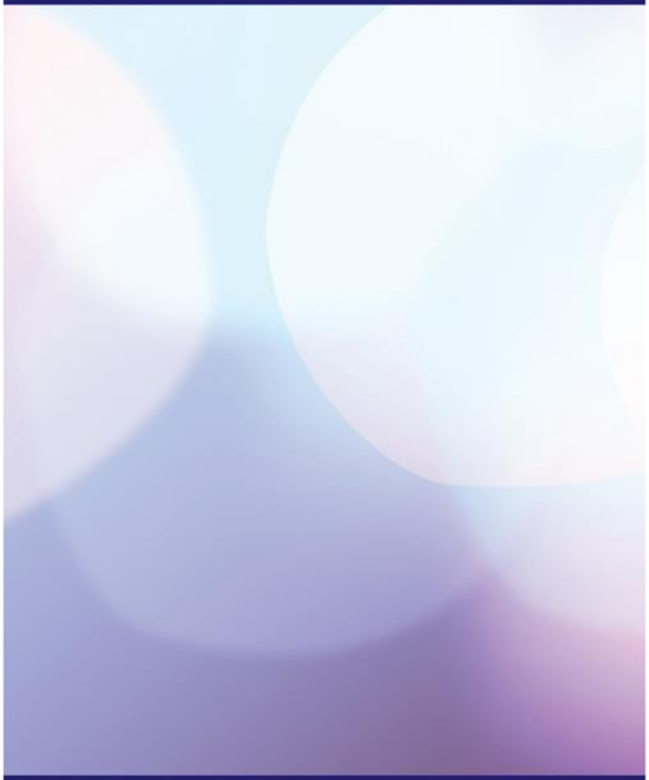

Final report for Ofcom

Assessment of the benefits of a change of use of the 700MHz band to mobile

27 October 2014

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1 Executive summary

Ofcom is currently assessing the case for internationally harmonised change of use of the 700MHz band (expected to be 694–790MHz) in line with the objectives laid out in its November 2012 UHF strategy statement.

Analysys Mason has been commissioned by Ofcom to carry out a study to quantify the benefits to society associated with a change of use of the 700MHz band for mobile broadband use.

The benefits assessed are firstly mobile network cost savings and secondly improvements in mobile coverage, capacity and/or performance. The high-level approach followed in this study is to make a comparison between worlds with and without a 700MHz change of use. In this context we have assessed the benefits to both operators and consumers of changing the use of the spectrum using a number of quantitative and qualitative methods.

The assessment of mobile network cost savings is combined with three other approaches to assess the benefits of a 700MHz allocation to mobile. Precise quantification of additional benefits beyond the network cost savings is difficult, but together these three further approaches allow us to identify likely boundaries to the range of additional benefits that allocating the 700MHz band to mobile broadband is likely to bring.

The approaches we have used to calculate the benefits of the change of use of the 700MHz band to mobile are summarised in Figure 1.1 below.

Figure 1.1: Summary of approaches to calculating benefits of a 700MHz change of use to mobile [Source: Analysys Mason, 2014]

Approach	Metrics equalised between 'with 700MHz' and 'without 700MHz' scenarios	What is being measured?
Network cost savings	Network capacity	The difference in the cost of the deployment of the necessary infrastructure to provide that capacity
Population coverage	None. This approach measures the average user throughput received at each population point	The cumulative frequency distribution of average user throughput at each population point with and without the 700MHz band
Adjusted technical value	Network capacity and quality of service (measured in terms of average user throughput)	Additional network costs incurred by the operator to both equalise network capacity and provide the same quality of service that a 700MHz allocation would enable using increased network density[1]
Commercial value	None. This approach considers increased willingness to pay by consumers for an improved quality of service	Value to operators (in terms of increased revenue and/or reduced non-network costs) of gaining access to the 700MHz band (e.g. through increased ARPU, reduce churn or reduced subscriber acquisition costs)

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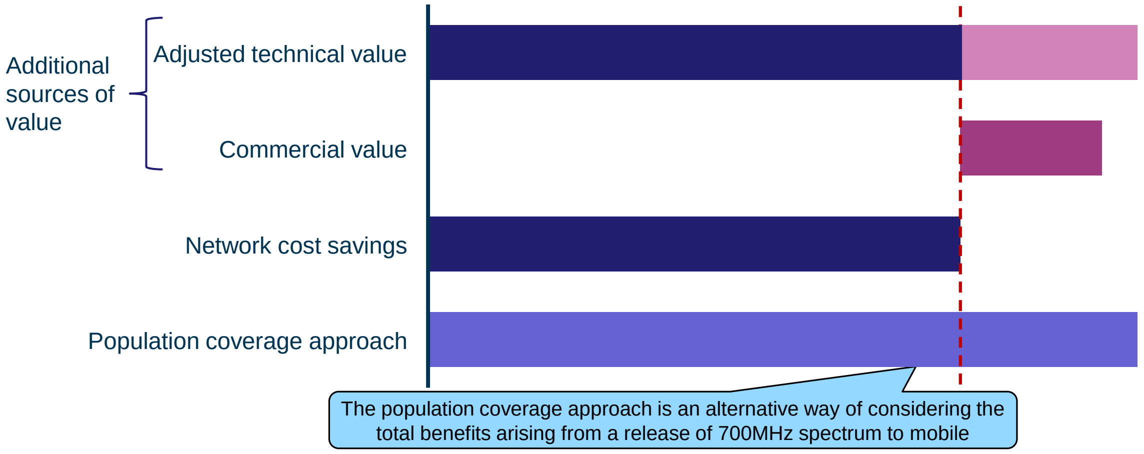
[1] The difference between the adjusted technical value and the network cost savings represents an estimate of the additional benefits of the 700MHz spectrum beyond the network cost savings.

The three methodologies which consider additional benefits are all attempting to quantify the same thing, namely improvements in quality of service, and so should not be considered cumulatively. In addition, it is only the commercial value and the additional benefits component of the adjusted technical value methodologies that can be considered purely additional to the network cost savings, and even then there may be a risk of overestimating the benefit. An illustration of the overlap between the four benefit assessments can be seen in Figure 1.2 below.

Figure 1.2: Illustration of the overlap between approaches for deriving the benefit from the change of use of the 700MHz band [Source: Analysys Mason, 2014]



This report does not consider the potential costs to broadcasters, consumers or other stakeholders from re-allocating spectrum currently used for other purposes such as digital terrestrial television (DTT) and programme-making and special events (PMSE), which we understand are being considered separately by Ofcom.

This document presents the key findings of our study, including an explanation of the methods used to calculate these benefits and the outputs of our calculations. We note that there may be other factors which would account for additional benefits to those reported, such as those outlined in Ofcom's Call for Inputs.[2]

Whilst the exact level of the benefits of a 700MHz allocation to mobile broadband are somewhat uncertain, our analysis has shown that:

- Benefits arising from network cost savings are likely to have a present value (PV) of between GBP195 million and GBP927 million, excluding terminal value and depending on the assumptions made (including assuming that 2×30MHz of spectrum in the 700MHz band is

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[2] *Future use of the 700 MHz band,* see http://stakeholders.ofcom.org.uk/binaries/consultations/700mhz-cfi/summary/UHF_SI_call_for_inputs.pdf

made available for mobile broadband services), with a ‘central range’ (defined below) of between GBP485 million and GBP766 million.[3]

- Additional benefits, excluding terminal value, arising from improved coverage, capacity and performance are less certain, but, based on our adjusted technical value approach, are likely to range between GBP182 million and GBP658 million, with a central range of GBP386 million to GBP484 million, for operators, with further benefits to consumers also possible.[4]

Therefore we would expect substantial benefits to arise from a 700MHz allocation to mobile, which Ofcom will need to weigh up carefully relative to the transition costs and opportunity costs of such an allocation to current spectrum users and consumers.

Below we set out in turn the details of our calculations of the network cost savings and of the additional benefits arising from a 700MHz allocation to mobile broadband.

1.1 Network cost savings

To quantify the network cost savings we have developed a consolidated model. This is based on the structure of the Analysys Mason model used in the 2013 Analysys Mason and Aegis Systems report on the opportunity cost of the spectrum used by DTT and digital audio broadcasting[5] and makes use of many of the inputs to the Real Wireless model behind its 2012 report for Ofcom, *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–30*.[6] In order to derive certain input parameters for our consolidated network cost saving model we have also made use of an Ofcom model developed to test compliance with the 800MHz (4G) coverage obligation.

The consolidated model calculates the total mobile network traffic and the distribution of traffic across sites and compares this to a calculation of the total capacity per site for a generic operator,[7] as illustrated in Figure 1.3 below. The consolidated model’s calculations of network cost savings are based on an assessment of the number of sites which the generic operator could avoid building if more spectrum (in the 700MHz band) were to be made available for mobile use. The year-on-year network costs are calculated over a 20-year period from 2022[8] in a case with and without a

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[3] If 2×40MHz of spectrum in the 700MHz band were to be used for mobile services we estimate a range of GBP259 million to GBP1236 million, with a ‘central range’ of GBP646 million to GBP1022 million.

[4] Again this is based on 2×30MHz of spectrum being used for mobile. The corresponding ranges assuming a 2×40MHz allocation are GBP243 million to GBP877 million, with a central range of GBP515 million to GBP646 million. Using our commercial value approach a range of GBP76 million to GBP1099 million for 2×30MHz of spectrum has been derived.

[5] *Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting*, see http://stakeholders.ofcom.org.uk/consultations/aip13/

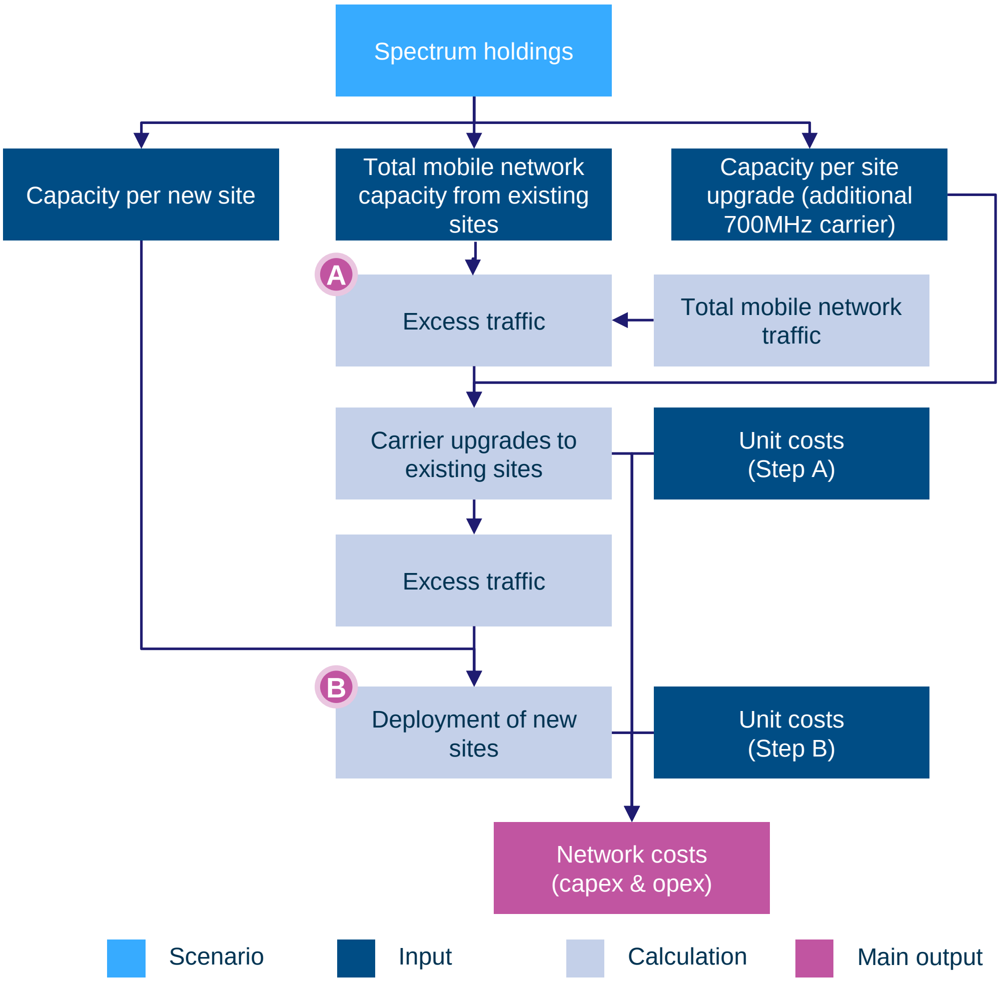
[6] *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–30*, see http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

[7] The generic operator is assumed to have a market share of 25% in the UK, carrying 25% of the traffic and holding roughly 25% of the available spectrum. The generic operator is also assumed to have in place a network of sites roughly comparable to those of actual UK mobile operators. We note that each of the four UK mobile operators have different characteristics to our generic operator and therefore may derive different network cost savings from the 700MHz spectrum.

[8] The model actually runs for 24 years from 2018 but any network cost savings are only realised after the change of use of 700MHz spectrum, which occurs in 2022 in the majority of the scenarios which we have considered.

change of use of 700MHz spectrum, and the PV of these network costs is calculated in each case.[9] The difference in these PVs represents the PV of the network cost savings to the generic mobile operator of holding 700MHz spectrum. As requested by Ofcom, our results are presented excluding any terminal value arising beyond the modelled period. We note that the exclusion of a terminal value does not take account of cost savings which may occur beyond the modelled period and therefore provides results which may not fully illustrate the overall level of network cost savings likely to be achievable by operators.

Figure 1.3: Flow of the network cost saving calculation in the Analysys Mason model [Source: Analysys Mason, 2014]



There are a number of key inputs to the model, which have a material impact on the results. Given the uncertainty over the value of some of these key input parameters, we have developed high and low scenarios, made up of combinations of parameters. Although extreme, these scenarios are not completely unrealistic given the level of uncertainty associated with certain input parameters. These scenarios are described in Figure 1.4, below, with a further description of the input values for each of the key parameters provided in Section 3.2.

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[9] The PV is calculated using the Spackman discounting approach, described in Section 3.2.8, and can include or exclude a terminal value. Unless otherwise stated our results exclude a terminal value.

In addition we have developed two further scenarios which bound a smaller central range of values which we expect to describe the range of network cost savings that would be most likely to develop. These scenarios are also described in Figure 1.4, below as the ‘central range’ high scenario and ‘central range’ low scenario, with the scenarios previously described being referred to as the ‘wide range’ scenarios.

Figure 1.4: Parameter inputs to the high and low scenarios [Source: Analysys Mason, 2014]

Key parameters	**‘Wide range’ high scenario**	**‘Central range’ high scenario**	**‘Central range’ low scenario**	**‘Wide range’ low scenario**
Traffic forecast[10]	High case	High case	Low case	Low case
Offloading	High case	High case	Low case	Low case
Spectral efficiency forecast	Low case	Low case	Mid case	Mid case
Proportion of new sites that are six sector	0%	0%	50% of the sites capable of being upgraded to six sector	50% of the sites capable of being upgraded to six sector
Future spectrum availability	Spectrum Scenario 1 (low)	Spectrum Scenario 2 (mid)	Spectrum Scenario 2 (mid)	Spectrum Scenario 2 (mid)
Unit costs	High case	Mid case	Mid case	Low case
Proportion of shared new build sites	25% new sites	50% new sites	50% new sites	90% new sites
Starting sites	16 000	16 000	17 500	17 500
Traffic distribution across sites	Steeper distribution	Steeper distribution	Steeper distribution	Shallower distribution
Traffic served by sub-1GHz spectrum only	22%	22%	18%	18%

The results of our wide and central range high and low scenarios, with a change of use of the 700MHz band in 2020 and in 2022, are shown in Figure 1.5 on the next page. The values shown represent the network cost savings arising from an allocation of 2×10MHz of 700MHz spectrum to the generic operator.

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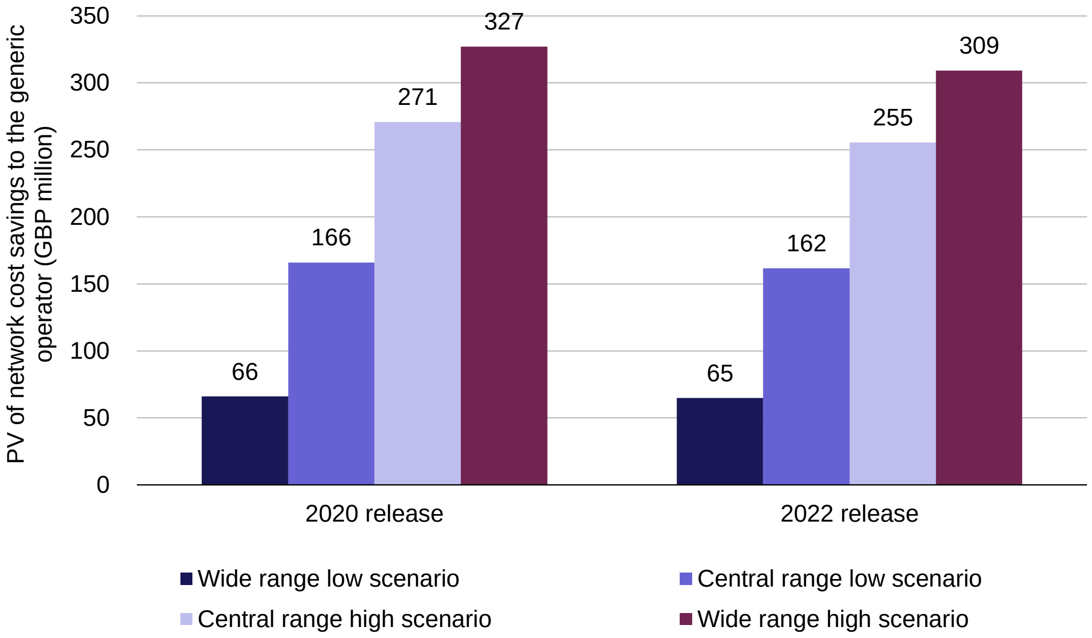
[10] The busy-hour proportion in both the high and low scenario is set at 7.5%.

Figure 1.5: PV of network cost savings of spectrum to the generic operator under a change of spectrum use in 2020 and 2022 [Source: Analysys Mason, 2014]



While the modelling gives the network cost savings to the generic operator associated with a subset of the 700MHz band, this can be scaled up to give the network cost savings achievable through use of the entire band, which is most likely to be either 2×30MHz or 2×40MHz depending on the band plan selected, as shown for a 2022 change of use of the 700MHz band in Figure 1.6.

There are various ways in which this scaling up process can be carried out. We investigate the alternatives in Section 4.2, but for the results below (and elsewhere in this report unless stated otherwise) we scale up from 2×10MHz to 2×30MHz or 2×40MHz using a simple multiplication by 3 or 4 respectively. This approach is designed to reflect 3 or 4 operators, similar to the generic operator we model, each receiving a 2×10MHz allocation of spectrum in the 700MHz band.

Figure 1.6: PV of network cost savings of the 700MHz band 2022 change of use with different band plans, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
‘Wide range’ low scenario	65	195	259
‘Central range’ low scenario	162	485	646
‘Central range’ high scenario	255	766	1022
‘Wide range’ high scenario	309	927	1236

1.2 Additional benefits analysis

There are likely to be additional benefits of a 700MHz mobile allocation, beyond the network cost savings, and these may well be significant. However, the additional benefits are subject to greater uncertainty than the network cost savings. In particular, these benefits are difficult to quantify precisely and our approach is to identify likely boundaries.

We first consider an alternative to the network cost savings calculation we have described above: a *population coverage approach*. This aims to measure population coverage (as defined by a specified average user throughput) with and without 700MHz spectrum. The difference represents the benefit of 700MHz in terms of the increased quality of service provided to consumers. This gives a qualitative understanding of the benefits to consumers of allocating the 700MHz band to mobile broadband.

We then go on to consider two alternative approaches to allow us to elaborate on the form and rough magnitude of the additional benefits introduced above.

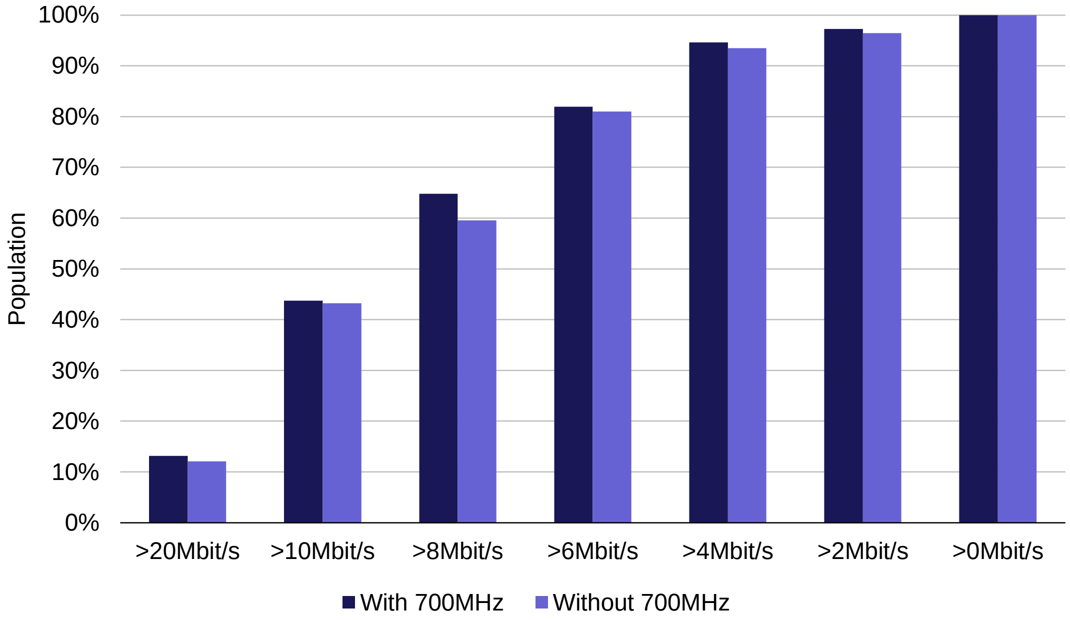
- An *adjusted technical value approach*, which calculates the additional network costs that would be incurred by operators were they to provide the same quality of service that a 700MHz allocation would enable, but without access to the 700MHz spectrum and instead using increased network density.
- A *commercial value approach*, which measures the value to operators, over and above network cost savings, of gaining access to 700MHz spectrum. Availability of this spectrum may make it possible for operators to offer improved quality of service and thus increase average revenue per user (ARPU), reduce churn or reduce subscriber acquisition costs (SAC).

Whilst these two approaches do not provide strict upper or lower bounds on the magnitude of the benefit that allocating the 700MHz band to mobile broadband is likely to bring, they can give us an idea of its magnitude and indicate that it may be significant. In particular, we note that these approaches consider the additional benefits to operators only; it is possible that significant additional benefits to consumers could exist above and beyond the magnitude of benefits which are set out above.

1.2.1 Population coverage approach

For this approach, the Ofcom model used to test compliance with the 800MHz (4G) coverage obligation was used to calculate the proportion of population coverage at different signal to interference plus noise ratio (SINR) levels corresponding to different levels of single user throughput. This calculation was performed both with and without 700MHz spectrum. The results, and the differences between them, are illustrated in Figure 1.7 below.

Figure 1.7: Illustration of the effects of 700MHz on achievable throughput [Source: Analysys Mason, 2014]



We believe that the population coverage approach gives a good qualitative understanding of the benefits to consumers of the allocation of 700MHz spectrum to mobile broadband. The diagram above shows, for example, that the proportion of the population covered with a throughput of over 8Mbit/s increases by over 5 percentage points (pp), from 59.6% to 64.8% with use of 700MHz for mobile.

1.2.2 Adjusted technical value approach

We have calculated the adjusted technical value of the 700MHz band by reducing the carrier capacity in our consolidated model after the 700MHz change of use date by a factor of 12%. The factor of 12% was identified by analysis of signal levels at different population points with and without 700MHz spectrum[11] and with different levels of network loading; it is a proxy for the increased costs that would be incurred to provide a network performance and coverage equivalent to that possible using 700MHz spectrum if that spectrum were not available. This approach reflects not only the provision of network capacity by the operator without 700MHz, but also the densification of infrastructure in order to provide an improved quality of service equal to that available with access to the 700MHz band.

This adjusted technical value methodology has been applied to the high and low scenarios from our consolidated model of network cost savings for the generic operator with 2×10MHz of 700MHz spectrum and an assumed 2022 change of use of the spectrum to mobile. This results in mark-ups of 63% and 94% to the network cost saving results, as shown in Figure 1.8 below.

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[11] In the 'without 700MHz' case we consider a network with a greater number of sites than in the 'with 700MHz' case. This is to ensure that the benefits calculated by this method are additional to the network cost savings and that there is no double counting. The reasons for this are described in more detail in Section 3.3.2.

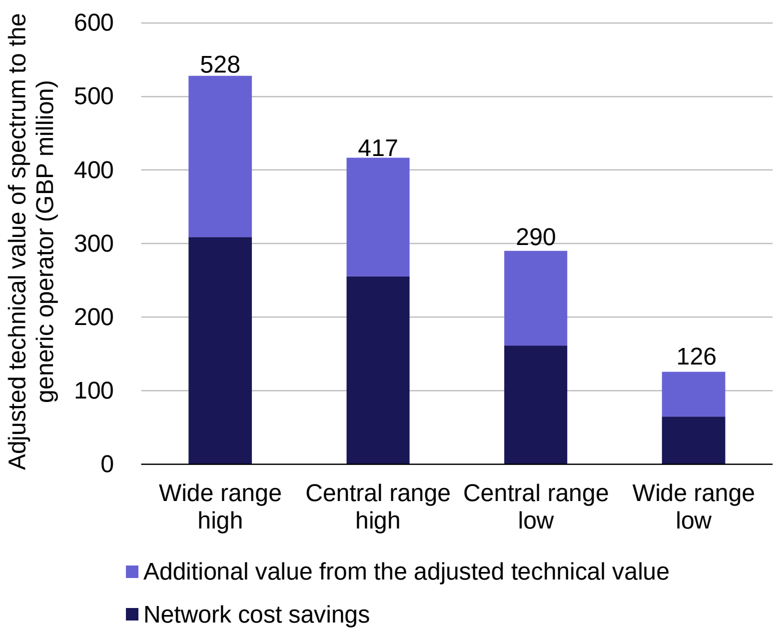

Figure 1.8: Adjusted technical value of spectrum to the generic operator under a change of spectrum use in 2022 [Source: Analysys Mason, 2014]

The adjusted technical value results for the generic operator can be scaled up to give the overall value for band plans of 2×30MHz and 2×40MHz, as for the network cost savings. The adjusted technical values shown in Figure 1.8 above include both the network cost savings and the additional benefits of improved coverage, capacity and performance. In order to estimate only the additional benefits, the network cost savings, as shown in Section 1.1, can be stripped out, giving values for the different band plans as shown in Figure 1.9 below.

Figure 1.9: Additional benefits of the 700MHz band with different band plans, as calculated by the adjusted technical value approach, GBP million [Source: Analysys Mason, 2014]

	Additional benefits of 2×10MHz of 700MHz to the generic operator	**Additional benefits of a 2×30MHz allocation of 700MHz**	**Additional benefits of a 2×40MHz allocation of 700MHz**
‘Wide range’ low scenario	61	182	243
‘Central range’ low scenario	129	386	515
‘Central range’ high scenario	161	484	646
‘Wide range’ high scenario	219	658	877

1.2.3 Commercial value approach

The population coverage approach examines the level of service improvement experienced by consumers in aggregate as a result of allocating 700MHz spectrum to mobile services. As described in the section above on the adjusted technical value, even after new sites are built to account for a capacity shortfall resulting from not having access to the 700MHz spectrum, some level of improved service is still likely to be achieved with 700MHz spectrum. Providing such an improved service should allow operators to generate some amount of commercial value, typically defined as comprising the net present value (NPV) of future increases in revenue or reductions in non-network costs resulting from additional spectrum, in this case the 700MHz band. We note that this commercial value may not exceed the cost of additional network infra-structure deployment in the case where spectrum in the 700MHz band is not available

It would be difficult to precisely calculate this commercial value. Instead, the commercial value assessment attempts to quantify the approximate magnitude of the upside that could be generated for mobile operators. This value may arise through any combination of an increase in ARPU, reduced churn, reduced subscriber acquisition/retention costs, or an increase in service penetration.[12]

We have developed a high-level calculation of the commercial value for our modelled generic operator. It is relatively straightforward to establish the NPV of benefits which would arise from given increases in ARPU or subscriber numbers, or reductions in non-network costs. However, it is much harder to establish the exact level of, for example, increases in ARPU which would arise from providing improved coverage, capacity or performance.

We have therefore tested the magnitude of this NPV of benefits for ranges of improvements in these key performance indicators which are likely to be reasonable. Given the uncertainty regarding the precise impact of QoS improvements on the drivers of commercial value the results should be considered as an indicator of the likely magnitude of the operator upside, rather than a detailed projection.

The commercial value approach estimates a range for the likely lower bound for the additional benefits of improved coverage, capacity and performance resulting from a 700MHz allocation to mobile. The range calculated is likely to be a lower bound because only the benefits to operators are captured and not any additional consumer surplus.[13]

Our analysis found that the commercial value would vary significantly depending on how the mobile market evolves, as well as how consumers respond to the improved services that 700MHz could enable. Figure 1.10 below shows the extreme ranges of the commercial value to the generic operator, that could be possible with a 2022 change of use of the spectrum to mobile, and the key assumptions which drive these outputs. The central case represents the likely response to the availability of 700MHz for mobile broadband services, but we have modelled high and low cases to represent the edges of the range we expect to be possible. The fact that this range is so wide reflects the relative uncertainty in our estimations. Moreover, exactly where in the range the value falls would likely depend on many factors.

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[12] For individual operators valuing spectrum licences, value may also arise due to expectations of increases in market share, but in this analysis we consider only expansional rather than distributional effects (i.e. those effects which increase the value of the mobile market – making the pie bigger – rather than those which merely redistribute the value between operators).

[13] In addition the assessment does not consider any strategic component of commercial value that individual operators may ascribe to 700MHz spectrum, for instance due to expectations of increases in market share due to disadvantaging other operators).

Scenario	Upper case	Central case	Lower case
Commercial value – change of use in 2022 (GBP million)	366	119	25
ARPU	50p premium eroded over five years	25p premium eroded over five years	25p premium eroded over three years
Churn	Drops to 5% and returns to 10% baseline over five years	Drops to 7.5% and returns to 10% baseline over five years	Drops to 7.5% and returns to 10% baseline over three years
SAC	Rise with inflation	Rise with inflation	Rise with inflation

Figure 1.10: Range of possible commercial value to generic operator of allocating 700MHz to mobile broadband [Source: Analysys Mason, 2014]

In general, we expect that the adjusted technical value would provide a higher estimate of the benefit to operators than the commercial value approach. This is because it reflects the costs of the provision of a quality of service which operators may not consider to be profitable to provide. In other words, the costs of providing the improved service, which the adjusted technical value measures, may exceed the commercial value which can be derived from providing it. Therefore, scenarios in which the commercial value exceeds the adjusted technical value are considered less likely.

1.2.4 Summary of additional benefits

The quantitative estimates of additional benefits to operators from the change of use of the full 700MHz band in 2022 as calculated by the adjusted technical value and commercial value approaches are summarised in Figure 1.11 below. We note that these two methods are different approaches to calculating the same additional benefits. They should therefore be considered as alternative estimates of the additional benefits and not added together.

These approaches collectively indicate that substantial additional benefits are likely to arise for operators, resulting from improved coverage, capacity and performance of allocating the 700MHz band to mobile broadband, but that the precise value of these benefits may lie within a very wide range. For the adjusted technical value approach we also provide results from within our narrower central range.[14]

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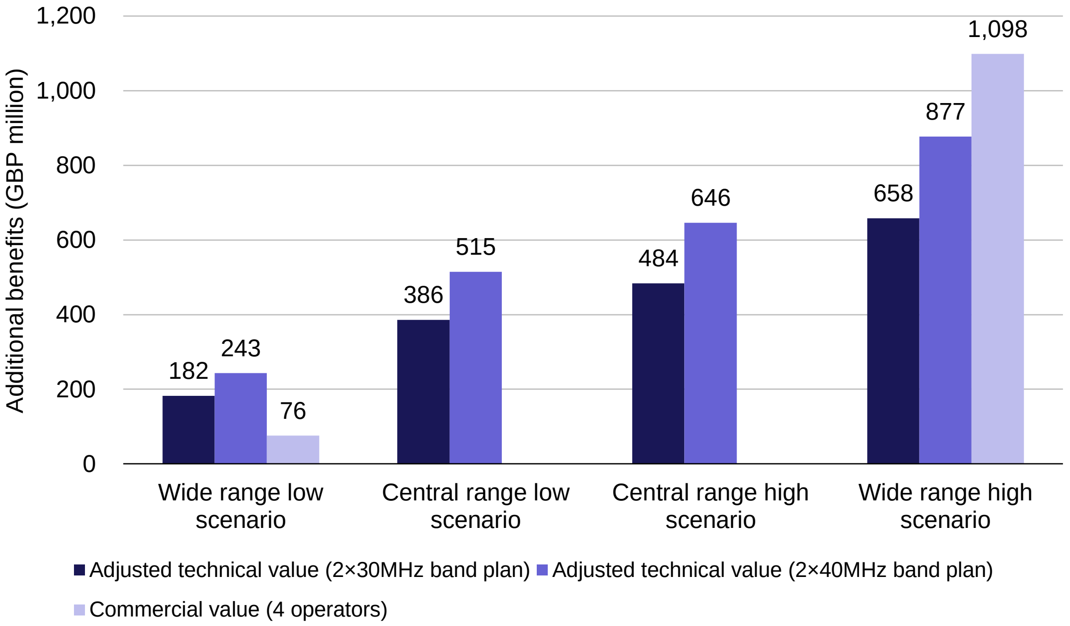
[14] We do not calculate a central range of results using the commercial value approach, on which we generally place less emphasis.

Figure 1.11: Illustration of the additional benefits originating from a 2022 change of use of the 700MHz band, under high and low, central and wide range, scenarios [Source: Analysys Mason, 2014]



2 Introduction

Ofcom is currently assessing the case for internationally harmonised change of use of the 700MHz band (expected to be 694–790MHz) in line with the objectives laid out in its November 2012 UHF strategy statement, specifically:

- enabling the release of additional low-frequency spectrum for mobile broadband use, to help meet the rapidly increasing demand for mobile data capacity
- securing the ongoing delivery of the benefits provided by digital terrestrial television (DTT).

The April 2013 Call for Inputs, regarding the potential decision to change the use of the 700MHz band to mobile, identified a number of potential benefits of such a move, including:

- meeting demand for mobile data services
- improved indoor and rural coverage.

The purpose of this study is to quantify the benefits associated with change of use of the 700MHz band. These benefits are likely to result firstly from mobile network cost savings and secondly from improvements in mobile coverage, capacity and/or performance. The high-level approach followed in this study is to make a comparison between worlds with and without a change of use of the 700MHz band, recognising that there is likely to be a trade-off between the cost savings and improvements in coverage, capacity and/or performance that can be achieved.

- Our work takes as inputs three existing models created by or for Ofcom, namely:

- a model of the opportunity cost of broadcast spectrum, including the 700MHz band (built by Analysys Mason)
- a model of techniques for increasing the capacity of wireless broadband networks (built by Real Wireless)
- a model to carry out an assessment of compliance with the 800MHz (4G) coverage obligation (built by Ofcom).

This report does not consider the potential costs to broadcasters, consumers or other stakeholders of re-allocating spectrum currently used for other purposes such as DTT and PMSE.

The remainder of this document is laid out as follows:

- Section 3 describes the methodology used for each of the approaches followed in this study to calculate the benefits of a 700MHz allocation to mobile broadband
- Section 4 presents the outputs of the mobile network cost savings calculation
- Section 5 sets out the likely magnitude of any additional benefits associated with improved coverage, capacity and performance of mobile networks as a result of access to 700MHz spectrum

- Section 6 draws together the results of the different approaches followed to provide a range of values for the likely cost savings and benefits of a 700MHz band allocation to mobile.

The report includes a number of annexes containing supplementary material relating to the three models, which this study uses as inputs:

- Annex A provides an overview of the models previously developed by and for Ofcom, which have been used as an input to this study
- Annex B describes how those models differ in terms of their key inputs and algorithms
- Annex C contains an analysis of the differences in results from the models.

3 Methodology

3.1 Introduction

As stated in Section 2, the analysis in this study falls into two main areas:

- an analysis of the network cost savings achievable by mobile operators as a result of having access to 700MHz spectrum
- an analysis of the additional benefits which can be derived from improved coverage, capacity and/or performance on mobile networks as a result of having access to 700MHz spectrum.

In summary, the assessment of mobile network cost savings is combined with three other approaches to assess the benefits of a 700MHz allocation to mobile. Precise quantification of additional benefits beyond the network cost savings is difficult, but together these three further approaches allow us to identify likely boundaries to the range of additional benefits that allocating the 700MHz band to mobile broadband is likely to bring.

The approaches we have used to calculate the benefits of the change of use of the 700MHz band to mobile are summarised in Figure 3.1 below.

Figure 3.1: Summary of approaches to calculating benefits of a 700MHz change of use to mobile [Source: Analysys Mason, 2014]

Approach	Metrics equalised between ‘with 700MHz’ and ‘without 700MHz’ scenarios	What is being measured?
Network cost savings	Network capacity	The difference in the cost of the deployment of the necessary infrastructure to provide that capacity
Population coverage	None. This approach measures the average user throughput received at each population point	The cumulative frequency distribution of average user throughput at each population point with and without the 700MHz band
Adjusted technical value	Network capacity and quality of service (measured in terms of average user throughput)	Additional network costs incurred by the operator to both equalise network capacity and provide the same quality of service that a 700MHz allocation would enable using increased network density[15]
Commercial value	None. This approach considers increased willingness to pay by consumers for an improved quality of service	Value to operators (in terms of increased revenue and/or reduced non-network costs) of gaining access to the 700MHz band (e.g. through increased ARPU, reduce churn or reduced subscriber acquisition costs)

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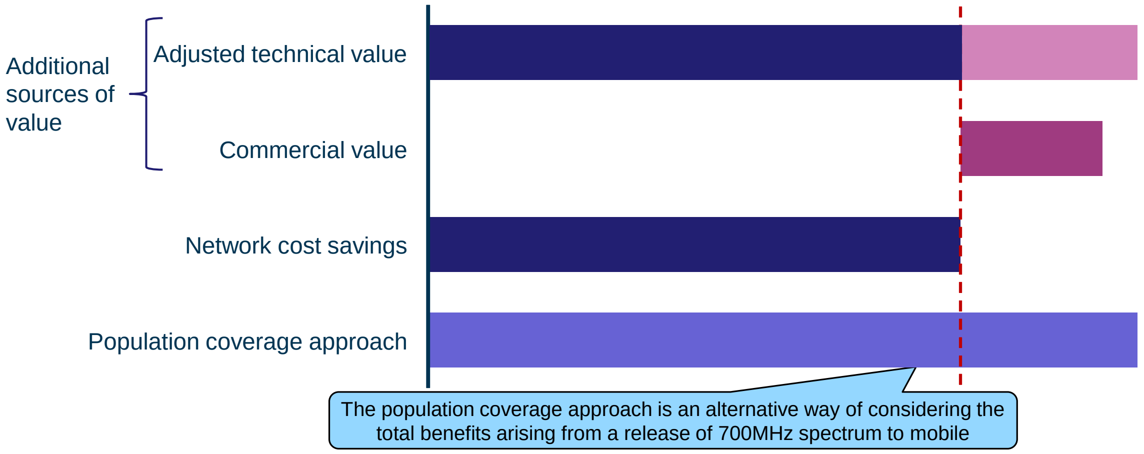
[15] The difference between the adjusted technical value and the network cost savings represents an estimate of the additional benefits of the 700MHz spectrum beyond the network cost savings.

The three methodologies which consider additional benefits are all attempting to quantify the same thing and so should not be considered cumulatively. In addition, it is only the adjusted technical value and commercial value methodologies that can be considered purely additional to the network cost savings, and even then there may be a risk of overestimating the benefit. An illustration of the overlap between the four benefit assessments can be seen in Figure 3.2 below.

Figure 3.2: Illustration of the overlap between approaches for deriving the benefit from the change of use of the 700MHz band [Source: Analysys Mason, 2014]



The population coverage approach is an alternative way of considering the total benefits arising from a release of 700MHz spectrum to mobile

The remainder of this section describes the approaches we have followed in order to analyse both the network cost savings and the additional benefits.

Network cost savings

To quantify the network cost savings we have developed a consolidated model. This is based on the structure of the Analysys Mason model used in the 2013 Analysys Mason and Aegis Systems report on the opportunity cost of the spectrum used by DTT and digital audio broadcasting[16] and also makes use of many of the inputs to the Real Wireless model behind its 2012 report for Ofcom, *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–30*.[17] In order to derive certain input parameters for our consolidated network cost saving model we have also made use of the Ofcom model developed to test compliance with the 800MHz (4G) coverage obligation.

Throughout the remainder of this report we refer to these key reports in the following way:

- the network cost saving model developed for this report is referred to as the *consolidated model*

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[16] *Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting*, see http://stakeholders.ofcom.org.uk/consultations/aip13/

[17] Real Wireless, *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–30*, see http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

- the Analysys Mason model of the opportunity cost of broadcast spectrum is referred to as the *Analysys Mason model*
- the Real Wireless model used for the 2012 Real Wireless report referenced above is referred to as the *Real Wireless model*
- the Ofcom 4G coverage obligation compliance model is referred to as the *Ofcom model*.

At the outset we note that none of the three pre-existing models were constructed precisely for the purpose for which our consolidated model is used. The three models and their original purpose are summarised in Annex A, and details of the key inputs, assumptions and algorithms used are discussed in Annex B.

Details of the approach we have used to develop our consolidated model are set out in Section 3.2. It is recommended that the annexes referenced above are read in conjunction with the description of our consolidated model in this section.

Additional benefits of improved coverage, capacity and performance

There are likely to be additional benefits of a 700MHz mobile allocation, beyond the network cost savings, and these may well be significant. However, the additional benefits are subject to greater uncertainty than the network cost savings. In particular, these benefits are difficult to quantify precisely and our approach is to identify likely boundaries.

We first consider an alternative to the network cost savings calculation we have described above: a *population coverage approach*. This aims to measure population coverage (as defined by a specified average user throughput) with and without 700MHz spectrum. The difference represents the benefit of 700MHz in terms of the increased quality of service provided to consumers. This gives a qualitative understanding of the performance benefits to consumers of allocating the 700MHz band to mobile broadband.

We then go on to consider two alternative approaches to allow us to elaborate on the form and rough magnitude of the additional benefits introduced above.

- An *adjusted technical value approach*, which calculates the additional network costs that would be incurred by operators were they to provide the same quality of service that a 700MHz allocation would enable, but without access to the 700MHz spectrum and instead using increased network density. This approach may form an upper bound to the value to operators of allocating the 700MHz band to mobile broadband, since they may not choose to follow this approach commercially, for example if they are unable to fully monetise the performance improvements to an extent which would cover the incremental deployment costs.. That being said, this approach may understate the overall benefits of 700MHz because the benefits to consumers of improved network performance are not considered.

- A *commercial value approach*, which measures the value to operators, over and above network cost savings, of gaining access to 700MHz spectrum. Availability of this spectrum may make it possible for operators to offer improved quality of service and thus increase average revenue per user (ARPU), reduce churn or reduce subscriber acquisition costs (SAC). This approach forms a lower bound on the additional benefits from a 'consumer + operator' perspective, as it does not capture increases in consumer surplus.

Whilst these two approaches do not provide strict upper or lower bounds on the magnitude of the benefit that allocating the 700MHz band to mobile broadband is likely to bring, they can give us an idea of the magnitude and indicate that it may be significant. In particular, we note that these approaches consider the additional benefits to operators only; it is possible that significant additional benefits to consumers could exist above and beyond the magnitude of benefits which are set out above.

