Assessment of future mobile competition and award of 800 MHz and 2.6 GHz

Annexes 7 - 12

Statement

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Annex 7

LTE macrocell modelling results

Introduction

A7.1 This annex presents the key results from our technical analysis of the performance of LTE macrocell networks using paired spectrum which has been drawn upon to inform our policy analysis in Section 4 of Annex 2 of the statement.

A7.2 We are particularly concerned with comparing the performance achieved by networks using different portfolios of spectrum with a range of frequency bands and bandwidths, and how this affects the ability of a national wholesaler to be credible. As such our technical model has been developed and parameters selected with this aim in mind.

A7.3 The technical model we have used is essentially the same as that developed for the March 2011 and January 2012 consultations. Following a detailed review of responses to the January 2012 consultation and further internal analysis, a number of the parameters and assumptions have been changed. For a comprehensive description of the modelling methodology and the underlying parameters and assumptions see Annex 8 and for an overview of the technical responses to the January 2012 consultation and how we have addressed these see Annex 10.

A7.4 Our technical modelling focuses on the macrocell downlink capability of networks to offer illustrations and insight into particularly coverage and capacity. In reality the performance seen by users in a mobile network is influenced by a large number of interlinked factors that interact with each over in a highly dynamic fashion. For instance, the performance a user will achieve will depend on: their location within a cell; the location of others users relative to them and relative to the network; the local topology of the network; and the type of service being demanded. It is not realistic to develop a technical model that could capture every possible dynamic variation with enough certainty on which we could base our policy. Our relatively simple model therefore enables the capture of key metrics, in particular coverage, throughput and capacity that allow a comparison between networks operating at different frequencies and bandwidths. The downlink SINR based Monte Carlo approach is an approach consistent with those of establishing network performance by regulators and some mobile operators.

A7.5 Our analysis does not make detailed predictions of uplink performance; such performance will be highly dependent on the nature of the services being demanded by users (e.g. data-rates required, the degree of uplink/downlink asymmetry etc) and is also to a certain extent within the control of the operator, through traffic shaping and charging models. We note that LTE has not been specified with provision of perfectly symmetric services and the original requirements[1] limit suggest a difference in uplink to downlink data rates of a factor of 2. The practical implementation of LTE actually suggests that for a given link the uplink is likely to be a much smaller percentage of the downlink; for example Holma and Toskala[2] demonstrate uplink and downlink budgets that are balanced for data-

[1] 3GPP TR 25.913 V9.0.0, “Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN)”: http://www.3gpp.org/ftp/Specs/html-info/25913.htm. This specification targets a peak downlink rate of 100Mbit/s and an uplink of 50Mbit/s
[2] H. Holma & A.Toskala, “LTE for UMTS: Evolution to LTE-Advanced“, 2nd Ed, Wiley 2011,

rates of 64kbit/s and 1024kbit/s respectively. Thus high uplink data-rate traffic is inevitably going to be more difficult to support over wide coverage areas. As a result of some responses to our January 2012 consultation, we have also explored the implications of uplink limitations as a result of uplink TCP acknowledgements required in order to support the downlink throughput and how this might influence downlink performance. See A7.105 for further detail. This analysis is less sophisticated than our unconstrained downlink analysis.

A7.6 Our model does not include alternative methods of dealing with capacity (for example in dense traffic ‘hot-spots’) or coverage (for example in particularly hard to serve locations) by techniques such as microcells, Wi-Fi off-load or deploying femtocells, which are considered elsewhere in our analysis. The performance of the macrocell component of the access network that our analysis considers is likely to be the component that is influenced most by differences in frequency.

A7.7 Any attempt to derive the performance of a mobile network using a theoretical modelling approach is inevitably going to be affected by a number of sources of uncertainty:

- Firstly, as is the case with any model, our model is only an approximation to reality. This is particularly true as we are modelling very variable parameters (e.g. propagation losses and indoor coverage);

- Secondly, our model is forward looking; it attempts to predict the performance of networks that have not yet been deployed. The actual performance of LTE networks which will be deployed in the frequency bands considered here is uncertain. Our model includes estimates of current LTE performance and potential improvements in performance as the technology matures for which we have limited evidence;

- Thirdly, we have some actual data from individual mobile operators. Where possible, we have attempted to validate the model and assumptions against data from individual operators.

A7.8 The extent of this uncertainty is reflected in the number of comments and differing views expressed on the modelling methodology, parameters and assumptions in response to our March 2011 and January 2012 consultations[3].

