scenario	Release date of 3600-3800 MHz	Release date of 3800-4200 MHz	Frequency sharing criteria
Base Case	2022	After 2028	ITU-R criterion
Alternate Case 1	2018	2022	ITU-R criterion
Alternate Case 2	2018	2022	Link performance aware
Alternate Case 3	2018	2022	Advanced frequency sharing

Appendix C: Economic model assumptions

C.1 Traffic demand assumptions

Table C-1:

Year	Monthly data consumption (PB/month)	Source
2012 2015 2020 2025 2030	17 68 437 1,893 5,963	Plum's projection based on Cisco VNI 2014

C.2 Geotype assumptions

Table C-2:

Parameter	Value used	Source	Comments
Population density threshold for geotype (persons per sqkm) Hotspot Dense urban Urban Suburban Rural	 13,910 10,910 4290 202 0	Plum's calibration based on 2011 UK census and data from Qualcomm for London in 2011	
Average subscriber density for geotype (subscribers per sqkm) Hotspot Dense urban Urban Suburban Rural	 300,000 50,000 16,000 1,200 30	Plum's calibration based on 2011 UK census and data from Qualcomm for London in 2011	
Area size by geotype ('000 sqkm) Hotspot Dense urban Urban Suburban Rural	 0.06 0.10 2.34 34.64 205.97	Plum's calibration based on 2011 UK census and data from Qualcomm for London in 2011	

C.3 Demographic and market assumptions

Table C-3:

Parameter	Value used	Source	Comments
Population growth rate	2%	Plum's estimate based on UN data	
Number of operators	4	Ofcom	Based on the present number of operators in the market that have launched service

C.4 Network assumptions

Table C-4:

Parameter	Value used	Source	Comments
Percentage of traffic in busy hour	8%	Estimated based on traffic profile graphic for the UK in Heikkinen and Berger[31]	
Percentage of traffic in the downlink			
2013	86%	Plum 2011 study for Ericsson and Qualcomm	
2015	89%		
2020	90%		
2025	90%		
2030	90%		
Percentage of network capacity that is usable accounting for mismatch of supply and demand in some locations	80%	Plum's estimate	
Average total sites[32] per sqkm for each geotype in 2012:			
Hotspot	85	Plum's estimate based on OFCOM's Sitefinder database and 2011 data from Qualcomm	
Dense urban	20		
Urban	6		
Suburban	0.6		
Rural	0.1		
Sectors per BTS by cell type			
macro cell	3		
outdoor small cell	1		

[31] http://dspace.mit.edu/bitstream/handle/1721.1/62579/MIT-CSAIL-TR-2011-028.pdf?sequence=1

[32] A site that is shared by multiple operators is counted as multiple sites.

Parameter	Value used	Source	Comments
Number of bands that can be supported by cell type macro cell outdoor small cell	 multiple multiple	Cost models in the public domain including WIK, a paper published by DAS Forum and Huawei[33]	
Number of carrier per band by cell type macro cell outdoor small cell	 multiple up to 3	Cost models in the public domain including WIK and a paper published by DAS Forum and Huawei[34]	
Spectrum efficiency[35](bps/Hz/cell) 2013 2030	 0.45 1.6	Plum's estimate based on vendors' view	
Average target user speed (Mbps) 2013 2030	 1 Mbps 18 Mbps	Plum's estimate based on discussion with vendors	These throughput rates are assumed to ensure there is reasonable growth in expected speed over the modelling period. The model then channelizes to the total available bandwidth at these throughput rates (using the assumed GoS), whereas under real operating conditions data packets are multiplexed statistically.
Required Grade of Service (maximum blocking rate for data transmission)	1%	Plum's estimates based on international benchmarks	
TDD downlink-to-uplink subframe ratio	3:1	Huawei	
Percentage of macro cells that are suitable for C-band deployment by geotype Hotspot Dense urban Urban Suburban Rural	 60% 40% 40% 20% 0%	Plum's estimates	

C.5 Infrastructure cost assumptions

Table C-5 below shows the values that have been used in the models for the input variables relating to infrastructure cost.