The details of our three approaches to calculating the benefits of improved coverage, capacity and/or performance, including those additional to the network cost savings we calculate separately, are described in Section 3.3.

3.2 Network cost savings model

3.2.1 Introduction to the network cost savings model

Summary of approach

We have based the consolidated network cost saving model around the spectrum requirements of a generic operator, as in the Analysys Mason model of the opportunity cost of broadcast spectrum.

The detailed approach followed in the Analysys Mason model of the opportunity cost of broadcast spectrum, and hence in our consolidated network cost saving model, is described in Annex A and Annex B.

Briefly, the model's calculations of network cost savings are based on an assessment of the number of sites which the modelled generic operator[18] could avoid building if more spectrum (in the 700MHz band) were to be made available to it. The model looks at a 24-year period[19] from the start of 2018, with an optional terminal value included in the assessment of the present value of cost savings to the generic operator. To provide a consistent framework for analysis involving scenarios with different modelling periods, the PV results are reported in 2014 real terms. In line with direction provided by Ofcom, a terminal value is not included in the results presented in this report (unless otherwise specified).

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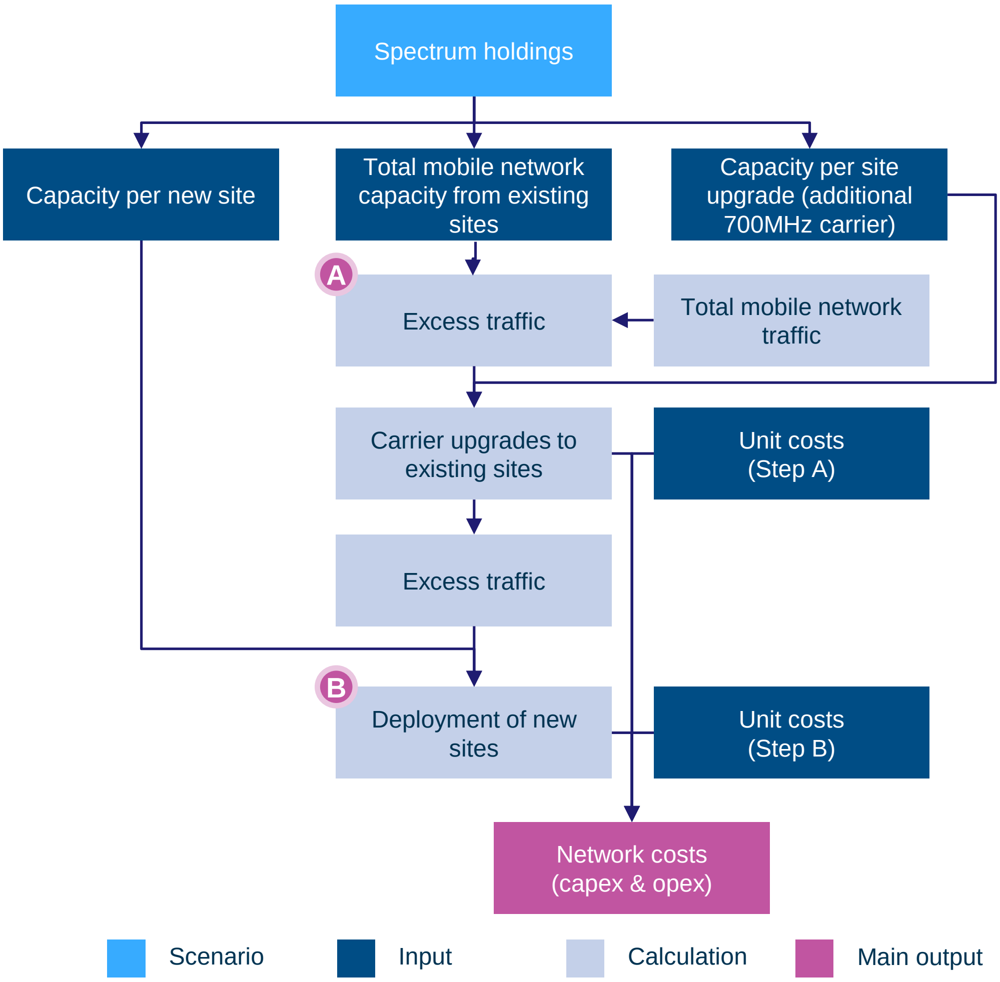
[18] The generic operator is assumed to have a market share of 25% in the UK, carrying 25% of the traffic and holding roughly 25% of the available spectrum. The generic operator is also assumed to have in place a network of sites roughly comparable to those of actual UK mobile operators. We note that each of the four UK mobile operators have different characteristics to our generic operator and therefore may derive different network cost savings from the 700MHz spectrum.

[19] Twenty four years gives a duration of twenty years from 2022, which is one of the main 700MHz change of use dates which we test in our scenarios. This is the same as the duration of initial licence periods for UK mobile operators and is also similar to the length of the modelled period in both the Analysys Mason and Real Wireless models. We therefore consider this to be the most appropriate modelling period.

The consolidated model calculates the total mobile network traffic and the distribution of traffic across sites and compares this to a calculation of the total capacity per site, as illustrated in Figure 3.3 below.

This approach enables a calculation of exactly how many new sites are needed given the generic operator's spectrum portfolio without 700MHz and how many could be avoided given access to different amounts of 700MHz spectrum, at different times. By taking into account the costs of each capacity upgrade option, the year-on-year network costs are calculated in the case with and without a change of use of 700MHz spectrum to mobile, and the present value (PV) of these network costs is calculated in each case. The difference in these PVs represents the technical value, or network cost savings, of the 700MHz spectrum to the generic mobile operator.

Figure 3.3: Flow of the network cost saving calculation in the Analysys Mason model [Source: Analysys Mason, 2014]



To calculate the network infrastructure requirement the model uses an algorithm that can be summarised as follows:

- Calculate how many sites are unable to carry the required amount of traffic using existing capacity

- For any such sites, if any 700MHz spectrum is available, calculate whether adding the available 700MHz carrier will provide sufficient capacity

- For any of these sites where this is not the case, split a site (i.e. build a new site and share traffic equally between the overloaded site and the new site)

- Repeat this calculation each year and apply the relevant unit costs for sites and carriers so as to calculate the incremental network costs.

The value of the 700MHz spectrum therefore arises because it allows for the cheaper site upgrade (Step A in the above diagram) to be applied at a proportion of sites rather than the more expensive new site (Step B), which is the default option in the absence of any 700MHz spectrum being available.

Key inputs

There are a number of key inputs to the model, which include:

- traffic forecasts, offload and busy-hour assumptions
- capacity assumptions (including spectral efficiency, sectorisation, spectrum holdings of the generic operator and device availability)
- unit costs of equipment
- site sharing assumptions and initial site numbers
- the approach to small cells
- the distribution of traffic across sites
- the distribution of traffic within cell areas
- the approach to discounting for the PV calculation and whether a terminal value is included.

These key inputs to the model are discussed in turn in Sections 3.2.1 to 3.2.8 below.

Given the uncertainty over some of the key input parameters, when we come to present results in Section 4 we provide a range of values based on combinations of input parameters which we would expect to provide upper and lower bounds for the likely network cost savings (i.e. a *high scenario* and a *low scenario*). In order to define these high and low scenarios we therefore set *high case* and *low case* parameter values for each individual input parameter and choose an appropriate combination to define our scenarios.

In addition, in Section 4 we report on a sensitivity analysis illustrating the sensitivity of the model to the values chosen for the key input parameters. For the purpose of this sensitivity testing we have created a set of '*mid case*' input parameter values, which lie between the respective high and low cases (i.e. around the centre of what we consider to be the plausible range). Where all input parameters are set to the mid-case values, we have developed a *sensitivity mid case* which forms the basis of our sensitivity testing. This sensitivity mid case does not necessarily represent our view of the most likely level of cost saving, but we consider it informative in helping us report on the sensitivity of the model to different parameter values by testing the change in network cost savings from the sensitivity mid case when individual parameter values are adjusted.

In the sections below we reference the choices of parameter values in terms of the low, mid and high cases.

3.2.2 Demand

Traffic levels and offloading

As in both the Analysys Mason and Real Wireless models, traffic in our consolidated model is built up as the product of forecasts of relevant device numbers in the market and forecasts of data traffic generated per device over the modelled period. The model considers mobile data traffic to be generated on both handsets (specifically smartphones) and mobile broadband devices (such as laptops and tablets).

We have extrapolated the Real Wireless mid-case penetration, traffic per device and offload proportion forecasts from their end point in 2030 out to 2050 using the compound annual growth rate (CAGR) values set out in Annex B.3. We have also carried out a similar extrapolation of the Analysys Mason model's base-case traffic net of offload and developed an explicit offloading forecast based on Analysys Mason Research forecasts of cellular data traffic and Wi-Fi data traffic generated by cellular connected devices.

As in the original Analysys Mason model, a long-run level for the parameters has been set for 2050 and interpolated towards, rather than forecasting using a specific growth rate of traffic in each year. Although there are differences between the current traffic levels and those forecast for 2013 in the original model we do not consider that this should have an impact on the long-run traffic level. However, 2013 actuals suggest that traffic may be slower to reach the level of the long-term forecast and therefore we have adopted a different interpolation curve.

The offload proportions used in the model represent the offload of traffic to Wi-Fi and femtocells. However, femtocells are currently used mainly for voice and messaging offloading and to boost coverage for such services; as such, the total offload of data traffic onto femtocells is very low and the vast majority of our offload forecast relates to Wi-Fi. A summary of these forecasts is shown in Figure 3.4 below.

The pre-offload traffic forecasts are best considered as a whole, rather than focusing on the individual elements of penetration and traffic per device. For example, high traffic may be a result of new services such as machine-to-machine (M2M) taking off, rather than of each member of the population having three smartphones.

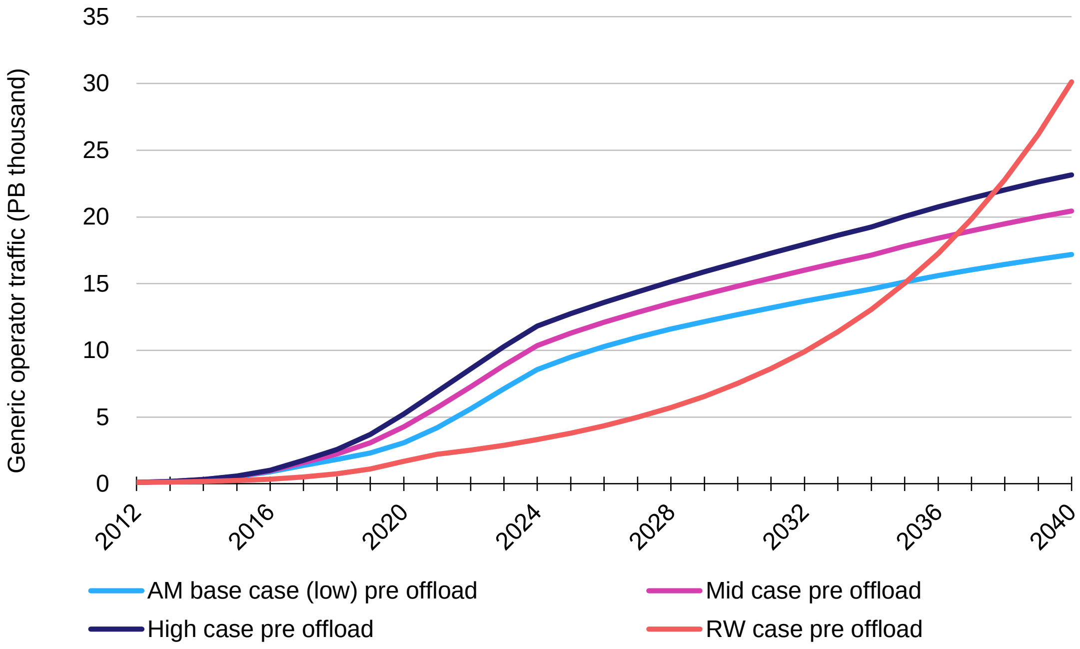
Figure 3.4: Components of the traffic forecasts extrapolated from the Real Wireless and 2013 Analysys Mason models [Source: Analysys Mason, 2014]

	Market device penetration (%)		Traffic per device, pre offload (MB/sub/month)		Offload proportion (%)
	Smartphone	**MBB**	**Smartphone**	**MBB**	
Analysys Mason 2015	66%	13%	4291	34 017	64%
Real Wireless 2015	90%	37%	340	2738	42%
Analysys Mason 2025	98%	24%	20 735	122 497	76%
Real Wireless 2025	190%	187%	935	10 787	46%
Analysys Mason 2035	100%	25%	33 125	166 040	77%
Real Wireless 2035	256%	222%	2020	34 569	51%
Analysys Mason 2040	100%	25%	37 670	178 640	77%
Real Wireless 2040	297%	245%	2967	61 700	53%

As the UK mobile market currently has four competing networks, we have assumed a 25% market share of subscribers for our modelled generic operator, across both handsets and mobile broadband devices.

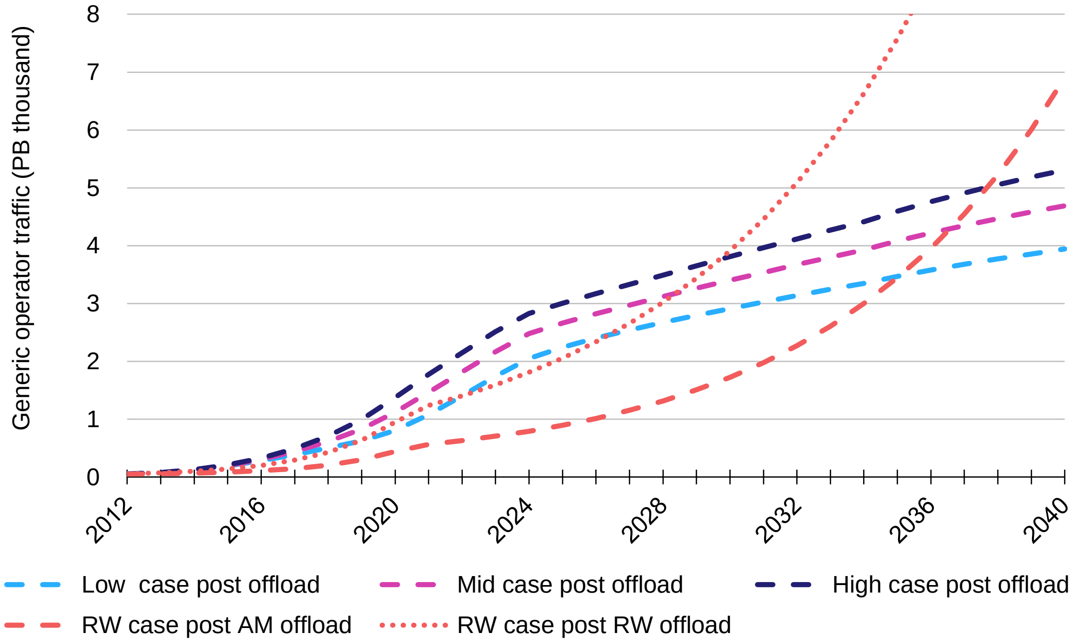
We have used a combination of the Real Wireless model and Analysys Mason model penetration and traffic per device parameter values to produce four gross traffic scenarios to test for the generic operator, as shown in Figure 3.5 on the next page. These traffic scenarios include a case based on the Analysys Mason model assumptions and one based on the Real Wireless assumptions. As we consider the growth in the final years of the Real Wireless model demand forecast, driven by very high penetration forecasts, to be very aggressive, the mid- and high-case gross traffic forecasts for our consolidated model use a weighted average of the Analysys Mason model and Real Wireless model penetration forecasts, combined with Analysys Mason model forecasts of traffic per device. This approach results in traffic forecasts with shapes similar to that extrapolated from the 2013 Analysys Mason model.

Figure 3.5: Modelled traffic forecasts, pre offload [Source: Analysys Mason, 2014]



The consolidated model calculates the most cost-effective way to provide the capacity required to carry the traffic net of offload. The gross traffic forecasts in Figure 3.5 above are combined with offload proportion forecasts to give net traffic curves, as shown in Figure 3.6 below.

Figure 3.6: Modelled traffic forecasts, post offload[20] [Source: Analysys Mason, 2014]



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[20] The extrapolated Real Wireless model traffic forecast post Real Wireless offload illustrated in Figure 3.6 reaches 37 billion TB in 2040.

Figure 3.6 above shows post-offload traffic forecasts for our low, mid and high cases. The figure also shows the post-offload traffic forecast using (extrapolated) pre-offload traffic forecasts from the Real Wireless model combined with either the Real Wireless model offload forecast or the main offload forecast used for the low, mid and high cases in our consolidated model, derived from Analysys Mason Research data.

As can be seen in Figure 3.7 below, the level of gross, pre-offload, traffic growth between 2012 and 2030 is greater than that for traffic net of offload relative to both the Analysys Mason[21] and Real Wireless[22] 2012 traffic figures. For example, the 2030 mid case traffic pre-offload is 146× the Analysys Mason gross traffic in 2012, while the post-offload 2030 traffic is only 65× the Analysys Mason 2012 post-offload traffic. As illustrated in Figure 3.5 and Figure 3.6 above, traffic is forecast to continue to grow past 2030 in all cases; by 2040 the Analysys Mason mid-case is 202× the Analysys Mason 2012 traffic pre-offload and 90× post-offload. Similarly, the Real Wireless case with Real Wireless offload in 2040 is 298× the Analysys Mason 2012 traffic pre-offload and 284× post-offload. This demonstrates a considerable range of uncertainty in the level of growth in demand for mobile data in the coming decades.

Figure 3.7: Increase in traffic volumes between 2012 and 2030 [Source: Analysys Mason, Real Wireless 2014]

	Pre-offload scalar		Post-offload scalar	
	Relative to Analysys Mason 2012 traffic	**Relative to RW (RW offload) 2012 traffic**	**Relative to Analysys Mason 2012 traffic**	**Relative to RW (RW offload) 2012 traffic**
Low case	125	136	56	52
Mid case	146	159	65	61
High case	164	178	73	68
Real Wireless case (AM offload)	74	81	33	31
Real Wireless case (RW offload)	74	81	75[23]	70

The consolidated model includes the facility to sensitivity test the mid-case offload forecast with offload proportions which are 7.5% higher or lower (high- and low-case assumptions).

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[21] The Analysys Mason 2012 number is taken from the broadcast spectrum AIP model, which was constructed in late 2012. We believe these correspond fairly closely to 2012 actuals.

[22] The Real Wireless work which produced the 2012 traffic figures was carried out partway through 2012 and therefore the figures represent a forecast rather than an actual.

[23] The fact that this number is the same as the corresponding pre-offload number implies that the 2030 RW offload parameters are similar to the 2012 Analysys Mason offload parameters (i.e. around 48%).

Busy-hour assumptions

The Real Wireless model dimensions three daily busy hours, two of which peak at 6% of daily traffic, while the Analysys Mason model uses a value of 7.5% of busy-day traffic, in line with Ofcom's revised 2011 Wholesale Call Termination model[24] (which used a value of 8% for voice and messaging traffic and 7.5% for data).

Mobile cost modelling studies for other national regulatory authorities have, in our experience, used values in the range of 6–9% for similar time periods. The consolidated model therefore uses a figure of 7.5% of busy-day traffic in the busy hour. We consider it unlikely that there will be a significant rise from this 7.5% busy-hour traffic level, while in the extreme it is possible that this busy-hour traffic proportion may fall. Therefore we have also tested a proportion of 6% (roughly in line with that used the Real Wireless model), a proportion of 8% (to represent the minor increase in busy hour we believe could be possible in the most extreme circumstances) and a linear glide path from 15% in 2013 to 6% in 2033 (to understand the effect of different levels of peakiness in the diurnal distribution of traffic with an extreme starting point).

The other parameters relevant to determining the busy hour of 250 busy days per year and an 80% proportion of traffic on the busy days have been taken from the Ofcom 2011 mobile LRIC model.

3.2.3 Capacity per site

Capacity per site is driven primarily by spectral efficiency assumptions, the number of sectors per site and the quantity of spectrum available. We consider each of these in turn below.

Spectral efficiency

The spectral efficiency forecast comprises a number of components:

- a forecast for peak spectral efficiency by technology (bps/Hz/sector)
- a forecast of which technologies are used in each band over time
- adjustments to account for real network characteristics and overhead requirements.

We note that the forecast of the spectrum bands available is clearly also important (see Figure 3.12) in determining how spectral efficiency influences overall capacity per site.

We have developed a single spectral efficiency forecast for HSPA technology for the consolidated model, since we expect future innovation be mainly focused on LTE technology. In addition, during much of the model assessment period HSPA is expected to be deployed in a single band only, and therefore the forecast has little impact on the overall resulting network spectral efficiency. We have based our spectral efficiency forecast on previous published Analysys Mason forecasts[25] but extended them for Releases 10, 11 and 12 which are currently being developed and

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[24] See http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

[25] Analysys Mason, *LTE infrastructure: worldwide demand drivers and base station forecast 2012–2017* (2012) and Analysys Mason, *Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting*

deployed.[26] We do not expect significant development in HSPA beyond Release 12 and therefore do not model further improvements beyond this release, expected to be commercially deployed by 2022 (at the beginning of the model assessment period).

Release 10 has a 47% improvement over Release 8 as a result of features such as improved carrier aggregation (four-carrier support), resulting in some level of decrease in transmission overheads[17]. The bulk of Release 11 and Release 12 improvements are expected to be as a result of the introduction of enhancements in carrier aggregation, multiflow, uplink beamforming and improved modulation techniques, as well as heterogeneous networks (HetNets). Nokia Siemens Networks has suggested that these features may deliver a 30% improvement in average uplink data rates.[27] Given that some of these expected gains are attributable to the use of wider bandwidths, we estimate that a forecast improvement of 25% across the two releases would represent a reasonable estimate of the actual improvements realised in HSPA spectral efficiency in these releases, given real-world device mix and other limitations.

We have used HSPA release dates assumed by Real Wireless[28] and extended the trend in preparation for known future releases. Figure 3.8 below summarises the consolidated model HSPA spectral efficiency forecast based on the trends described above, which give a forecast that is also fairly comparable to that published by the FCC[29] with an estimate of 0.72bps/Hz/sector for Release 6 and a range of 1.08–1.29bps/Hz/sector for Release 7.

Figure 3.8: Spectral efficiency forecast for HSPA [Source: Analysys Mason, 2014]

Standard	Spectral efficiency (bits per second per Hz per sector)	Estimated capacity improvement per site	Adoption
HSPA R6	0.55	n/a (this is the reference HSPA site)	2000
HSPA R7, HSPA+	1.11	100% increase over HSPA R6	2005
HSPA R8, dual carrier	1.31	18% increase over HSPA R7	2014
HSPA R9, dual carrier and MIMO	1.5	15% increase over HSPA R9	2016
HSPA R10	1.93	47% improvement over R8	2018
HSPA R11	2.14	25% uplift over R10 split over two releases, based on toned down ‘up to’ uplift values from MIMO, multiflow, 64QAM, 8 carrier	2020
HSPA R12	2.37		2022

(2013), which are broadly in line with Real Wireless, *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–2030*.

[26] See http://www.3gpp.org/Releases

[27] Nokia Siemens Networks, Long Term HSPA Evolution (2011). See http://www.nsn.com/system/files/document/hspa_evolution.pdf

[28] Real Wireless, *The timing of the consumer and operator features available from HSPA and LTE* (2012). See http://www.realwireless.biz/the-timing-of-the-consumer-and-operator-features-available-from-hspa-and-lte-devices/

[29] FCC, ‘The Broadband availability Gap’, *OBI Technical Paper No.1* (2010), Exhibit 4E: HSPA Rel6 = 0.72; HSPA Rel7 = 1.08–1.29. See http://www.broadband.gov/plan/broadband-working-reports-technical-papers.html

Since there is more uncertainty relating to the future development of spectral efficiency in LTE technology, which we envisage will be developed throughout the model period, we have devised two plausible scenarios; one high and one low, as summarised in Figure 3.9.

Figure 3.9: LTE spectral efficiency forecast [Source: Analysys Mason, 2014]

Standard	Spectral efficiency (bits per second per hertz per sector)			Comments	Adoption
	Low	Mid	High		
LTE R8–10	1.57	1.57	1.57	20% uplift on HSPA R8	2012
LTE R11	2.3	2.3	2.3	Nearly 50% uplift on R10, primarily by supporting higher-order MIMO	2015
LTE R12	3.45	3.45	3.45	50% uplift on LTE R11	2017
LTE R13	3.73	3.92	4.01	12% uplift for HetNets, in addition to spectral efficiency gains	2019
LTE R14	3.95	4.32	4.53	25% uplift for HetNets, in addition to spectral efficiency gains which continue to increase on a curve of diminishing gains until 2037 (after which we assume it remains flat)	2021
LTE R15	4.02	4.54	4.85		2023
LTE R16	4.08	4.70	5.10		2025
LTE R17	4.09	4.79	5.27		2027
LTE R18	4.10	4.85	5.40		2029
LTE R19	4.10	4.89	5.49		2031
LTE R20	4.10	4.92	5.56		2033
LTE R21	4.10	4.94	5.60		2035
LTE R22	4.10	4.95	5.64		2037

We have used future release dates for Release 9 and Release 10 as published in *The timing of the consumer and operator features available from HSPA and LTE*' (Real Wireless, 2012) and structured our forecasts around an assumption of new releases every second year for future known releases. This is slightly less often than the 18-month period between releases suggested by Real Wireless,[17] but similar to the timetable described by 3GPP and by 4G Americas[30] (which implies a two-year cycle and a lag of three to four years after standards freeze until the first global release – given that the first deployment may not always be in the UK, a modelled five- to six-year lag is more pragmatic). The numbering of releases beyond Release 12 does not necessarily correspond to our expectation of actual release dates. However, it allows us to structure our forecast of the development of spectral efficiency in a simple manner.

As with HSPA, we have based the initial years of our spectral efficiency forecast for LTE on previously published Analysys Mason forecasts[25] (up to Release 12).

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[30] 4G Americas, *4G Mobile Broadband Evolution Rel10, Rel11 and Beyond* (2012). See http://www.4gamericas.org/documents/4G%20Mobile%20Broadband%20Evolution-Rel%2010%20Rel%2011%20and%20Beyond%20October%202012.pdf

- LTE Releases 8–10: This represents existing deployments of LTE. We have calculated that a typical deployment has spectral efficiency of 1.57bps/Hz/sector by applying a 20% uplift to the spectral efficiency of HSPA Release 8 in line with the uplift of LTE over high-end 3G estimated by Real Wireless.[31] This is also in line with other recent studies.[32]

- LTE Release 11: We assume a further uplift of just under 50% in Release 11 (to be adopted in 2015) for a spectral efficiency of 2.3bps/Hz/sector. This is slightly lower than the 2.4bps/Hz/sector in our previously published forecast. However, it is similar to some upper estimates for LTE-Advanced but takes into account the timing of deployment as well as the possibility of an increase in the deployment of MIMO and other more advanced features over this timescale
  - The China Academy of Telecommunication Research of MIIT, *Spectrum Bandwidth Requirements for IMT services in China by 2020* (2013) suggests 2.2bps/Hz/sector in 2018
  - Real Wireless, *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–2030* (2012) estimated 2.6bps/Hz/sector with deployment growing from around 2014 and peaking in 2019
  - Huawei, *LTE-A and beyond* (2010) estimates that LTE-A has spectral efficiency of 2.3bps/Hz/sector.

- LTE Release 12: Another uplift of 50% is assumed from Release 11 to Release 12, as further advances in higher-order MIMO (e.g. 4×4 and some 8×8), beamforming and coordinated multipoint transmission (CoMP) become more mainstream. This is a similar uplift to that applied in our previous forecast (i.e. the Analysys Mason model) between the equivalent releases for this time period.[25]

Beyond Release 12, however, it is more difficult to forecast gains in spectral efficiency, and high and low sensitivity cases are required. From Release 13 onwards, release-on-release spectral efficiency gains are projected to decrease by either 85% (in the low case) or 70% (in the high case) every two years, in a manner similar to the trend projected by Real Wireless. In the low case this results in slow growth and a plateau in spectral efficiency being reached quickly (by Release 18 in 2029), representing a scenario in which there is little investment in improving spectral efficiency (for instance, in a future scenario where demand does not grow significantly). In the high case the opposite is true, and a plateau is only reached in 2037 where the trend is not projected any further as a result of further uncertainty over the possible limits to spectral efficiency.

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[31] Real Wireless, *4G Capacity Gains* (2011). See http://www. stakeholders.ofcom.org.uk/.../2011/4g/4GCapacityGainsFinalReport.pdf

[32] Ryvasy Research, *Efficient Use of Spectrum* (2011, see www.rysavy.com/Articles/2011_05_Rysavy_Efficient_Use_Spectrum.pdf) and *4G Americas Mobile Broadband Explosion* (2012) estimated typical values of 1.4bps/Hz/sector (see http://www.4gamericas.org/documents/4G%20Americas%20Mobile%20Broadband%20Explosion%20August%2020121.pdf). The China Academy of Telecommunication Research of MIIT, *Spectrum Bandwidth Requirements for IMT services in China by 2020* (2013, see http://www.gsma.com/spectrum/wp-content/uploads/2013/02/Spectrum-Requirement-for-China-2020.pdf).

In addition to these trends an uplift is applied to account for HetNets starting to have a significant impact from Release 13 in 2019, reaching a maximum 25% uplift in spectral efficiency in Release 14 in 2021.

The above trends combine to give a plausible range of improvements of up to 3.6× increased spectral efficiency over 35 years in the high case and 2.6× in the low case. This is more conservative than the 6.2-fold increase by 2030 recently estimated by Real Wireless.[17] Real Wireless spectral efficiency for a three-sector, two-antenna macrocell site reaches 10.2bps/Hz/site after loading, traffic mix and overhead adjustments. This is equivalent to 18.46bps/Hz/site before these adjustments are applied, which is marginally higher than the 16.91bps/Hz/site spectral efficiency of a three-sector, two-antenna site with LTE R22 technology in the high spectral efficiency scenario. The low and mid spectral efficiency scenarios give results for spectral efficiency per site that are not much lower, at 12.30bps/Hz/site and 14.84bps/Hz/site respectively.

As described above we include mid-case parameter values which are halfway between the high and low case, as shown in Figure 3.9.

Figure 3.10 below summarises the assumed deployment of HSPA and LTE between bands. Note that not all bands are allocated to mobile broadband in all spectrum holding scenarios (see Figure 3.12). Broadly speaking, we estimate that any bands allocated to mobile broadband from 2014 onwards will deploy LTE technology. For the remaining bands which are already in operation with HSPA or GSM (900MHz, 1800MHz and 2.1GHz), we assume that GSM and HSPA will continue to be used until 2021, at which point they will convert to LTE, with the exception of the 2.1GHz band which continues to use HSPA throughout the model period, since the equipment roadmap for this band over these timescales is less clear and a “3G switch-off” is likely to still be some time away.

Figure 3.10: Technology by band [Source: Analysys Mason, 2014]

Band	Technology deployed	Available
450–470MHz	LTE in all years	2030
470–694MHz	LTE in all years	2030
700MHz	LTE in all years	2020/2022
800MHz	LTE in all years	2013
900MHz	GSM and HSPA up to 2021 and LTE thereafter	2011*
1.3–1.5GHz	LTE in all years	2030
1452–1492MHz	TD-LTE in all years	2018
1800MHz	Partly GSM up to 2021 and LTE thereafter	2012*
2.1GHz	HSPA in all years	2001
2.1GHz TDD	TD-LTE in all years	2018
2.3GHz TDD	TD-LTE in all years	2016
2.6GHz	LTE in all years	2013
2.6GHz TDD	TD-LTE in all years	2013
2.7–2.9GHz	TD-LTE in all years	2025

Band	Technology deployed	Available
3.5GHz	LTE in all years	2016
3.6–3.8GHz	TD-LTE in all years	2018
3.8–4.2GHz	LTE in all years	2025

Note: * = dates of liberalisation for non-GSM use.

Whilst the above spectral efficiency forecasts are designed to push towards the high and low ends of a plausible range for real-world deployments (considering device mix and other practical limitations in exploiting all features of a release) they need to be adjusted further to account for real-world usage. There are three significant adjustments that we have identified on the basis of work carried out by Real Wireless,[33] Plum Consulting[34] and Analysys Mason:[35]

- **Realistic traffic mix adjustment**: the majority of active users do not continuously stream data at the maximum downlink data rate available to them. This parameter accounts for the mix of traffic ranging from video streaming with a high minimum throughput rate to voice packets with high overhead requirements, and also for the fact that not all users are adjacent to the base station (scale spectral efficiency inputs by 65%)
- **Loading adjustment**: in reality networks are not fully loaded, in order to meet quality-of-service and network stability requirements for users in the cell area who may be distributed unevenly or moving within and between cells. Furthermore, operators usually deploy networks with a certain margin of excess capacity to account for future traffic growth (scale spectral efficiency inputs by 85%)
- **Overheads**: there is a requirement to adjust spectral efficiency to account for the distinction between demand generated by consumers and network-generated demand (i.e. overhead). This overhead demand is required by the network for signalling and control of the network (scale spectral efficiency inputs by 77% for HSPA and by 80% for LTE, which is more efficient).

Sectors per site

In building the consolidated model we have represented the sites deployed as *tri-sector macrocell equivalents*, since this configuration is the most commonly deployed in the UK and the cost per unit capacity across different cell types is broadly similar over the modelling period. This is discussed in Section 3.2.6 with respect to small cells. Differences between small cells and one-,

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[33] Real Wireless, *4G Capacity Gains* (2011) and Real Wireless, *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–2030* (2012). See http://stakeholders.ofcom.org.uk/binaries/research/technology-research/2011/4g/4GCapacityGainsFinalReport.pdf and http://www.ofcom.org.uk/static/uhf/real-wireless-report.pdf respectively.

[34] Plum Consulting, *Valuation of public mobile spectrum at 825–845MHz and 870–890MHz* (2011). See http://www.communications.gov.au/__data/assets/pdf_file/0013/144220/Plum-Consulting-Valuation-of-public-mobile-spectrum-at-825-845-MHz-and-870-890-MHz.pdf

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

two- and tri-sector macrocells are, however, accounted for when calibrating the costs and capacity of the tri-sector macrocell equivalent deployed in the model, and are therefore represented implicitly.

Six-sector sites are considered explicitly in the model, as there is scope for these to have a large effect[36] on network capacity. Where a new site is required to meet demand, the model considers whether it may be more cost effective to install a six-sector site (only incurring equipment costs, such as for new multi-frequency antennas) rather than a new tri-sector site, thus saving on new site acquisition and preparation costs.

The consolidated model takes into account that not all sites are suitable for supporting six-sector sites. In our experience operators have not been particularly enthusiastic about six-sector upgrades, and where they have considered upgrading to six-sector sites there have been severe constraints on the proportion of sites that could feasibly be upgraded. In particular, there are constraints on the suitability of sites for this upgrade, related to space for equipment and other practical concerns. For this reason we have limited the proportion of sites suitable for a six-sector upgrade to 50% of new sites. The model therefore varies the proportion of these ‘suitable’ sites that are upgraded to six sectors. Since there is a degree of uncertainty in the proportion that are actually six sector, our low case is 0% (reflecting the case where six-sector site advantages are outweighed by their relative costs). In the high case we assume that 75% of upgradeable sites, i.e. a significant majority that are capable of supporting six sectors actually do so.

It is clear that six-sector sites are capable of providing greater capacity than their tri-sector equivalents, where all else is equal. However, capacity is not simply increased in line with the number of sectors since there are inefficiencies introduced at sector boundaries. The uplift from a single-sector cell to a tri-sector cell is widely agreed to be around 3.0×. However, the uplift from a single-sector cell to a six-sector cell is not quite as well established because the number deployed is relatively low, leaving a small evidence base. Values as high as 5.4×–5.6× have been quoted,[37] but we consider these to be optimistic compared to real-world deployments. Nokia Siemens Networks has suggested at the low end that a 40–50% uplift over a tri-sector site is more typical in real-world deployments.[38]

Our experience suggests that an uplift of 5.0× from the capacity of a single-sector cell to a six-sector cell is representative of the multiple that operators have successfully gained in real-world

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[36] If all new sites used six-sector upgrades rather than deploying new tri-sector sites, the number of new sites deployed could approach half of the tri-sector deployment equivalent, depending on the sectorisation gain assumed.

[37] Nokia Siemens Networks, *All in one mobile site solution boosts 2G, 3G and LTE network coverage and capacity* (2009); Jaana Laiho et al, *Radio network planning and optimisation for UMTS*, 2nd ed., Wiley (2006). See http://nsn.com/sites/default/files/document/NokiaSiemensNetworks_2009_11_04_en_High-Performance_Site_Solution.pdf and http://uap.unnes.ac.id/ebook/icare%20ebook%202007/John.Wiley.and.Sons.Radio.Network.Planning.and.Optimisation.for.UMTS.2nd.Edition.Feb.2006.eBook-BBL/John.Wiley.and.Sons.Radio.Network.Planning.and.Optimisation.for.UMTS.2nd.Edition.pdf

[38] Nokia Siemens Networks, *Mobile broadband with HSPA and LTE – capacity and cost aspects* (2010). See http://www.nsn.com/system/files/document/Mobile_broadband_A4_26041.pdf

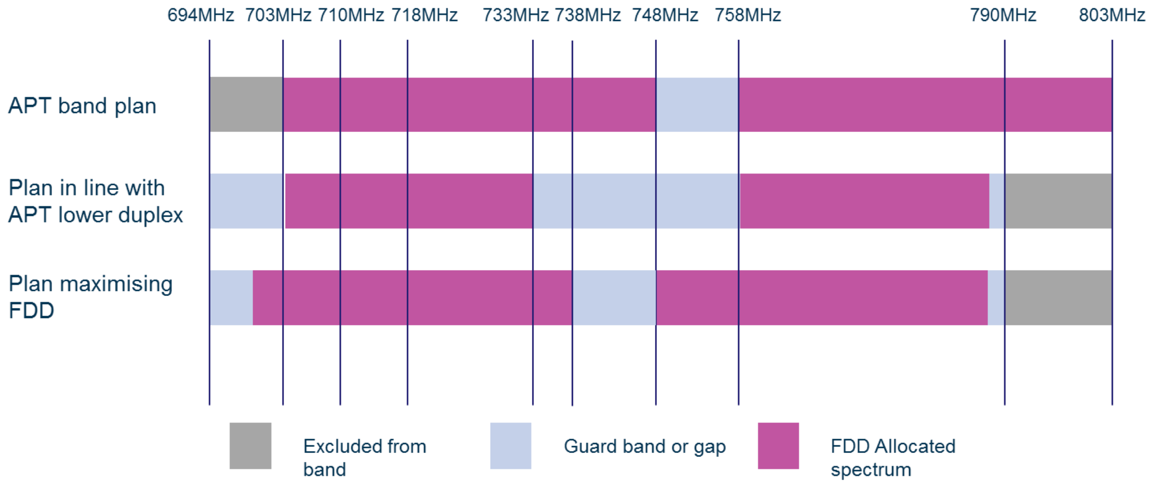
deployments. Therefore, where six-sector cells are deployed in our calculations an uplift of 5.0× over a single-sector cell is assumed.

Spectrum holdings

► *Spectrum holdings in the 700MHz band*

The UK has a number of options for allocating the 700MHz band to mobile, two of which are illustrated in Figure 3.11 below (alongside the APT band plan, which overlaps with the UK 800MHz band). The UK is likely to follow a Europe-wide decision on the 700MHz band plan. Europe could choose to harmonise with the APT band plan as far as the available spectrum will allow, awarding 2×30MHz of usable spectrum to mobile operators. At the other extreme, the UK could choose to maximise the spectrum available for mobile by allocating 2×40MHz of the 700MHz band to mobile broadband. However, by maximising the spectrum sold and moving away from harmonisation, the UK may be limiting itself with regard to device availability.

Figure 3.11: 700MHz band plan options in the UK [Source: Analysys Mason, 2014]



At the present time it is unknown whether any potential change of use of 700MHz spectrum will be made up of 2×30MHz or 2×40MHz of spectrum appropriate for mobile usage, although we note that there is currently growing international momentum behind the 2×30MHz plan.

In addition there is uncertainty over when this 700MHz spectrum first becomes available, with the most likely availability date being in 2022, although we have also tested alternative availability dates as part of our sensitivity analysis.

Of this available spectrum we consider valuing a holding of 2×10MHz of 700MHz spectrum for our generic operator to be the most reasonable assumption. However, the amount of 700MHz spectrum held has an impact on the per-MHz network cost savings, because for each incremental 2×5MHz lot of spectrum that is added to the generic operator’s portfolio, there is a reduction in the incremental number of new-build sites avoided. Therefore we have also tested the impact on the network cost savings for the generic operator of winning both 2×5MHz and 2×15MHz in the 700MHz band.

► *Generic operator spectrum holdings excluding the 700MHz band*

Ofcom has provided information on potential additional allocations of spectrum to mobile envisaged during the modelled time period, and their likelihood.[39] We have used this information to develop four spectrum sensitivity scenarios to be tested, which are defined in Figure 3.12 below. In the first scenario only the bands most certain to be used for mobile are considered, whilst in the fourth scenario a much larger number of bands, which may or may not ultimately be used for mobile services, are used. We consider Scenario 2 to be most likely and therefore use this in our mid case (i.e. the assumption we make when sensitivity testing the impact of other input parameter values).

Our generic operator's spectrum holdings (excluding the 700MHz spectrum band) equate to roughly one quarter of the total available mobile spectrum. This reflects Ofcom's goal of maintaining four credible national wholesale operators. The specifics of the generic operator spectrum holding sensitivities are shown in Figure 3.12 below.

Figure 3.12: Generic operator spectrum holdings [Source: Analysys Mason, 2014]

Spectrum band	Date from which spectrum is available	Total spectrum allocated from the band	Generic operator spectrum holding
450–470MHz	2030	2×5MHz	2×5MHz
470–694MHz	2030	2×112MHz	2×20MHz
800MHz	2013	2×30MHz	2×10MHz
900MHz	2011[40]	2×35MHz	2×10MHz
1.3–1.5GHz	2030	2×25MHz	2×5MHz
1452–1492MHz	2018	40MHz	10MHz
1800MHz	2012[40]	2×72MHz	2×15MHz
2.1GHz	2001	2×60MHz	2×15MHz
2.3GHz TDD	2016	40MHz	10MHz
2.6GHz	2013	2×70MHz	2×15MHz
2.6GHz TDD	2013	40MHz	10MHz
2700–2900MHz	2025	2×100MHz	2×25MHz
3.5GHz	2016	190MHz	45MHz
3600–3800MHz	2018	2×100MHz	2×25MHz
3800–4200MHz	2025	2×200MHz	2×50MHz

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[39] In line with the priorities set out in Table 11 of the Mobile Data Strategy Consultation published in November 2013. See, http://stakeholders.ofcom.org.uk/binaries/consultations/mobile-data-strategy/summary/MDS_Condoc.pdf

[40] Dates of availability for the 900MHz and 1800MHz bands are set as the dates of band liberalisation for non-GSM use.

These spectrum holdings are available to the generic operator in different combinations across the different spectrum scenarios, as shown in Figure 3.13 below.

Figure 3.13: Details of spectrum availability by scenario [Source: Analysys Mason, 2014]

Spectrum band	Scenario 1	Scenario 2	Scenario 3	Scenario 4
450–470MHz				✓
470–694MHz				✓
800MHz	✓	✓	✓	✓
900MHz	✓	✓	✓	✓
1.3–1.5GHz			✓	✓
1452–1492MHz		✓	✓	✓
1800MHz	✓	✓	✓	✓
2.1GHz	✓	✓	✓	✓
2.3GHz TDD	✓	✓	✓	✓
2.6GHz	✓	✓	✓	✓
2.6GHz TDD	✓	✓	✓	✓
2700–2900MHz			✓	✓
3.5GHz	✓	✓	✓	✓
3600–3800MHz		✓	✓	✓
3800–4200MHz			✓	✓

The consolidated model considers the downlink capacity per site. Where TDD (unpaired) spectrum is used for TD-LTE, it is assumed that two-thirds of the capacity is to be used for downlink.