A7.9 Whilst the results presented in this annex reflect the best knowledge we have as a regulator from our own research, expertise and information received from stakeholders, it is unrealistic to believe that our model can be anything more than illustrative of the real performance of actual LTE networks. In developing our model we have exercised our best judgement and accounted for views of stakeholders in selecting appropriate methodology, parameters and assumptions, whilst bearing in mind the purpose of the results as described in A7.2. We recognise that others may disagree with our approach and there may well be alternatives.

A7.10 We believe that the model is useful in comparing the relative variation in performance between macrocell networks operating at different frequencies. It is less useful in providing information on absolute performance. The results of our model should not be taken as a definitive prediction of macrocell network performance.

[3] See Annex 10

A7.11 The results presented here do not consider questions of technology or equipment availability, for instance the support or lack of support for certain combinations of bandwidth and frequency band in the 3GPP standards.

Physical behaviour of networks at different frequencies

A7.12 The performance of a radio link is typically determined by its signal to interference plus noise ratio (SINR), i.e. the higher the SINR the better the performance. SINR can be used to characterise how difficult it is to serve a user at a particular location; relatively high SINRs being characteristic of easy to serve users/locations and relatively low SINRs being characteristic of difficult to serve users/locations. In a mobile network, the main source of interference in the downlink (i.e. transmissions from the base station to the user) is from cells neighbouring the serving cell which transmit on the same set of frequencies and times. For the uplink (i.e. from the user to the base station) it is from the terminals of other users which transmit on the same set of frequencies.

A7.13 Across a network there will be a wide range of users in a variety of easier and more difficult to serve locations. Difficult to serve users might typically be found deeper in-buildings, and/or further from the serving base station, and/or have an obstructed path between their location and the serving base station etc. LTE implements an adaptive modulation and coding scheme. When SINR is high, a higher order modulation scheme is used (e.g. 64 QAM giving 6 bits per symbol) with a coding scheme that implements little or no redundancy which gives greater throughput. When SINR is low, a lower order modulation scheme is adopted (e.g. QPSK giving just 2 bits per symbol) with a coding scheme that implements a significant amount of redundancy. This allows the receiver to decode increasingly poor quality signals. However, when SINR gets very low the receiver is unable to effectively decode the wanted signal or maintain synchronisation with the network and the link is lost completely.

A7.14 As an example, as users get deeper into buildings, building penetration loss (BPL) rises. ‘On average’ this would affect the wanted signal from the serving cell just as much as the unwanted (interfering) signals from other surrounding cells[4]. So, ‘on balance’, it might be expected that the signal and interference would be attenuated roughly equally; hence the signal to interference ratio (SIR) would remain constant. However, the fact that the shadowing and BPL for the wanted and unwanted signals are not completely correlated means that SINR would be likely to degrade somewhat at greater depths indoors. In addition, the receiver noise floor[5] also needs to be accounted for. This noise floor has a fixed minimum value (due to thermal noise and the receiver’s noise figure) so as the wanted signal gets weaker the SINR degrades even more quickly and performance reduces further.

A7.15 When performance is dominated by interference (i.e. the interference power is significantly greater than the noise) a link is often referred to as ‘interference limited’ and conversely, when performance is dominated by noise (i.e. noise power is significantly greater than the interference) a link is often referred to as ‘noise limited’. When networks are interference limited, performance differences between frequencies are minimised and when they are noise limited, performance differences between frequencies are likely to be at their greatest. This is because signals attenuate differently at high and low frequencies as they propagate from

[4] The ‘on balance’ here refers to the overall effect over all locations. For any specific location this will not hold true.
[5] The noise generated within the receiver itself above thermal noise.

their source. Higher frequencies attenuate more rapidly with distance and as they get deeper into buildings their losses may also increase more rapidly than lower frequencies and the level of the wanted signal will approach the receiver noise more rapidly at higher frequencies than lower ones. Hence it will consequently have a lower SINR and poorer performance, i.e. it will have more locations where it is 'noise limited'. It should be stressed that there is no hard limit between 'noise limited' and' interference limited' cases, there being a smooth transition from one to the other as the network loading increases.

A7.16 A consequence of the above is that we would, in general, expect networks with relatively few sites (i.e. having large physical distances between their base stations) to have proportionately more locations that are 'noise limited' at higher frequencies than at lower ones than a network with many more base stations. Hence they would have both a poorer overall performance and a greater performance difference between high and low frequencies. Also, as users get deeper and deeper into buildings, if there is a greater building penetration loss at higher frequencies, there will be more locations inside buildings that are 'noise limited'. Hence higher frequencies will have poorer performance at greater depths within a building.