[33] http://www.thedasforum.org/wp-content/uploads/2013/02/DAS-And-Small-Cell-Technologies-Distinguished-2_4_13.pdf

[34] http://www.thedasforum.org/wp-content/uploads/2013/02/DAS-And-Small-Cell-Technologies-Distinguished-2_4_13.pdf

[35] This refers to the average spectral efficiency across a cell taking into consideration site loading.

Table C-5:

Network cost type	Value used	Source	Comments
Discount rate (commercial discount rate)	8%	Ofcom	
CAPEX per band for macro cell - cost of each set of antennas and RF (GBP '000)	10	Estimates from NSN[36]	These are costs for macro cell sites.
Base station CAPEX for macro cell (GBP '000)	20		
Site establishment cost for macro cell (GBP '000)		Estimates from NSN[37]	
Civil works	60		
Installation and commissioning	8		
Backhaul for macro cell		Analysys Mason, Plum's estimates based on conversations with vendors	
Urban (fibre-based product)	15		
Suburban/rural (microwave)	13		
CAPEX for integrated outdoor small cell unit ('000)	6	Plum's estimate based on Huawei's numbers	
OPEX as % of CAPEX		Analysys Mason, Plum's estimates based on conversations with vendors	These are both for macro cells and outdoor small cells
Non-backhaul	5%		
Backhaul			
Urban	30%		
Suburban/rural	15%		
Site rental per year (GBP '000)		Plum's estimate	
Urban	20		
Suburban/rural	4		

[36] These numbers are cross-checked with figures published by Analysys Mason in Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting, Analysys Mason, Aegis Systems, 2013: http://stakeholders.ofcom.org.uk/binaries/consultations/aip13/annexes/report.pdf.

[37] Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting, Analysys Mason, Aegis Systems, 2013: http://stakeholders.ofcom.org.uk/binaries/consultations/aip13/annexes/report.pdf.

C.6 Spectrum assumptions

Table C-6 shows the total amount of downlink spectrum assumed to be available and in use in the different bands for the entire market (MHz) outside of the coordination areas that are the output of the technical studies.

Table C-6:

Band	2014	2016	2018	2020	2022	2024	2026	2028	2030
700MHz	0	0	0	45	45	45	45	45	45
800MHz	20	20	30	30	30	30	30	30	30
900MHz	17	22	26	30	30	30	30	30	30
1.4GHz	0	40	50	50	52	56	60[38]	60	60
1.8GHz	13	26	38	50	60	70	75	75	75
2.1GHz	60	60	60	60	60	60	60	60	60
2.3GHz TDD	0	30	30	30	40	40	40	40	40
2.6GHz TDD	0	38	38	38	38	38	38	38	38
2.6GHz	47	70	70	70	70	70	70	70	70
3.4-3.6GHz TDD	30	143	143	143	143	143	143	143	143
3.6-3.8GHz TDD	0	0	0	0	150	150	150	150	150
3.8-4.2GHz TDD	0	0	0	0	0	0	0	300	300

The following points should be noted:

- For all TDD spectrum bands, it is assumed that 3/4 of all the timeslots are used for downlink transmission in order to support a downlink to uplink ratio of 3:1. Therefore, for simplicity, we assume that a bandwidth equivalent to 3/4 of the total bandwidth is used for downlink transmission.
- Linear interpolation is used to estimate the bandwidth in the years between 2012, 2015, 2020, 2025 and 2030. This gives rise to bandwidth sizes that are rounded to the nearest whole rather than the nearest 10.
- In the case of 2.3GHz, it is assumed that only 40MHz of spectrum will be released in 2015 and no additional spectrum will be released until 2022. In 2022, 20MHz of additional spectrum is assumed to be released on a shared basis. Because this bandwidth does not cover the entire population and is not available 100% of the time, the effective bandwidth released is only

[38] There are proposals for an extension of the SDL band by 20MHz on both sides of the existing 40MHz bandwidth according to Qualcomm. However, only the lower extension has been supported by the CEPT going into WRC, while the upper extension is subject to further studies. Therefore, we conservatively assume that in total there will only be 60MHz in the time period we are considering.

12.8MHz (assuming 100% population coverage). Therefore, from 2022, the equivalent downlink bandwidth for the band rises to 40MHz.

Notes

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