Device availability

We have assumed that 700MHz-capable devices will enter the market in 2016 to reflect the development of 700MHz networks and their compatible devices in other countries. Device take-up has been extrapolated from Analysys Mason Research figures on historical take-up of smartphones and is forecast to grow exponentially, as shown in Figure 3.14. The same take-up curve is used for devices compatible with the 450–470MHz and 470–698MHz spectrum bands, with the start date in line with the 2030 change of use in spectrum Scenario 4, as set out in Figure 3.12 above.

We have also tested the impact on the model of a delayed take-up of 700MHz-compatible devices in the case of a 2×40MHz band plan, to account for the impact of selecting a band plan with less international harmonisation and therefore a less developed device ecosystem. This is illustrated in Figure 3.14 below.

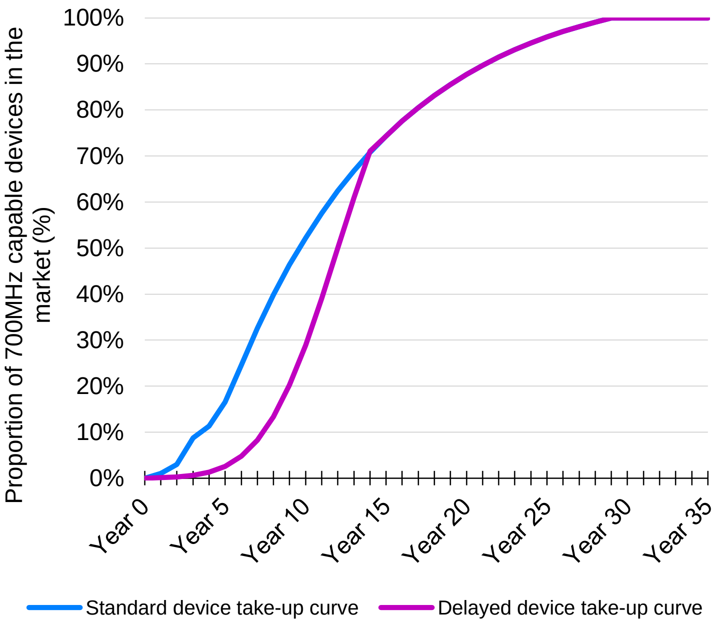

Figure 3.14: Take-up curves of 700MHz-capable devices [Source: Analysys Mason, 2014]

The cost of handsets and mobile broadband devices has not been considered in the calculation of network cost savings, although it is likely that the selected 700MHz band plan would have an impact on the cost of 700MHz-compatible devices to operators and consumers. The selection of a band plan with widespread international harmonisation, such as 2×30MHz, in line with the APT band plan illustrated in Figure 3.11 above, would mean that the devices supporting this band would be produced in greater volumes and would be less expensive. This effect might offset the difference in network cost savings between an APT-compatible (2×30MHz) band plan and a 2×40MHz band plan in which more spectrum is available.

3.2.4 Unit costs of equipment

Having access to additional spectrum, in the form of the 700MHz band, reduces the number of additional mobile sites that a mobile operator needs to build in order to provide the necessary capacity. This reduction in site builds reduces both the opex and capex of the mobile operator. The consolidated model assesses the costs savings with respect to both opex and capex across a number of cost elements. The unit costs of network assets and their corresponding price trends are taken from those used in the Analysys Mason model. These are comparable to the cost inputs to Ofcom’s revised 2011 mobile Wholesale Cost of Termination model and are shown in Figure 3.15 below. In general, annual unit opex is assumed to be around 10% of unit capex, except in the case of backhaul where we expect opex to form a higher proportion.

Figure 3.15: Capex, opex and annual price trends on modelled cost elements [Source: Analysys Mason, 2014]

Cost element	2014 capex (GBP)	2014 opex (GBP)	Price trend
New site build (including civil works)	118 458	11 846	2.5%
Carriers for one frequency band on a tri-sectored macrocell	6000	600	0%
HSPA base station	3500	350	0%
LTE base station	4200	420	0%
TD-LTE base station	4620	462	0%
Backhaul[41]	15 000	4500	0%
Total for new site[42]	**151 778**	**18 178**	
Total for additional 700MHz carrier	**6000**	**600**	
Cost of six-sector upgrade	43 076	n/a	2.5%

To further validate our cost assumptions, we have compared these to unit cost information collated from recent network cost models published by various European regulatory bodies. While each of these models separates out assets in different ways, we have been able to confirm that the unit cost inputs in our consolidated model lie within the same range as those used in the various regulatory models, as shown for new-site build capex in Figure 3.16 below.

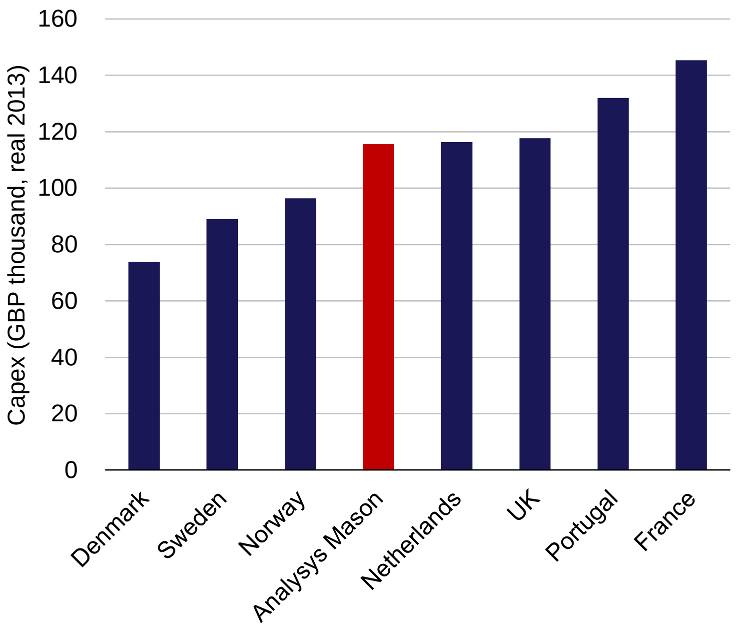

Figure 3.16: Comparison of the model new-site build capex to that used in European network cost models [Source: Analysys Mason, 2014]

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[41] The model assumes that any sites which are upgraded to include 700MHz carriers already have relatively high numbers of other carriers and have therefore previously converted to using leased lines for backhaul. Therefore we do not assume any incremental costs for backhaul when a 700MHz carrier is added to a site.

[42] This assumes that only carriers for one frequency band are added. A site loaded with all available frequency bands, with 700MHz available in 2012, would incur capex of GBP183 450 and opex of GBP21 345.

These cost figures are used in our mid case. We have tested the impact of both a 10% uplift (a high case) and a 10% reduction (a low case) in unit capex and opex in the model. We have also tested the impact of costs rising at a faster rate to reflect a scenario in which it becomes more difficult, and costly, to acquire / build new sites as network density increases.

Asset replacement

The consolidated model includes consideration of equipment lifetimes and therefore replacement capex, in a similar way to the Real Wireless model. The modelled equipment lifetimes have been chosen from a review of the recent publicly available European network cost models, including Ofcom's 2011 Wholesale Call Termination model. The asset lifetimes used in the consolidated model are shown in Figure 3.17 below.

Cost element	Asset lifetime (years)
New site build (including civil works)	20
Carriers for one frequency band on a tri-sectored macrocell	15
HSPA base station	8
LTE base station	8
TD-LTE base station	8
Backhaul[41]	8
Six-sector upgrade	20

Figure 3.17: Asset lifetimes [Source: Analysys Mason, 2014]

3.2.5 Site sharing assumptions

The Analysys Mason model and the Real Wireless model took different approaches to the concept of site sharing. The Real Wireless model effectively assumes that 100% of new-build macrocell sites are shared[43] (as described in Annex B.7), whilst the Analysys Mason model does not include site sharing arrangements.

In the consolidated model we have incorporated site sharing, assuming a market with two infrastructure sharing pairs of operators: each operator in each group is responsible for 50% of capex and opex related to shared site costs but for 100% of its own active equipment. However, we have not adopted the Real Wireless assumption that 100% of new-build sites will be shared. Our experience suggests that in practice operators would not be willing to share all new sites, for strategic reasons (such as retaining the option to deploy more of their own equipment at the site in the future) or unwillingness to share in the costs of serving a localised hotspot that may only be relevant to one operator. In addition, there may be practical reasons for not sharing sites, such as a lack of space for equipment from multiple operators. We therefore assume that a maximum of 50% of new-build sites can be shared, such that when a new site needs to be built there is a 50% probability that it can be shared.

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[43] We were not able to determine whether only passive equipment is shared or whether active equipment is also shared in the Real Wireless analysis.

We have also tested cases in which: 25% of new-build sites can be shared; 90% of new sites can be shared; an increasing proportion of sites (from 0% in 2011 to 50% in 2050) can be shared; and a case in which there is no infrastructure sharing in the modelled period. In addition we have also tested the impact of sharing the capex and opex related to active equipment, representing a scenario in which infrastructure sharing is more developed.

Note that our consolidated model is only concerned with the sharing of new sites. Sharing of existing sites does not affect the network cost savings arising from access to 700MHz spectrum since the cost savings of sharing these sites would arise in both our factual and counterfactual scenarios (i.e. both with and without the 700MHz spectrum).

Starting sites

. In the Consolidated model we have adopted the 17 500 initial number of physical sites which the generic operator has access to (i.e. the number of sites on day 1 of the modelled period) used in Analysys Mason's previous work on the opportunity costs of broadcast spectrum.[44] In particular, we model an initial number of sites ranging between the highest and lowest per-operator numbers reported for the various operators in Ofcom's technical modelling in support of the combined award final decision (800MHz and 2.6GHz).[45] 17,500 is a little higher than the average number of sites reported by operators. However, recent site sharing agreements suggest that this slightly higher number of sites is appropriate for our generic operator.

We are also testing initial site numbers of 12 000, 16 000 and 18 500, in line with inputs to the Analysys Mason model and the Real Wireless model.[46] This also reflects the 12 000-site and 18 000-site synthetic networks used in the Ofcom model.

3.2.6 Small cells

As discussed in Section 3.2.3, the main calculations in the consolidated model consider tri-sector macrocell 'equivalents' which implicitly take account of the use of small cells. This approach has been used since the cost per unit capacity for small cells is forecast to be equivalent to that of macrocells. Combined with the HetNet assumption on the efficiency of deploying both types of cell this means the network can be dimensioned in a more straightforward manner in terms of multiples of macrocell equivalents.

To validate this assumption we compared the cost per unit capacity of an indoor small cell and a typical tri-sector macrocell over the period 2012–2030.

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[44] *Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting*, see http://stakeholders.ofcom.org.uk/consultations/aip13/

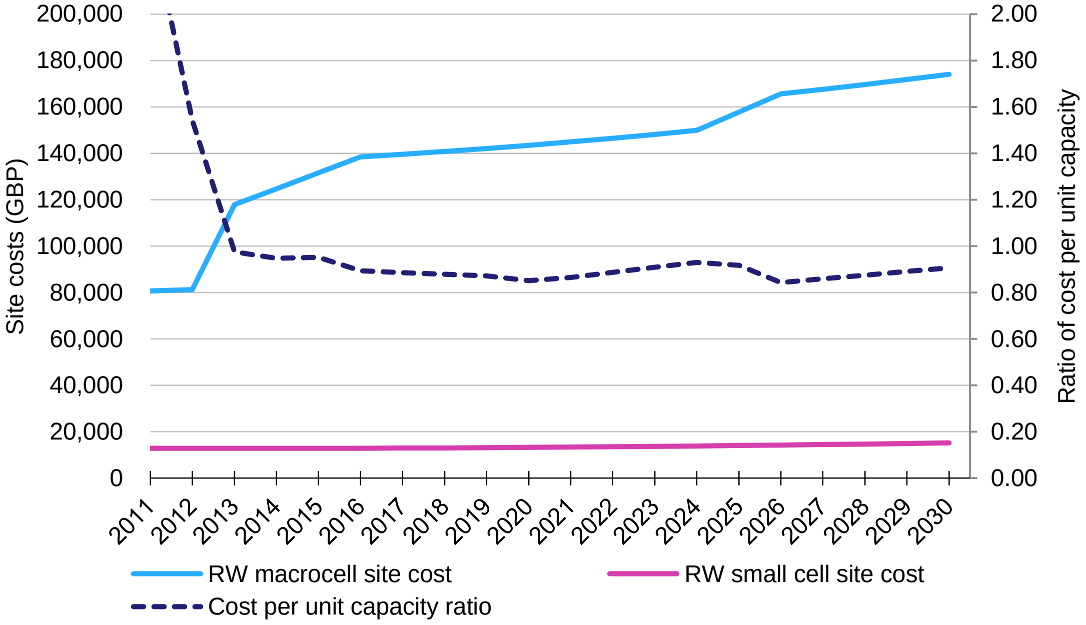
[45] See http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/Annexes1-6.pdf

[46] As discussed in Section 4, our range of scenarios use values of 17,500 or 16,000 initial sites. 12,000 and 18,000 initial sites are also tested as part of our sensitivity testing.

This analysis combined the assumptions made in the Real Wireless[47] model on: spectral efficiency, spectrum availability, site and equipment costs, as well as the evolution of small-cell capability to support multiple sectors.

We found that the cost per unit capacity for both macrocells and small cells falls dramatically in the modelled period, driven primarily by improvements in spectral efficiency and, in the case of macrocells, a greater availability of spectrum (which could be exploited more fully on macrocells but not by small cells).[48] The imbalance in the number of sectors and spectrum bands simultaneously supported leads the initial advantage in cost per unit capacity of macrocells to be quickly eroded and results in a relatively even cost per unit capacity over most of the modelled period. As shown in Figure 3.18 below, macrocells are forecast to be slightly more cost effective.

Figure 3.18: Site costs and ratio of cost per unit capacity for macrocells against small cells [Source: Analysys Mason calculations based on Real Wireless, 2014]



This result validated our assumption that the difference in cost per unit capacity is sufficiently small over the modelling period that it does not require explicit modelling. This does not mean that small cells will not be deployed, however. On the contrary, planning permission issues in urban areas are likely to necessitate their use. Rather, we believe that modelling their deployment through a 'macrocell equivalents' approach is capable of capturing the correct network costs.

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[47] *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–30*, see http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

[48] PA Consulting, *Predicting Areas of Spectrum Shortage* (2009). See http://stakeholders.ofcom.org.uk/binaries/research/technology-research/shortage.pdf , also found that the limited number of bands that can be supported by small cells places severe limitations on the net efficiency of spectrum utilisation in a network.

3.2.7 Traffic distribution

Distribution of traffic across geotypes

The split of traffic and sites across geotypes for the modelled generic operator in our consolidated model is taken from the site and traffic splits used by Ofcom for the average operator in its calls to mobile (CTM) model for assessing the costs of mobile termination.[49] This is in line with the methodology used in the Analysys Mason model and results in a higher traffic per site figure for the most urban geotypes, as shown in Figure 3.19 below.

Geotypes	Proportion of generic operator sites	Proportion of generic operator traffic
Urban	7%	13.20%
Suburban 1	35%	60.82%
Suburban 2	12%	14.43%
Rural 1	13%	6.08%
Rural 2	13%	1.75%
Rural 3	4%	0.41%
Rural 4	5%	0.21%
Highways	11%	3.09%

Figure 3.19: Traffic and site split across geotypes [Source: Analysys Mason, 2014]

Distribution of traffic across sites

In addition to the split of traffic between geotypes, we have also modelled a distribution of traffic across sites within each individual geotype. We have used a traffic distribution derived within the model governed by a formula of the form $y = a \times \ln(x) + b$.

The model includes two combinations of the parameters a and b, to give the traffic distribution scenarios illustrated in Figure 3.20 below. The steeper distribution curve has been derived from the Analysys Mason model but adjusted such that 100% of traffic is carried across 99% of sites, rather than the 85% of sites previously used.

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[49] See http://www.ofcom.org.uk/static/wmvct-model/model-2011.html

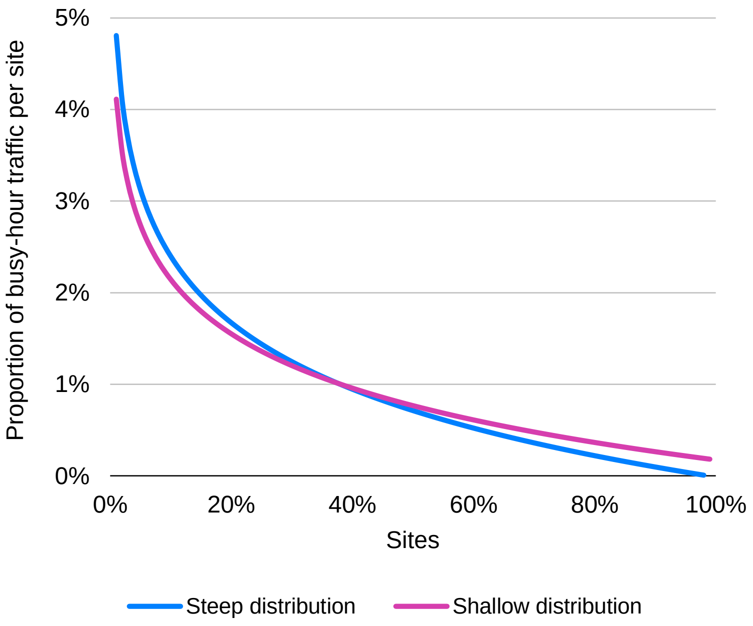

Figure 3.20: Illustration of the distribution of traffic across sites scenarios [Source: Analysys Mason, 2014]

The Ofcom model allows us to consider the number of population points for which any given site is the main server (i.e. provides the strongest signal). This allows us to calculate the proportion of population served by each site and, using population as a proxy for traffic, the distribution of traffic across sites.[50] The model has been run with an 18 000-site synthetic network to determine the number of population points which receive their strongest signal from each site, and the shallower distribution curve uses the parameters a and b given when a logarithmic line of best fit is applied to these results.

We have used the steep distribution of traffic curve in the majority of our main scenarios, with the shallow distribution of traffic curve used only in our low scenario. This is because the steep curve is based on Analysys Mason’s experience of real network data, rather than being derived from the synthetic network in the Ofcom model. We note that the choice of distribution can potentially have a quite large impact on the outputs, as set out in our sensitivity testing in Section 4.2.

Distribution of traffic within a cell

We also use the Ofcom model to calculate the effects of the distribution of traffic within cells, and thus quantify the proportion of post-offload traffic that can only be carried by sub-1GHz spectrum, and not by supra-1GHz. This is another key driver of the deployment of new sites and new low-frequency carriers at existing sites within both the Analysys Mason model and the consolidated model.

Specifically, we use the Ofcom model to test what proportion of the population[51] will be covered by a threshold level of SINR[52] with sub-1GHz spectrum (700MHz) and supra-1GHz spectrum

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[50] Note this assumes in effect that the traffic generated at each population point is equal, when weighted by the population at each population point (i.e. the size of each household).

[51] This assumes that the distribution of population is a reasonable proxy for the distribution of traffic.

[52] The threshold chosen is equivalent to 2Mbit/s, which is in line with the coverage obligation for the 800MHz licence.

(1800MHz). The Analysys Mason model originally assumed that 30% of traffic per cell can only be served by sub-1GHz spectrum.

This issue is addressed in the Real Wireless model through the use of a site deployment algorithm that considers the spatial distribution of points of demand. The current consideration of this in the Analysys Mason model is more simplistic, hence robustness can be lent to this input parameter by using the Ofcom model to derive the proportion of traffic that can only be carried by sub-1GHz spectrum.

The value for this parameter is obtained by comparison of the population coverage of an 18 000-site synthetic network when using 700MHz or 1800MHz. The values obtained when using 1800MHz use an SINR threshold that includes a handover margin; this is the margin that ensures handover between frequencies during an intra-cell handover. This margin takes the same values as would be expected for an inter-cell handover, i.e. ranging from 2 to 5dB but with 3–4dB the most commonly used in our experience.

The calculation results are as follows:

- 18% of traffic; using a handover margin of 4dB
- 14.5% of traffic; using a handover margin of 3dB.

However, we consider that the Ofcom model is likely to overestimate coverage and therefore underestimate the coverage difference between different frequency bands. This is primarily because:

- An assumption of a ‘lightly loaded’ cell is used. This assumption will increase coverage at all frequencies

- The Ofcom model measures whether a population point is covered by applying an SINR threshold of -5dB, but it does not also apply a reference signal received power (RSRP) threshold; where interference is not the constraining factor, this will form the minimum requirement for a device to connect to a network

- A synthetic network is used, which we consider is likely to provide improved coverage over a real network with the same number of sites.

Conversely, our approach assumes that all population points generate equal traffic, which may have the effect of increasing the value of our sub-1GHz parameter. This is because population points in the outer part of the cell may in practice generate below-average traffic since there is likely to be less available bandwidth for them to use.

On balance, however, we consider that the parameter values calculated using the Ofcom model are likely to be low. In addition, therefore, we have run a variant of the Ofcom model (i.e. a version which is slightly different from the coverage compliance model), as used in the 4G competition assessment, with an 18 000-site synthetic network and a handover margin of 3dB. This gives results that produce a parameter value of 22%.

We therefore test the following parameter values in our consolidated model:

- **18% of traffic**, based on the coverage obligation model with a 4dB handover margin in our low case
- **22% of traffic**, based on the competition assessment model with a 3dB handover margin in our high case.

We also include sensitivity tests to take account of some more extreme parameter values:[53]

- 14.5% of traffic, based on the coverage obligation model with a 3dB handover margin as a low value sensitivity
- 25.5% of traffic, a value equidistant the other side of our 18-22% scenario range as a high value sensitivity.

We note that, in our opinion, the 18 000-site synthetic network is likely to overestimate coverage relative to any actual network with the same number of sites and produce an underestimate of the coverage delta used to calculate the distribution of traffic within cells. Therefore, the parameter range set out above could be considered conservative.

3.2.8 Discounting approach

Discounting methodology within the modelled period

Ofcom has requested that the consolidated model discounts the annual costs using the Spackman approach, as adopted for discounting in cost–benefit analysis (CBA) by the Joint Regulators Group (JRG)[54] in 2012. This approach involves annualising the modelled generic operator’s capex using the weighted average cost of capital (WACC) for a mobile operator of 6.2% pre-tax real; the resulting flows of costs (opex and annualised capex) and benefits are then discounted at the social time preference rate (STPR) or social discount rate of 3.5% (also pre-tax real). Costs incurred during the model period are included in the PV of network cost savings, even if they are annualised over a number of years after the end of the model period. The implementation of the Spackman discounting approach is illustrated for a five-year model, with annualisation over five years, in Figure 3.21 below.

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[53] We also test 20% (the mid-point of our central 18–22% range) as part of our sensitivity testing in Section 4.2.

[54] See http://stakeholders.ofcom.org.uk/consultations/discounting-for-cbas/?a=0

Figure 3.21: Illustration of the Spackman approach in a model with a five-year modelling period [Source: Analysys Mason, 2014]

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Capex in year (GBP)	5	5	5	5	5	0
Opex in year (GBP)	2	2	2	2	2	0
Capex annualised using a WACC of 8.86% over the five-year asset lifetime (GBP)	1.28	1.28	1.28	1.28	1.28	0
Total annualised capex (GBP)	0	1.28	2.56	3.84	5.12	6.40
Total annualised capex plus opex (GBP)	2	3.28	4.56	5.84	7.12	8.40
Discount factor derived from the social discount rate of 3.5% pre-tax real	100%	94%	89%	84%	79%	74%
Discounted costs (GBP)	2.00	3.09	4.05	4.89	5.62	6.25
PV for the five-year modelling period (GBP)	30.17[55]					
Terminal value (GBP)	98.49					
PV including terminal value (GBP)	128.65					

The Spackman approach has been adopted due to the nature of the network cost savings that would result from a change of use of the 700MHz band. Although the cost savings fall on the mobile operators, much of the benefit resulting from this may be passed onto consumers. This combination of both consumer benefits and operators' investment in the network suggests to us (and to Ofcom) that the Spackman approach is appropriate, as it both accounts for the financing costs and makes use of the social discount rate to reflect the benefits to society. Within the model, capex is annualised over a 20-year period for the purposes of the Spackman methodology, reflecting the longest lifetimes of any modelled assets.

A discount rate is used by both the Analysys Mason and Real Wireless models to convert the costs of network deployment, with and without the change of use of the 700MHz band to mobile, to present values using a standard discounting methodology. The consolidated model also has the functionality to discount using this approach. In previous work for Ofcom, such as the Wholesale Call Termination study,[24] the WACC for a mobile operator of 6.2% pre-tax real (8.86% pre-tax nominal) has been used as the discount rate. However, we have also tested the STPR of 3.5% suggested by HM Treasury's Green Book as the discount rate in our standard discounting methodology as this may be appropriate for calculating the costs and benefits of 700MHz spectrum to society, not to the network operators.

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[55] If the annualised capital costs beyond the modelling period are excluded from the PV less the terminal value, then this quantity falls to GBP19.66 (with a corresponding rise in the terminal value to GBP109.00).

Terminal value

While the majority of the results presented in this report exclude terminal value, the model also produces PV results including a terminal value. This terminal value is based on the sum to perpetuity of future network costs, with costs in each future year assumed equal to those in the final year of the modelling period. We have also tested a terminal value calculated for 20 years past the end of the modelling period, rather than to perpetuity; the use of such a short-term terminal value may mitigate against the risks arising from the inherent uncertainty associated with forecasts this far into the future.

Under the Spackman discounting methodology, the PV excluding terminal value includes the annualised values of capital costs incurred in years which fall within the modelling period but which are partly accounted for in years beyond the modelling period. These annualised capital costs accounted for beyond the modelling period are netted off of the terminal value such that the terminal value only includes costs incurred in years after the model period, thereby avoiding duplication. This approach allows for all costs incurred in the modelled period to be included in the calculated PV excluding the terminal value.

3.3 Additional benefits of improved coverage, capacity and performance

In this section we primarily consider additional benefits of improved coverage, capacity and performance in mobile networks, above and beyond the network cost savings which we have set out our approach to calculating in Section 3.2.

The network cost saving calculation is subject to some uncertainty, but the consolidated model enables us to quantify the cost savings and to test how they vary with changed input parameter values.

However, the additional benefits described in this section are subject to greater uncertainty. In particular, these benefits are difficult to quantify precisely and our approach is to identify likely boundaries.

We first consider an alternative to the network cost savings calculation we have described above: the population coverage approach. We then go on to consider two alternative approaches to allow us to elaborate on the form and rough magnitude of the additional benefits introduced above.

- the adjusted technical value approach
- the commercial value approach

In the remainder of this section we consider these three approaches for analysing the benefits of 700MHz, including the benefits additional to the network cost savings.

Together, the last two approaches allow us to identify a likely range of values for the additional benefits that allocating the 700MHz band to mobile broadband is likely to bring. However, as with the network cost saving calculations, it is important to note that these approaches do not provide strict upper or lower bounds on the magnitude of the benefit. Whist the adjusted technical value approach may provide a likely upper bound (for the modelled period) on the size of this benefit to mobile operators, there may be additional consumer surplus which this approach does not capture. Without a detailed study involving consumer participation it is difficult for us to comment on the size of this benefit, other than to say that we would expect it to be large.

3.3.1 Population coverage approach

In this approach we measure the benefit to consumers in terms of an increase in single user throughput and an increase in coverage at a given single user throughput that would be expected from using the 700MHz band to deliver mobile broadband. This approach produces some metrics representing the improved service for consumers, without placing a monetary value on that benefit. This can be viewed as an alternative representation of the network cost saving benefits which are calculated using our consolidated model.

The Ofcom model enabled us to make these calculations, using the approach described below.

The model was run twice, once for a network[56] with 700MHz and then again for a network without 700MHz (but with the remainder of the generic operator's spectrum holdings). When running the model with 700MHz the network loading was slightly reduced from 85% to 75%[57] to reflect the fact that the same amount of traffic is being carried on a network with greater capacity (relative to the case without 700MHz).

In each case this approach gave an SINR distribution across population points, from which the single user throughput could be calculated[58] (using the mapping function[59] between SINR and spectral efficiency).

With these two distributions the proportion of the population that can achieve certain throughputs was calculated, in order to create a histogram. The results of this approach are illustrated and discussed in Section 5.1.

3.3.2 Adjusted technical value approach

This approach draws on the outputs from different scenarios of the consolidated network cost model to calculate the additional network costs which would be incurred by operators to provide the same quality of service that a 700MHz allocation would enable, but without using this spectrum and instead relying on increased network density. This replication of the quality of

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[56] The network used was the 12 000-site synthetic network.

[57] Adding 2×10MHz of 700MHz spectrum to the generic operator's spectrum holdings increases these holdings by around 9%. Therefore the network loading could be expected to reduce by around 9%, from 85% to around 77%. Given that sub-1GHz spectrum may be slightly more heavily loaded than the network average and that 700MHz spectrum would help to avert this, we reduce the effective loading slightly further to 75%.

[58] For a given spectral efficiency there is a one-to-one mapping to the single-user throughput which will be achieved.

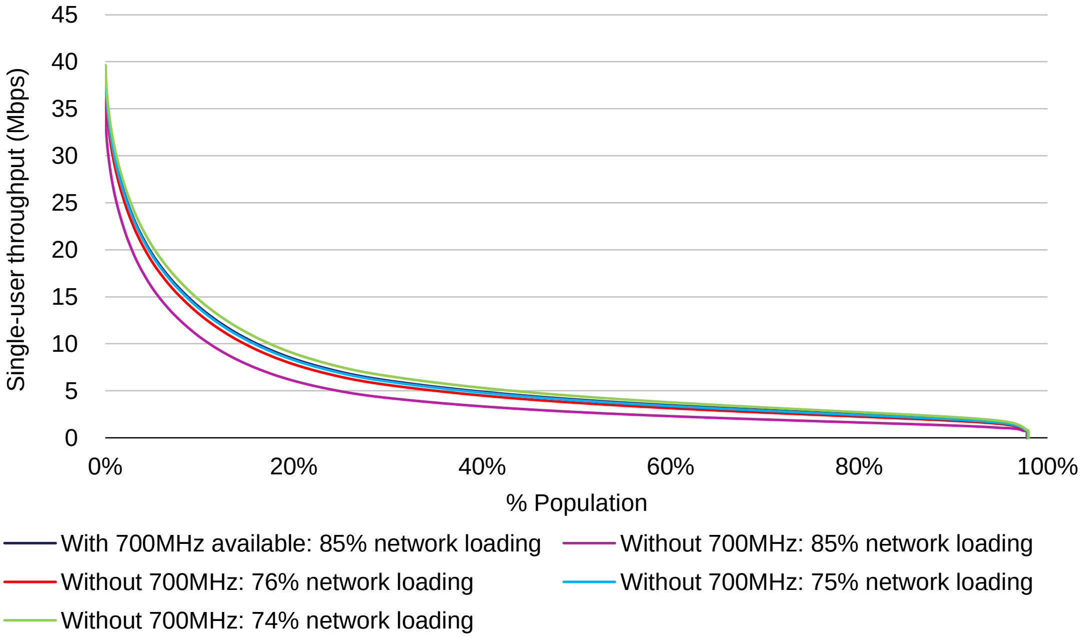
[59] This mapping function is described in detail in Annex 14 of Ofcom's second combined award consultation document. http://stakeholders.ofcom.org.uk/consultations/award-800mhz-2.6ghz/

service enabled by use of the 700MHz band will represent a likely upper bound on the additional benefit to operators of improved coverage, capacity and performance. This is because it is unlikely that operators would commercially choose to 'replicate' the 700MHz quality of service if the spectrum were not available (as it would not be more profitable to do so). However, it may not represent an upper bound on the benefits to consumers, since consumers may be willing to pay a higher amount than operators are able to monetise.[60]

We calculated this adjusted technical value by first using the Ofcom model to calculate the variation in network loading that will enable a network without 700MHz spectrum to provide the same performance (user throughput vs. population covered) as a network with 700MHz spectrum available. In other words, this involved calculating the extent to which the number of users served by each cell needs to be reduced in order to provide each user with the same throughput they would have received had the 700MHz carrier been available.

The first step was to obtain the distribution of user throughput across the population for a network that has 700MHz spectrum available for a given network load; in this instance the loading was set to 85% (representing a highly loaded network). The next step was to find the network load in a scenario with no 700MHz spectrum with a comparable performance in terms of user throughput and population coverage; through a process of iteration and comparison this was found to be a 75% network loading. A comparison of a number of distributions, including the 85% loaded with 700MHz and the 75% loaded without 700MHz, can be seen in Figure 3.22. Comparing the 85% loading scenarios with and without 700MHz also provides an illustration of the single-user throughput advantage enjoyed by the 'with 700MHz' network with equivalent network loading.

Figure 3.22: Variation in user throughput across population for networks with and without 700MHz available at different network loadings [Source: Ofcom, 2011]



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[60] We note that in practice it might also be the case that this approach calculates a value greater than the total benefit to operators and consumers.

This reduction from 85% loading to 75% loading represents a 12%[61] decrease in effective cell capacity, which was used to inform a change in the inputs to our consolidated model. Within the consolidated model this decrease in effective carrier capacity is taken into account by applying this parameter as a decrease in spectral efficiency, as a proxy for carrier capacity.

The cost difference between the scenario with 700MHz and the scenario without 700MHz and with reduced effective cell capacity (as shown and discussed in Section 5.2) represents the adjusted technical value,[62] i.e. the cost savings that the generic operator will make by using 700MHz spectrum to serve a given population with a certain level of throughput instead of extending the network to achieve this level of performance.

One way to think about the adjusted technical value is to consider three different site types making up the generic operator's network.

- **Type 1 sites**: These are sites covering areas in which there is a benefit from deploying 700MHz carriers to provide extra capacity in order to carry the required amount of traffic
- **Type 2 sites:** These are sites in areas where there is no need to deploy 700MHz carriers to provide additional capacity, but there may be a network performance benefit from doing so
- **Type 3 sites**: These are sites in areas where there is no capacity or performance benefit from deploying 700MHz carriers (in other words the sites are under-utilised).

The consolidated network cost saving model determines the number of type 1 sites and measures the cost savings to the operator of being able to deploy 700MHz carriers on existing sites of this type rather than deploying additional new sites to cover the same areas. The adjusted technical value calculation then goes on to assess the number of type 2 sites and applies the same cost-saving calculation. Type 3 sites do not have 700MHz carriers deployed and are equivalent in both the network with 700MHz and the network without 700MHz.

It is possible that the adjusted technical value calculation may overstate the benefits of 700MHz to the generic operator. This is because analogous to the measured benefits in the areas covered by type 2 sites in the network with 700MHz, there may be similar performance benefits, which are not measured, in the areas covered by type 1 sites in the 'without 700MHz' network. This is because in the 'without 700MHz' network a new 700MHz carrier cannot be deployed on type 1 sites and a new site covering the same area is built instead. If this new site provides greater network performance benefits than a new 700MHz carrier on the existing site, then there may be some unmeasured benefit in the 'without 700MHz' case. This unmeasured benefit could in theory partially offset the measured benefit in the areas covered by type 2 sites in the 'with 700MHz' case

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[61] Decreasing loading from an initial 85% to 75% is a 12% reduction, as we are taking the 85% as the baseline loading; i.e. 10/85 = 0.12.

[62] This differs from the "standard technical value" or network cost savings ordinarily calculated by the consolidated network model whereby the difference is measured between a scenario with 700MHz and one without 700MHz, but with the same effective carrier capacity.

and hence lead to an overstatement of the performance benefits of having 700MHz spectrum available.

We believe the magnitude of any unmeasured benefit without 700MHz is likely to be small, and therefore any overstatement of the benefit to the generic operator will be correspondingly small. However, we explore this in more detail in Section 5.2.

3.3.3 Commercial value approach

The population coverage approach examines the level of service improvement experienced by consumers in aggregate as a result of allocating 700MHz spectrum to mobile services. As described in the section above on the adjusted technical value, even after new sites are built to account for a capacity shortfall resulting from not having access to the 700MHz spectrum, some level of improved service is still likely to be achieved. Providing such an improved service should allow operators to generate a commercial value, typically defined as comprising the net present value (NPV) of future increases in revenue or reductions in non-network costs resulting from additional spectrum, in this case the 700MHz band.

It would be difficult to precisely calculate this commercial value. Instead, the commercial value assessment attempts to quantify the approximate magnitude of the upside that could be generated for mobile operators. This value may arise through any combination of an increase in ARPU, reduced churn, reduced subscriber acquisition/retention costs, or an increase in service penetration.[63]

We have developed a high-level calculation of the commercial value for our modelled generic operator. It is relatively straightforward to establish the NPV of benefits which would arise from given increases in ARPU or subscriber numbers, or reductions in non-network costs. However, it is much harder to establish the exact level of, for example, increases in ARPU which would arise from providing improved coverage, capacity or performance.

We have therefore tested the magnitude of this NPV of benefits for ranges of improvements in these key performance indicators which are likely to be reasonable.

The commercial value approach estimates a range for the likely lower bound for the additional benefits of improved coverage, capacity and performance resulting from a 700MHz allocation to mobile. The range calculated is likely to be a lower bound because only the benefits to operators are captured, and not any additional consumer surplus.

In order to identify the likely impact of an improved quality of service (QoS) in terms of coverage and performance (i.e. single-user throughput) on commercial value we have estimated the likely magnitude of the impact on its drivers (e.g. ARPU, subscriber numbers, etc., as identified above).

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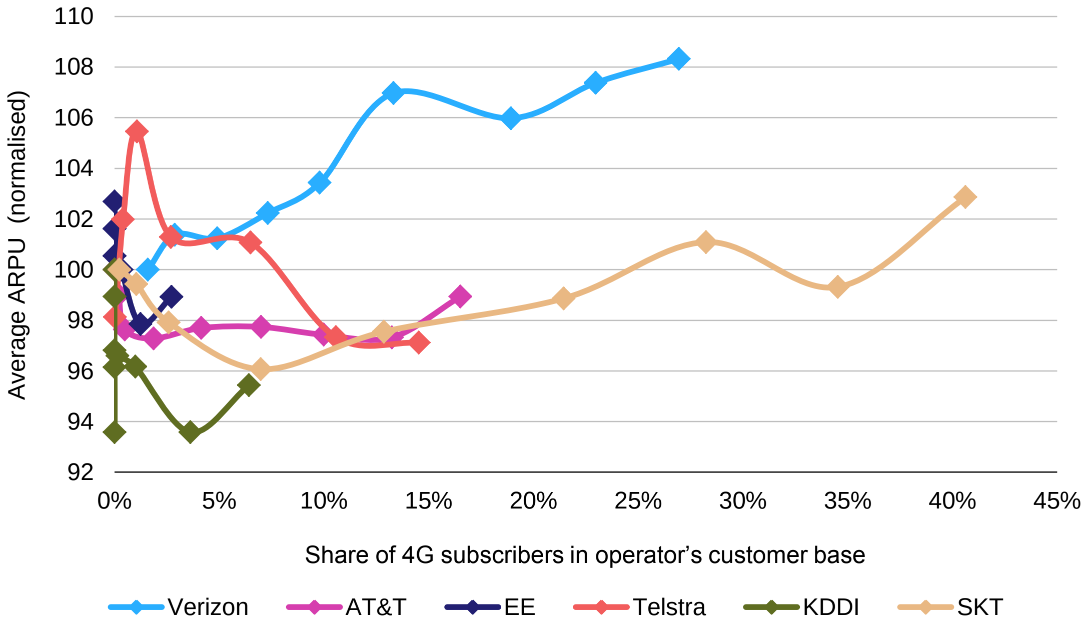
[63] For individual operators valuing spectrum licences, value may also arise due to expectations of increases in market share, but in this analysis we consider only expansional rather than distributional effects (i.e. those effects which increase the value of the mobile market rather than those which merely redistribute the value between operators – making the pie bigger).

Benchmark evidence on willingness to pay for 4G services relative to 3G is one input used in identifying this mapping between QoS and drivers of commercial value. In particular, the move to 4G services can be seen as a proxy for use of the 700MHz band by mobile operators, as both result in service improvements for users. As can be seen in Figure 3.23 below, a number of early-adopter operators of 4G technologies have benefited from an increase in ARPU as their share of 4G subscribers has grown.[64] This may indicate that the service improvements due to 4G are resulting in higher willingness to pay among subscribers. In the UK, Everything Everywhere has claimed that ARPU for 4G subscribers is 10% higher than ARPU for other subscribers. Even if long-run ARPU trends return to their pre-4G pattern of falling after the high-usage early adopters have all upgraded and the technology has reached the mass market, it is likely that ARPU will remain at a higher level than it would have been without the provision of LTE services. We believe that the same logic applies to the introduction of additional sub-1GHz spectrum (i.e. the 700MHz band) to the market though the scale of the impact may differ. This is discussed below in the section headed *ARPU*.

Figure 3.23: Evolution of ARPU relative to adoption of 4G services [Source: Analysys Mason, 2014]



As with the methodology used for the network cost saving calculation, our commercial value approach tests a combination of high and low scenarios that we could consider likely bounds to the impact on key drivers of operators’ commercial value (ARPU, churn and SAC[65]) brought about by the QoS improvements afforded by the launch of 700MHz spectrum in 2022.

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[64] This is relative to a situation in which ARPU for mobile operators does not typically increase in nominal terms.

[65] We do not expect there to be a significant impact on other drivers, except for network costs (which are accounted for in the network cost saving calculation).

Range of impacts on parameters

We have developed a plausible range of changes in ARPU, churn and SAC that may arise because of the improved user experience that 700MHz may enable mobile operators to provide. We consider each of these in turn below.

► *ARPU*

The baseline for this indicator takes Analysys Mason's published forecast[66] ARPU for handset and mobile broadband subscribers in the UK from 2010 to 2017 and assumes that ARPU plateaus until 2022 (assumed to be the launch year for 700MHz services). We estimate that the baseline scenario without any 700MHz spectrum would result in a continued real-terms plateau in ARPU for both handset and mobile broadband subscribers.

However, if 700MHz spectrum was allocated to mobile broadband we would expect the impact on ARPU to lie within the following range of scenarios:

- no change in ARPU
- a small initial rise in ARPU in 2022 in response to improved services, and then a linear decline back to the long-term trend over a period of approximately three years
- a small initial rise in ARPU in 2022 in response to improved services, and then a longer linear decline back to the long-term trend over a period of approximately five years.

Evidence of long-term ARPU trends following 4G launch (for example, as seen in Figure 3.23) suggests that the ARPU premiums triggered by the launch of 4G do not appear to endure as 4G penetration continues to rise, so a limit of five years is reasonable. This is modelled as a temporary increase in ARPU in the case of the change of use of the 700MHz spectrum to mobile, which falls over a period of up to five years to the level of ARPU in the counterfactual scenario without a change in use of the 700MHz spectrum. It is also unlikely that there would be no impact on ARPU whatsoever. Whilst the first and third options listed above are possible, we expect the middle case to be the most likely.

Our expectation is that without an improvement in services such as that afforded by LTE or with significant additional low-frequency spectrum, operators will find that ARPU continues to decline in real terms as has been the trend in recent years. It is difficult to forecast key performance indicators with much certainty over the timescales considered by the consolidated model, but we estimate that growth in line with inflation (i.e. no growth in real terms) would be the most plausible long-term trend if LTE was deployed but no additional sub-1GHz spectrum was allocated to mobile broadband. This reflects the steady roll-out of LTE devices and continued incremental improvements in device and network technology that we would otherwise expect.

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[66] Analysys Mason, *Mobile broadband in Europe: forecasts and analysis 2012–2017*, 2012, see http://www.analysysmason.com/Research/Content/Reports/Mobile-broadband-Europe-forecasts-Dec2012-RDMM0/

Improved user experience would stop a further real-terms decline in ARPU,[67] and some commentators have suggested that ARPU increases of as much as EUR8 to EUR10 per annum[68] (approximately GBP6 to GBP8) could be expected in both voice and mobile broadband subscriptions as this is accommodated within consumer willingness to pay.

If significant additional low-frequency spectrum were made available to mobile broadband, such as in the 700MHz band, we expect that a small premium could be realised immediately after the deployment of 700MHz spectrum, due to a step-change improvement in user experience. This change could either be sustained, or more likely would erode over time as the relatively modest improvement in coverage and throughput seen in Section 3.3.1 becomes less significant in comparison to technological advances. We assume that the premium is the same for both voice and mobile broadband subscribers.

Willingness to pay data from McKinsey and Company[68] and analysis of ARPU response to LTE deployments by Analysys Mason[67] indicate that a premium of approximately GBP0.50 per month is a plausible value to expect in response to the availability of improved services following the deployment of 700MHz for mobile broadband services should the improved QoS be of similar magnitude to the deployment of LTE. This is equivalent to an initial 4% increase across all subscribers or alternatively 10% of subscribers paying an initial premium of GBP5.00 per month. The distribution of willingness to pay may vary across the subscriber base but even concentrating the costs among a small proportion of early adopting subscribers would be a reasonable assumption to make.

However, the magnitude of improvements to QoS as a result of the deployment of 700MHz for mobile broadband services relative to LTE is unclear. We have therefore modelled premiums of GBP0.00, GBP0.25 and GBP0.50 to investigate the possible range of impacts.

The McKinsey study did not consider whether this premium is sustainable, whilst data from the Analysys Mason study found that the initial premium eroded over the following years, with the rate of decline varying depending on the deployment. We have therefore modelled a monthly premium of GBP0.25 and GBP0.50[69] from the point where 700MHz is made available, declining in a linear fashion to a premium of 0 after three or five years. This linear decline could lead to quite a conservative estimate of the level of benefit since in reality the benefit may be sustained at its initial level to begin with before tailing off more rapidly in later years. We note that the initial premium of GBP0.50 is also similar to the value used by Real Wireless[17] when testing the affordability of network investment in the future.

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[67] Analysys Mason, *The launch of 4G can improve revenue performance but cannot alone compensate for difficult market conditions, 2013*, see http://www.analysysmason.com/Research/Content/Comments/LTE-launches-revenue-Aug2013-RDTN0-RD008/#06%20August%202013

[68] McKinsey and Company, *Seizing the 4G opportunity*, see http://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/telecoms/pdfs/seizing_4g_2012-02.ashx

[69] These values are in 2022 nominal terms. GBP0.50 in 2022 is equivalent to approximately GBP0.42 in 2014 terms using the model's Spackman discounting methodology and GBP0.25 is equivalent to approximately GBP0.21 in 2014 terms.

► *Churn*

Quarterly subscriber churn is fairly stable for UK mobile operators at between 2% and 3%, and has been at approximately this level for much of the past decade.[70] We consider it reasonable to expect this level of churn to remain broadly steady over the modelled time period.

In our 'without 700MHz' scenarios we assume that churn would remain stable at 10% per annum. In our 'with 700MHz' scenarios we assume that subscriber churn would decline due to improved satisfaction with the service that an operator is able to provide; we assume that this results in an immediate reduction in churn to approximately 7.5%, followed by a gradual return to the baseline over a period of between three and five years. We assume that all operators have the same timescales for improvement of services and devices, such that there is no increase in churn arising from an operator making improvements more quickly than other operators. Since churn could be influenced by other factors that affect competitiveness within the market we have tested a range from no decline to a decline to 5% followed by a return to the baseline over three or five years. We assume that the change in churn is the same for both voice and mobile broadband subscribers.

Since this study considers costs and benefits at a market level the churn level is a multiplier for SAC to calculate the overall acquisition costs. It does not alter the subscriber numbers considered in the calculation.

► *Subscriber acquisition costs*

We have assumed that SAC evolve over time independent of the change of use of 700MHz spectrum because, for the most part, these costs are a function of costs such as handset subsidies, marketing and operating retail channels. These factors are therefore more related to the level of competitiveness between mobile operators than to their spectrum holdings. However, we have tested the effect of the following options for evolution of SAC, because these will affect the commercial value derived from different churn assumptions:

- SAC rise with inflation
- SAC grow by 1% per annum in nominal terms
- SAC remain flat in nominal terms
- SAC decline by 1% per annum in nominal terms.

We assume that both mobile voice and mobile broadband SAC follow the same trend. By testing a range of values we have been able to report a range of possible commercial values that may occur, depending on the evolution of the competitive landscape in the mobile broadband market over the modelled time period.

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[70] Analysys Mason Research, *Telecoms Market Matrix Western Europe 2Q 2013*, see http://www.analysysmason.com/Research/Content/Data-set/TMM-WE/

Additional network costs

The impacts on ARPU, SAC and churn assume that improved QoS is available nationwide and not just within cell areas that ‘need’ 700MHz carriers in order to provide sufficient low-frequency capacity to meet demand. Therefore it is appropriate to calculate the commercial value net of the costs incurred in deploying and operating 700MHz at sites that would not otherwise be upgraded to make use of 700MHz spectrum (as defined by the network cost saving assessment in the consolidated model). This is because the commercial value could not be realistically achieved with 700MHz deployed only at capacity constrained sites.

Therefore we calculate the number of sites that are not upgraded to deploy 700MHz spectrum by the generic operator and assume that these are deployed in the first year that 700MHz spectrum is available. Operational expenditure incurred is treated in the same way i.e. the cost of operating sites that are not required to meet capacity demands are allocated to additional network costs whilst the costs of those required to meet capacity are accounted for in the consolidated model instead.

Results

We have used the above inputs to calculate the difference in cashflow between a ‘with 700MHz’ scenario and a ‘without 700MHz’ scenario in each year (excluding network cost savings). This method assumes that changes in other key drivers of revenue remain relatively unchanged or are accounted for by the changes in ARPU, churn and SAC (e.g. subscriber retention costs are accounted for in churn and SAC). We then applied the same methodology as used in the network cost savings calculation to find the NPV (using the Spackman approach) of this benefit over the same time period. The model does not calculate the terminal value of the benefit in the NPV output because the operator benefits all occur within the modelled period and there is therefore no terminal value to this component of the calculation.[71]

The overall results represent an estimated range for the lower bound for the additional benefits of improved coverage, capacity and performance resulting from a 700MHz allocation to mobile broadband. Given the uncertainty regarding the precise impact of QoS improvements on the drivers of commercial value the results should be considered as an indicator of the likely magnitude of the operator upside, rather than a detailed projection.

We have also tested each of the key performance indicators to assess the impact that a range of plausible changes in a single indicator at a time would make. All the results of this analysis are presented in Section 5.3.

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[71] The additional network costs are also primarily incurred in the early years of the model, although there is a small enduring operational expenditure associated with the operation of 700MHz sites. However, beyond the modelled period we exclude this from the NPV since we do not consider that this cost should be allocated fully to a benefit which has long since ceased to exist. In other words, were there no other reason to continue operating 700MHz carriers on sites which are not capacity constrained, then the carriers could be decommissioned.

4 Outputs of the network cost savings model

The consolidated model calculates the costs of new sites, upgrades and carriers in each of the 24 modelled years from 2018–2041 and uses this information to calculate the present value (PV) of network costs in the case in which the generic operator has a 2×10MHz holding in the 700MHz band and one in which there is no allocation of 700MHz to mobile broadband. The difference in the PV between these two cases provides an estimate of the network cost savings of a 2×10MHz assignment of 700MHz spectrum to the generic operator.

While the modelling calculates the network cost saving to the generic operator associated with a subset of the 700MHz band (2×10MHz), this can be scaled up to give an indication of the network cost savings which might apply were the entire band, most likely either 2×30MHz or 2×40MHz depending on the band plan selected, to be allocated to mobile broadband.

Given the uncertainty over some of the key input parameters, we have tested the impact of the allocation of the 700MHz band to mobile across a number of scenarios and sensitivities.

In Section 4.1 we provide a range of values based on combinations of input parameters which we would expect to provide reasonable upper and lower bounds for the likely network cost savings (i.e. a ‘*central range’ high scenario* and a ‘*central range’ low scenario*). To define these ‘central range’ high and low scenarios we selected values for each input parameter in what we consider to be the most appropriate combinations to provide a realistic view of the possible range of network cost savings. Given the uncertainty over some of the input parameters, we have also defined and tested further ‘wide range’ high and low scenarios that give a wider, yet still plausible range of results.

In Section 4.2 we describe the sensitivity tests we have carried out on the values of individual input parameters. As explained in Section 3.2.1, for the purpose of this sensitivity testing we created a set of ‘*mid-case’* input parameter values, which lie between the respective high and low cases (i.e. around the centre of what we consider to be the plausible ranges for each input parameter). To test the sensitivity of the model to an individual input parameter, we set all parameter values to the respective mid case and then changed a single parameter value to the low case and the high case, considering the resulting impact on the PV of network cost savings.

4.1 High and low scenarios

We have developed high and low scenarios, both for a central and a wide range. These are made up of combinations of parameters that give rise to scenarios which, in the case of the wide range scenarios, although extreme, are not completely unrealistic given the level of uncertainty associated with certain input parameters. While the wide range is plausible, we consider the parameters for the narrower central range to be more likely to arise and therefore the results to be more indicative of the present value of the network cost saving which would arise from the change of use of the 700MHz band to mobile.

Our high and low scenarios are not intended to adjust every input parameter in the model in a complementary direction, as we feel that this would move away from what is realistic. For example, in the high scenarios, in which gross traffic is high, propensity to invest in offloading techniques (among both operators and consumers) would likely be higher and therefore we have used a high offloading scenario to represent the impact of such an investment.

This approach, in which we seek to represent the realistic impact of various parameter choices on other parameters, allows the exclusion of some of the more implausible and extreme results and shifts focus to a range of more likely values.

A detailed list of the values for key parameters used in creating these scenarios is shown in Figure 4.1 below, with reference in each case to the ranges of parameter values defined in Section 3.2 (usually with reference to high, mid and low cases).

Figure 4.1: Parameter inputs to the high and low scenarios [Source: Analysys Mason, 2014]

Key parameters	'Wide range' high scenario	'Central range' high scenario	'Central range' low scenario	'Wide range' low scenario
Traffic forecast[72]	High case	High case	Low case	Low case
Offloading	High case	High case	Low case	Low case
Spectral efficiency forecast	Low case	Low case	Mid case	Mid case
Proportion of new sites that are six sector	0%	0%	50% of the sites that are capable of being upgraded to six sector	50% of the sites that are capable of being upgraded to six sector
Future spectrum availability	Spectrum Scenario 1 (low)[73]	Spectrum Scenario 2 (mid)[73]	Spectrum Scenario 2 (mid)[73]	Spectrum Scenario 2 (mid)[73]
Unit costs	High case	Mid case	Mid case	Low case
Proportion of shared new build sites	25% new sites	50% new sites	50% new sites	90% new sites
Starting sites	16 000	16 000	17 500	17 500
Traffic distribution across sites	Steeper distribution	Steeper distribution	Steeper distribution	Shallower distribution
Traffic served by sub-1GHz spectrum only	22%	22%	18%	18%

In most cases, we have identified reasonable high and low parameter values and assigned these to the scenarios such that the high scenarios for both the wide and central range share a parameter,

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[72] The busy-hour proportion in both the high and low scenarios is set at 7.5%.

[73] For details of the inputs to the spectrum scenarios, see Section 3.2.3.

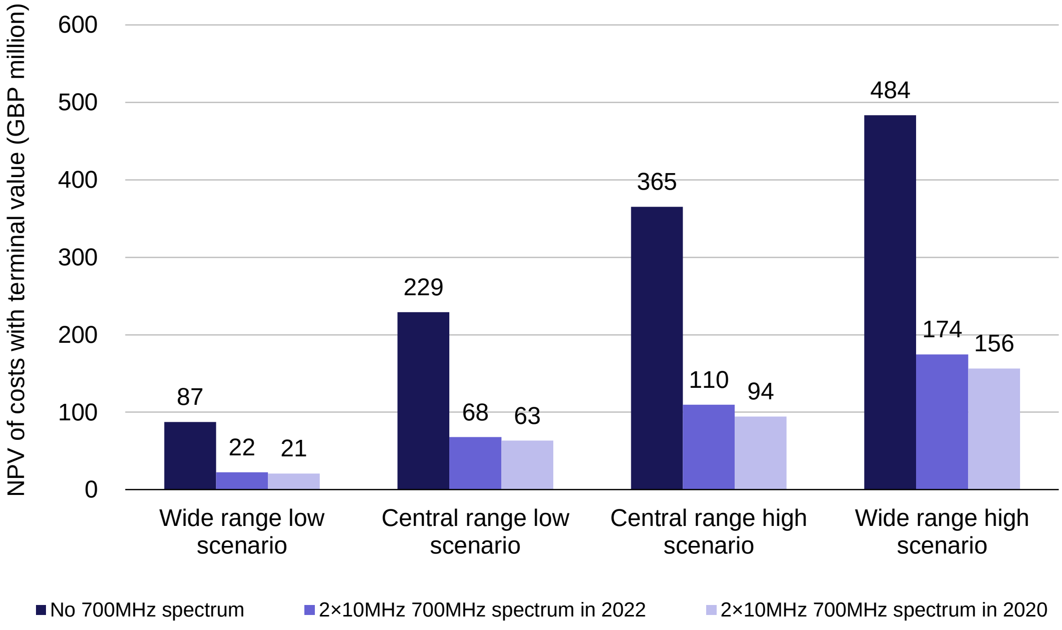
while the wide and central range low scenarios share a different parameter. The exceptions to this are:

- future spectrum availability parameters, which only vary in the wide range high scenario
- unit costs parameters, which vary in the wide ranges but not between low and high in the central range
- unit cost parameters, which vary between the high and low scenarios in the wide range (which are both different from the central range values), but there is no variation between low and high scenarios within the central range
- proportion of shared new-build sites parameters, which vary between the high and low scenarios in the wide range (which are both different from the central range values), but there is no variation between low and high scenarios within the central range
- traffic distribution parameter, which only varies in the wide range low scenario because we have focused on the steep curve (which is based on Analysys Mason's experience involving real network data), as opposed to the shallow curve (derived from the synthetic network in the Ofcom model).

In the case of the spectral efficiency forecast, it is the low and mid parameter values that are used to make up the main scenarios, due to uncertainty over the high spectral efficiency growth in future releases and greater confidence in the more-conservative forecasts being achieved.

Figure 4.2 below shows the PV of network costs (in 2014 real terms) of the central and wide range high and low scenarios in three cases: no 700MHz spectrum allocation, a 2×10MHz allocation (to the generic operator) in 2020, and a 2×10MHz allocation in 2022. These results are quoted for a model using the Spackman discounting approach, not including a terminal value.

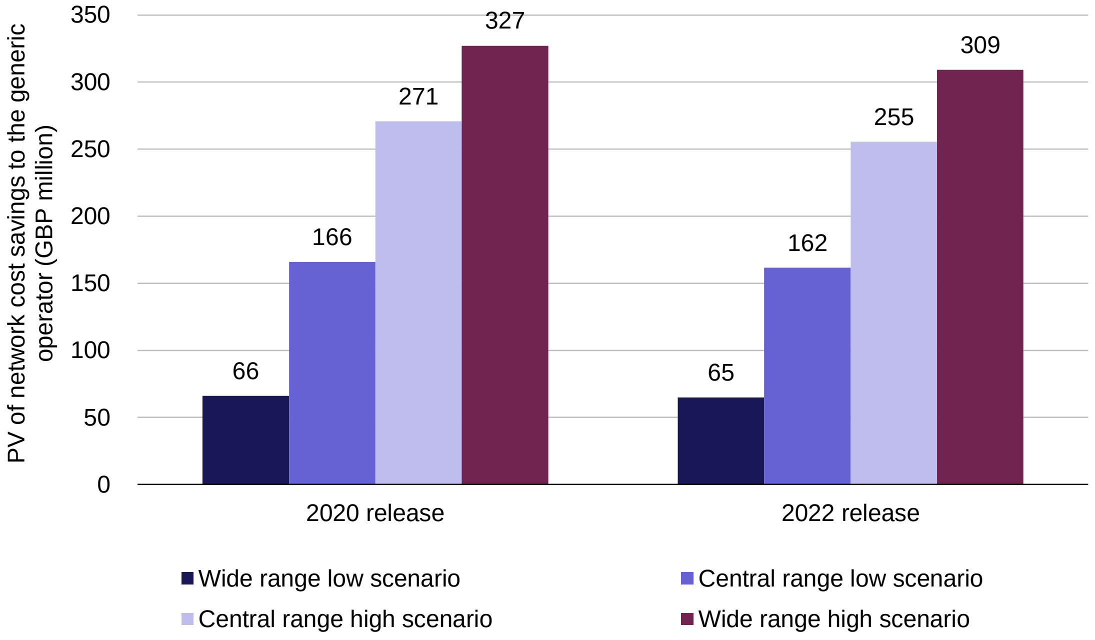
Figure 4.2: PV of different spectrum holding scenarios in the high and low scenarios with a change of use of the 700MHz spectrum in 2020 and 2022 [Source: Analysys Mason, 2014]



The earlier 700MHz change of use date of 2020 gives lower PV of costs results, as there is more time over which the lower-cost 700MHz carriers can be used as a solution to capacity constraints rather than requiring new site builds.

The network cost savings arising from the 2×10MHz allocation of 700MHz spectrum to the generic operator can be found by calculating the difference in the PV of the network costs between scenarios where the generic operator holds no 700MHz spectrum and where it holds 2×10MHz of 700MHz spectrum. These network cost savings of the 2×10MHz allocation of 700MHz to the generic operator are shown in Figure 4.3 below. As can be seen, scenarios with the earlier change of use date result in a higher network cost saving in PV terms than those with the later change of use date.

Figure 4.3: PV of network cost savings of spectrum to the generic operator under a change of spectrum use in 2020 and 2022 [Source: Analysys Mason, 2014]



As previously discussed, there is uncertainty over the 700MHz band plan to be used in any future allocation of the 700MHz band to mobile, although a band plan of either 2×30MHz of 2×40MHz appears most likely. We have therefore extrapolated[74] the network cost savings of both such band plans under the high and low scenarios with a change of use of the 700MHz band in 2022, with the spectrum allocated in lots of 2×10MHz. These network cost savings are shown in Figure 4.4.

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[74] The generic operator PV has been extrapolated up to give the PV of the whole band assuming that either three or four generic operators will be awarded a 2×10MHz lot of 700MHz spectrum. Alternative methods of extrapolating up to give the PV of the whole band using different 700MHz lot sizes are discussed and tested in Section 4.2.

Figure 4.4: PV of network cost savings of the 700MHz band under different scenarios, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
'Wide range' low scenario	65	195	259
'Central range' low scenario	162	485	646
'Central range' high scenario	255	766	1022
'Wide range' high scenario	309	927	1236

4.2 Sensitivity testing

Due to uncertainty regarding the values of several key inputs to the network cost saving calculation, we have conducted sensitivity-based testing in order to understand these inputs and any non-linearity in their impacts. To avoid confusion, we have developed a *sensitivity mid case* in the model using parameter values set to values in the centre of what we consider to be the plausible ranges, as shown in Figure 4.5. As mentioned earlier, this sensitivity mid case does not necessarily represent our view of the most likely level of cost saving as we cannot state with certainty that any one value within the central range is more likely than another. However, we consider that choosing a single set of parameter values is more practical in helping us report on the sensitivity of the model to different values.

Key parameters	Sensitivity mid-case parameters
Traffic forecast	Mid case
Proportion of traffic in the busy hour	7.5%
Spectral efficiency forecast	Mid case
Proportion of new sites that are six sector	50% of sites that are capable of being upgraded to six sector
700MHz spectrum allocation	2×10MHz
700MHz band change of use date	2022
Future spectrum availability	Spectrum Scenario 2 (mid)[73]
Unit costs	Mid case
Proportion of shared new build sites	50%
Starting sites	17 500
Traffic distribution across sites	Steeper distribution
Traffic served by sub-1GHz spectrum only	20%
Discounting methodology	Spackman
Terminal value treatment	Excluded

Figure 4.5: Parameter inputs chosen for the sensitivity mid case [Source: Analysys Mason, 2014]

The sensitivity mid case produces a PV of network cost savings of GBP211 million for 2×10MHz of 700MHz spectrum; with three or four generic operators awarded a 2×10MHz lot of 700MHz spectrum, this would scale up to GBP634 million for a 2×30MHz allocation and GBP845 million for a 2×40MHz allocation.

We have run a number of sensitivities which vary the values of individual input parameters from this sensitivity mid case; these are considered in more detail below.

Traffic and offload forecast

We have tested the impact of a number of gross traffic and offload proportion forecast combinations, focusing on the five net traffic forecasts illustrated in Figure 3.6 earlier. Specifically, Real Wireless extrapolated traffic forecasts both with Real Wireless offload forecasts and Analysys Mason mid case offload forecasts as well as the Analysys Mason low, mid and high case traffic forecasts, all with mid case offload. These five net traffic scenarios are based on the inputs to the Analysys Mason model and the Real Wireless model and, in the consolidated model, produce the PV of network cost savings to the generic operator as shown in Figure 4.6 below.

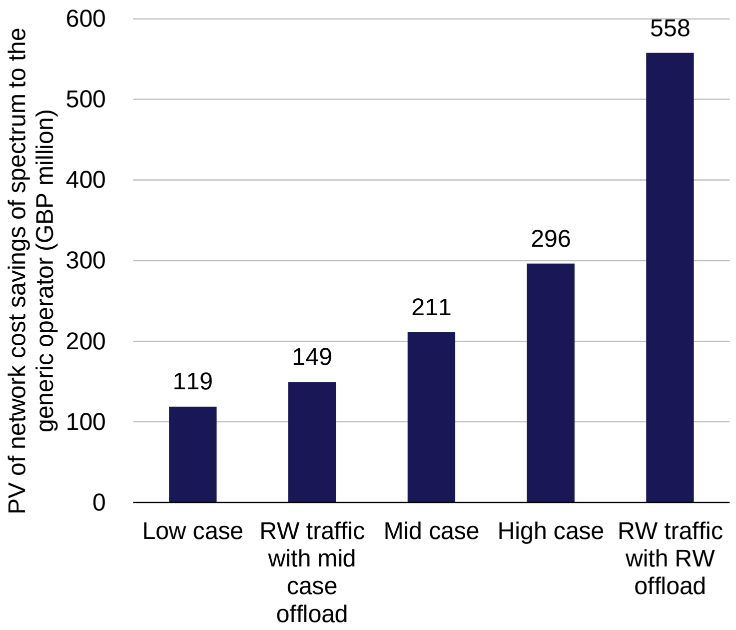


Figure 4.6: PV of network cost savings of spectrum to the generic operator under different traffic inputs [Source: Analysys Mason, 2014]

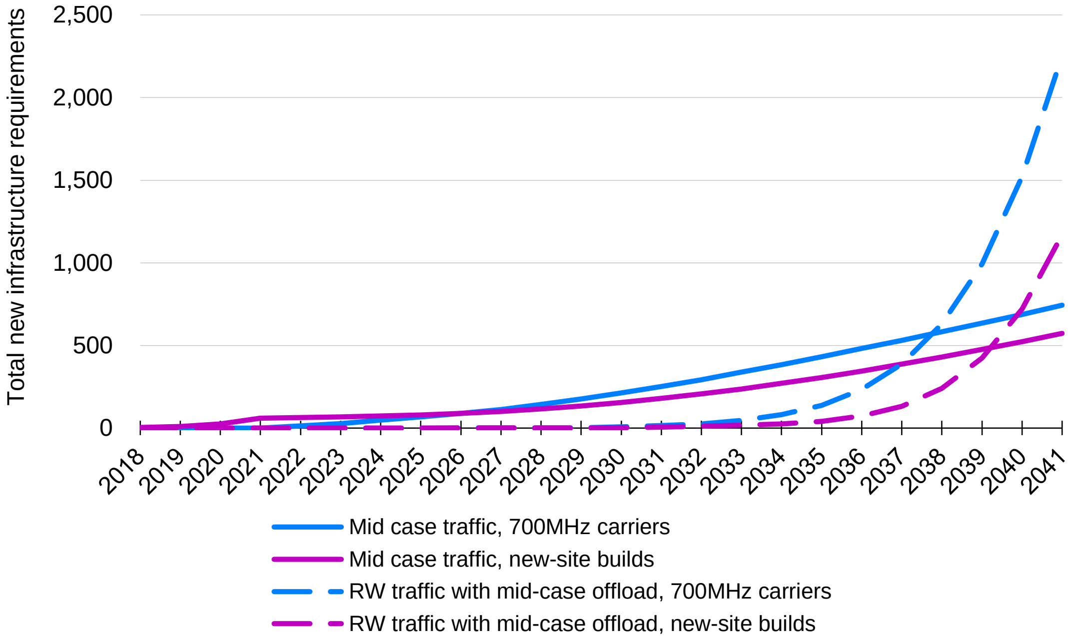
The impact of increasing the traffic net of offload in the model is to increase the value of the 700MHz band, as can be seen from the comparisons of the low, mid and high post offload traffic scenarios in Figure 4.7 below.

Figure 4.7: PV of network cost savings of the 700MHz band with different traffic and offload forecasts, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
Low-case traffic	119	357	476
Real Wireless traffic, mid-case offload	149	448	598
Mid-case traffic	211	635	845
High-case traffic	296	889	1185
Real Wireless traffic, Real Wireless offload	558	1673	2230

The two scenarios based on the Real Wireless gross traffic forecasts have a more exponential traffic growth profile than those based on the Analysys Mason model gross traffic inputs. As a result, using the Real Wireless model traffic with the mid-case offload parameters results in a lower network cost saving than under the mid traffic scenario (also with mid-case offload), despite there being more net traffic on the network post-2035. This is due to how the traffic growth profile influences the roll-out of 700MHz carriers and new sites, as shown in Figure 4.8, and how the costs of these infrastructure roll-outs are discounted.

Figure 4.8: Roll-out of new sites and carriers under the mid-case traffic and the Real Wireless traffic, mid-case offload assumptions [Source: Analysys Mason, 2014]



Proportion of traffic in the busy hour

We use a busy-hour proportion of 7.5% in our sensitivity mid case, in line with the data busy hour used in Ofcom's revised 2011 Wholesale Call Termination model.[24] We have also tested busy-hour traffic proportions of 8% and 6%, as well as a 20-year glide path that declines from 15% in 2013 to 6% in 2033, as shown in Figure 4.9.

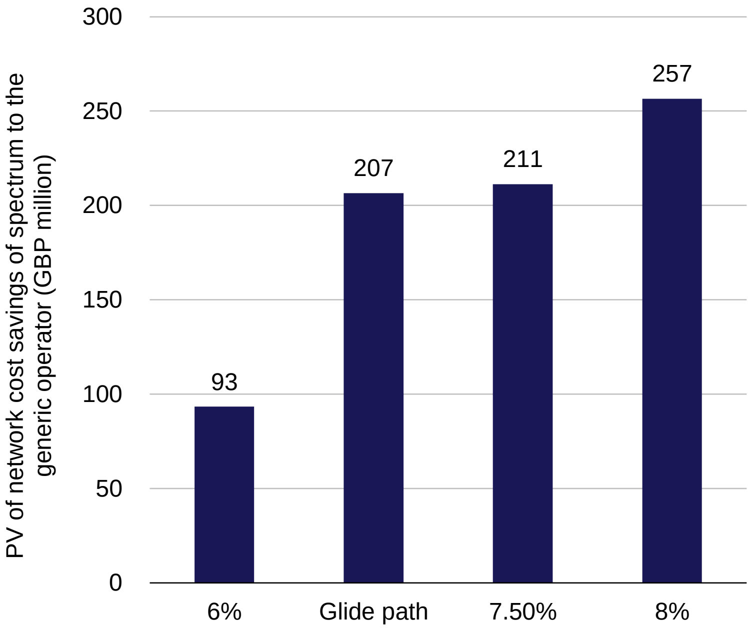


Figure 4.9: PV of network cost savings of spectrum to the generic operator under different busy-hour assumptions [Source: Analysys Mason, 2014]

As shown in Figure 4.10, the impact of increasing the average busy-hour proportion over the modelling period is to increase the value of the 700MHz band, as the network is required to carry a higher peak traffic level.

Figure 4.10: PV of network cost savings of the 700MHz band with different busy-hour proportions, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	**PV of network cost savings of a 2×30MHz allocation of 700MHz**	**PV of network cost savings of a 2×40MHz allocation of 700MHz**
6% busy-hour proportion	93	280	373
Busy-hour proportion glide path	207	620	826
7.5% busy-hour proportion	211	634	845
8% busy-hour proportion	257	770	1026

Developments in spectral efficiency

Since spectral efficiency is a key driver of the number of sites that must be deployed (and of the difference between the original Analysys Mason model and the Real Wireless model), we have tested three variations in the level of improvements in spectral efficiency for LTE technologies. The impact of the change in spectral efficiency on the PV of network cost savings is shown in Figure 4.11 below.

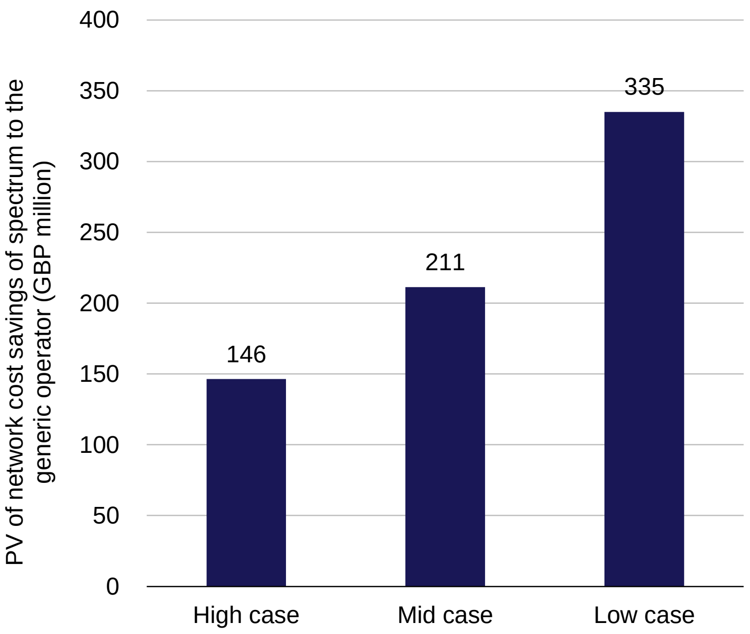


Figure 4.11: PV of network cost savings of spectrum to the generic operator under different spectral efficiency assumptions [Source: Analysys Mason, 2014]

As shown in Figure 4.12 below, the network cost savings arising from access to the 700MHz band falls when the spectral efficiency increases. This is because, with higher spectral efficiency, the spectrum bands can carry more traffic before additional infrastructure deployment is required.

Figure 4.12: PV of network cost savings of the 700MHz band with different busy-hour proportions, GBP billion [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
High spectral efficiency	146	439	585
Mid-case spectral efficiency	211	634	845
Low spectral efficiency	335	1005	1340

Treatment of six-sector sites

The consolidated model tests different proportions of six-sector site upgrades for the 50% of new site builds we consider will be suitable for supporting six-sector sites. The model has been used to test the effect of upgrading the following proportions of 'suitable' sites to six sectors: 0%, 50% and 75%. The impact of the six-sector site upgrade on the PV of generic operator network cost savings is shown in Figure 4.13 below.

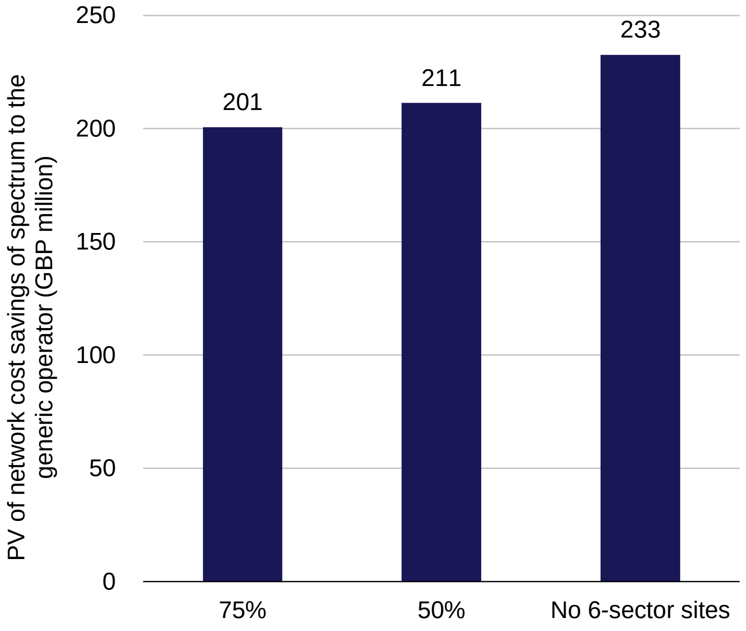


Figure 4.13: PV of network cost savings of spectrum to the generic operator under different six-sector proportion assumptions [Source: Analysys Mason, 2014]

An increase in the proportion of sites upgraded to six sectors increases the capacity per site, thus reducing the value of the 700MHz spectrum band as shown in Figure 4.14. However, the impact is relatively minor because there is an additional cost of upgrading a site to six sectors which is not a long way below that of building a new site when normalised for the amount of additional capacity provided.

Figure 4.14: PV of network cost savings of the 700MHz band with different six-sector site proportions, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	**PV of network cost savings of a 2×30MHz allocation of 700MHz**	**PV of network cost savings of a 2×40MHz allocation of 700MHz**
75% of sites capable of six-sector upgrade	201	602	803
50% of sites capable of six-sector upgrade	211	634	845
No six-sector sites	233	698	930

700MHz spectrum holdings

As well as the case in which the generic operator wins 2×10MHz in the 700MHz band, we have tested two other assignments to the generic operator of 2×5MHz and 2×15MHz. Testing the resulting network cost savings reveals the effect of different sizes of carrier being assigned to the generic operator, as shown in Figure 4.15.

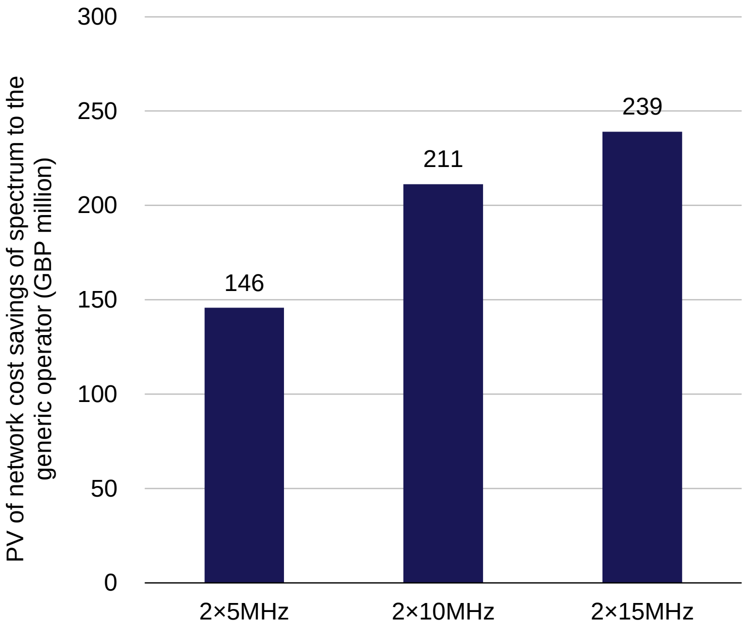


Figure 4.15: PV of network cost savings of spectrum to the generic operator under different 700MHz spectrum holding assumptions [Source: Analysys Mason, 2014]

While a lower allocation of the 700MHz band reduces the network cost savings to the generic operator, it increases the per-MHz network cost saving (as shown in Figure 4.16). For each incremental 2×5MHz lot of spectrum that is added to the generic operator's portfolio, the number of new-build sites avoided decreases. In other words, 2×10MHz of spectrum reduces the number of new site builds required by less than twice the reduction brought about by 2×5MHz of new spectrum. This means that, from a network cost saving perspective, 2×10MHz is not worth as much as double 2×5MHz of spectrum, and therefore generates lower network cost savings on a per-MHz basis.

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator (GBP million)	PV of network cost saving per MHz of the generic operator's 700MHz allocation (GBP million/MHz)
2×5MHz	146	29
2×10MHz	211	21
2×15MHz	239	16

Figure 4.16: PV of network cost savings per MHz to the generic operator under different 700MHz spectrum allocations [Source: Analysys Mason, 2014]

In our other sensitivities we have scaled up the value to the generic operator of a 2×10MHz allocation of 700MHz to give values for band plans with 2×30MHz and 2×40MHz of spectrum. This has been done by assuming that there are three or four identical generic operators who are each awarded a 2×10MHz lot. However, the consideration of different size spectrum lots allows us to extrapolate the value of the band in different ways (as is considered in more depth in Section 4.2).

Timing of the change of use of the 700MHz spectrum to mobile

While our high and low cases are considered with 700MHz change of use to mobile dates of 2020 and 2022, we have also tested sensitivities to examine the impact of change of use in both 2018 and 2026. Figure 4.17 below illustrates the impact on network cost savings of modifying the change of use date.

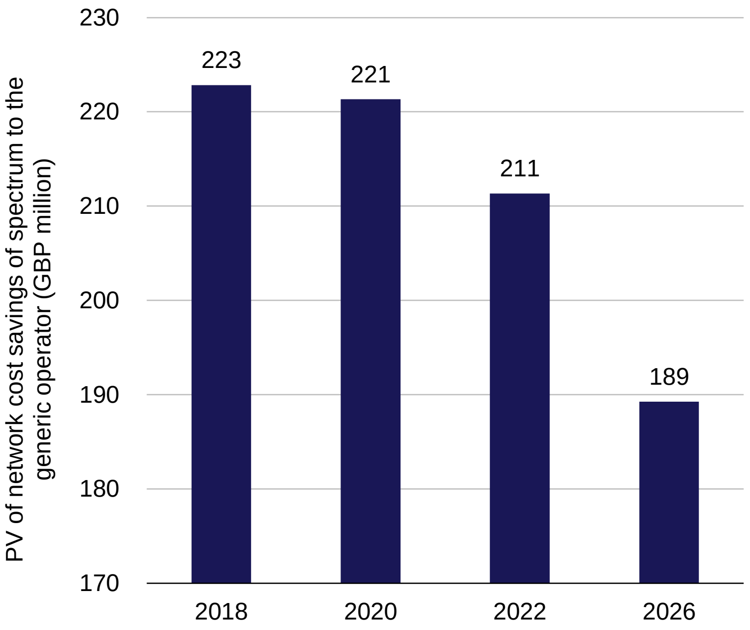


Figure 4.17: PV of network cost savings of spectrum to the generic operator under different 700MHz spectrum change of use date assumptions [Source: Analysys Mason, 2014]

The impact on mobile operators of delaying the change of use of 700MHz spectrum is to reduce the value of the spectrum to them, as can be seen from the full band values for the different launch dates in Figure 4.18. This is because many additional sites would already need to be built in advance of the later spectrum change of use dates in the absence of any 700MHz spectrum being available for mobile use. There is a relatively small reduction in network cost savings as the change of use date moves from 2018 to 2020, but beyond 2020 the cost savings begin to reduce more significantly.

Figure 4.18: PV of network cost savings of the 700MHz band with different 700MHz change of use dates, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
2018	223	669	891
2020	221	664	885
2022	211	634	845
2026	189	568	757

The change of use to mobile of additional spectrum bands over the time period considered

As discussed in Section 3.2.3, there are certain spectrum bands other than the 700MHz band that are not yet, but potentially could be, allocated to mobile broadband in the future. We cannot be certain what the eventual band plans and change of use dates of these bands might be. We have therefore considered the impact on the network cost saving calculation of different potential assignments of spectrum, as shown in Figure 3.12 earlier. The results of the network cost savings calculation under these spectrum allocations are shown in Figure 4.19 below.

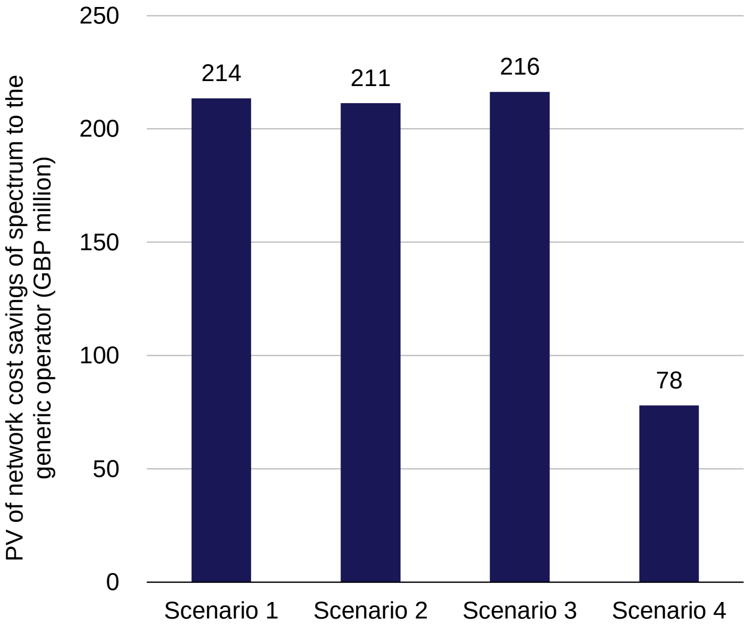


Figure 4.19: PV of network cost savings of spectrum to the generic operator under different future spectrum assumptions [Source: Analysys Mason, 2014]

As can be seen in Figure 4.20, differences in the allocation of supra-1GHz spectrum have a relatively small effect on the network cost savings of a 700MHz allocation. However, the option which involves the largest assignment of low-frequency spectrum, Scenario 4, significantly reduces the network cost savings of 700MHz spectrum to mobile operators. Alternatively, if 700MHz were to be allocated to mobile then it is likely that the additional network cost savings achievable with further sub-1GHz spectrum release available to mobile would be lower.

Figure 4.20: PV of network cost savings of the 700MHz band with different future spectrum availability to mobile, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
Scenario 1	214	641	854
Scenario 2	211	634	845
Scenario 3	216	649	865
Scenario 4	78	234	312

In the PV results shown above and throughout the rest of Section 4, a PV with the change of use of the 700MHz band is always compared to the same counterfactual; that is the PV of network costs in a network with no 700MHz allocation to mobile. The PV in Scenario 4 is much lower than that under the other spectrum scenarios, as the 470–694MHz band spectrum is capable of providing similar coverage and capacity benefits to the 700MHz band. Therefore, the benefits of a 700MHz change of use under spectrum Scenario 4 would tail off after the 2030 allocation to mobile of the 470–694MHz spectrum, in line with the take-up of mobile devices compatible with the 470–694MHz band. However, if spectrum Scenario 4 were to occur (in which the spectrum in the 470–694MHz band is made available), it would almost certainly be accompanied by or follow a change of use of the 700MHz band. Therefore, we also compare the PV with 700MHz spectrum allocation to mobile under spectrum Scenario 4 to a counterfactual in which the 700MHz band is made available in conjunction with the 470–694MHz band in 2030.

Under this alternative counterfactual, we calculated that the PV of network costs is very similar to that under the original counterfactual. Therefore there is no discernible change in the PV of network cost savings from having 700MHz spectrum available from 2022, whichever counterfactual is used. This is because the majority of required sites in any scenario in which 470–694MHz is made available to mobile in 2030 are already built by 2030. This occurs with or without change of use of the 700MHz band in 2030 in the counterfactual. In other words, the 470–694MHz band alone can cause almost the same fall in new site deployments as when made available in conjunction with 700MHz, despite likely later device availability for the band (since compatible devices are still pervading the subscriber base at a rate in line with, or faster than, the growth in traffic).

Unit costs for network equipment

We have tested variations of plus or minus 10% in capex and opex from the mid-case unit-cost inputs to the model. The network cost saving results with these different unit costs are shown in Figure 4.21.

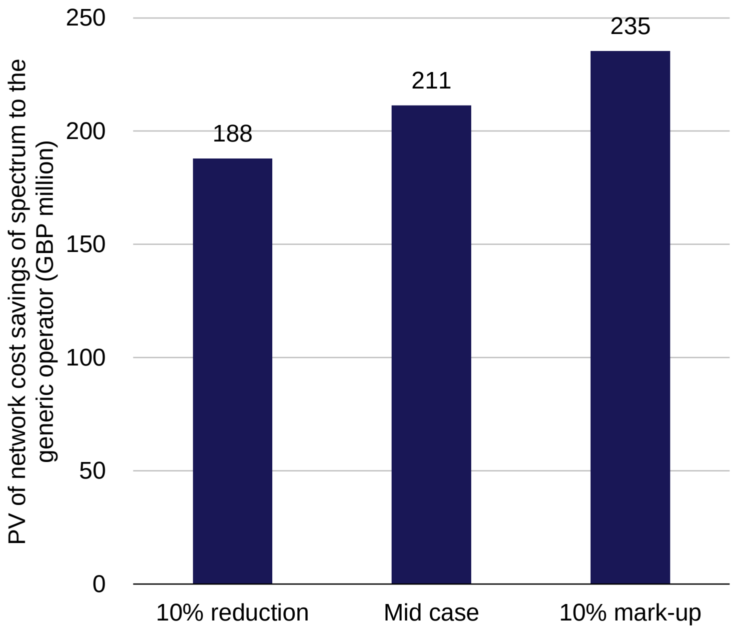


Figure 4.21: PV of network cost savings of spectrum to the generic operator under different unit-cost assumptions [Source: Analysys Mason, 2014]

These generic operator network cost savings can be scaled up to give the network cost savings for the entire band. As shown in Figure 4.22, lower unit costs for network equipment translate into a lower network cost saving arising from access to the 700MHz band.

Figure 4.22: PV of network cost savings of the 700MHz band with different unit costs, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	**PV of network cost savings of a 2×30MHz allocation of 700MHz**	**PV of network cost savings of a 2×40MHz allocation of 700MHz**
Costs with a 10% reduction	188	564	751
Mid-case costs	211	634	845
Costs with a 10% mark-up	235	706	941

► *Unit costs rising more rapidly over time*

We have additionally considered the impact of varying the cost trends to reflect the possibility that as network density increases, the difficulty, and hence the cost, of building new sites rises. To test this we have adjusted the cost trend on new site builds from 2.5% to 5% per annum in nominal terms. The impact of this change in unit cost trends on the network cost saving results is shown in Figure 4.23 below.

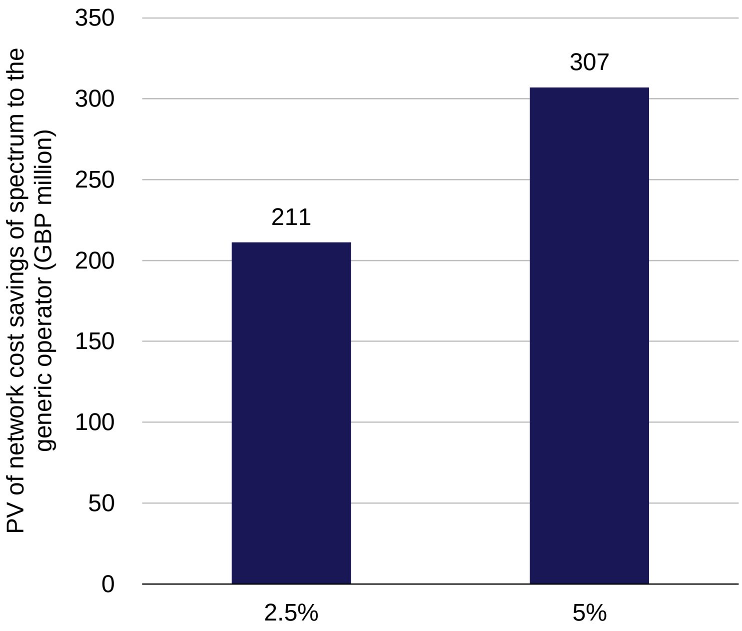


Figure 4.23: PV of network cost savings of spectrum to the generic operator under different cost trend assumptions [Source: Analysys Mason, 2014]

This increase in site build cost trends increases the PV of network cost savings of the change of spectrum use and has a greater impact on the PV than the increase in unit costs shown in Figure 4.22 above.

Figure 4.24: PV of network cost savings of the 700MHz band with different new site build cost trends, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	**PV of network cost savings of a 2×30MHz allocation of 700MHz**	**PV of network cost savings of a 2×40MHz allocation of 700MHz**
2.5% cost trend	211	634	845
5% cost trend	307	921	1228

Proportion of shared new-build sites

We have tested cases in which 90%, 50% and 25% of new-build sites can be shared, as well as a case where there is a steadily increasing proportion of sites that can be shared (from 0% in 2011 to 50% in 2050), and a case in which there is no infrastructure sharing in the modelling period. The network cost savings available to the generic operator with these different proportions of site sharing are illustrated in Figure 4.25 below.

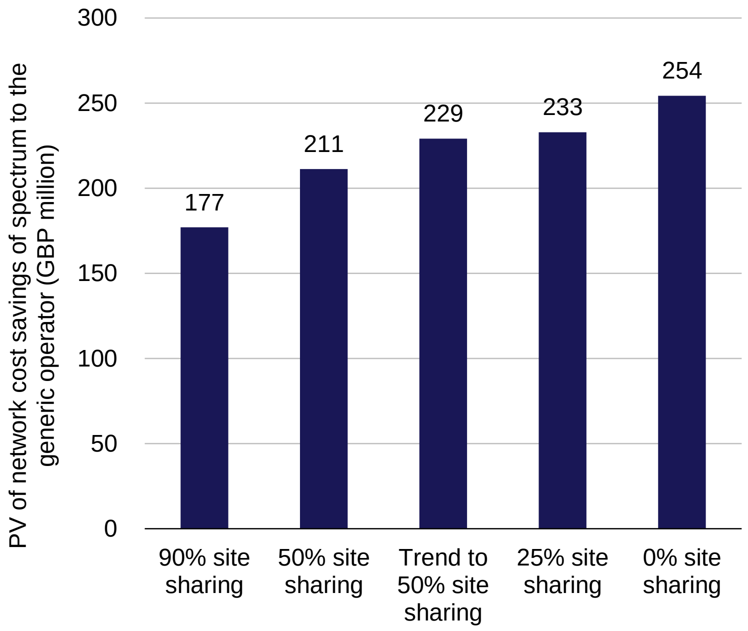


Figure 4.25: PV of network cost savings of spectrum to the generic operator under different site sharing assumptions [Source: Analysys Mason, 2014]

As can be seen in Figure 4.26, the greater the average level of site sharing over the modelling period, the lower the network cost savings which are achievable.

Figure 4.26: PV of network cost savings of the 700MHz band with different levels of site sharing, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	**PV of network cost savings of a 2×30MHz allocation of 700MHz**	**PV of network cost savings of a 2×40MHz allocation of 700MHz**
90% site sharing	177	531	708
50% site sharing	211	634	845
Glide path from 0% in 2011 to 50% in 2050	229	688	917
25% site sharing	233	698	931
0% site sharing	254	763	1017

► *Extent of site sharing*

The proportion of sites shared has a relatively low impact on the model results. This can be attributed to the assumption that only the new build site costs are shared among the operators while active equipment costs remain unshared. Figure 4.27 below shows the impact of changing which costs are shared by the operators under the assumption of 50% of new sites shared. In particular we consider scenarios in which only passive infrastructure is shared and in which both passive and active infrastructure are shared.

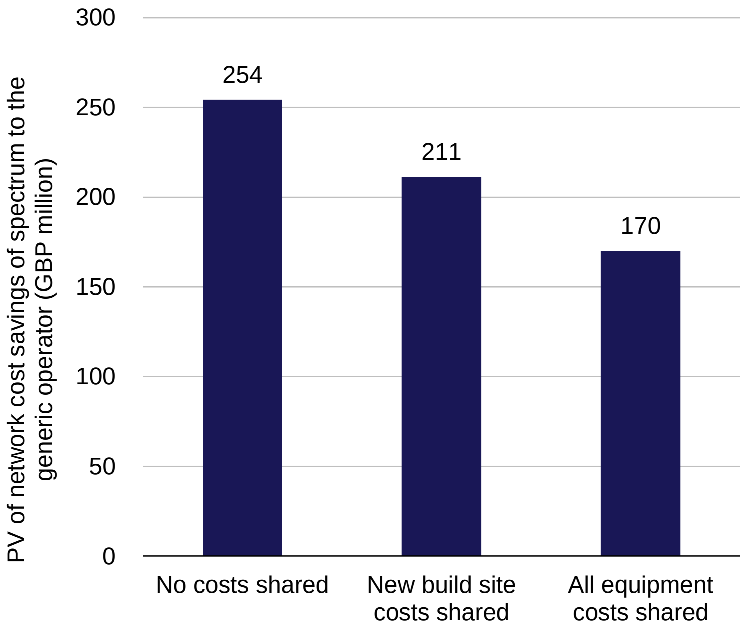


Figure 4.27: PV of network cost savings of spectrum to the generic operator under different equipment cost sharing assumptions [Source: Analysys Mason, 2014]

As shown in Figure 4.28, additionally sharing the active equipment costs for shared sites reduces the PV of network cost savings of the 700MHz band.

Figure 4.28: PV of network cost savings of the 700MHz band with different levels of equipment cost sharing, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
No costs shared	254	763	1017
New build site costs shared	211	634	845
All equipment costs shared	170	510	680

Initial site numbers

We have modelled initial site numbers based on those in Ofcom's technical modelling in support of its combined award final decision (800MHz and 2.6GHz), of 18 500, 17 500 and 16 000 sites. We have also calculated the network cost savings for a generic operator network with 12 000 starting sites. The PV of network cost savings for a generic operator with these initial numbers of sites can be seen in Figure 4.29.

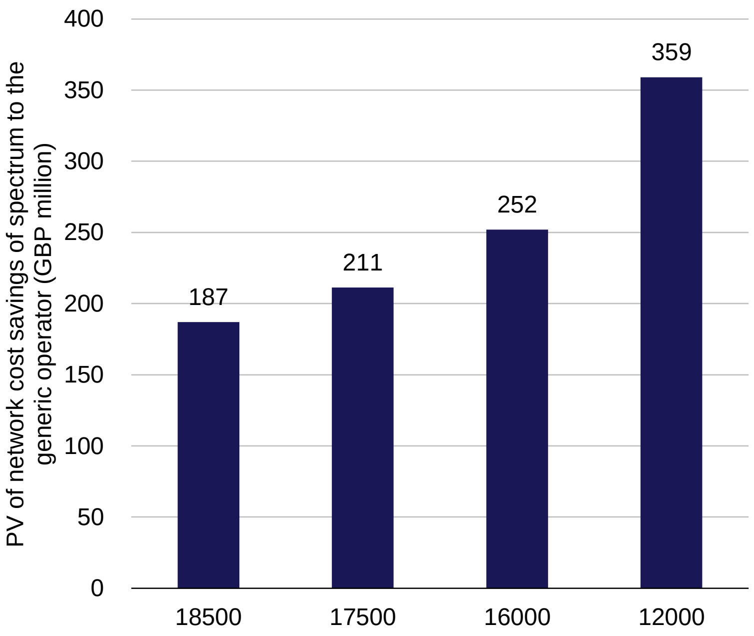


Figure 4.29: PV of network cost savings of spectrum to the generic operator under different starting site assumptions [Source: Analysys Mason, 2014]

A reduction in the initial number of sites increases the need for additional sites or carriers at the start of the modelling period and thus increases the value of the 700MHz spectrum band, as shown in Figure 4.30.

Figure 4.30: PV of network cost savings of the 700MHz band with different 700MHz starting site numbers, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	**PV of network cost savings of a 2×30MHz allocation of 700MHz**	**PV of network cost savings of a 2×40MHz allocation of 700MHz**
18 500 sites	187	561	748
17 500 sites	211	634	845
16 000 sites	252	756	1008
12 000 sites	359	1077	1436

Traffic distribution across sites

We have tested the impact on the network cost savings of two different distributions of traffic across sites within any given geotype; the results are illustrated in Figure 4.35 below. These traffic distribution profiles are governed by a formula of the form $y = a \times \ln(x) + b$, as discussed in Section 3.2.6 earlier.

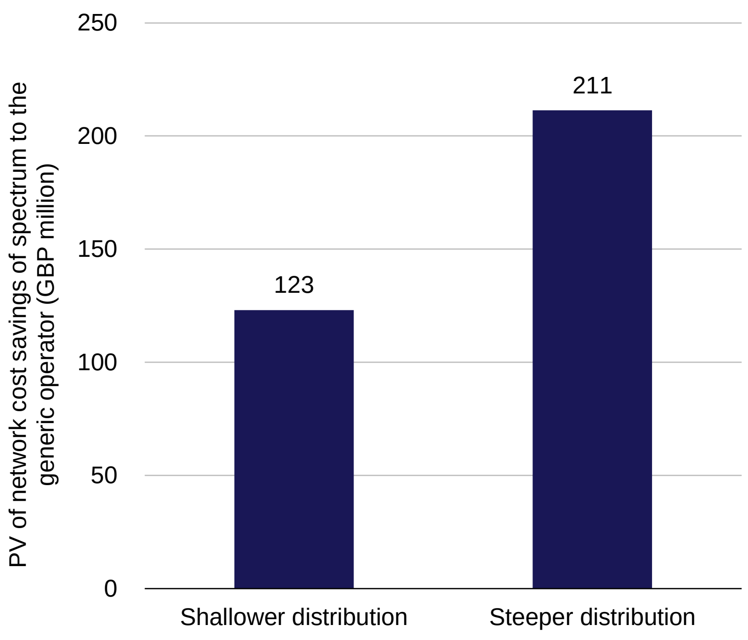


Figure 4.31: PV of network cost savings of spectrum to the generic operator under different traffic distribution across sites assumptions [Source: Analysys Mason, 2014]

As can be seen in Figure 4.32, a steeper traffic distribution, such that the busiest sites carry a higher volume of traffic, therefore requiring more capacity to serve this, results in a higher network cost saving for the 700MHz band. The relative difference between the results with the two distributions tends to be higher in scenarios with a lower absolute network cost saving.

Figure 4.32: PV of network cost savings of the 700MHz band with different traffic distribution profiles, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	**PV of network cost savings of a 2×30MHz allocation of 700MHz**	**PV of network cost savings of a 2×40MHz allocation of 700MHz**
Shallower traffic distribution profile	123	369	492
Steeper traffic distribution profile	211	634	845

Traffic distribution within site areas

As discussed in Section 3.2.7, the results of our calculations of the proportion of the population covered by a threshold level of SINR using the Ofcom model suggest that values of 25.5%, 22%, 20%, 18% and 14.5% are an appropriate range of values to test for the proportion of traffic generated in areas that can only be served by sub-1GHz spectrum bands. The network cost savings of a 2×10MHz generic operator allocation under these different proportions are illustrated in Figure 4.33 below.

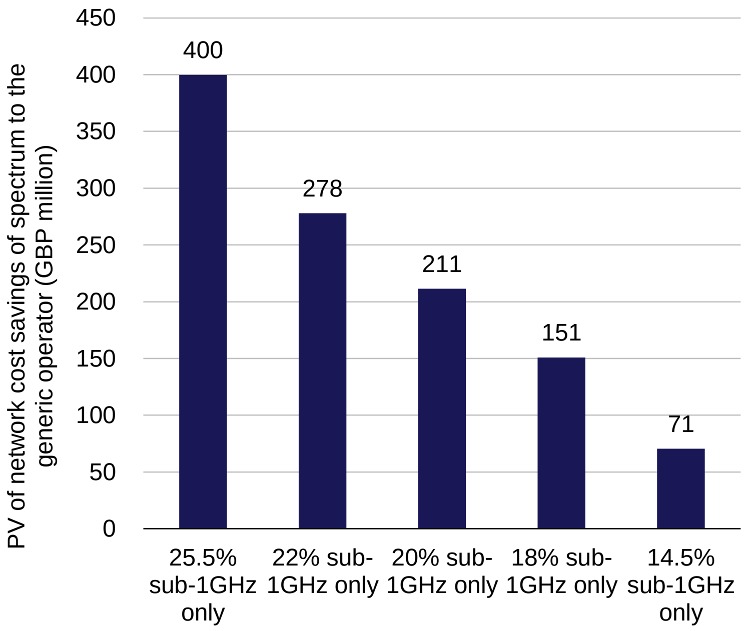


Figure 4.33: PV of network cost savings of spectrum to the generic operator under different sub-1GHz specific traffic assumptions [Source: Analysys Mason, 2014]

As shown in Figure 4.34 below, the network cost savings provided by a 700MHz allocation decrease when the proportion of sub-1GHz specific traffic is reduced. This reflects the fact that much of the value of the band originates from the additional capacity it provides towards the cell edges, where the capacity is otherwise more limited (being only served by the 800MHz and 900MHz bands).[75]

Figure 4.34: PV of network cost savings of the 700MHz band with different sub-1GHz specific traffic proportions, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
25.5% sub-1GHz specific traffic	400	1199	1599
22% sub-1GHz specific traffic	278	834	1112
20% sub-1GHz specific traffic	211	634	845
18% sub-1GHz specific traffic	151	452	603
14.5% sub-1GHz specific traffic	71	212	282

Although we have run these scenarios, we feel that the assumption of 14.5% sub-1GHz specific traffic is unlikely to be realistic given that the 18 000-site synthetic network is likely to produce an

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[75] In spectrum scenario 4, spectrum in the UHF bands also provides sub-1GHz capacity after 2030.

underestimate of the coverage delta between low- and high-frequency spectrum, as discussed in Section 3.2.7 earlier.

Discounting methodology

The consolidated model discounts costs using the Spackman approach, although we have also tested the impact on the results of using a standard discounting methodology to convert the costs of network deployment to present values. The discount rates tested are the mobile operator regulated WACC of 6.2% pre-tax real (8.86% pre-tax nominal) and the social discount rate of 3.5% suggested by HM Treasury's Green Book. The PV of network cost savings to the generic operator using these different discounting methodologies can be seen in Figure 4.35, both with terminal value to perpetuity and without terminal value.

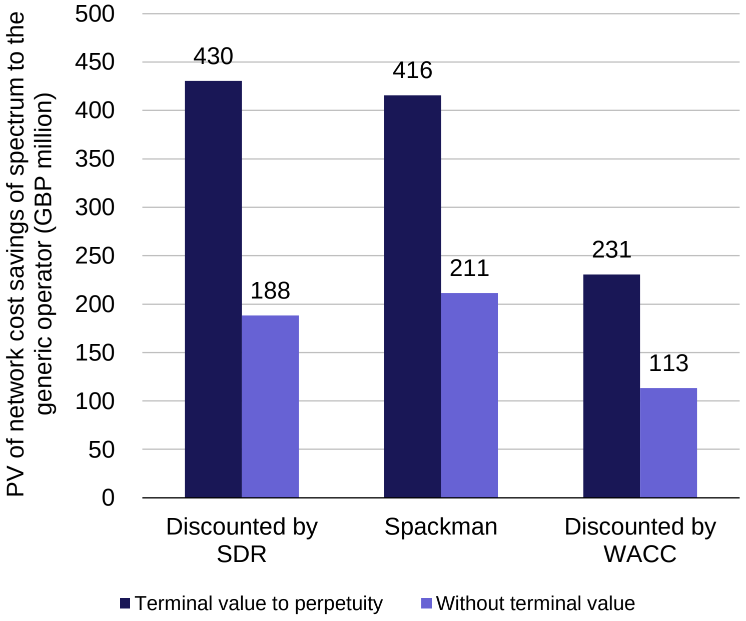

Figure 4.35: PV of network cost savings of spectrum to the generic operator under different discounting methodologies [Source: Analysys Mason, 2014]

It can be seen in Figure 4.35 that the proportion of the network cost saving made up of the terminal value is dependent on the discounting methodology used. Under the Spackman discounting approach, the terminal value makes up around 49% of the total. This is in line with the proportion of value in the terminal value, 51%, when a standard discounting methodology is used and the results are discounted by the WACC. For a standard discounting methodology using the SDR as the discount rate the proportion of value arising in the terminal value is slightly higher, at 56%. In general it is to be expected that the proportion of value arising in the terminal value will be higher for a lower discount rate. However, the Spackman discounting methodology results in a lower proportion of value in the terminal value than a standard discounting approach using the SDR, because capital costs are annualised over a 20-year period following the year in which they are incurred and are therefore discounted to a greater extent than they would be under a standard discounting approach with the same discount rate. This reduces the proportion of value arising in later years and hence the proportion which is part of the terminal value.

The total network cost savings achievable from allocating the whole of the 700MHz band to mobile with the various discounting approaches are shown in Figure 4.36, which illustrates that a higher discount factor has the impact of reducing the network cost savings when a traditional discounting approach is used. The use of the Spackman discounting approach produces a higher network cost saving when a terminal value is not included.

Figure 4.36: PV of network cost savings of the 700MHz band with different discounting methodologies, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
Discounted by social discount rate	188	565	753
Spackman	211	634	845
Discounted by WACC	113	340	453

Terminal value

The consolidated model results quoted up to this point in the report exclude a terminal value unless otherwise stated. However, the model also produces network cost savings results inclusive of a terminal value, calculated both to perpetuity and for only 20 years past the end of the modelling period, as shown in Figure 4.37 below.

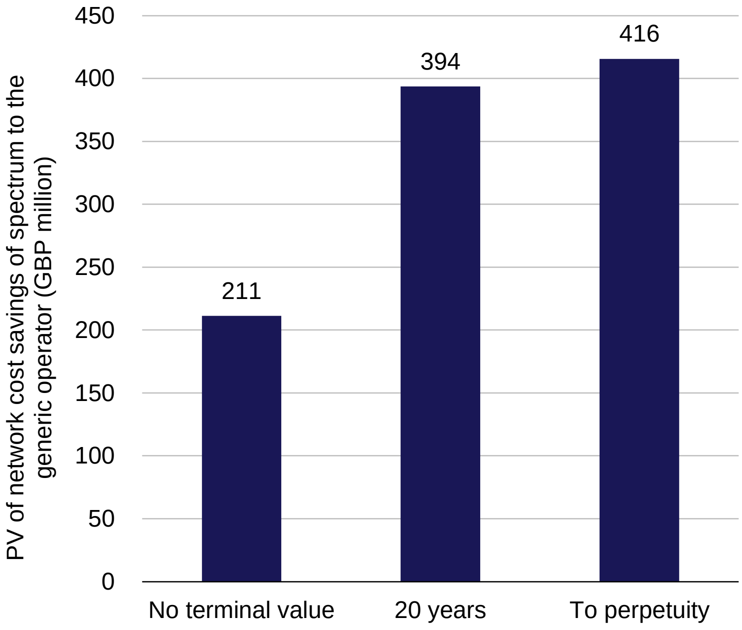

Figure 4.37: PV of network cost savings of spectrum to the generic operator with different approaches to the terminal value calculation [Source: Analysys Mason, 2014]

The inclusion of the entire terminal value or a terminal value calculated over a period of 20 years increases the calculated 700MHz band value, as shown in Figure 4.38. Whilst results in this report are generally presented without terminal value, we note that the exclusion of a terminal value provides results which do not fully illustrate the network cost savings likely to be achievable by operators.

Figure 4.38: PV of network cost savings of the 700MHz band with different terminal value approaches, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
No terminal value	211	634	845
20-year terminal value	394	1181	1574
Terminal value to perpetuity	416	1247	1663

Alternative scaling of 2×10MHz cost saving to full band cost savings

As discussed in Section 4.1, we have extrapolated our generic operator results to estimate the network cost savings achievable for the entire 700MHz band by scaling up the PV of 2×10MHz of 700MHz spectrum assuming either three or four generic operators in the market receive such spectrum allocations. This allows us to give network cost saving for the entire 700MHz band under band plans with 2×30MHz and 2×40MHz of allocated spectrum.

However, as shown in Figure 4.16, the per-MHz network cost saving value varies quite significantly when the generic operator is assigned different amounts of 700MHz spectrum. This is because for each *incremental* 2×5MHz lot of spectrum that is added to the generic operator’s portfolio, the number of new-build sites avoided decreases. Therefore we can use the PV of network cost saving results calculated for different 700MHz lot sizes to extrapolate alternative network cost saving totals for each band plan.

We have therefore used the following combinations of spectrum assignments to give full band network cost saving estimates:

- 2×30MHz band plan
  - three lots of 2×10MHz
  - two lots of 2×10MHz and two lots of 2×5MHZ
  - one lot of 2×15MHz and three lots of 2×5MHz

- 2×40MHz band plan
  - four lots of 2×10MHz
  - two lots of 2×15MHz and two lots of 2×5MHZ
  - one lot of 2×15MHz, two lots of 2×10MHz and one lot of 2×5MHz.

These combinations are in line with our model assumption of a generic operator with 25% market share and no new entrants to the market. The full band values created using these combinations of spectrum assignment are shown in Figure 4.39 and Figure 4.40 below.

	PV of network cost savings of a 2×30MHz allocation of 700MHz
Three lots of 2×10MHz	634
Two lots of 2×10MHz; two lots of 2×5MHz	714
One lot of 2×15MHz; three lots of 2×5MHz	676

Figure 4.39: PV of network cost savings of the 700MHz band with a 2×30MHz band plan and different 700MHz holdings, GBP million [Source: Analysys Mason, 2014]

	PV of network cost savings of a 2×40MHz allocation of 700MHz
Four lots of 2×10MHz	845
Two lots of 2×15MHz; two lots of 2×5MHz	770
One lot of 2×15MHz; two lots of 2×10MHz; one lot of 2×5MHz	807

Figure 4.40: PV of network cost savings of the 700MHz band with a 2×40MHz band plan and different 700MHz holdings, GBP million [Source: Analysys Mason, 2014]

Delayed device availability

The adoption of a 2×40MHz band plan would not enable alignment with the widely used APT band plan and would therefore reduce global harmonisation. This could result in a lower proportion of devices initially able to support the band in the UK, or in a slower roll-out of devices.

In order to test the possible impact of such a delay in device availability we have tested a case in which devices compatible with the selected 2×40MHz band plan do not become available until 2018, two years later than the 2016 compatible device launch date used in the other sensitivities and scenarios.[76] In addition, we have used a slower take-up curve as illustrated in Figure 3.14 earlier.

The impact of this delay in device availability, as shown in Figure 4.41, is to reduce the PV of the network cost savings for the 700MHz spectrum to the generic operator under spectrum holding assumptions of 2×5MHz, 2×10MHz and 2×15MHz.

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[76] We note that this sensitivity is fairly simple in nature and further work would be required to establish the details of delays in device availability (and their impact on network cost savings) which may result from a band plan not being aligned with the APT band plan.

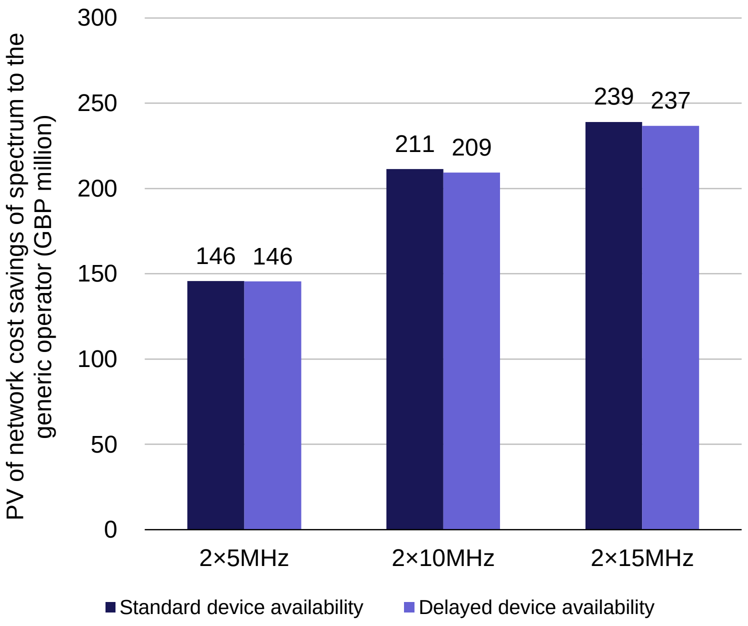


Figure 4.41: Comparison of PV of network cost savings of spectrum to the generic operator with delayed 700MHz compatible device availability [Source: Analysys Mason, 2014]

The results shown in Figure 4.41 are likely to underestimate the impact on network cost savings of selecting a non-harmonised band plan. As discussed in Section 3.2.3, there would be an increase in device cost and therefore the PV of network cost savings would fall further than the reduction arising purely as a result of delayed device availability. Therefore the magnitude of the impact of delayed device availability on the results relative to that of adding an additional lot of 2×10MHz to the band plan should not be taken as evidence that the 2×40MHz band plan would be preferable to 2×30MHz aligned with the APT band plan.

These reduced PV of network cost saving results can be used to extrapolate new cost-saving estimates for the entire 700MHz band under a 2×40MHz band plan, as shown in Figure 4.42. These results are all lower than those calculated with earlier device availability, shown in Figure 4.40.

	PV of network cost savings of a 2×40MHz allocation of 700MHz
Four lots of 2×10MHz	837
Two lots of 2×15MHz; two lots of 2×5MHz	765
One lot of 2×15MHz; two lots of 2×10MHz; one lot of 2×5MHz	801

Figure 4.42: PV of network cost savings of the 700MHz band with a 2×40MHz band plan and different 700MHz holdings, GBP million [Source: Analysys Mason, 2014]

4.2.2 Summary of sensitivity results

We have calculated the network cost savings from the change of use of the 700MHz band to mobile and tested the sensitivity of this to a variety of different assumptions relating to the key inputs. The more realistic of the sensitivity values calculated and discussed in Section 4.2 are summarised in Figure 4.43 below. The table shows the highest and lowest reasonable network cost saving results generated by running sensitivities on each parameter.

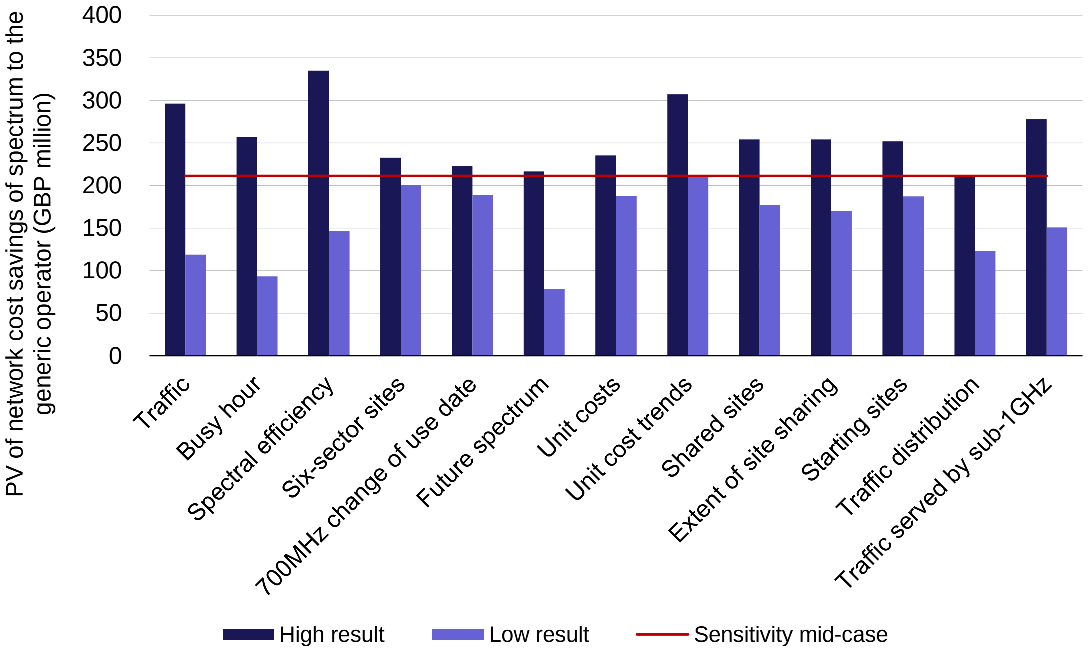
We must stress once more that these sensitivities are all run relative to our sensitivity mid case, which does not necessarily provide the most realistic view of future network cost savings.

Figure 4.43: Summary of sensitivity values for the 700MHz generic operator PV of network cost savings [Source: Analysys Mason, 2014]

Parameter	High	Low	High result (GBP million)	Low result (GBP million)
Traffic forecast	High post-offload traffic	Low post-offload traffic	296	119
Proportion of traffic in the busy hour	8%	6%	257	93
Spectral efficiency forecast	Low case	High case	335	146
Proportion of new sites that are six-sector	0%	75% of sites that are capable of being upgraded	233	201
700MHz band change of use date	2018	2026	223	189
Future spectrum availability	Scenario 3[73]	Scenario 4[73]	216	78
Unit costs	Costs with a 10% mark-up	Costs with a 10% reduction	235	188
Unit cost trends	New site build cost trends of 5%	New site build cost trends of 2.5%	307	211
Proportion of shared new-build sites	0%	90%	254	177
Extent of site sharing	No equipment costs	All equipment costs	254	170
Starting sites	16 000	18 500	252	187
Traffic distribution across sites	Steeper distribution	Shallower distribution	211	123
Traffic served by sub-1GHz spectrum only	22%	18%	278	151

The network cost savings under both the high and low sensitivities are further illustrated in Figure 4.44 below. The sensitivity mid-case is shown by the red line.

Figure 4.44: PV of network cost savings of spectrum to the generic operator under different sensitivity tests [Source: Analysys Mason, 2014]



Sensitivities have also been run on non-technical parameters, including the discounting methodology, terminal value approach and the approach to extrapolating results to produce a cost saving estimate for the entire 700MHz band.

With regard to the discounting approach, the Spackman approach used to produce the majority of results lies just above the results produced using a standard approach that discounts by either the social discount rate or by the WACC. However, when the terminal value is included in these results, the Spackman approach gives a PV of network cost savings that falls between those calculated using a standard approach discounting by the social discount rate and discounting by the WACC. In particular, the inclusion of the terminal value increases the Spackman approach result by approximately 49%, while under a standard depreciation approach, the increase is between 51% and 56%. Under the Spackman approach, the PV of network cost savings is not reduced significantly as a result of using a 20-year terminal value, rather than a terminal value to perpetuity.

We have calculated the PV of network cost savings for different lot sizes (2×5MHz, 2×10MHz and 2×15MHz). The per-MHz network cost saving value falls as the lot size increases, because for each *incremental* 2×5MHz lot of spectrum that is added to the generic operator’s portfolio, the number of new-build sites avoided decreases. These PVs with different lot sizes have allowed us to extrapolate estimates for network costs savings resulting from the entire 700MHz band in a number of different ways, while adhering to the model assumption of a generic operator with 25% market share and no new entrants to the market. In such scenarios the results produced are generally higher than with a straightforward scaling (whereby only 2×10MHz lots are assigned).

We consider that delayed 700MHz-compatible device deployment may be a possibility if a 2×40MHz band plan is adopted, as this would not align with the APT band plan and would therefore reduce global harmonisation. Such a delay would reduce the PV of network cost savings across all 700MHz lot sizes.

5 Consideration of the additional benefits of improved coverage, capacity and performance

In this section we set out the results of our calculations to estimate the additional benefits of improved coverage, capacity and performance resulting from an allocation of the 700MHz band to mobile broadband.

As mentioned in Section 3.3, these additional benefits are subject to a great deal of uncertainty. We have set out two alternative approaches to allow us to elaborate on the form and rough magnitude of the additional benefits. However, in practice these benefits are difficult to quantify precisely and our approach is to identify likely boundaries.

Prior to considering these two approaches in Sections 5.2 and 5.3 we consider an alternative way of considering the benefits captured by the network cost saving calculation in Section 5.1. We then provide a brief summary of our findings in Section 5.4.

5.1 Results of population coverage approach

As described in Section 3.3.1, the Ofcom model with an 18 000-site synthetic network was used to calculate the proportion of population coverage at different SINR levels, corresponding to different levels of single-user throughput. This calculation was performed both with and without 700MHz spectrum. The results, and the differences between them, are illustrated in Figure 5.1 and Figure 5.2 below.

Figure 5.1: Illustration of the effects of 700MHz on achievable single user throughput [Source: Analysys Mason, 2014]

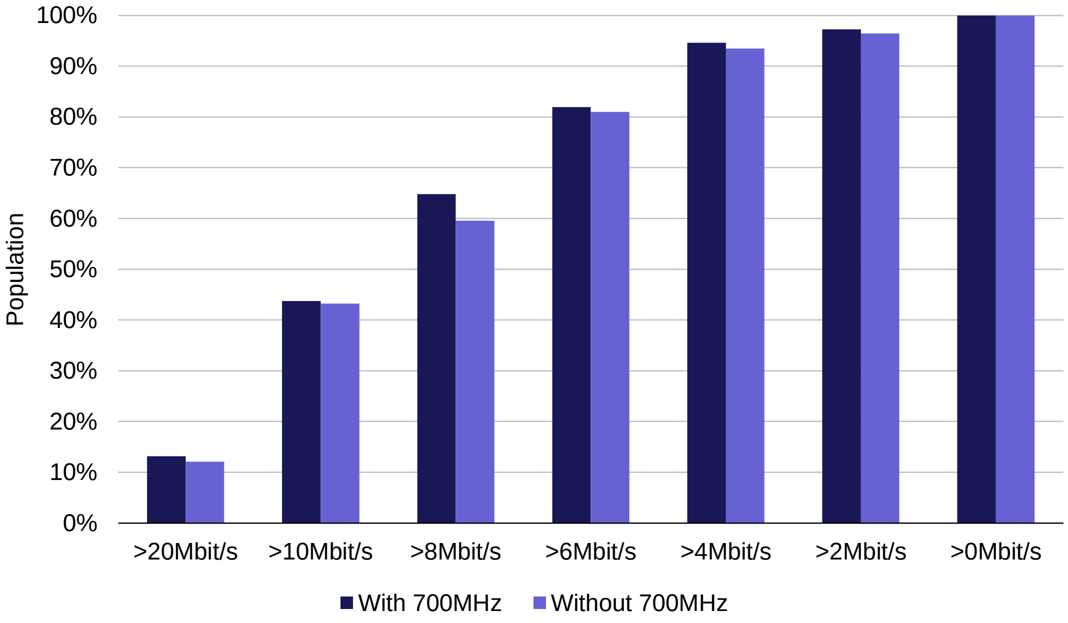


Figure 5.2: Achievable throughput with and without 700MHz [Source: Analysys Mason, 2014]

	With 700MHz		Without 700MHz	
User throughput (Mbit/s)	**% of users**	**Cumulative % of users**	**% of users**	**Cumulative % of users**
<1Mbit/s	1.93%	100.00%	2.35%	100.00%
1–2Mbit/s	0.82%	98.07%	1.20%	97.65%
2–3Mbit/s	1.08%	97.25%	1.18%	96.45%
3–4Mbit/s	1.52%	96.17%	1.78%	95.27%
4–5Mbit/s	3.72%	94.65%	3.80%	93.50%
5–6Mbit/s	8.96%	90.93%	8.72%	89.69%
6–7Mbit/s	8.24%	81.97%	8.08%	80.98%
7–8Mbit/s	8.96%	73.73%	13.30%	72.90%
8–9Mbit/s	13.25%	64.77%	8.60%	59.59%
9–10Mbit/s	7.79%	51.52%	7.74%	50.99%
10–11Mbit/s	3.50%	43.74%	6.64%	43.25%
11–12Mbit/s	6.22%	40.23%	5.75%	36.61%
12–13Mbit/s	5.39%	34.02%	4.90%	30.86%
13–14Mbit/s	4.26%	28.63%	1.92%	25.96%
14–15Mbit/s	1.70%	24.36%	3.22%	24.04%
15–16Mbit/s	3.00%	22.66%	2.74%	20.82%
16–17Mbit/s	2.51%	19.66%	1.17%	18.08%
17–18Mbit/s	1.11%	17.16%	2.12%	16.91%
18–19Mbit/s	2.00%	16.05%	1.89%	14.80%
19–20Mbit/s	0.92%	14.05%	0.85%	12.91%
>20Mbit/s	13.13%	13.13%	12.06%	12.06%

We believe that the population coverage approach gives a good qualitative understanding of the benefits to consumers of the allocation of 700MHz spectrum to mobile broadband. The diagram above shows that the proportion of the population covered with an SINR enabling throughput of more than 4Mbit/s increases by 1.2 percentage points (pp), from 93.5% when 700MHz is not available to 94.7% when 700MHz is available. At the opposite end of the scale, when considering the higher user throughputs, the number of users in areas where it is possible to achieve throughputs of over 8Mbit/s increases by over 5pp, from 59.6% to 64.8% of the population. Further, for supra-20Mbit/s throughputs the proportion increases by approximately 1pp, from 12.1% to 13.1%.

These results suggest that, all else being equal, allocation of the 700MHz band to mobile would increase achievable single-user throughputs, on average.

This difference in population coverage described above represents the benefit to consumers of the 700MHz band being allocated to mobile broadband, because the service provided is improved, in terms of single-user throughput.

It may not be straightforward to quantify the value of the increase in ‘high-quality’ coverage; however, we can draw on previous work to inform this, as described in the following section.

5.2 Results of adjusted technical value approach

The approach assesses the additional network costs that would be incurred by operators were they to provide the same quality of service that a 700MHz allocation would enable, but without access to the 700MHz spectrum and instead using increased network density. We have calculated the adjusted technical value of the 700MHz band using the 12% decrease in effective cell capacity factor set out in Section 3.3. Carrier capacity in the model is reduced by this factor of 12% after the date of 700MHz allocation to mobile. This causes an increase in the PV of network costs in the scenarios without access to the 700MHz band to reflect not only the provision of additional network capacity, but also a quality of service equal to that available with access to the 700MHz band.

This adjusted technical value methodology has been applied to the wide range high, central range high, central range low and wide range low scenarios with a 2022 change of use date for the 700MHz band, as set out in Section 4.1. This gives mark-ups of 71%, 63%, 80% and 94% to the network cost saving results respectively, as shown in Figure 5.3 below.

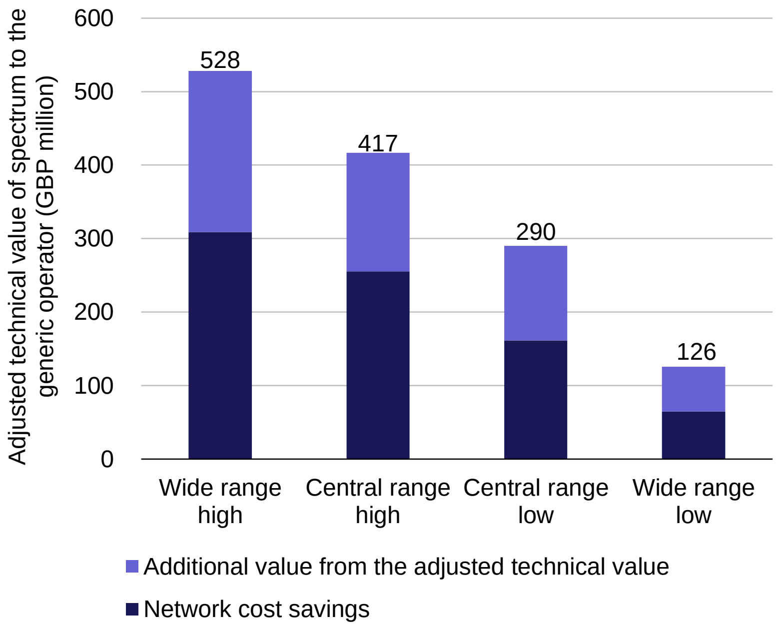


Figure 5.3: Adjusted technical value of spectrum to the generic operator under a spectrum change of use in 2022 [Source: Analysys Mason, 2014]

If calculated from the network cost saving results with a 2020 change of use date, the mark-ups are 70%, 62%, 79% and 93% respectively. This gives a wide range high scenario adjusted technical value of GBP556 million, central range high scenario value of GBP439 million, central range low scenario value of GBP298 million and a wide range low scenario value of GBP128 million to the generic operator. This range forms a likely upper bound to the value to operators, over the modelled period, of allocating the 700MHz band to mobile broadband.

The adjusted technical value results from Figure 5.3 can be scaled up to give the overall benefit for band plans, including both 2×30MHz and 2×40MHz. These values for the different band plans are shown in Figure 5.4 below.

Figure 5.4: Adjusted technical value of the 700MHz band with different band plans, GBP million [Source: Analysys Mason, 2014]

	Adjusted technical value of 2×10MHz of 700MHz to the generic operator	Adjusted technical value of a 2×30MHz allocation of 700MHz	Adjusted technical value of a 2×40MHz allocation of 700MHz
‘Wide range’ low scenario	126	377	502
‘Central range’ low scenario	290	871	1161
‘Central range’ high scenario	417	1251	1667
‘Wide range’ high scenario	528	1585	2113

The adjusted technical value includes both the network cost savings and the additional benefits of improved coverage and performance. In order to estimate only the additional benefits, we can strip out the network cost savings calculated in Section 4.1 from the adjusted technical value figures shown in Figure 5.4 above. The results are shown in Figure 5.5 below.

Figure 5.5: Additional benefits of the 700MHz band with different band plans, as calculated by the adjusted technical value approach, GBP million [Source: Analysys Mason, 2014]

	Additional benefits of 2×10MHz of 700MHz to the generic operator	PV of additional benefits of a 2×30MHz allocation of 700MHz	PV of additional benefits of a 2×40MHz allocation of 700MHz
‘Wide range’ low scenario	61	182	243
‘Central range’ low scenario	129	386	515
‘Central range’ high scenario	161	484	646
‘Wide range’ high scenario	219	658	877

Possible overstatement of additional benefits

In Section 3.3.2 we discussed how the adjusted technical value could potentially overstate the benefit of 700MHz to the generic operator. We explore this point in more detail below.

In particular, we considered that whilst there is a measured benefit of having 700MHz spectrum available for sites of type 2,[77] there may be an unmeasured performance improvement for areas covered by type 1 sites in the 'without 700MHz' case. This unmeasured performance improvement could arise because, where 700MHz carriers are deployed in the 'with 700MHz' case, new sites are deployed in their place in the 'without 700MHz' case. Deploying an additional site increases capacity to a greater extent than deploying an additional carrier. Therefore there is a risk that by building more sites in the 'without 700MHz' network this network is able to deliver a higher level of performance than the 'with 700MHz' network in the areas covered by type 1 sites.

This effect is partially offset by the fact that even in the 'with 700MHz' network there is a need to deploy *some* additional sites to meet the capacity requirements in areas served by type 1 sites. This is because in the areas with highest traffic, deploying a 700MHz carrier will not provide sufficient capacity to meet the growing traffic levels, so an additional site may be deployed as well. In areas where this happens the 'with 700MHz' network will have greater capacity and potentially improved performance relative to the 'without 700MHz' network (it will have the same number of sites as the 'without 700MHz' network but with extra 700MHz carriers on each site).[78]

The magnitude of this net unmeasured performance improvement cannot be calculated in a straightforward manner. However, it is possible to carry out some analysis to consider whether it is likely to be large or small.

We start by considering the number of sites which fall within each of the three categories set out in Section 3.3.2. The split of sites among the different categories (and indeed the total number of sites in the network) varies depending on which scenario we look at in our consolidated model. This is demonstrated in Figure 5.6 below, considering the number of sites in 2021, prior to the availability of 700MHz spectrum.

Figure 5.6: Number of sites of each type in 2021 by scenario [Source: Analysys Mason, 2014]

Scenario	Type 1 sites	Type 2 sites	Type 3 sites	Total number of sites
High	2 504	1 119	12 460	16 083
Central range – high	2 232	979	12 866	16 077
Central range – low	1 605	866	15 057	17 528
Low	861	581	16 071	17 513

We then consider, within the pool of sites of type 1, the number of site areas where there may be an unmeasured performance improvement in the 'with 700MHz' case and the number of site areas

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[77] As defined in Section 3.3.2, type 2 sites are those where 700MHz carriers do not need to be added for capacity reasons, but there may be a performance benefit in doing so. In contrast, type 1 sites are those where 700MHz carriers, or new sites, need to be deployed in order to address capacity constraints.

[78] For sites in areas such as this where a 700MHz carrier does not provide sufficient capacity, we consider it likely that an operator would still deploy a 700MHz carrier in the 'with 700MHz' case. This is because it provides an initially cheaper upgrade solution when future capacity requirements are unknown and because it will likely provide some performance benefit which the operator may, at least in part, be able to monetise. Furthermore deploying 700MHz carriers on such sites may delay or prevent the need for further site requirements in the area beyond our modelled period.

where there may be an unmeasured performance improvement in the ‘without 700MHz’ case. This is summarised in Figure 5.7 below.

Figure 5.7: Number of type 1 sites with a potential unmeasured benefit in the ‘with’ and ‘without’ 700MHz cases [Source: Analysys Mason, 2014]

Scenario	‘Without 700MHz’ network new sites	‘With 700MHz’ network new sites and carriers	Sites with potential unmeasured performance improvement in the ‘without 700MHz’ case	Sites with potential unmeasured performance improvement in the ‘with 700MHz’ case
High	2 504	803	1 701	803
Central range – high	2 232	561	1 671	561
Central range – low	1 605	426	1 179	426
Low	861	186	675	186

Of the areas covered by type 1 sites, Figure 5.7 indicates that there are likely to be a greater number of site areas exhibiting an unmeasured performance improvement in the ‘without 700MHz’ case than in the ‘with 700MHz’ case (i.e. our additional benefits calculation risks overstating rather than understating the benefit). Taking the low scenario as an example, in the ‘without 700MHz’ network 861 sites would be built, but 186 of these sites would also be built in the ‘with 700MHz’ network. Therefore in the ‘without 700MHz’ network there are 675 sites with a potential unmeasured performance improvement from 700MHz change of use, compared to 186 sites with an unmeasured performance improvement in the ‘with 700MHz’ network.

The difference between the final two columns in Figure 5.7 may give some indication of the extent of the net unmeasured performance improvement in the ‘without 700MHz’ case. Overall we expect the magnitude of the net unmeasured performance improvement in the ‘without 700MHz’ case to be small, for two main reasons:

- The above discussion considers sites with a *potential* unmeasured performance improvement. However, only in a minority of cases is there likely to be an *actual* unmeasured performance improvement

- The magnitude of the unmeasured performance improvement is not the same for areas covered by sites with an unmeasured performance improvement in the ‘with 700MHz’ and in the ‘without 700MHz’ cases. In particular, we would expect that there may be a larger unmeasured performance improvement per site in the ‘with 700MHz’ case, although it is not possible to be certain of this.

We consider each of these reasons in turn below.

► *Sites with an actual unmeasured performance improvement*

Although the number of sites with a potential unmeasured performance improvement is reasonably significant, we would only expect a proportion of these sites to actually exhibit an unmeasured performance improvement.

- An additional site in the 'without 700MHz' network will only exhibit an unmeasured performance improvement if the 700MHz carrier deployed in the 'with 700MHz' case is near full capacity. We cannot precisely determine the capacity level above which there will be a benefit, because we do not know the exact location in which new sites will be built in the 'without 700MHz' network. However, in line with the benefits measured for type 2 sites using the adjusted technical value approach, we might expect a performance improvement in the 'without 700MHz' case when over 88%[79] of the capacity of the 700MHz carrier is used in the 'with 700MHz' case.

- Analysis of type 2 and type 3 sites suggests that the number of type 1 sites with an unmeasured performance improvement may be quite small. In total there are between 13 579 and 16 652 sites of either type 2 or type 3, depending on the scenario. Of these only between 581 and 1 119 (i.e. between 3% and 8%) are near to full capacity (i.e. are type 2 sites) and therefore exhibit an unmeasured performance improvement.

- Although we may expect a higher proportion of sites of type 1 to be near full capacity (these are sites with the highest traffic in the first place but are then split) it seems likely that only a modest number of sites would actually exhibit an unmeasured performance improvement.

► *Differences in the magnitude of the unmeasured performance improvement per site area in the 'with 700MHz' and the 'without 700MHz' cases*

Given that low-frequency capacity generally forms the bottleneck in our consolidated model, it is likely that performance benefits arise due to an increased number of low-frequency carriers rather than due to increased numbers of high-frequency carriers. We therefore consider the number of low-frequency carriers at type 1 sites in the 'with 700MHz' and 'without 700MHz' cases.

The generic operator begins with 800MHz and 900MHz spectrum and can add these carriers to its sites. If it has access to 700MHz spectrum (the 'with 700MHz' case) then it can add a third low-frequency carrier to a site covering a given area. On the other hand, if it has no access to 700MHz spectrum (the 'without 700MHz' case) then it can add a new site to cover traffic generated in the same area. This would allow for a second 800MHz carrier and second 900MHz carrier, resulting in a total of four low-frequency carriers.

In the 'with 700MHz' case, if a new site is added then this leads to a total of six low-frequency carriers, compared to four in the 'without 700MHz' case. Therefore the unmeasured performance improvement per site in the 'with 700MHz' case could potentially be greater than in the 'without 700MHz' case.

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[79] This is based on the 12% capacity adjustment we use in the adjusted technical value approach.

► *Conclusion on the magnitude of the unmeasured benefit*

For the reasons mentioned above it seems likely that any net unmeasured performance improvement in the ‘without 700MHz’ case is small.

We have previously mentioned that the additional benefits calculated by the adjusted technical value approach may overstate the benefits of 700MHz to operators, because operators may not commercially choose to improve performance to the levels which 700MHz would allow for without having access to this spectrum, for example if they are unable to fully monetise the performance improvements to an extent which would cover the incremental costs of deploying 700MHz.[80] However, beyond this consideration, we believe that the adjusted technical value approach is unlikely to significantly overstate the benefits to operators of having access to 700MHz spectrum for the modelled period.

5.3 Results of commercial value approach

As described in Section 3.3.3, the commercial value approach attempts to quantify the range of potential additional benefits to operators that could be produced as a result of the improved coverage, capacity and performance operators could provide to consumers following an allocation of the 700MHz band to mobile broadband.

The population coverage approach indicates that there is a modest improvement in single user throughput across all users, regardless of the speeds they are currently capable of receiving as a result of their location in the coverage network. Section 3.3.3 describes why we expect this technical benefit (even after sites have been added to account for any capacity shortfall) to translate into a commercial value, by considering plausible impacts on key drivers of revenue and non-network costs from the mobile operator perspective. Section 3.3.3 also explains the values we chose for each parameter.

Our analysis found that the commercial value would vary significantly depending on how the mobile market evolves, as well as how consumers respond to the improved services that 700MHz could enable. Figure 5.8 below shows the extreme ranges of the commercial value that could be possible, although we are confident that the central case is the most representative of the likely responses to the availability of 700MHz spectrum for mobile broadband.

The values in the tables below relate to the generic operator holding a 25% market share and assume a holding of 2×10MHz of 700MHz spectrum. The calculation relates to the same assessment period as for the adjusted technical value and uses the same Spackman methodology to discount benefits accruing in future years. As discussed in Section 3.3.3 some additional network costs are netted off the calculated commercial benefit to derive the results set out below. Therefore there is a small variation in the commercial value results depending on which scenario in the consolidated network cost saving model is used. However, this impact is very small compared to

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[80] On the other hand, we also previously mentioned that the adjusted technical value, like other approaches followed in this study, may understate the overall benefits of 700MHz because the benefits to consumers of improved network performance are not considered.

other factors which we sensitivity test below and we therefore provide all results based on the sensitivity mid-case in our consolidated model.

Scenario	Upper bound	Central case	Lower bound
Commercial value – change of use in 2022 (GBP million)	366	119	25
ARPU	50p premium eroded over five years	25p premium eroded over five years	25p premium eroded over three years
Churn	Drops to 5% and returns to 10% baseline over five years	Drops to 7.5% and returns to 10% baseline over five years	Drops to 7.5% and returns to 10% baseline over three years
SAC	Rise with inflation	Rise with inflation	Rise with inflation

Figure 5.8: Range of possible commercial value to generic operator of allocating 700MHz to mobile broadband [Source: Analysys Mason, 2014]

The commercial value approach calculates a likely lower bound for the additional benefits of improved coverage and performance resulting from a 700MHz allocation to mobile. This is because, as with the other approaches to calculating benefits detailed in this report, only the benefits to operators are captured, not any additional consumer surplus. Therefore we would expect the lower bound to the additional benefits in the modelling period to be in the region of GBP119 million, as our central case is the most likely response. The variation seen in the sensitivity tests we undertook supports this conclusion. However, if market conditions were shifted to the extremes that can currently be considered to be plausible, this could push the commercial value closer to the bounds identified above.

5.3.1 Sensitivity testing

ARPU

Figure 5.9 below demonstrates the sensitivity of the commercial value (to the operator) to the ARPU scenarios we identified in Section 3.3.3. Both the high and low values are generated by scenarios we deem to be at the extremes of what is plausible. On the basis of the studies discussed in Section 3.3.3 we believe it is likely that some ARPU premium could be extracted by operators as a result of improved services, although we do not believe that improved services would be likely to generate a premium that consumers would value at the same level indefinitely. Therefore we are confident that the most plausible scenario is one in which a small premium in ARPU could initially be generated (of the order of GBP0.25 per subscriber per month), and would then be eroded over a period of approximately five years. Nonetheless, there is a high level of uncertainty over the exact value.

Scenario	Resulting commercial value (GBP million)
No premium	-83[82]
25p premium eroded over three years	25
25p premium eroded over five years	88
50p premium eroded over three years	130
50p premium eroded over five years	242

Figure 5.9 Sensitivity of commercial value to ARPU[81] [Source: Analysys Mason, 2014]

Note: Each of the above results assumes that churn falls to 7.5% and then returns to 10% over three years, and that SAC rises with inflation.

Churn

Figure 5.10 below demonstrates that a 1pp reduction in churn in one year, followed by a return to the long-term baseline of 10% annual subscriber churn over three years represents a difference in commercial value of approximately GBP25 million to the market. Commercial value responds quite linearly to changes in churn, since it is a product of SAC, churn and the number of subscribers in the market.

If there were no impact on churn then the value of the impact on ARPU net of the additional technical costs is the only remaining component of commercial value. In the scenario used below this corresponds to GBP25 million

Scenario	Resulting commercial value (GBP million)
Drop to 5% then return to 10% over 3 years	150
Drop to 6% then return to 10% over 3 years	125
Drop to 7% then return to 10% over 3 years	100
Drop to 8% then return to 10% over 3 years	75
Drop to 9% then return to 10% over 3 years	50
No change (10% flat)	25

Figure 5.10: Sensitivity of commercial value to churn[81] [Source: Analysys Mason, 2014]

Note: Each of the above results assumes that there is an initial ARPU premium of 25p per month (returning to the inflation-only growth baseline over five years) and that SAC grows with inflation.

SAC

SAC are unaffected by 700MHz directly, although they do scale the value of the impact on churn. Figure 5.11 below shows the magnitude of the impact that a change in SAC would have, under the

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[81] Assuming deployment of 700MHz in 2022.

[82] This negative value indicates that the costs of upgrading the network outweigh the benefits accrued from deploying 700MHz across the network. If this was truly the case the operator would not upgrade the network and the true commercial value in this scenario would therefore be zero.

same churn scenario. This demonstrates that the level of SAC has a modest impact on commercial value, but this is partly because SAC is not thought to be a volatile parameter in the mature UK market.

Scenario	Resulting commercial value (GBP million)
Grows with inflation	119
Grows by 1% in nominal terms	105
Remains flat in nominal terms	98
Declines by 1% in nominal terms	90

Figure 5.11 Sensitivity of commercial value to SAC[81] [Source: Analysys Mason, 2014]

Note: Each of the above results assumes that there is an ARPU premium of 25p per month (returning to the inflation-only growth baseline over five years) and a fall in churn to 7.5% (returning to 10% over five years).

5.4 Summary of additional benefits

It is not straightforward to assess the magnitude of any additional benefits of improved coverage, capacity and performance as a result of a 700MHz allocation to mobile. In this section we summarise outputs from the two quantitative approaches we have used to help indicate roughly how large this benefit might be.

Whilst these approaches do not provide strict upper or lower bounds on the magnitude of the benefit, they can give us an idea of the magnitude and indicate that it may be significant.

The **adjusted technical value approach** suggests that the additional benefits to the generic operator arising from 2×10MHz of 700MHz may fall in the range of GBP61 million to GBP219 million in PV terms. Where in this range the output of the calculation falls depends on the value of the key input parameters in the consolidated model of network cost savings. However, for a given set of input parameters we would expect the adjusted technical value to provide an upper bound on the additional benefit to operators over the modelled period. For a 2×30MHz band plan, the adjusted technical value would suggest a value for additional benefits to operators bounded by the range GBP182–658 million, whilst for 2×40MHz this range would increase to GBP243–877 million. Within these ranges we have also calculated central ranges of results which are GBP386-484 million for a 2×30MHz band plan and GBP515–646 million for a 2×40MHz band plan.

The **commercial value approach** demonstrates that the range of values of the additional benefits is likely quite large. Our high-level estimates suggest a benefit to the generic operator in the range of GBP25–366 million for a 2×10MHz assignment in the 700MHz band, with a central case of GBP119 million. Exactly where in the range the value falls would likely depend on many factors.

Extrapolating this generic operator level value to the market level depends, in particular, on whether 2×30MHz or 2×40MHz were allocated to mobile broadband. Taking the central case to exemplify this; if 2×40MHz were allocated then a market-level value of GBP474 million could be assumed as four operators could provide the same improved QoS with each having a 2×10MHz assignment. We have not, under this approach, sought to scale up the generic operator benefit to the whole band using any alternative division between different (generic) operators.

If a 2×30MHz band plan were chosen we would expect the benefit to be at least three times the value to the generic operator based on three assignments of 2×10MHz, i.e. GBP356 million. However, in practice this benefit may be greater since subscribers may migrate to one of the three operators able to provide a higher quality of service with 700MHz.

The overall levels of additional benefit for the whole 700MHz band under the commercial value approach are summarised below in Figure 5.12.

Description	Commercial value (GBP million)		
	High	Central	Low
Generic operator (25% of market with 2×10MHz of 700MHz)	366	119	25
Total market (4 players, 3 of which have 2×10MHz of 700MHz)	1099	356	76
Total market (4 players, each with 2×10MHz of 700MHz)	1466	474	101

Figure 5.12: Operator and market level commercial value [Source: Analysys Mason, 2014]

In general, we expect that the adjusted technical value would provide a higher estimate of the benefit to operators than the commercial value approach, and so scenarios in which the commercial value exceeds the adjusted technical value are considered less likely.

Finally, we note that these approaches consider the additional benefits *to operators*; it is possible that significant additional benefits to consumers could exist above and beyond the magnitude of benefits which are set out above.

6 Conclusions

In this study we have attempted to quantify the benefits associated with the potential change of use of the 700MHz band to mobile, resulting from mobile network cost savings and improvements in mobile coverage, capacity and/or performance.

In general, our calculations have made a comparison between worlds with and without a change of use of the 700MHz band, recognising that there is likely to be a trade-off between the cost savings and improvements in coverage, capacity and/or performance that can be achieved (additional coverage has an avoidable cost).

We have split the calculation of benefits into two categories: network cost savings and additional benefits of the 700MHz change of use. To quantify the network cost savings we have developed a consolidated model based on the Analysys Mason model of the opportunity costs of broadcast spectrum and the 2012 Real Wireless model. The calculation of the additional benefits of a 700MHz mobile allocation beyond these network cost savings has followed two separate approaches to give an indicative range of values, along with a more qualitative analysis of the overall benefits.

This section summarises our main findings from both of these categories of benefit calculations.

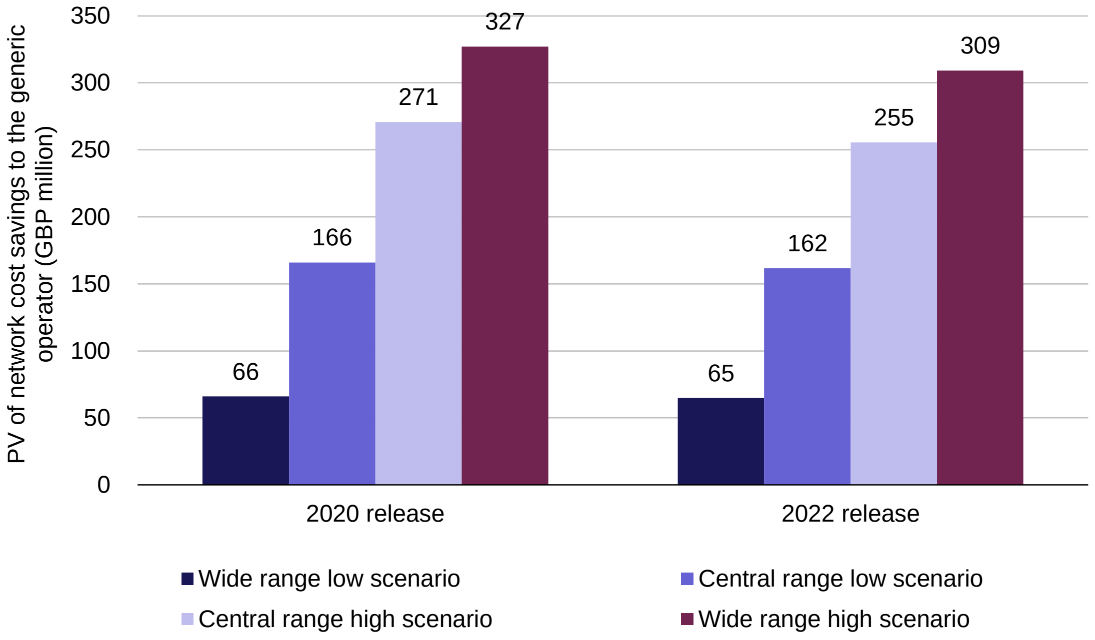
6.1 Network cost savings

Several key input parameters have an impact on the outputs of our consolidated model of network cost savings. As a result we have developed high and low scenarios for which we have calculated the network cost savings of a 2×10MHz allocation of 700MHz band spectrum to the generic operator, with spectrum allocated to mobile in 2020 or 2022. We have selected combinations of input parameter values that give rise to scenarios which, although extreme, are not completely unrealistic given the level of uncertainty associated with certain input parameters.

As requested by Ofcom, our results are presented excluding any terminal value arising beyond the modelled period. We note that the exclusion of a terminal value does not take account of cost savings which may occur beyond the modelled period and therefore provides results which may not fully illustrate the overall level of network cost savings likely to be achievable by operators.

The PV of network cost savings to the generic operator of a 2×10MHz allocation of 700MHz under these scenarios is shown in Figure 6.1 below, with the later change of use date (2022) resulting in lower network cost savings.

Figure 6.1: PV of network cost savings of spectrum to the generic operator under a spectrum change of use in 2020 and 2022 [Source: Analysys Mason, 2014]



There is uncertainty over the band plan to be used in any future allocation of the 700MHz band to mobile, with the most likely possibilities being that a band plan of either 2×30MHz or 2×40MHz would be used. We have therefore extrapolated the network cost savings of both such band plans under the high and low scenarios with 700MHz band change of use in 2022, with the spectrum allocated in lots of 2×10MHz. These network cost savings are shown in Figure 6.2 below and suggest that a not insignificant network cost saving may result from allocation of the 700MHz band to mobile.

Figure 6.2: Network cost savings of the 700MHz band with different band plans, GBP million [Source: Analysys Mason, 2014]

	Network cost savings of 2×10MHz of 700MHz to the generic operator	PV of network cost savings of a 2×30MHz allocation of 700MHz	PV of network cost savings of a 2×40MHz allocation of 700MHz
‘Wide range’ low scenario	65	195	259
‘Central range’ low scenario	162	485	646
‘Central range’ high scenario	255	766	1022
‘Wide range’ high scenario	309	927	1236

6.2 Additional benefits of improved coverage, capacity and performance

In addition to the network cost savings to operators there are also likely to be additional benefits to both consumers and operators of a 700MHz mobile allocation, due to improved coverage, capacity and performance of mobile networks.

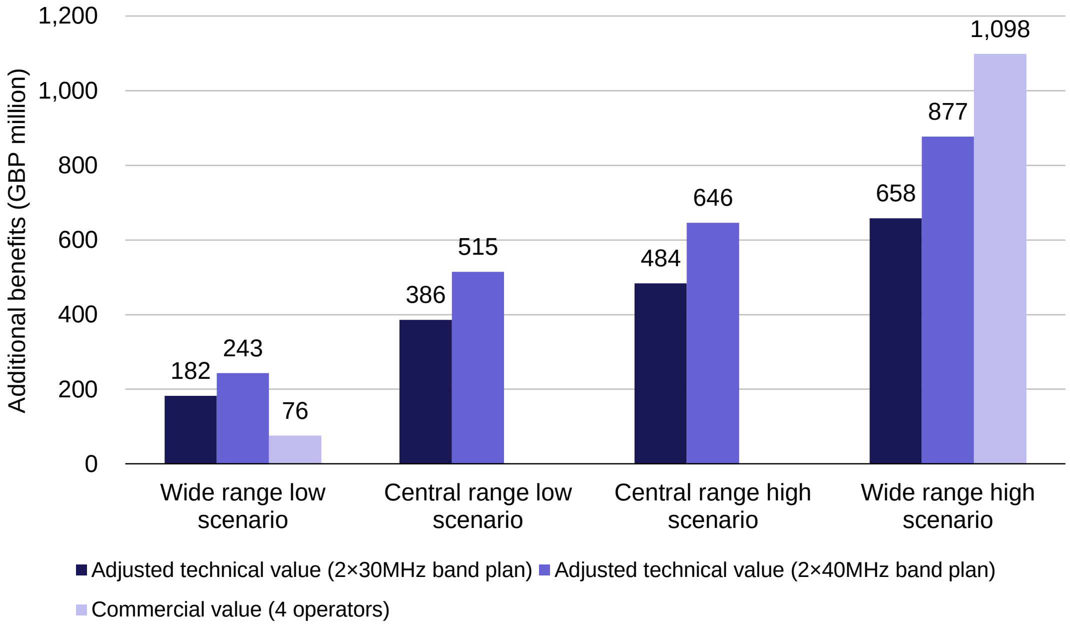
However, the additional benefits are subject to greater uncertainty than the network cost savings. In particular, these benefits are difficult to quantify precisely and our approach is to identify likely boundaries. We have considered two alternative approaches to allow us to elaborate on the form and rough magnitude of the additional benefit.

- The *adjusted technical value approach*, as set out in Section 5.2, forms a likely upper bound to the value to operators of allocating the 700MHz band to mobile broadband
- The *commercial value approach*, as set out in Section 5.3, estimates the value of these additional benefits which operators are likely to be able to monetise and therefore forms a likely lower bound on the value from a consumer and operator combined perspective.

Whilst these approaches do not provide strict upper or lower bounds on the magnitude of the benefit, they can give us an idea of the magnitude and indicate that it may be significant. In particular, we note that these approaches consider the additional benefits to operators; it is possible that significant additional benefits to consumers could exist above and beyond the magnitude of benefits which are set out above.

The quantitative estimates of additional benefits to operators from the change of use of the full 700MHz band in 2022 as calculated by these two methods are shown in Figure 6.3 below. These indicate that substantial additional benefits to operators resulting from improved coverage, capacity and performance of allocating the 700MHz band to mobile broadband are likely to arise, but that the precise value of these benefits may lie within a very wide range.

Figure 6.3: Illustration of the additional benefits originating from 2022 change of use of the 700MHz band, under high and low, central and wide range, scenarios [Source: Analysys Mason, 2014]

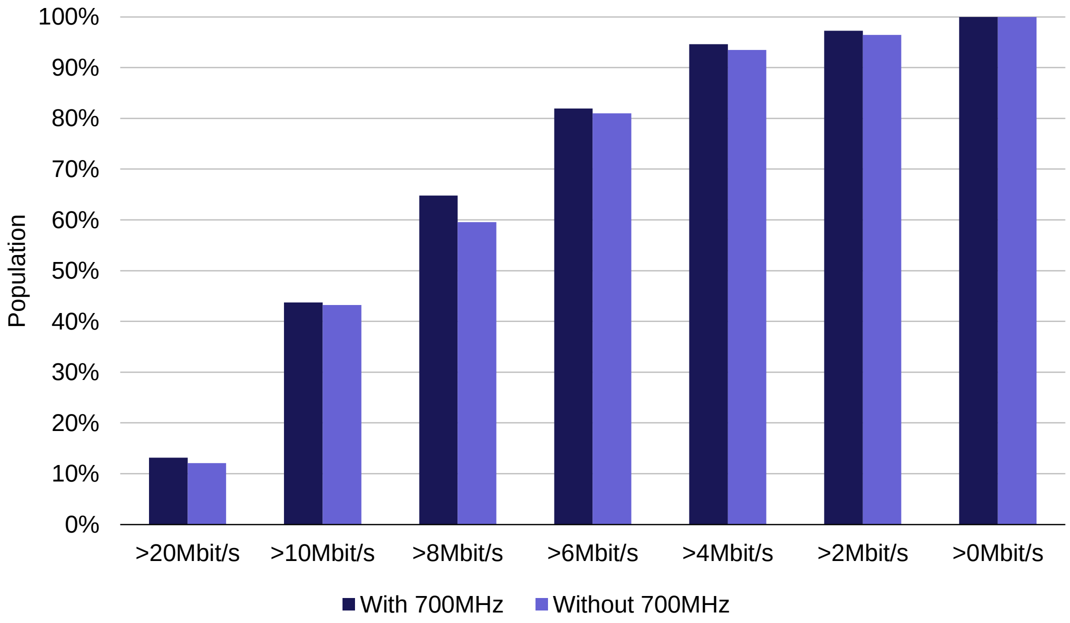


The adjusted technical value approach produces an uplift of between 63% and 94% on the network cost savings results we have calculated for spectrum change of use in 2022.

The commercial value approach demonstrates that the range of values of the additional benefits is likely quite large. Our high-level estimates suggest a benefit to a single operator in the range of GBP25–366 million, with a central case of GBP119 million, scaling up to GBP356 million for a market in which three operators receive a 2×10MHz spectrum assignment, as in the 2×30MHz band plan extrapolation for the PV of network cost savings and the adjusted technical value. Exactly where in the range the value falls would likely depend on many factors, including the band plan chosen and, in particular whether 2×30MHz or 2×40MHz were allocated to mobile broadband.

We have also considered an alternative approach to considering the overall level of benefits which are captured by our consolidated model of network cost savings. Qualitatively, the population coverage approach provides some evidence of the benefits to consumers of allocating the 700MHz band to mobile broadband. Figure 6.4 below illustrates the impact on single user throughputs for consumers when 700MHz is allocated to mobile broadband services. For example, the number of users in areas where it is possible to achieve throughputs of over 8Mbit/s increases by over 5pp of the population, from 59.6% to 64.8%.

Figure 6.4: Illustration of the proportion of population able to achieve particular levels of single user throughput [Source: Analysys Mason, 2014]



6.3 Summary of results

Whilst the exact level of the benefits of a 700MHz allocation to mobile broadband are somewhat uncertain, our analysis has shown that:

- Benefits arising from network cost savings are likely to have a present value (PV) of between GBP195 million and GBP927 million, excluding terminal value and depending on the assumptions made (including assuming that 2×30MHz of spectrum in the 700MHz band is made available for mobile broadband services), with a central range of between GBP485 million and GBP766 million.[83]
- Additional benefits, excluding terminal value, arising from improved coverage, capacity and performance are less certain, but, based on our adjusted technical value approach, are likely to range between GBP182 million and GBP658 million, with a central range of GBP386 million to GBP484 million, for operators, with further benefits to consumers also possible.[84] Using our commercial value approach a range of GBP76 million to GBP1099 million has been derived.[85]

Therefore we would expect substantial benefits to arise from a 700MHz allocation to mobile, which Ofcom will need to weigh up carefully relative to the costs of such an allocation to current spectrum users and consumers.

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[83] If 2×40MHz of spectrum in the 700MHz band were to be used for mobile services we estimate a range of GBP259 million to GBP1236 million, with a central range of GBP646 million to GBP1022 million.

[84] Again this is based on 2×30MHz of spectrum being used for mobile. The corresponding ranges assuming a 2×40MHz allocation are GBP243 million to GBP877 million, with a central range of GBP515 million to GBP646 million.

[85] This assumes that 2×30MHz is being used for mobile and 3 operators use 2×10MHz each. For a 2×40MHz band plan with 4 operators each holding 2×10MHz, the range of values rises to GBP101 million to GBP1466 million.

Annex A Overview of models previously developed

This section provides a brief overview of the three models that have been produced in earlier work for Ofcom and are relevant to this study, namely:

- the Analysys Mason model of the opportunity cost of broadcast spectrum, including the 700MHz band (Section A.1)
- the Real Wireless model of techniques for increasing the capacity of wireless broadband networks (Section A.2)
- the Ofcom model to carry out an assessment of compliance with the 800MHz (4G) coverage obligation (Section A.3).

A.1 The Analysys Mason model

In March 2013, Ofcom published the Analysys Mason and Aegis Systems report on the opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting.[86] The study calculated the opportunity costs associated with the use of spectrum for a variety of applications, including mobile broadband services in the 694–790MHz spectrum block, referred to in our report as the 'harmonised 700MHz band'.

The model of the opportunity cost of mobile as an alternative use in the 700MHz spectrum band is based around the spectrum requirements of a generic operator. The model's calculations of network cost savings are based on an assessment of the number of sites which the modelled generic operator could avoid building if more spectrum (in the 700MHz band) were to be made available to it. The model looks at a 20-year period from the start of 2015, with a terminal value included in the assessment of the present value (in 2015 terms) of cost savings to the generic operator.

A.1.1 Model overview

The Analysys Mason model calculates the total mobile network traffic and the distribution of traffic per site and compares this to a calculation of the total capacity per site, as illustrated in Figure A.1. This approach enables a calculation of exactly how many new sites are needed given the generic operator's existing spectrum portfolio and how many could be avoided given access to different amounts of 700MHz spectrum, at different times. By taking into account the costs of each capacity upgrade option, the year-on-year network costs are calculated in the case with and without the change of use of the 700MHz band to mobile, and the PV of these network costs is

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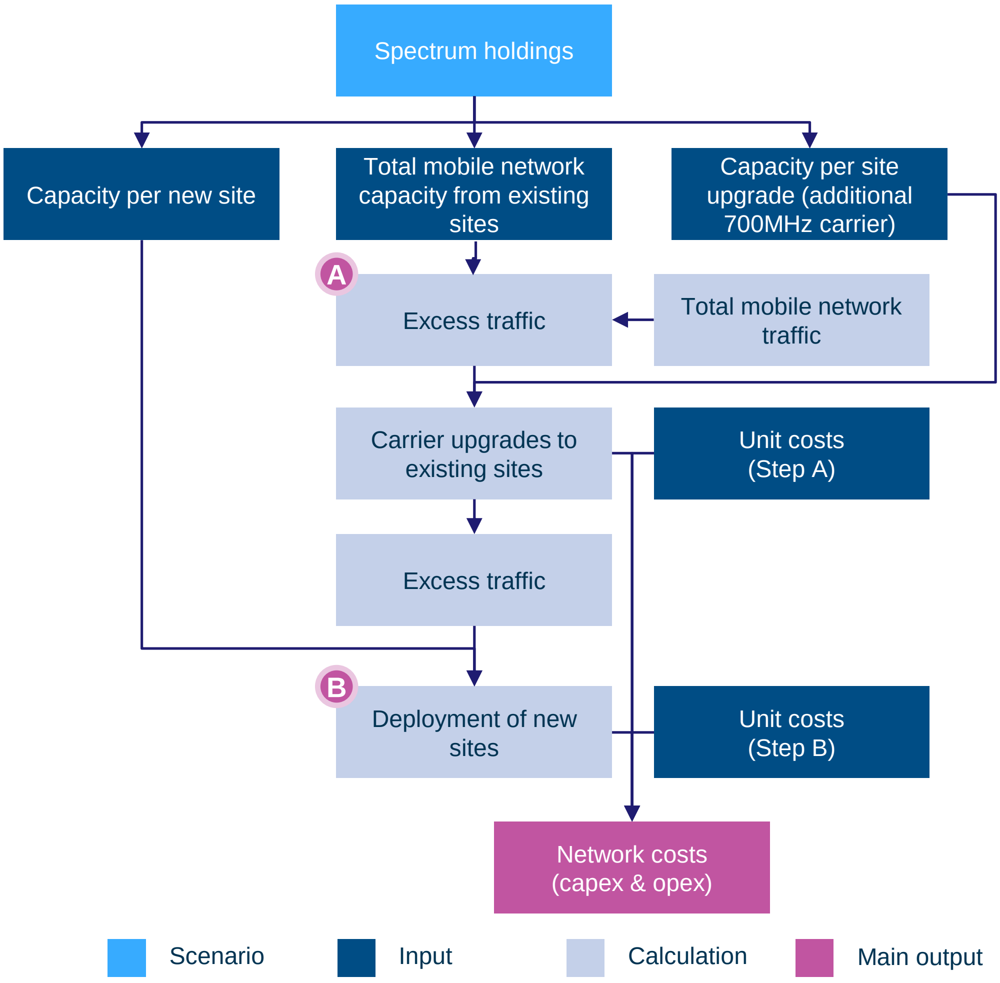
[86] Analysys Mason and Aegis Systems, *Opportunity cost of the spectrum used by digital terrestrial TV and digital audio broadcasting* (2013), see http://stakeholders.ofcom.org.uk/consultations/aip13/

calculated in each case. The difference in these PVs represents the technical value, or network cost savings, of the 700MHz spectrum to the generic mobile operator.

Figure A.1: Flow of the network cost saving calculation in the Analysys Mason model [Source: Analysys Mason, 2013]



To calculate the network infrastructure requirement the model uses an algorithm that can be summarised as follows:

- Calculate how many sites are unable to carry the required amount of traffic using existing capacity
- For any such sites, if any 700MHz spectrum is available, calculate whether adding the available 700MHz carrier will provide sufficient capacity
- For any of these sites where this is not the case, split a site (i.e. a new site is built and traffic shared equally between the overloaded site and the new site)
- Repeat this calculation each year and apply the relevant unit costs for sites and carriers so as to calculate the incremental network costs.

The value of the 700MHz spectrum therefore arises because it allows for the cheaper site upgrade (Step A in the above diagram) to be applied at a proportion of sites rather than the more expensive new site (Step B), which is the default in the absence of any 700MHz spectrum being available.

Generic operator approach

The model considers the network costs to a generic operator of expanding its network to cover forecast demand increases for mobile services assuming access to different amounts of spectrum from the 700MHz band.[87]

As the UK mobile market currently has four competing networks, an assumption of a 25% market share of subscribers has been made for the modelled generic operator, across both handsets and mobile broadband devices. Similarly, the generic operator's spectrum holdings before the change of use of the 700MHz spectrum band equate to roughly one quarter of the total available mobile spectrum (prior to the possible availability of spectrum in the 700MHz band), reflecting Ofcom's goal to maintain four credible national wholesale operators. The generic operator is assumed to have spectrum holdings across all bands allocated for mobile services and an existing network of sites prior to the change of use of the 700MHz spectrum band.

Distribution of traffic and sites

In order to calculate the costs to the generic operator of providing sufficient capacity for all traffic, assumptions are made about the distribution of traffic and capacity (sites) across regions of different geographical types ('geotypes') and across sites within any given geotype:

- both the site and traffic split by geotype for the generic operator are equal to that of the average operator in the Ofcom Calls To Mobile ('CTM') modelling
- a traffic distribution of the form $y = a \times \ln(x) + b$ derived from traffic patterns observed from mobile operators we have worked with has been used to model the asymmetric distribution of traffic across sites.

Importance of low-frequency spectrum

While the generic operator's existing spectrum holdings will allow it to provide adequate coverage, there are still substantial advantages of sub-1GHz spectrum in the provision of capacity, as around 50% of the coverage area of each cell is outside the reach of supra-1GHz spectrum, as shown in the illustration of frequency band propagation characteristics in Figure A.2.

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[87] It is noted that each of the four UK mobile operators has different characteristics from those of the generic operator and therefore may have different values for the 700MHz spectrum.

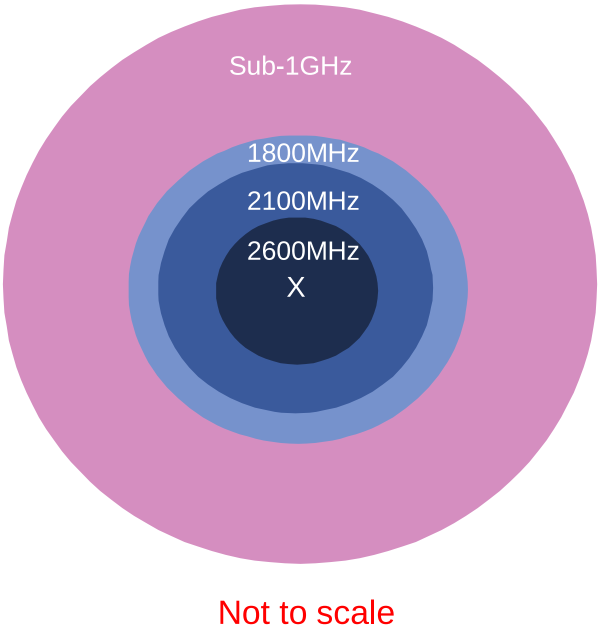


Figure A.2: Schematic illustration of the propagation characteristics of different frequency bands [Source: Analysys Mason, 2013]

The model makes the assumption that 30% of network traffic is generated outside the reach of supra-1GHz spectrum, and can therefore be carried only over lower frequencies, or by building new sites. This split between ‘low-frequency-specific’ and ‘non-low-frequency-specific’ traffic has an impact on the model structure, and these two traffic groupings are considered separately. However, it should be noted that the model assumes that the operator can use effective load balancing, in order to carry the traffic that does not need the sub-1GHz spectrum over supra-1GHz spectrum instead. In other words, it is assumed that the sub-1GHz spectrum can be dedicated to serving the harder-to-reach locations.

The number of additional carriers and sites required to provide adequate capacity for the traffic that can only be served by low-frequency spectrum is calculated first. Any remaining capacity of the sites deployed to service the low-frequency specific traffic is used to carry the remainder of the traffic. Additional calculations are then run to see if further sites are required in order to carry this remaining ‘non-low-frequency-specific’ traffic.

Key inputs

There are a number of key inputs to the model for which sensitivity tests are run to measure the change in network cost savings calculated relative to the base case. These key inputs include:

- traffic forecasts, offload assumptions and busy-hour inputs
- date of availability of 700MHz spectrum and 700MHz-capable devices
- generic operator 700MHz and other spectrum holdings
- weighted average cost of capital (WACC)
- initial site numbers
- technology roadmap and spectral efficiency.

These are described and compared to the other models in Annex B.

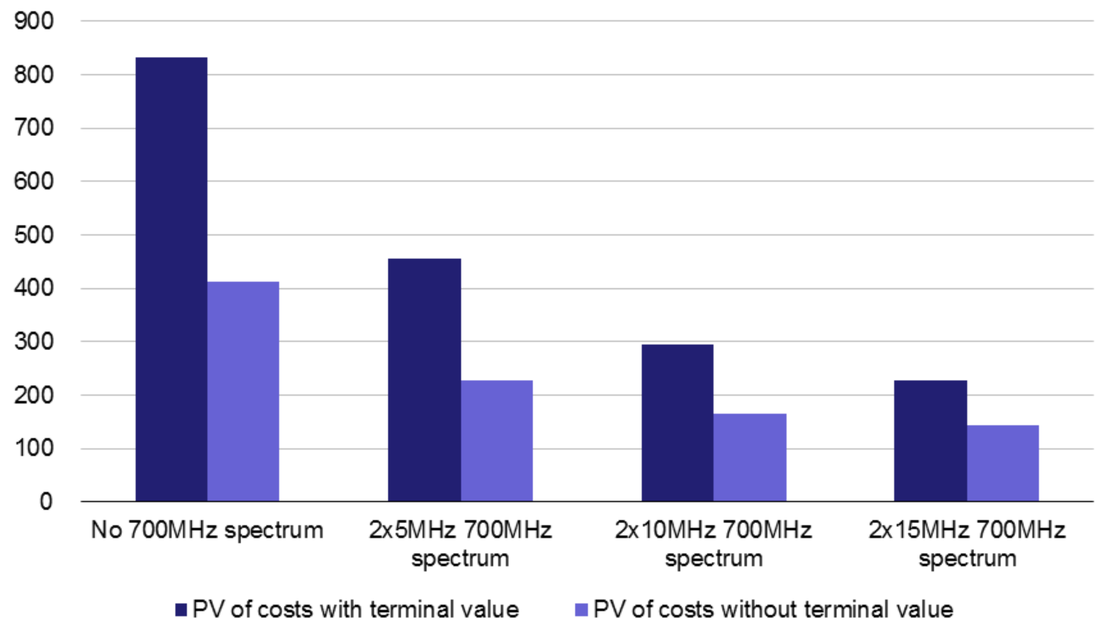
In addition, inputs for the network cost elements are taken from averages of values observed in other Analysys Mason work. In general, annual unit opex is assumed to be around 10% of unit capex. The unit costs in the model are generally similar to those used by Ofcom in the CTM modelling and replacing the unit costs with those previously used by Ofcom makes little difference to the results.

A.1.2 Results

The costs of new sites and carriers in each of the 20 modelled years (2015–2034) are calculated, with the present value (PV) of network costs in each spectrum holding scenario calculated using the WACC as a discount factor. A terminal value is also included in the PV, based on the sum to perpetuity of future network costs, with costs in each future year assumed equal (in real terms) to those in 2035.

Figure A.3 below shows the PV (in 2015 real terms) of the four 700MHz spectrum scenarios, with the costs to the generic operator decreasing as its allocation of 700MHz spectrum increases.

Figure A.3: PV of different spectrum holding scenarios in the Analysys Mason model, GBP million [Source: Analysys Mason, 2013]



The full value of the spectrum to the generic mobile operator is shown in Figure A.4 below.

Figure A.4: Value of 700MHz spectrum [Source: Analysys Mason, 2013]

	2×5MHz	2×10MHz	2×15MHz
Full value (GBP million)	378	539	606

The Analysys Mason model base case assumes that 2×40MHz of 700MHz spectrum is available and therefore that 2×10MHz per (generic) operator is the most relevant allocation. Thus a value of GBP2156 million is considered to be the full (2015) present value of the 700MHz band to the mobile industry. Note that the value per MHz in the above table decreases as more spectrum is allocated to the generic operator, reflecting the decreasing marginal benefit of additional spectrum.

A.2 The Real Wireless model

Real Wireless conducted a project for Ofcom, concluding in April 2012, to determine the role which existing and additional spectrum, in particular the 700MHz band, may play in meeting growing demand for wireless broadband in the period 2012–2030.[17]

Real Wireless examined the whole UK market through three study regions representing urban, suburban and rural environments which cumulatively generate a total of 6% of UK wireless traffic (and represent roughly 6% of the UK population).

The model seeks to determine the optimal deployment of cell sites within a number of scenarios incorporating various assumptions on demand, capacity-enhancing techniques and spectrum availability in order to estimate possible network cost savings within each scenario, with the 700MHz band becoming available in 2020, 2026 or not at all.

A.2.1 Model overview

The Real Wireless model considers network cost savings under a variety of scenarios (to account for uncertainty in future conditions) in three study areas:

- Urban – Central London, including City of London, City of Westminster and Kensington and Chelsea
- Suburban – West London, including Borough of Brent, Ealing, Harrow, Hillingdon and Hounslow
- Rural – Lincolnshire, including North Kesteven, East and West Lindsey, South Holland, Boston and Lincoln.

Figure A.5 below gives an overview of the algorithm used in the Real Wireless cost calculation. Wireless demand is forecast over the modelled period for the three study areas at three typical network busy-hour periods (9–10am, 5–6pm, 8–9pm) for indoor and outdoor traffic. In addition, site capacities and the theoretical cost of deployment/upgrade of sites are calculated based on a number of configurations.

This data is fed into a year-by-year site deployment algorithm that deploys sites to meet forecast demand at the lowest possible cost from 2012–2030, based on the costs and capacities calculated for each configuration.

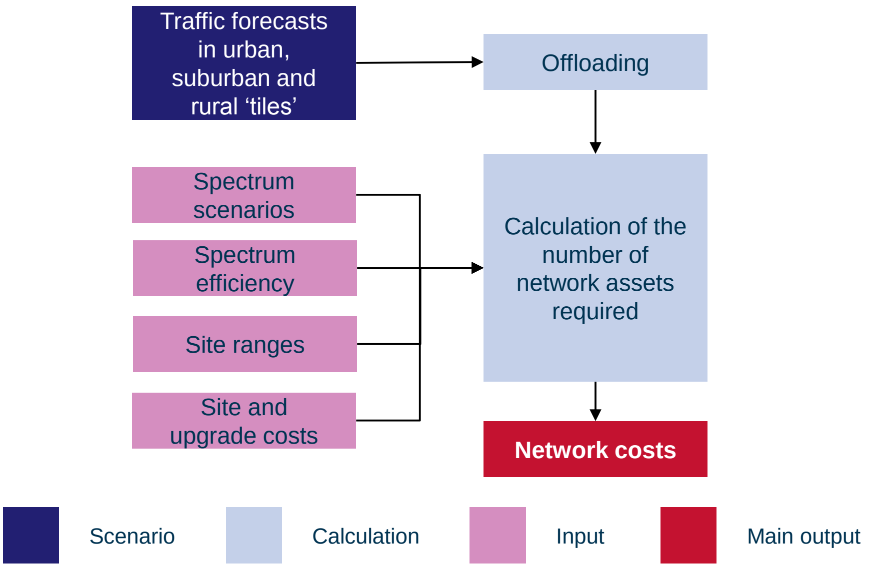


Figure A.5: Overview of Real Wireless network cost calculation [Source: Analysys Mason based on Real Wireless, 2013]

Demand

Real Wireless developed a demand forecast based on a number of published studies and forecasts, which was mapped to demand points across the three study areas based on population and transport links. Additional inputs include: split between residential, business and mobile users; service take-up; device mix; indoor/outdoor split; and diurnal variation.

In addition, 'implicit offload' to indoor small cells is considered, with a portion of demand assumed to take place in indoor environments such that it can be carried by Wi-Fi or indoor femtocells. Only demand net of indoor offload is considered in the site deployment calculations.

Site capacity

Theoretical site capacities are calculated for a range of possible configurations, depending on the availability of technologies in each modelled year. This depends primarily on spectrum efficiency and site ranges, which each take into account a number of factors. Figure A.6 illustrates the main inputs to these calculations

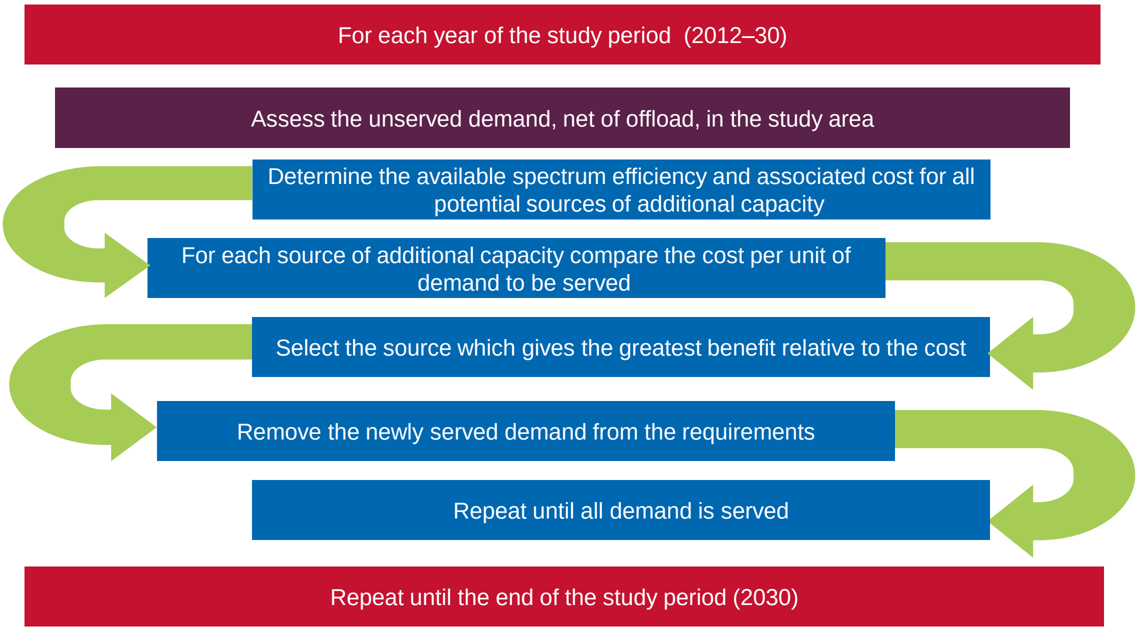
Figure A.6: Main inputs to spectrum efficiency and site range calculations [Source: Analysys Mason based on Real Wireless, 2013]

Spectral efficiency	Site range
Evolving MHz per generation	Maximum allowable path loss (MAPL) for selected cell-edge throughput requirements in Mbit/s
Evolving antenna count per device	Minimum user bandwidth
Environmental scaling	Signal to interference plus noise ratio (SINR) cut-off values
Site configuration (sectors, transmitters, bands used)	SE21 Hata propagation model according to clutter type

Number of sites

The model starts in 2012 with no sites deployed and one year at a time builds out a network of macrocells and outdoor small cells[88] in order to meet the forecast demand, based on the site configurations available in that year and the capacities calculated, as described above. This is repeated until 2030 is reached, as shown in Figure A.7 below.

Figure A.7: Site deployment and upgrade algorithm [Source: Analysys Mason based on Real Wireless, 2013]



The above calculation gives as an output the deployment of equipment over time, enabling capital and operational expenditures to be calculated over the model period. It should be noted that the costing continues from 2030 to 2040, adding further expenditure in this period. However, during this period the model assumes that the network no longer grows (i.e. the relevant costs are opex and capex for the replacement of assets). This period with a static network is analogous in some ways to the terminal value calculation in the Analysys Mason model, although it is materially different in terms of its impact on the calculation and its economic justification. We understand that this extra ten-year period is included to reflect both a longer model period but with reduced propensity to error in forecast parameters (such as further improvements to spectral efficiency or cost trends) and in order to reduce bias against innovations that come into effect only late in the initial 2012–2030 model period. The full 2012–2040 costs are discounted using a social discount rate to give an PV in 2012 real terms.

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[88] This includes microcells and picocells deployed in outdoor areas but not indoor femtocells. Traffic carried by femtocells is included in the traffic deemed to be offloaded.

A.2.2 Results

Figure A.8 below shows the summary of network cost savings estimated by Real Wireless for its mid-demand and mid-capacity scenarios with the change of use of 700MHz in 2020, 2026 and not at all. This chart therefore implies a cost saving to network operators over the years 2012–2040[89] of GBP2.4 million in the Central London (urban) study area, GBP5.8 million in the West London (suburban) study area and GBP1.8 million in the Lincolnshire (rural) study area where 700MHz spectrum becomes available for mobile broadband in 2020.

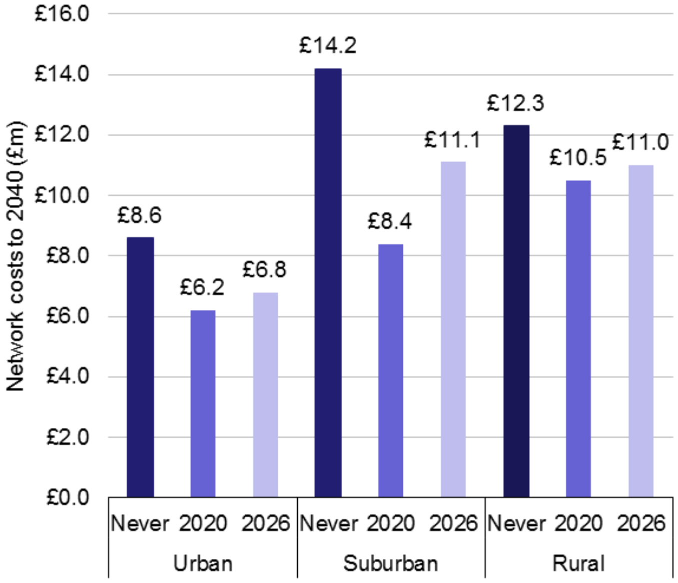

Figure A.8: Impact of 700MHz timing on network cost (mid-demand and mid-capacity scenarios) [Source: Real Wireless, 2012]

Real Wireless estimated that the aggregated study area represented 6% of UK traffic in 2011. The sum of network cost savings across the three study areas is GBP10.0 million. A simple scaling of the network cost savings in the three study areas (i.e. from 6% to 100%) implies a national network cost saving of GBP167 million.

We note that Real Wireless has indicated that the model was not designed for extrapolation to the entire UK. However, we feel that such an extrapolation is representative of the magnitude of the results which a similar modelling exercise including the whole of the UK would yield. Therefore, although the extrapolation is not entirely accurate we use it as a simple means to compare results between the Analysys Mason and Real Wireless models in Section Annex C. For this purpose we use the calculated extrapolation of GBP167 million of network cost savings, since we are not aware of what weightings should be applied to individual study areas.

A.3 The Ofcom model

Ofcom has undertaken a modelling exercise to answer a number of technical questions concerning coverage of future LTE networks. In particular the Ofcom model assesses the relative coverage (both

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[89] The network is deployed and grows over the period 2012–2030, and then over 2030–2040 the network remains static. Network cost savings are calculated over the period 2012–2040.

in terms of speed of connection and percentage of population) of different hypothetical networks and how this varies with the number of sites, the available spectrum and the level of network loading.

Ofcom has considered a simulation area that it believes to be representative of the UK in terms of geographical factors as well as the network deployment focus of operators. Scenarios modelled in the simulation area are then extrapolated to reflect the national level. In this simulation area, performance of LTE network operations in the 800MHz, 1800MHz and 2600MHz bands is considered for a range of network sizes, representing 21 different 'synthetic' national networks at two different loading scenarios (15% and 85% loaded).

A.3.1 Modelling approach

The model functions in the following way:

- A synthetic network is created to cover the simulation area, as well as a buffer zone (to avoid edge effects). This network is of a particular design to represent a national network of a given size following characteristics of current mobile macro-site networks.

- For each population point (UK census area centroid), the signal to interference plus noise ratio (SINR) is calculated. This is achieved by considering signals from the 20 closest sites[90] in the network.

- Using these values of SINR, the performance (downlink throughput) for a single user at each population point is calculated.

The above steps are repeated, varying the following parameters:

- network size
- network loading
- carrier bandwidths
- building penetration depths
- frequency.

Synthetic network

The simulation area chosen was a 100km by 100km square, as shown in Figure A.9. For this area, plus a 20km buffer, a range of 21 synthetic networks were created. These represent national networks of: 500 sites and 1000 to 20 000 sites (in 1000-site increments). These networks were designed to be representative of existing operators' macro networks when considering both location and antenna heights.

All base stations were given the following characteristics:

- All assumed to be 3-sectored macrocells using a 2×2 MIMO configuration

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[90] For some population points fewer than 20 sites will be considered, because there may not be 20 sites that are capable of providing a signal with above a threshold SINR.

- Antenna patterns are theoretical and based on equations from the 3GPP specifications, except for horizontal and vertical 3dB beam widths, which are derived from real antennas covering 800–2100MHz (extrapolated to include 2600MHz as well).

Examples of synthetic network base station locations are shown in Figure A.10 This displays networks of 16 000 and 20 000 national equivalent sites.[91]

Figure A.9: Simulation area [Source: Ofcom, 2011]

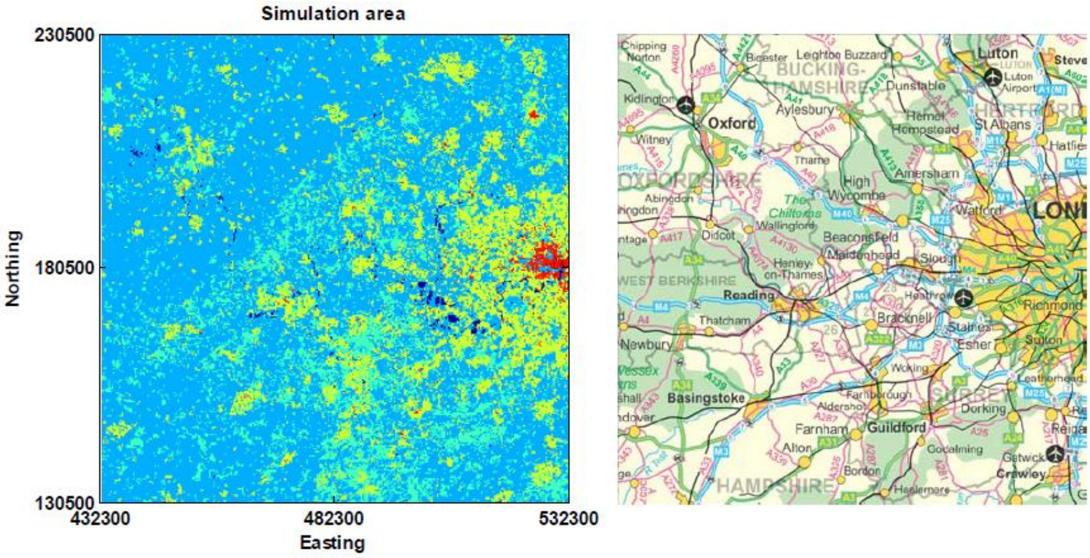
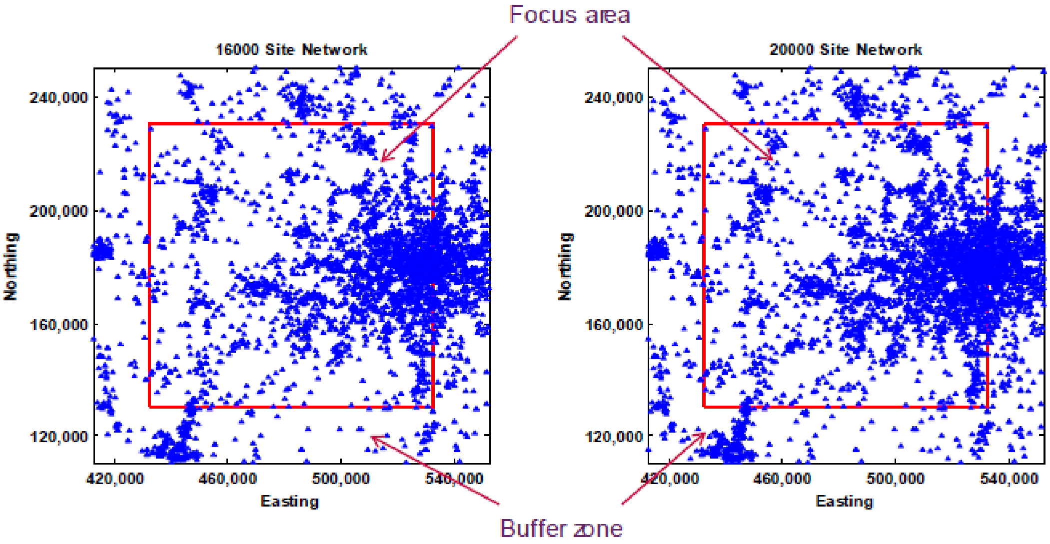


Figure A.10: Examples of synthetic network base station locations, 16 000 sites (left) and 20 000 sites (right) [Source: Ofcom, 2011]



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[91] The Ofcom model refers to the number of sites in the network in terms of national equivalent sites. This means that a number of sites are deployed within the simulation area at a density consistent with a national network of 16 000 or 20 000 sites.

We note that Ofcom has provided us with a copy of the model that uses data for a full national network of 18 000 sites, as opposed to the representative synthetic networks discussed above. This is the data that we have used to help develop our consolidated model, as discussed in Section 3.

SINR distribution

For each population point a clutter category is established based on geographical location. Shadow fading and building penetration loss values are also established based on normally distributed random variables.

The distance and angle between the population point and each of the 20 closest base station sector antennas is calculated, as well as their respective gain in the direction of the population point. This allows the path-loss between the base stations and population points to be obtained.

Interference is then calculated from the non-serving base stations (as well as the non-serving sectors of the serving base station). This is also the point at which network loading is taken into account. This enables an SINR to be calculated for each population point.

Throughput calculation

From these SINR values a throughput can be obtained for each population point. This is achieved by using an attenuated and truncated form of the Shannon bound.[92]

A.3.2 Results

Given that each result is calculated at the level of a UK census population area it is possible to weight each result by the population of its respective area to give the performance of any given synthetic network as a function of the population served; hence enabling coverage obligations to be tested against different network specifications.

This model enables the following attributes of a network to be calculated:

- **Coverage** (% population) vs. number of sites, for different values of: minimum downlink speed, building penetration, network loading, frequency and bandwidth
- **Single user throughput** (Mbit/s) vs. coverage (% population), for different values of: number of sites, building penetration, network loading, frequency and bandwidth
- **Capacity** – sites required vs. users simultaneously able to access the service (% population), for different values of: guaranteed data rate, network loading, building penetration, frequency and bandwidth.

The outputs of the model are therefore not directly comparable to the Analysys Mason or Real Wireless models and are not summarised here.

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[92] See Annex A of 3GPP TR 36.942, “Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios”, http://www.3gpp.org/ftp/Specs/html-info/36942.htm

Annex B Key inputs, assumptions and algorithms used in models previously developed

B.1 Overview

This annex primarily focuses on comparing the key inputs, assumptions and algorithms used by the Analysys Mason and Real Wireless models. These models can be compared in a fairly direct manner, since both are designed to calculate network cost savings. The Ofcom coverage model does not attempt to calculate network cost savings, but rather the level of coverage provided, and so is not easily comparable in the same way. However, where the Ofcom model uses parameters that are in common with the Analysys Mason and Real Wireless models we have compared the assumptions made in all three models.

The comparison below considers the Base case scenario from the Analysys Mason model and the Mid scenario[93] for the Real Wireless study. The choice of the Mid scenario was confirmed after discussion with Real Wireless in which it was stressed that the High and Low scenarios were considered as extreme cases during model development.

In the following sub-sections we go through the major categories of parameters sequentially and set out the differences in input assumptions. In the corresponding sub-sections of Annex C we then analyse the impact on the calculated network cost savings of these different inputs.

B.2 Time period

Both Analysys Mason and Real Wireless make use of multi-year models to calculate the network cost savings due to use of the 700MHz band. However, there are differences in the respective implementations of these multi-year models, particularly with regard to the base year chosen for reporting costs, the modelled periods and the use of a terminal value, as shown in Figure B.1 below.

Figure B.1: Assumptions related to time period [Source: Analysys Mason, Real Wireless, 2013]

Assumption	Analysys Mason model	Real Wireless model
Base year	Values discounted to 2015 real terms	Values discounted to 2012 real terms
Modelled time period	20-year period, 2015–2034	19-year period: 2012–2030 Additional ‘static’ period: 2030–2040
Terminal value	Based on the sum to perpetuity of future network costs, with costs in each future year assumed to equal those in 2035[94]	Network costs for 2030–2040 with no network growth: analogous to a conventional terminal value but differs conceptually and in value

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[93] That is, the combination of the mid-demand and mid-capacity scenarios.

[94] Network costs are relatively stable in the latter part of the Analysys Mason model period, and therefore basing the terminal value solely on final-year network costs does not result in a materially different terminal value from that obtained by basing it on the last few modelled years.

The Analysys Mason model calculates a conventional terminal value as the sum to perpetuity of future network costs, with costs in each future year assumed to equal those in 2035.[95] This is calculated as the 2035 discounted network cost multiplied by (1 – (1/ (1+WACC))).[96]

This method of calculating a terminal value is well justified from an economic standpoint. In practice it has the disadvantage that it implicitly includes future values that are subject to increasing uncertainty over time, such as traffic forecasts. Arguments could therefore be made to omit a terminal value from the model results. However, such uncertainty can also be mitigated, in part, by testing a range of plausible scenarios.

The Real Wireless model produces a 'hybrid terminal value' figure. This gives a result between that which would be obtained using a conventional terminal value calculation (as used in the Analysys Mason model), and that which would be obtained by removing the terminal value from the model. Real Wireless calculated the costs for a static network between 2030 and 2040 (i.e. an extra ten years after the network deployment algorithm ends), with the costs computed on a present value basis. The relevant costs during the 2030–2040 period are therefore only opex and replacement capex.

This hybrid terminal value has been used to counter what Real Wireless describes as a bias arising from changes introduced late in the model period, such as the deployment of assets with long lifetimes. By not extending costs to perpetuity and freezing the network in 2030, Real Wireless argued that the approach is less vulnerable to uncertainty over traffic projections than a more conventional terminal value approach.

B.3 Demand

B.3.1 Traffic and offloading forecasts

Traffic in both the Analysys Mason and Real Wireless models is built up as the product of forecasts of relevant devices in the market and forecasts of data traffic generated per device over the modelled period. Traffic offloaded to Wi-Fi or indoor small cells is then removed either explicitly or implicitly. Traffic levels are not considered in the Ofcom model.

Within the Analysys Mason model, the total post-offload traffic is divided by four before being used in the model to give the traffic carried by the generic operator.

Figure B.2 summarises the assumptions related to traffic and offloading used in the two models.

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[95] The Analysys Mason model runs to 2035 but only includes values up to the end of 2034 as part of the quoted 20-year modelled period. The 2035 network costs are calculated only for use in the terminal value calculation.

[96] This is multiplying the 2035 network costs expressed in 2015 real terms by a factor which works out the sum to perpetuity of the geometric progression with first term 2035 costs and constant ratio of the WACC (discount rate).

Figure B.2: Assumptions related to traffic and offloading [Source: Analysys Mason, Real Wireless, 2013]

Assumption	Analysys Mason model	Real Wireless model
Population forecast	EIU forecast to 2030, with the 2020–2030 CAGR used to forecast population out to 2035	ONS 2011 projection
Device penetration	Smartphone penetration rises from 45–100% and MBB penetration rises from 9–25% over 2012–2035	Penetration changes from 52–227% for smartphones, 6–95% (tablets), 6–106% (laptops) and 8–2% (USB) over 2011–2030; 3G phone penetration falls from 99–0% over 2011–2021, derived from the assumptions in Figure B.3 below
Device usage	Usage per subscriber per month for smartphones rises from 692–6000MB and MBB usage rises from 5047–30 000MB over 2012–2035	Usage per subscriber per month for the average handset device rises from 100–1273MB, and average MBB device usage rises from 1465–17 236MB over 2012–2030, derived from the assumptions in Figure B.3
Small cell offload	Main offload assumptions are implicitly factored into the above traffic forecasts	40% in 2012, rising to 48% in 2030
Indoor/outdoor split	Not explicitly considered	80% of traffic originates indoors in 2012, rising to 95% in 2024

Both the Real Wireless and Analysys Mason models consider traffic to be the product of the data usage of mobile handsets and mobile broadband devices and the number of devices in the market, with the Real Wireless forecasts shown in Figure B.3 below. These inputs are used to give forecasts of the total annual traffic in the market before any offloading takes place.

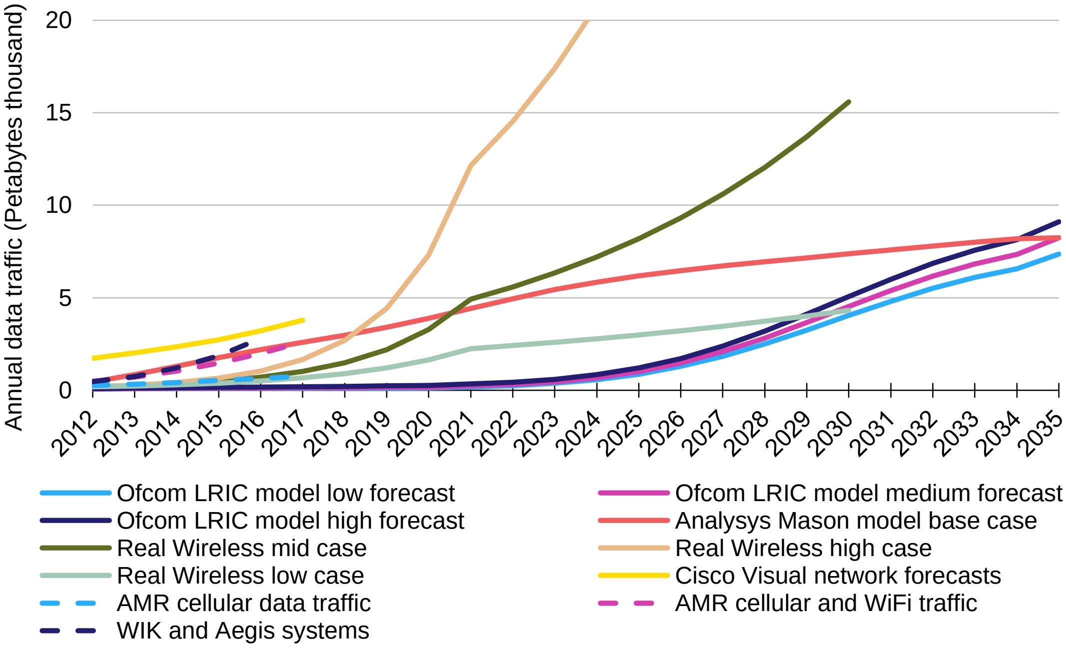
Figure B.3: Growth assumptions for penetration and traffic in the Real Wireless model [Source: Real Wireless, 2013]

	Smartphone	Tablet	Laptop	USB modem	3G phone
2011 penetration	52%	6%	6%	8%	99%
Penetration CAGR 2012–2020	14%	33%	35%	1%	-49%
Penetration CAGR 2021–2030	3%	2%	2%	-12%	-100%
2030 penetration	227%	95%	109%	2%	0%
2012 device traffic (MB/month)	270	751	2633	1125	10
Device traffic CAGR 2012–2020	10%	15%	15%	13%	11%
Device traffic CAGR 2021–2030	8%	13%	12%	4%	0%
2030 device traffic (MB/month)	1273	7936	25 686	4810	26

The Real Wireless report gives device volume and traffic numbers which can be used to derive full market traffic; both pre and post small-cell offload, while the Analysys Mason model uses only post-offload traffic (excluding some additional active offload, discussed below) as its demand input (i.e. the net traffic which must be carried on the mobile network).

By comparing the shape of the Analysys Mason and Real Wireless total network traffic curves in Figure B.4 it can be seen that the Analysys Mason model implicitly assumes an increasing proportion of offload traffic over time.

Figure B.4: UK market level post-offload wireless demand[97] *[Source: Analysys Mason, Real Wireless, Ofcom, Cisco, WIK and Aegis Systems, 2013]*[98]



The Analysys Mason model also makes use of an active offloading parameter, associated with mobile network operators actively seeking to offload traffic from their mobile networks by setting up, or buying third-party access to, Wi-Fi hotspots, most likely in urban locations, and directing devices on their network to automatically connect using Wi-Fi where available.

The difference between the Analysys Mason base case and the Real Wireless Mid scenario forecasts for traffic can be attributed to the different assumptions of device penetration and traffic, particularly with regard to MBB devices. However, as shown in Figure B.5 below, the higher traffic per device assumptions in the Analysys Mason model go some way to cancelling out the higher penetration figures used in the Real Wireless model.

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[97] In the high traffic scenario of the Real Wireless model, annual data traffic post-offload is forecast to reach 61 127 Petabytes in 2030.

[98] AMR in the legend refers to Analysys Mason Research.

Figure B.5: Summary of the market traffic calculations in the models [Source: Analysys Mason, Real Wireless, 2013]

	Device penetration		Device traffic post offload (MB)		Annual market traffic post offload (PB)	
	Smartphone	**MBB**	**Smartphone**	**MBB**	**Smartphone**	**MBB**
Analysys Mason 2012	45%	9%	467	4795	143	313
Real Wireless 2012	59%	24%	162	879	63	123
Analysys Mason 2030	100%	25%	4500	22 500	3153	4214
Real Wireless 2030	227%	207%	662	8962	1159	14 434

B.3.2 Busy-hour assumptions

A mobile network is dimensioned to carry the traffic load at the busiest time, and therefore both the Analysys Mason and Real Wireless models use busy-hour assumptions in order to find the maximum level of demand the network will need to serve. The respective assumptions are summarised in Figure B.6 below.

Figure B.6: Assumptions related to busy-hour dimensioning [Source: Analysys Mason, Real Wireless, 2013]

Assumption	Analysys Mason model	Real Wireless model
Busy-hour dimensioning	Busy-hour parameters from Ofcom's 2011 mobile LRIC model, giving a 0.024% share of yearly traffic in the busy hour (see below to understand how this is derived)	Assumes three daily traffic "peaks" at 3% between 9–10am, 6% between 5–6pm and 6% between 8–9pm

The Analysys Mason model uses parameters from the Ofcom 2011 mobile LRIC model to derive the portion of traffic that will fall in the busy hour. The relevant parameters are:

- busy days per year: 250
- proportion of traffic in busy days: 80%
- proportion of busy-day traffic in the busy hour: 7.5%.

The Real Wireless model considers three different busy hours per day, as follows:

- 9–10am: 3% of busy-day traffic, with the majority generated from business locations
- 5–6pm: 6% of busy-day traffic, with the majority generated by commuters
- 8–9pm: 6% of busy-day traffic, with the majority generated at residential locations.

These traffic proportions were derived using 2011 data provided by Elisa on downlink traffic distribution during 27 hours in one Gateway GPRS Support Node (GGSN).

B.4 Capacity per site

B.4.1 Spectral efficiency

Both models calculate the capacity of each site by first deriving the capacity of a sector. This is done using inputs on various technology generation releases and their expected spectral efficiencies, as summarised in Figure B.7 below.

Figure B.7: Assumptions related to spectral efficiency [Source: Analysys Mason, Real Wireless, Ofcom, 2013]

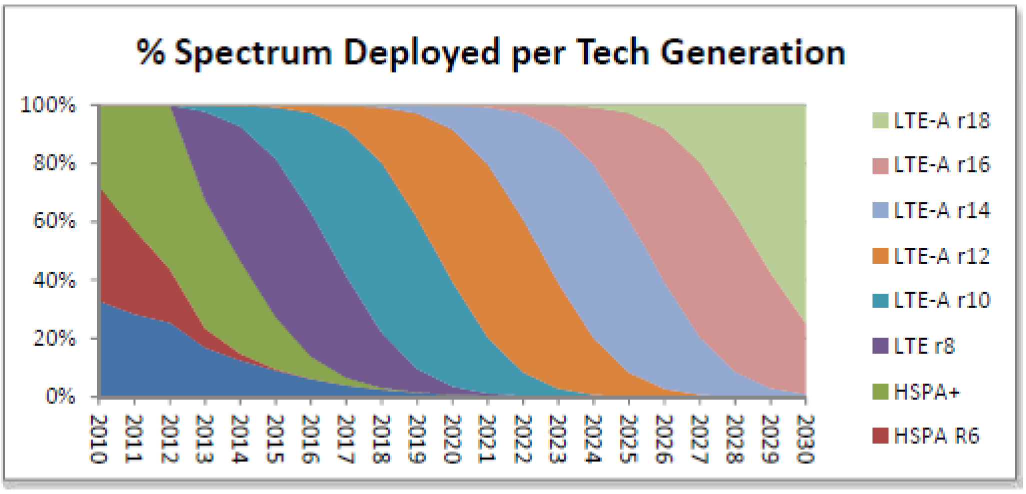
Assumption	Analysys Mason model	Real Wireless model	Ofcom model
Bits/second/Hz/sector	Set for each technology generation	Set for a changing mix of technologies	Varies as a function of SINR
Technology deployments	Technology upgrades deployed up to LTE Advanced 4×4 MIMO (available from 2017)	Technology upgrades released approximately every 18 months up to LTE Release 18	Snapshot in time
Adjustments	Overhead (network co-ordination) capacity of 23% for HSPA and 20% for LTE	Spectral efficiency adjusted to 65% of full value to account for real-world usage; 85% of cell capacity utilisation factor	Varies with distance from cell due to variations in SINR
Maximum macrocell density	Not explicitly considered	10 per sq km	Not explicitly considered
Sectors per macrocell	3	Either 3 or 6, depending on demand	3
Sector/site multipliers (sectorisation gains)	Bits/second/Hz/sector figures are multiplied by 3 to give the values per site	For sites with 3 sectors, bits/second/ Hz/sector figures are multiplied by 3; those with 6 sites are multiplied by 5.6	Bits/second/Hz/sector figures are multiplied by 3 to give the values per site

The Analysys Mason model uses a roadmap of the technologies used by the modelled generic operator in each band. This is combined with information on the release date and spectral efficiency of various technology releases to give the capacity of each band over time. The technology releases are considered up to LTE Advanced 4×4 MIMO (available from 2017, with a spectral efficiency of 2.40bits/second/Hz).

To calculate effective sector capacity the spectral efficiency inputs are scaled down using parameters for the overhead capacity required to co-ordinate the network, namely 23% for HSPA services and 20% for LTE.

While the Real Wireless model contains information on the spectral efficiencies of each technology generation and their levels of adoption by operators, this is implicitly taken into account by modelling the spectral efficiency of a changing mix of technologies, as shown in Figure B.8 below.

Figure B.8: Assumed evolution of spectrum usage by different technology generations in the Real Wireless model [Source: Real Wireless, 2013]



The Real Wireless model not only considers the technology generations currently announced for release (up to Release 12), but also models generations up to a potential Release 18, on the basis that historically releases have occurred at approximately 18-month intervals. The finding from Real Wireless's 2011 "4G capacity gains" study,[99] that spectral efficiency gains fall by 75% across every two releases, are used to forecast the spectral efficiency improvement of future generations.

The Real Wireless model also uses adjustment parameters to produce effective sector capacity, with 15% of capacity set aside for improvements in quality of service, ensuring network stability and allowing space for further demand growth. In addition, the spectral efficiency is further adjusted to 65% of this net amount to account for a real-world traffic mix (i.e. not all traffic is generated close to a site).

The Real Wireless spectral efficiency derivation methodology gives a growth in spectral efficiency per sector of 620% between 2012 and 2030.

The Ofcom model calculates spectral efficiency on a point-by-point basis, i.e. it assigns an individual spectral efficiency to every population point in the model. This efficiency is calculated from the SINR at that point by using an attenuated and truncated form of the Shannon bound. The distribution of this function is shown in Figure B.9. Using this distribution the single user throughput at each population point can be calculated.

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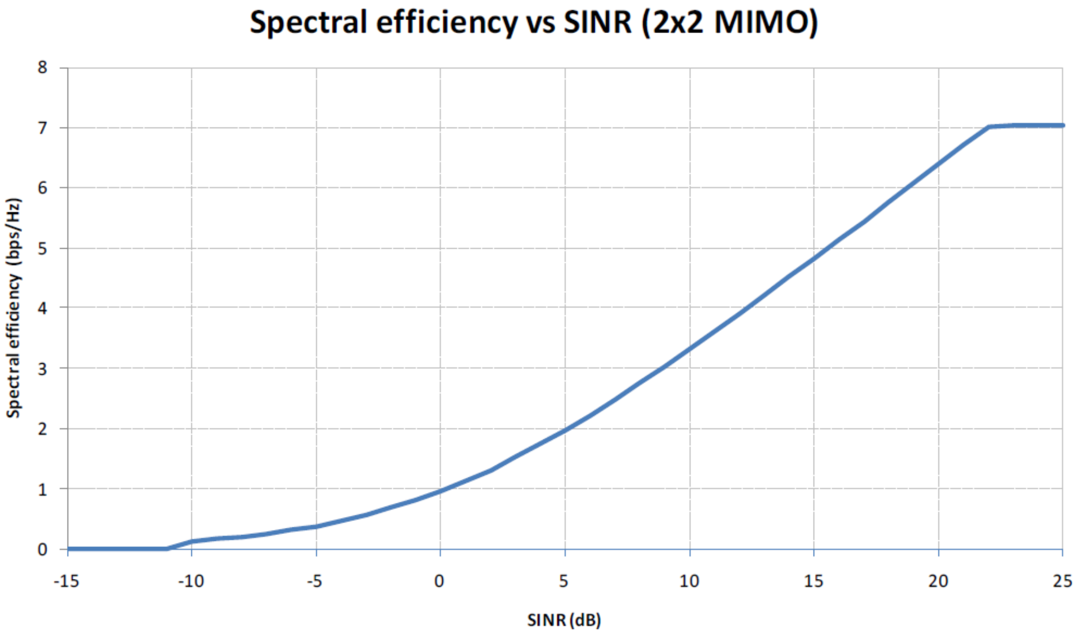
[99] See http://stakeholders.ofcom.org.uk/market-data-research/other/technology-research/2011/4G-Capacity-Gains/

Figure B.9: Distribution of spectral efficiency vs. SINR for a single sector [Source: Ofcom, 2011]



B.4.2 Sectorisation

In the Analysys Mason model, all sites are assumed to be tri-sectored macrocells, and so the capacity per site can be calculated by multiplying the capacity per sector figures by three. The Real Wireless model considers both tri-sector and 6-sector sites, with mark-ups from the per-sector capacity of 3 and 5.6 respectively. In 2012 63% of sites in the Real Wireless model are 6-sectored; this grows to 88% in 2030 if the 700MHz band changes use in 2020 and to 91% with no change in use of the 700MHz band. The Ofcom model assumes all sites to be tri-sectored.

B.4.3 Heterogeneous network assumption

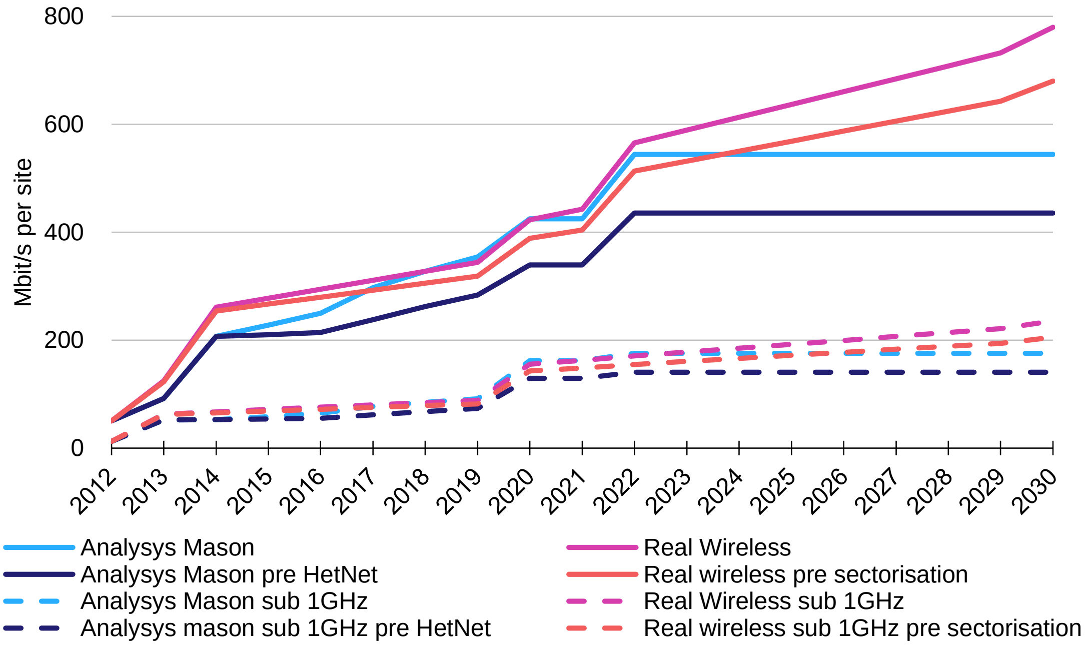
In the Analysys Mason model, further spectral efficiency gains are found though offloading to a heterogeneous network (HetNet). HetNets use a diverse set of base-station types in order to both eliminate coverage holes and improve capacity. The integrated addition of low-power nodes to the macro network provides gains through co-operation within the coverage area. This is modelled using an uplift to the site spectral efficiency.

Figure B.10: Assumptions related to heterogeneous network [Source: Analysys Mason, Real Wireless, 2013]

Assumption	Analysys Mason model	Real Wireless model
Heterogeneous network uplift	25% improvement in spectral efficiency per site by 2034	Small cells and macrocells chosen on a case-by-case basis

While the Real Wireless model does not explicitly consider a HetNet uplift factor, this has effectively already been taken into account in the higher spectral efficiency (bits/second/Hz) inputs and explicit consideration of outdoor small cells. The relationship between the Real Wireless site capacity pre and post gains through sectorisation and that in the Analysys Mason model, both with and without the modelled HetNet uplift, can be seen in Figure B.11 below.

Figure B.11: Generic operator macrocell capacity with Analysys Mason spectrum allocation [Source: Analysys Mason, Real Wireless, 2013]



If the Real Wireless spectrum allocation were to be used (as discussed in Section B.5), then site capacity would increase to 1554Mbit/s per site in 2030; however, capacity originating from sub-1GHz spectrum would remain the same, rising to 235Mbit/s per site. In the Analysys Mason base-case site capacity rises to 176Mbit/s.

The Real Wireless model contains different assumptions on spectral efficiency and sectorisation of outdoor small cells, which are discussed in Section B.8 below.

B.5 Spectrum holdings

Having access to additional spectrum reduces the number of additional mobile sites that need to be built by a mobile operator in order to provide both capacity and coverage. This reduction in required site numbers reduces both the opex and capex of the mobile operator. The Analysys Mason and Real Wireless models give details of their assumptions of spectrum allocated to mobile over time, as shown in Figure B.12 and Figure B.13.

Figure B.12: Downlink spectrum allocated to mobile services market in the Analysys Mason model [Source: Analysys Mason, 2013]

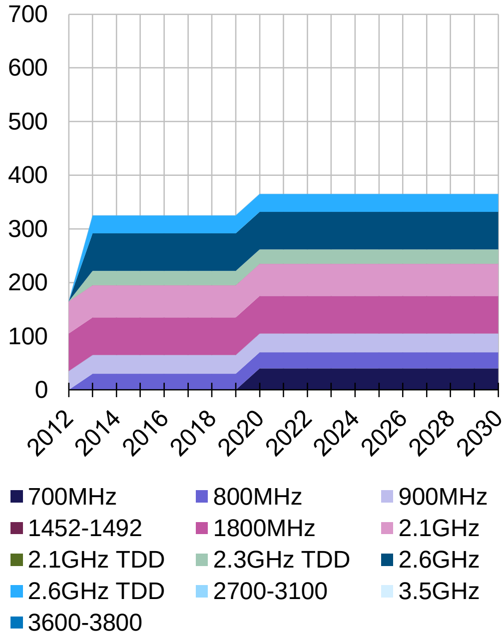
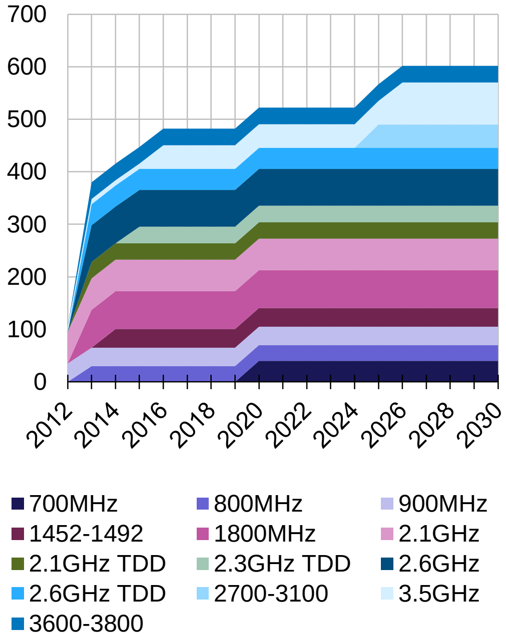


Figure B.13: Downlink spectrum allocated to mobile services market in the Real Wireless model [Source: Real Wireless, 2013]



Both models include a parameter for the proportion of TDD spectrum used for downlink traffic. In the Analysys Mason model this is 2/3, while in the Real Wireless model it is 89%. These parameters have been applied, respectively, to the total TDD spectrum available in the market to produce Figure B.12 and Figure B.13.

As can be seen, in both models a large amount of spectrum will already be available to mobile operators before the change of use of the 700MHz band; as such, national coverage for LTE (probably using 800MHz) will already be well established by the time of the change of use of the 700MHz band. 700MHz spectrum will therefore not result in any significant savings on the number of sites needed for coverage.

Different frequency spectrum bands have different characteristics with regard to propagation and penetration, and low-frequency sub-1GHz spectrum allocations are particularly important when considering the value of the 700MHz band. While the total spectrum available to mobile is much higher in the Real Wireless model, growing to 1015MHz by 2030 compared to 700MHz in the Analysys Mason model,[100] the assumptions of sub-1GHz spectrum are identical, with 2×105MHz allocated in both the Analysys Mason model and the Real Wireless model (assuming 2×40MHz is allocated in the 700MHz band).

The Analysys Mason model assigns roughly one quarter of the spectrum available in the market, excluding the 700MHz band, to the generic operator. Four scenarios are considered, in which the generic operator wins a varying amount of spectrum in the 700MHz band:

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[100] In the Real Wireless model this comprises 2×387MHz of paired spectrum and 241MHz of TDD spectrum, while in the Analysys Mason model there is 2×305MHz of paired spectrum and 90MHz of TDD spectrum.

- Scenario 1: 0MHz
- Scenario 2: 2×5MHz
- Scenario 3: 2×10MHz
- Scenario 4: 2×15MHz.

In both models the change of use of 700MHz spectrum in 2020 is tested as part of the base case and mid case. Spectrum use change in 2026 is also tested in both models, as well as a 2018 use change in the Analysys Mason model.

B.6 Unit costs of equipment

Having access to additional spectrum reduces the number of additional mobile sites that need to be built by a mobile operator in order to provide additional capacity. This reduction in site builds reduces both the opex and capex of the mobile operator; therefore the values chosen within the models for the unit costs associated with site-related assets can have a significant impact on network costs. Figure B.14 provides a summary of the unit-cost-related assumptions used in the Analysys Mason and Real Wireless models. Costs are not considered in the Ofcom model.

Figure B.14: Assumptions related to unit costs of equipment [Source: Analysys Mason, Real Wireless, 2013]

Assumption	Analysys Mason model	Real Wireless model
Capex	Unit capex values are taken from Analysys Mason's experience	Equipment costs are explicitly modelled on a per-site basis for both macrocells and small cells Software costs are considered implicitly
Opex	In general annual unit opex is around 10% of unit capex, although for backhaul more detailed assumptions are used to derive a higher opex figure	10% of active equipment capex
Cost trends	2.5% p.a. for site acquisition and build costs to reflect increasing labour costs and property prices; 0% for backhaul and electronic equipment	2.5% p.a. for site civil works and towers; -7.5% p.a. for antennas and other site equipment; -2% p.a. for backhaul
Asset lifetimes/ replacement cycle	Replacement capex not considered	Not specified for macrocells;[101] 5 years for outdoor small cells, 3 years for indoor small cells
Discount rates (discussed in Section B.9)	WACC of 8.86% pre-tax nominal (6.2% pre-tax real)	3.5% real social discount rate

In both the Analysys Mason and Real Wireless models the cost savings due to the additional spectrum are explicitly assessed with respect to both opex and capex across similar cost elements, as shown in Figure B.15 below.

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[101] We have requested this information from Real Wireless and await a response. The initial indication was that the lifetime for macrocells was significantly greater than for small cells.

While the Analysys Mason unit costs are stated explicitly in the model, we have had to derive some of the Real Wireless values from its report.[102] Real Wireless gives total macrocell new-build costs in each study area (urban, suburban and rural) and from this a total new-build cost for the average macrocell of GBP90 133 can be derived. Using information on the proportion of this total cost deriving from each asset group, average unit costs for the asset groups can be found, as shown in Figure B.15. We believe the cumulative cost of site civil works, towers and antennas in the Real Wireless model to be comparable to (i.e. cover the same asset deployment as) the new site build costs in the Analysys Mason model.

Additionally, the cost of adding a new spectrum band or carrier to a site is only stated for macrocells in the Real Wireless model. We have made an assumption of three sectors on a macrocell for every one sector on a small cell and therefore approximated the carrier cost for a Real Wireless model small cell as one third of that for a macrocell, GBP4333.

Figure B.15: Unit costs within the models in real 2011 terms [Source: Analysys Mason, Real Wireless, 2013]

Asset	Analysys Mason macrocell		Real Wireless macrocell		Real Wireless outdoor small cell	
	Capex (GBP)	Opex (GBP)	Capex (GBP)	Opex (GBP)	Capex (GBP)	Opex (GBP)
New site build	110 000	11 000	–	–	–	–
Carrier	6000	600	13 000	1300	4333	433
HSPA equipment	3500	350	–	–	–	–
LTE equipment	4200	420	–	–	–	–
TD-LTE equipment	4620	462	–	–	–	–
Backhaul	15 000	4500	9915	991	6000	600
Site civil works	–	–	49 573	4957	3350	335
Towers	–	–	15 323	1532	–	–
Antennas	–	–	5408	541	–	–
Other site equipment	–	–	10 816	1082	3300	330

In both models, the unit costs are estimated for a single year and projected forward across the model period by applying annual cost trends to the asset categories shown in Figure B.15 above. The Analysys Mason model sets all cost trends to zero, except that for new site build, which is set at +2.5%, to reflect increasing labour costs over time. The Real Wireless model assigns the following cost trend assumptions to all cost categories, for both macro and small cells, in line with those in Ofcom’s 2009 “Application of spectrum liberalisation and trading to the mobile sector” study and industry sources:

- Site civil works: +2.5%
- Towers: +2.5%
- Antennas: -7.5%

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[102] Macrocell carrier costs, as well as small cell backhaul, site civil works and other site equipment unit costs are stated explicitly in the Real Wireless report annexes.

- Other site equipment: -7.5%
- Backhaul: -2%.

The Real Wireless model takes into consideration the lifetime of the network equipment deployed and includes the capex on asset replacement in its network spend calculations. For replacement capex, the model considers a replacement cycle such that a unit of equipment deployed in year α with an economic lifetime of β will need replacement in each year $\alpha+\beta$, $\alpha+2\beta$, etc. until the end of the model period. Each asset replacement incurs the capex of a new unit of equipment in the replacement year.

The economic lifetime of macrocell equipment is not stated in the Real Wireless documentation; however, the model considers the economic lifetime of all outdoor small-cell cost components to be five years. Similarly, although indoor small cells are not explicitly considered in the Real Wireless model, they are assumed to have a replacement lifecycle of three years. We would therefore expect the lifetime for a macrocell to be (significantly) greater than five years.

B.7 Site sharing assumptions

The Real Wireless model, while considering the market in aggregate, assumes the presence of two shared networks over which mobile broadband traffic is split equally. This is consistent with the current direction of the market in which there are likely to be two pairs of mobile network infrastructure providers, MBNL and Cornerstone / Project Beacon.[103] While Real Wireless acknowledges that not all new site builds are shared in reality, the Real Wireless model assumes all additional sites will be built on a shared basis.

Site sharing in the Real Wireless model has the effect of reducing the capex and opex on new sites by a factor of two, which will serve to reduce the level of network costs that could be saved by 700MHz spectrum.

Neither the Analysys Mason model nor the Ofcom model considers site sharing.

Figure B.16: Assumptions related to site sharing [Source: Analysys Mason, Real Wireless, 2013]

Assumption	Analysys Mason model	Real Wireless model
Sites shared	0	All new sites
Initial sites	17 500	One network with 12 000 macrocell sites, the other with 18 000 deployed in year 1

Both the Real Wireless and Analysys Mason models make assumptions on the initial number of sites for networks: Real Wireless assumes that one shared network will have around 12 000 macrocell sites and the other 18 000, while Analysys Mason assumes that 17 500 sites are already

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[103] MBNL is the result of a network sharing agreement between EE and H3G, while Cornerstone / Project Beacon comprises O2 and Vodafone.

deployed by the generic operator. The Analysys Mason number is set slightly higher than the average for actual operators, to reflect the impact of site sharing agreements.

In the Real Wireless model, the first 6000 sites to be deployed are in effect taking advantage of sharing the larger network's sites and are treated as site upgrades rather than new site builds. Further requirements for macrocells in the modelled network will result in modelling of new builds, which will be shared by the operators.

B.8 Small cells

The Analysys Mason model notionally considers all new sites built to be macrocells. The assumption is equivalent to assuming that the cost per unit capacity of a small cell and a macrocell are equal. It may become impractical to build additional macrocells in dense urban areas at some stage in the future and therefore small cells may be needed, but in terms of network costs the Analysys Mason model effectively assumes that these provide equal capacity at the same cost as a macrocell equivalent, were it to be possible to deploy one.

The Real Wireless model explicitly considers the build-out of outdoor small cells to provide capacity for the cellular network. The small cells are modelled explicitly in a similar way to macrocells, with reduced range and site spectral efficiency assumptions. The number of bands supported by each small cell is also limited, although increasing over time. These small-cell assumptions are shown in Figure B.17 below.

The Ofcom model assumed that all sites are tri-sectored macrocells.

Figure B.17: Assumptions related to small cells [Source: Analysys Mason, Real Wireless, 2013]

Assumption	Analysys Mason model	Real Wireless model
Sectorisation	Not considered explicitly	Initially all 1-sector, but 50% of sites have 2 sectors by 2030
Bits/second/Hz/sector	Not considered explicitly	1/1.24 of the spectral efficiency of a macrocell sector
Spectrum bands supported	Not considered explicitly	Increases from 1 in 2012 to 5 by 2025

The small cells modelled by Real Wireless cover microcell, picocell and metrocell deployments. These are modelled as one cell type, capable of supporting 1 spectrum band in 2012, increasing to 5 in 2025, with per-sector spectral efficiency set at approximately 81% of a macrocell sector.

Information on small-cell unit costs, cost trends and replacement cycles are provided for the same assets as macrocells, as detailed in Section B.6. There is an additional cost trend applied to small cells to account for the greater price for provision of multiband cells. Using information on the costs of dual-band and single-band Wi-Fi access points, Real Wireless assumes that the equipment cost of a 5-band small cell in 2025 will be 50% higher than for a single-band small cell in 2012.

B.9 Discount rate

A discount rate is used by both the Analysys Mason and Real Wireless models to convert the costs of network deployment, with and without the change of use of the 700MHz band, to present values. The two models use different discount rates in order to do this, as shown in Figure B.18.

Figure B.18: Assumptions related to discount rate [Source: Analysys Mason, Real Wireless, 2013]

Assumption	Analysys Mason model	Real Wireless model
Discount rates	WACC of 8.86% pre-tax nominal (6.2% pre-tax real)	3.5% (real) social discount rate

The Analysys Mason model uses a weighted average cost of capital (WACC) value for its discount rate. This is set at 6.2% pre-tax real, or 8.86% pre-tax nominal, in line with the mobile operator WACC used in the Ofcom modelling of mobile termination.

The Real Wireless model makes use of a social discount rate of 3.5% in real terms, as set out in the HM Treasury Green Book since its update in July 2011.[104] This figure is used to take account of social time preference and is chosen because the goal of the model is to consider costs to society, not to a mobile operator. Real Wireless does also carry out sensitivity tests using a commercial discount rate, in acknowledgement of the fact that mobile operators do not make their decisions on equipment and technology deployment based on costs to society.

B.10 Other

There are a number of differences in parameters and model methodology other than those laid out in Sections B.2 to B.9 above. Those with the biggest impact on the model results are the assumptions regarding traffic distribution and the algorithm used to calculate network expansions to supply the necessary capacity. Another important issue is the proportion of the network for which costs are calculated, and therefore the scalar needed to give a comparable national market valuation. These parameters are detailed in Figure B.19 below.

Figure B.19: Other input assumptions [Source: Analysys Mason, Real Wireless, Ofcom, 2013]

Assumption	Analysys Mason model	Real Wireless model
Distribution of traffic across sites	Distributed within geotype using a function of the form y = a×ln(x)+b	Not explicitly considered as the model uses real site locations and traffic, but can be extracted from the model
Distribution of traffic within cells	30% of network traffic is generated outside the reach of supra-1GHz	Not explicitly considered as the model uses real site locations and traffic, but can be extracted from the model
Scaling to national level	Scaled up by 4 to convert from generic operator to total market	Divided by 6% to convert from regions with 6% of UK traffic to a national approximation

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[104] This social discount rate is quoted in real terms; using an interest rate of 3.5% gives a nominal social discount rate of 6.09%.

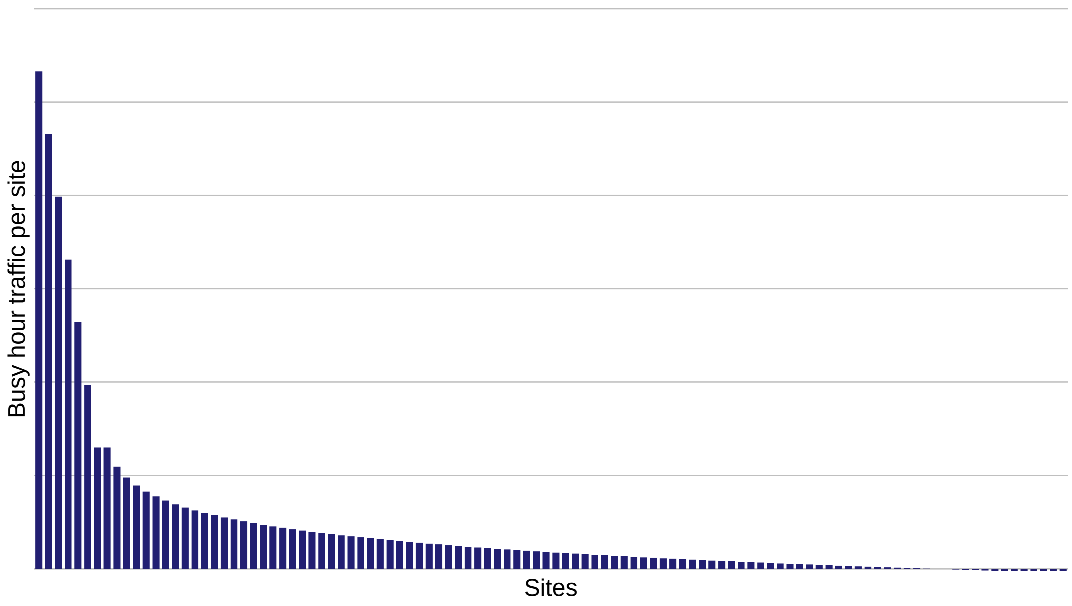
Assumption	Analysys Mason model	Real Wireless model
Distribution of traffic by location	Not explicitly considered	Split across business addresses, residential addresses and transport routes
Split of traffic by clutter type	Not explicitly considered	99% of devices located in urban and suburban clutter within urban and suburban geotypes; 1% located in urban and suburban clutter within rural geotypes
Indoor/outdoor split	Not explicitly considered	80% of traffic originates indoors in 2012, rising to 95% in 2024
Distribution of traffic among individuals	Implicit assumption that all users generate equal traffic	Distributed asymmetrically; 10% of users generate 80% of traffic in 2012, declining to 28% in 2030

The traffic in the Analysys Mason model is distributed across geotypes, across sites within any geotype, and within the coverage area of each site.

In order to split the traffic by geotype, the site and traffic splits used by Ofcom in its calls to mobile (CTM) model for assessing the costs of mobile termination[105] are used. The use of these inputs results in a higher traffic per site figure for the most urban geotypes.

In addition to the split of traffic between geotypes, the model assumes an uneven distribution of traffic across sites within any given geotype. A traffic distribution derived from traffic patterns observed from mobile operators has been used to implement this in the model. This relationship between busy-hour traffic per site and sites is of the form y = a×ln(x)+b and is illustrated in Figure B.20 below.

Figure B.20: Illustration of traffic distribution within geotypes [Source: Analysys Mason, 2012]



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[105] See http://www.ofcom.org.uk/static/wmvct-model/model-2011.html

As illustrated in Figure A.2 in Section A.1.1, sub-1GHz spectrum has great importance to mobile operators because of its superior propagation characteristics. While around 50% of the coverage area of each cell is outside the reach of supra-1GHz spectrum, the Analysys Mason model makes the assumption that 30% of network traffic is generated outside the reach of supra-1GHz spectrum, and can therefore be carried only over lower frequencies (i.e. the 700MHz, 800MHz or 900MHz bands), or by building new sites.

The Real Wireless traffic distribution is built up on a more granular basis, as traffic is first split across locations on the basis of business address, residential address and transport routes, specifically road and rail, at each time of day. This traffic is then evaluated per address or km of road/rail using data from the UK postcode database and the Ordnance Survey database, giving the quantity of demand for each busy hour at each location within the three study areas.

The Real Wireless traffic is then split by clutter type, indoor and outdoor locations and distribution among individuals. The split of traffic between clutter types acts to distribute traffic in line with demand. The distribution is based on assumptions of device location in certain clutter types, with 99% of total devices expected to be located in urban and suburban clutter within urban and suburban geotypes and only 1% located in urban and suburban clutter within rural geotypes. These parameters are derived from Ericsson’s traffic forecast[106] for traffic generation across different clutter types and assumptions on the proportion of open spaces and farmland in the study areas.

At this stage, traffic is then split into that originating from indoor and outdoor locations. This is considered important given the traffic offloading assumption in the Real Wireless model, according to which all traffic offload occurs indoors. Real Wireless uses a number of sources to estimate the proportion of traffic generated indoors throughout the model, with its Mid scenario assuming 80% in 2012, peaking at 95% in 2024 where it remains until 2030. The remaining balance is generated outdoors.

Finally, once average demand per address or km has been calculated for each study area the traffic is split asymmetrically across users such that the majority of traffic is generated by a small proportion of mobile users, with 10% of users generating 80% of traffic in 2012. There is a decline expected in the asymmetry of traffic among users and this decline is comparable with a Cisco forecast to 2017, at which time 10% of users generate 45% of traffic, with the rate of decline falling until 2030 when just 28% of traffic is generated by the top 10% of users. The traffic distribution among users in the Real Wireless model is illustrated in Figure B.21 below.

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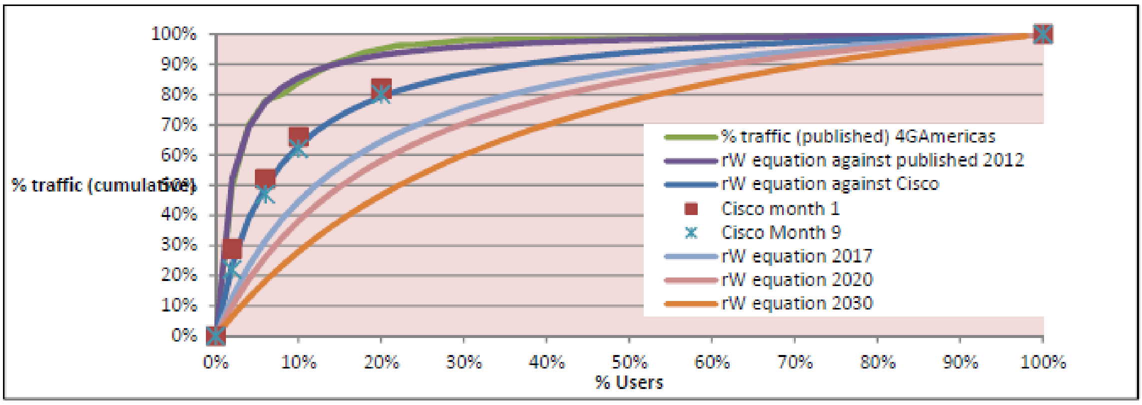
[106] “Traffic and Market data report ON THE PULSE OF THE NETWORKED SOCIETY”, Ericsson, November 2011.

Figure B.21: Evolution of distribution of traffic among individuals over time in the Real Wireless model [Source: Real Wireless, 2013]

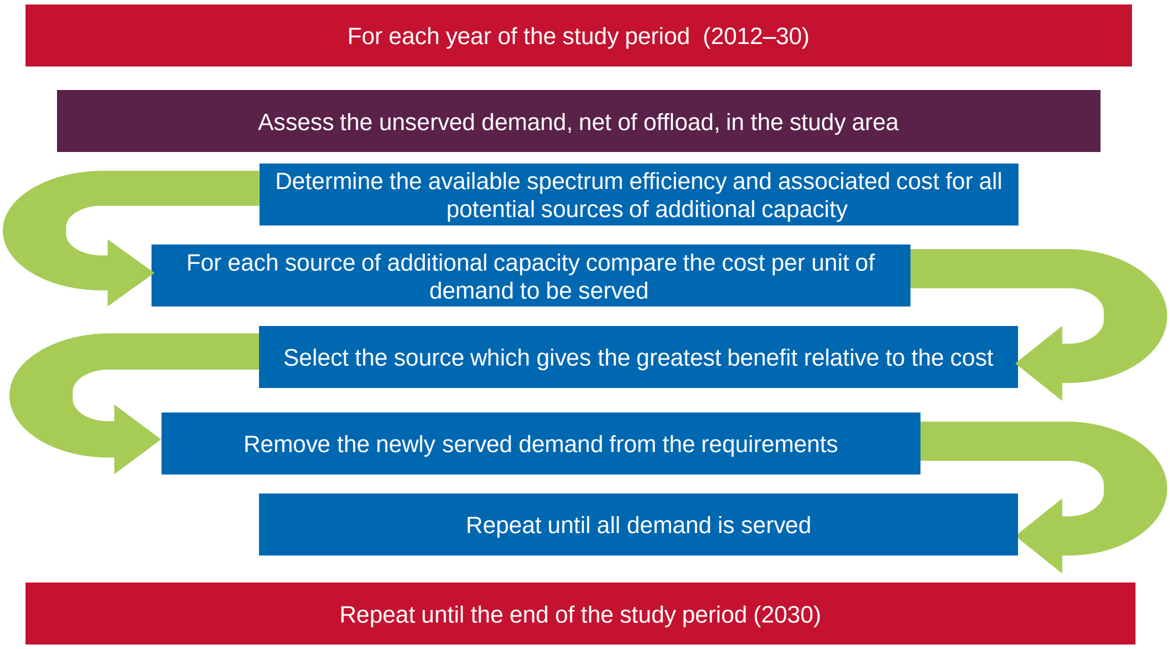


The algorithms applied to calculate the network infrastructure requirements in the two models are detailed in Sections A.1.1 (Analysys Mason) and A.2.1 (Real Wireless), although they are also summarised below.

The Analysys Mason model calculates the number of additional carriers and sites required to provide adequate capacity for the traffic that can only be served by low-frequency spectrum (or new sites). Any remaining capacity of the sites deployed to service the low-frequency specific traffic is used to carry the remainder of the traffic. Additional calculations are then run to see if any additional sites are required in order to carry this remaining 'non-low-frequency-specific' traffic.

The deployment of infrastructure in the Real Wireless model is carried out as shown in Figure B.22 below.

Figure B.22: Site deployment and upgrade algorithm [Source: Analysys Mason based on Real Wireless, 2013]



The results produced by the Analysys Mason and Real Wireless models are not directly comparable, as neither gives the value of the 700MHz band to the entire market. However, both results can be scaled up to give approximations of what this total value would be.

The Analysys Mason base case produces a value for 2×10MHz of 700MHz spectrum to a generic operator with 25% market share. As the model assumes that 2×40MHz of spectrum is allocated to mobile in total to the market, the result of GBP539 million can simply be multiplied by 4 to give a national market valuation of around GBP2.2 billion.

The Real Wireless model produces a valuation for the spectrum for the whole market in three study regions representing urban, suburban and rural environments which cumulatively generate a total of 6% of UK wireless traffic (and represent roughly 6% of the UK population). It is not possible to fully scale this up to a national level; however, a rough idea of an equivalent UK value can be extrapolated by dividing the regions' value of GBP10 million by 6% to give an approximate UK value of GBP167 million.[107]

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[107] Ofcom has stated that the UK value lies between GBP150–160 million, which differs from the calculated value of GBP167 million due to weightings of the different study areas when scaling up to the UK-level approximation.

Annex C Analysis of differences in results

C.1 Overview

In order to understand the differences between the outputs produced by the Analysys Mason model and the Real Wireless model we have carried out a detailed analysis of the impact of the differences identified in Annex B. The Analysys Mason model results for the technical value of 2×10MHz of 700MHz spectrum to a generic operator imply a network cost saving to all operators of GBP2.16 billion for 2×40MHz of 700MHz spectrum in 2015 real terms. This cost saving is achieved over the period 2015–2034, but including a terminal value, and assumes the spectrum is available from 2020.

In comparison, the Real Wireless study suggests a value of GBP6.3 million (2012 real terms) for the period 2012–2030, not including any terminal value for the three study areas (which represent 6% of UK wireless traffic demand). Using the same extrapolation approach as previously, this implies a national network cost saving of GBP105 million (2012 real terms).[108]

We modified the Analysys Mason model (with base case assumptions) to incorporate the Real Wireless model mid-case assumptions, aiming to reflect the Real Wireless results in the Analysys Mason model and in the process explain the impact of any methodological differences and differences in parameters. As previously indicated, we chose to compare the mid case since Real Wireless stressed that the low and high cases in the scenarios studied were extremes chosen as bounds, whereas the mid case was chosen to be more representative of expected future conditions.

The comparison does not imply that we agree with the Real Wireless approach or parameters: rather, it is intended to illustrate the impact of the differences in each area, to make sure that we have identified the most significant factors. We modify parameter values in the Analysys Mason model to illustrate the magnitude of difference resulting from each factor, because this provides an easy-to-use and consistent framework for such an analysis.

Figure C.1 below summarises the 13 key areas of difference and the magnitude of the impact on the Analysys Mason model when the Real Wireless assumptions are applied. It should be noted that the magnitude of these differences varies if applied in a different order. Figure C.1 first quantifies the conceptual differences arising from the time period modelled and the inclusion of a terminal value and then goes on to quantify the impact of changes in input parameters in the order in which these parameters are considered by the algorithms in the Analysys Mason model (and likely also in the Real Wireless model).

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[108] The Real Wireless model calculates cost savings for the period 2012–2040 to be GBP10.0 million for the three study areas, which implies an extrapolated national total of GBP167 million. Restricting the model to the period 2012–2030, and thereby removing the ‘static network period’ of 2030–2040, yields values of GBP6.3 million for the three study areas and an extrapolated national total of GBP110 million.

Figure C.1: Waterfall chart of cumulative impact of applying Real Wireless assumptions to the Analysys Mason model [Source: Analysys Mason, 2013]

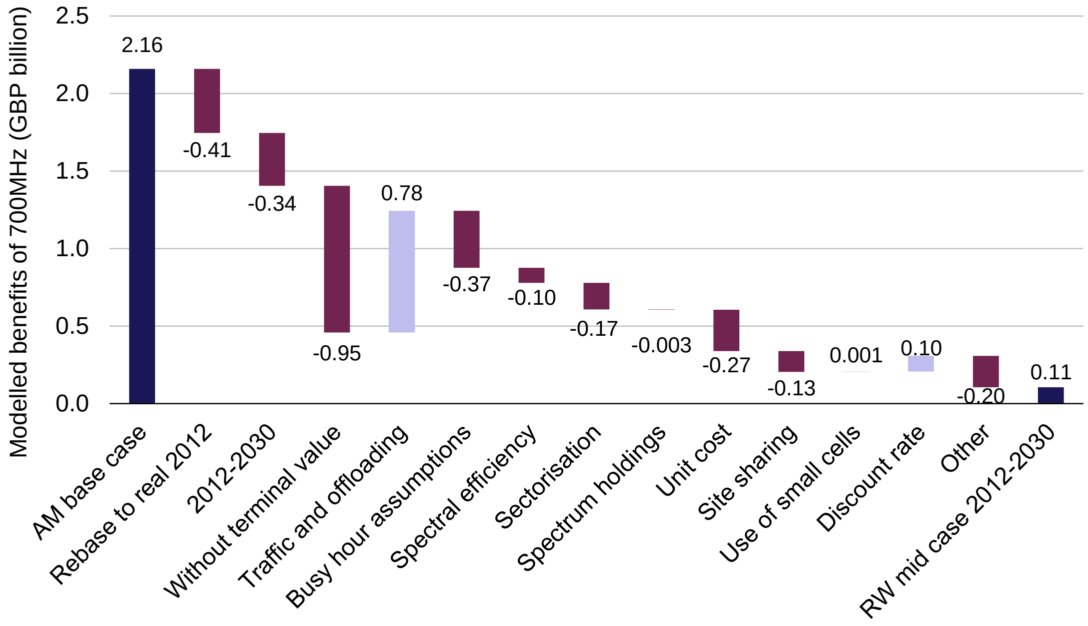
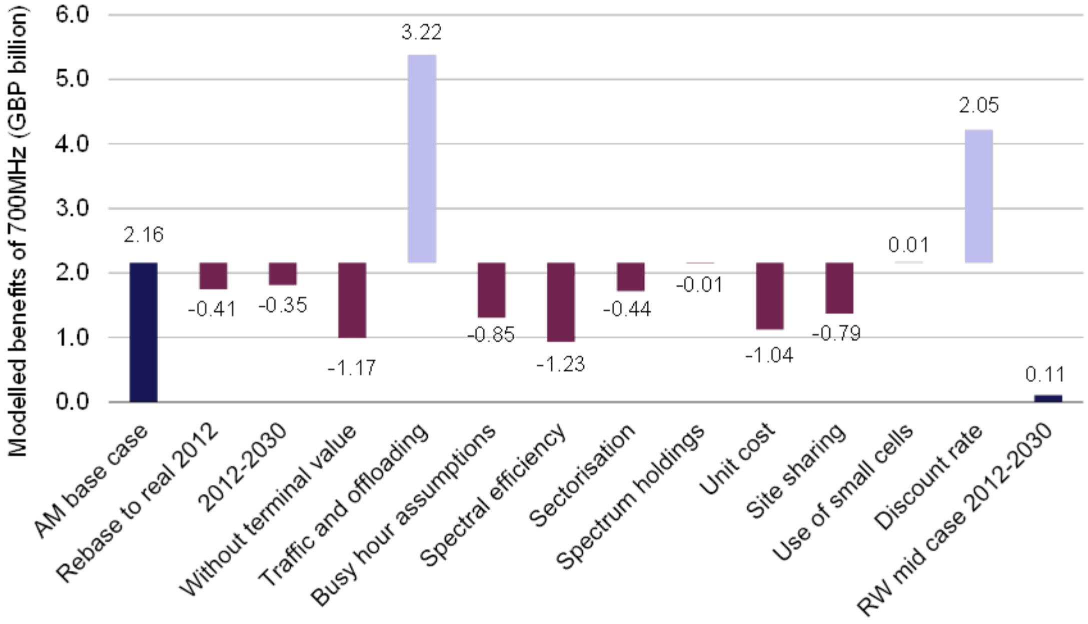


Figure C.2 below illustrates the impact of applying these assumptions individually, demonstrating the relative impact of varying each input parameter on the base model. We note that varying each input parameter individually by, in some cases, extreme amounts does not necessarily lead to a sensible scenario.

Figure C.2: Waterfall chart of impact of applying individual Real Wireless assumptions to the Analysys Mason model [Source: Analysys Mason, 2013]



In the following sub-sections we discuss each of the categories of difference shown in Figure C.1. Each sub-section considers the impact on network cost savings of the differences in inputs described in more detail earlier (in the corresponding sub-section of Section Annex B).

C.2 Time period

Rebase to 2012 real terms

The Analysys Mason model reported outputs in 2015 real terms whilst the Real Wireless model was based on 2012 real-term values. Rebasing the Analysys Mason model to 2012 to ensure that a fair comparison can be made between values has the impact of reducing modelled network cost savings by GBP411 million.

This rebasing does not take into account the use of different discount rates to calculate the present value. Real Wireless use a social discount rate of 3.5% whilst the Analysys Mason model uses a weighted average cost of capital (WACC) of 8.86% pre-tax nominal (6.2% pre-tax real).

Align start and finish year

The Analysys Mason model starts in 2015 and runs for 20 years whereas the Real Wireless modelling period is from 2012 to 2030. Aligning the Analysys Mason model to start in 2012 and run to 2030 reduces modelled network cost savings by a further GBP342 million.

Terminal value

The Analysys Mason model calculates a terminal value of network cost savings from the end of the modelled period into perpetuity whereas the Real Wireless model follows an approach that models the network for a further ten years after the initial 19-year model period, with no further network build-out. The Real Wireless approach is intended to provide an indication of costs over the period 2012–2040 free of equipment lifecycle effects, 'rather than as representing future costs on an absolute basis'.[109]

Removing the terminal value from the Analysys Mason model removes GBP946 million of network cost savings. Similarly, removing the Real Wireless costs generated in the period 2030–2040 reduces the sum of network cost savings across the three study areas from GBP10.0 million to GBP6.3 million. This results in a fall in the equivalent national extrapolation value from GBP167 million to GBP105 million.[110]

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[109] *Techniques for increasing the capacity of wireless broadband networks: UK, 2012–2030*; Real Wireless, p7 See http://www.ofcom.org.uk/static/uhf/real-wireless-report.pdf

[110] Note that the value of GBP167 million is not shown in Figure C.1.

In this way the impact of the difference in terminal value approach can therefore be considered to be GBP884 million.[111]

C.3 Demand

Traffic and offloading forecasts

The Analysys Mason model forecast for total network traffic is 2635PB in 2020 and 5619PB in 2030, which is lower than that used in the Real Wireless model. The Real Wireless model assumptions imply a network-level, post-offload data traffic forecast of 3282PB in 2020 and 11 592PB in 2030. Both models make different assumptions on penetration, usage and offload to calculate these forecasts (as described in Section B.3).

The impact of applying the Real Wireless calculated demand to the Analysys Mason model (after making the changes above) is to increase the network cost savings by GBP783 million.

Busy-hour assumptions

The Analysys Mason model uses the busy-hour parameters from Ofcom's 2011 mobile LRIC model, giving a 0.024% share of yearly traffic in the busy hour. The Real Wireless model calculates a series of busy-hour metrics for indoor and outdoor coverage in the morning, afternoon rush-hour and evening peaks (as described in Section B.3).

In order to incorporate the Real Wireless assumption into the Analysys Mason model the proportion of busy-day traffic in the busy hour was amended from 7.5% (as in Ofcom's 2011 mobile LRIC model) to 6%, in line with the two highest of the three peaks in the Real Wireless model (5–6pm and 8–9pm). The impact of this change to the Analysys Mason model is to reduce the network cost saving by GBP368 million.

C.4 Capacity per site

Spectral efficiency

The Real Wireless model assumes substantial gains in spectral efficiency over the modelled period, due to: improved encoding and modulation techniques in new releases of LTE and LTE-Advanced technology (as well as increasing adoption of newer releases); and evolving antenna counts per device.

The Analysys Mason model uses more-conservative forecasts of improvements to spectral efficiency (as described in detail in Section B.4). The Analysys Mason model assumes that the development of heterogeneous networks enables further improvements in spectral efficiency,

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[111] GBP946 million – (GBP167 million – GBP105 million)

assumed in the base case to be 25%. The Real Wireless model includes this impact within its spectral efficiency numbers.

The impact of removing the heterogeneous network assumption from the Analysys Mason model and implementing the Real Wireless spectral efficiency assumptions described above is to reduce the network cost savings by a further GBP96 million.

Sectors per site

Sectorisation gains can be made by deploying increased numbers of sectors and transmitters at macrocells. The Real Wireless and Analysys Mason models differ in their assumptions regarding the rate at which sites are upgraded with increasing numbers of transmitters and the sectorisation gains available. This is described in detail in Section B.4. The impact of adding in the sectorisation gains of allowing six-sector sites for new sites in the Analysys Mason model is to reduce network cost savings by GBP172 million.

C.5 Spectrum holdings

Updating the Analysys Mason model to reflect the spectrum holdings used in the Real Wireless model and described above in Section B.5 results in a GBP3 million fall in network cost savings. We note that this impact is relatively small because the differences in spectrum holdings all relate to high-frequency spectrum, whereas network costs are predominantly driven by a bottleneck in sub-1GHz spectrum.

C.6 Unit costs of equipment

Applying the unit capital costs of macrocell equipment and the associated operational costs from the Real Wireless model to the Analysys Mason model reduces the network cost savings by GBP267 million. The cost differences are described in Section B.6, but in general terms the Real Wireless model assumes lower costs for newer sites but higher costs for site upgrades, both of which serve to reduce network cost savings from new spectrum.

The impacts of replacement capex are expected to be relatively small but have not been tested, as they are not straightforward to incorporate into the Analysys Mason model.

C.7 Site sharing assumptions

While the Analysys Mason model is of a generic operator with a slightly higher number of initial sites than the average number of actual operator sites reported to reflect a small amount of site sharing, there is no further account taken of site sharing in the model.

The Real Wireless model assumes that there are two infrastructures, each carrying equal amounts of traffic, one with 12 000 sites and the other with 18 000 sites. It is assumed that the smaller operator can expand to 18 000 sites by sharing the larger network's sites. Moreover, additional site deployments for both infrastructure providers are assumed to be 100% shared.

The Real Wireless approach can be reflected in the Analysys Mason model by assuming that all new-build sites over the model period are shared and therefore the cost of sites (capex and opex) to each operator is halved. The cost of active equipment is still borne individually by each operator. The impact of applying the Real Wireless assumption of 100% site sharing is to reduce the network cost savings by GBP133 million.

C.8 Small cells

As described in Section B.8, the Real Wireless model assumes that as well as macrocells, network capacity can be provided by deploying outdoor small cells. The model uses a number of assumptions relating to spectral efficiency, sectorisation and the number of spectrum bands supported by these small cells to calculate figures for capacity per small site.

The Analysys Mason model considers the number of "macrocell equivalents" which are required. In order to implement the Real Wireless assumptions in the Analysys Mason model it is necessary to understand the number of small cells which are equivalent to a single macrocell in terms of both capacity and cost. Based on the Real Wireless model, the ratio of cost per unit capacity in macrocells to that for microcells can be calculated as approximately 1.01. This ratio was used to calculate weighted average unit capex and opex values for the combination of macrocells and microcells required in the Analysys Mason model.

The impact of applying the Real Wireless assumptions on small-cell efficiency through the weighted average unit costs is to increase the network cost savings by GBP1.0 million.

C.9 Discount rate

As discussed in Section B.9, while the Analysys Mason model discounts network costs using a real WACC of 6.2%, the Real Wireless model makes use of a real social discount rate of 3.5% to take account of the fact that these are the costs to society, not to the network operators.

The impact of applying the Real Wireless social discount rate of 3.5% in real terms is to increase the network cost savings by GBP102 million.

C.10 Other

The remaining category reflects other methodological differences, primarily the approach taken by the Analysys Mason model to parameterise the distribution of traffic between sites and the proportion of traffic that can only be served by sub-1GHz spectrum. There are some differences which cannot be quantified by changing the input assumptions. These parameterisations are analogous to elements of the Real Wireless model's deployment algorithm. This is described in more detail in Section B.10.

This category also includes the impact of incorporating replacement capex costs in the Analysys Mason model, as discussed in Section B.6.

These remaining differences reduce the network cost savings by a further GBP202 million.