Summary of modelling methodology and changes since January 2012

A7.17 Though our overall framework for modelling the performance of LTE macro networks remains, to a large extent, unchanged from that used for the January 2012 consultation, we have made a number of important changes to underlying details of the modelling in response to comments received from stakeholders.

Simulation areas

A7.18 Underlying all the technical results presented in this annex are SINR distributions generated across a number of simulation areas.

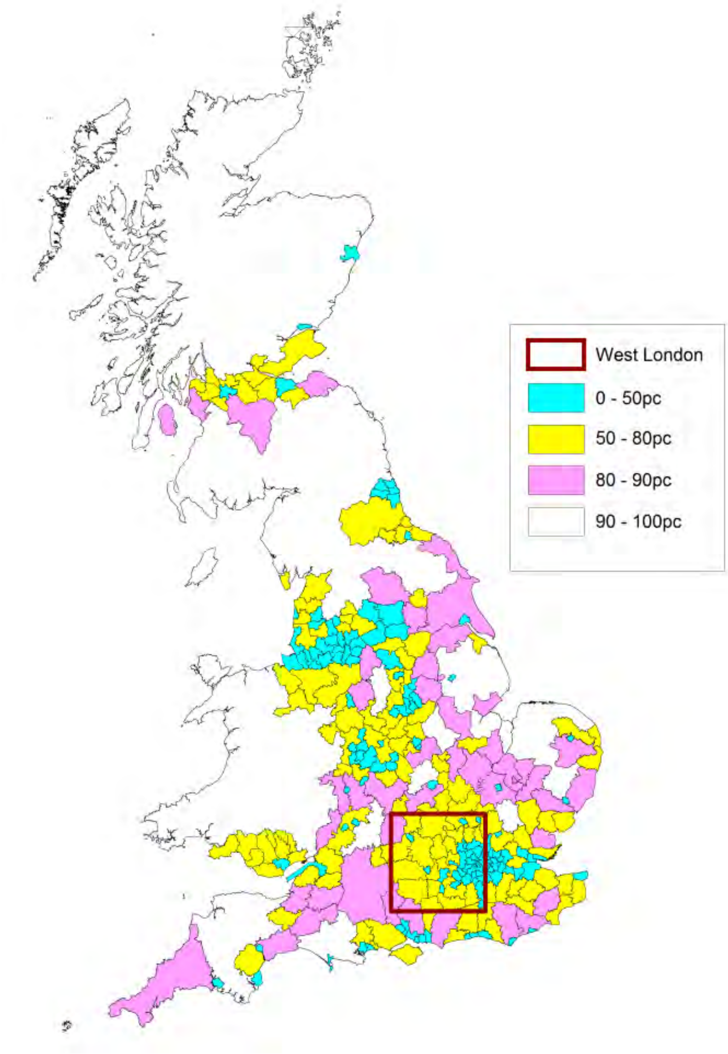
A7.19 For the January 2012 consultation we generated results for two 100km x 100km areas. The first stretching from central London at its eastern edge to past Oxford in the west (referred to as the 'West London' area). The second was approximately centred on the city of Cambridge (referred to as the 'Cambridge' area). A number of stakeholders responded to the January 2012 consultation querying how representative these areas were of a national picture. As a consequence, we are now generating results for three new more representative simulation areas. These being based on population density as follows:

- the zero to 50% most densely populated area;
- the 50% to 80% most densely populated area; and
- the 80% to 90% most densely populated area

A7.20 These areas are defined on the basis of local authority district boundaries but they exclude Northern Ireland due to lack of appropriate data. Hence the zero to 50% area is comprised of the most densely populated local authority districts in England, Scotland and Wales where 50% of the population live (from the 2001 census).We have not modelled the 90% to 100% area (i.e. the least densely populated regions) partly because we consider the quality of service in more densely populated areas to be more important for determining whether a national wholesaler is able to be credible.

A7.21 See Figure A7.1 below for an illustration of the new simulation areas together with the 'West London' area from the January 2012 consultation for comparison.

Figure A7.1: Simulation areas



A7.22 Table A7.1 below gives a breakdown of the population, the number of households and the average population per household for each of the three simulation areas (excluding West London).

Table A7.1: Population and household statistics

Area	HHs	Total Population	Pop per HH
0-50%	11,992,771	28,588,215	2.38
50-80%	7,100,905	17,162,838	2.42
80-90%	2,355,925	5,648,553	2.40
National	24,485,625	58,791,867	2.40

Overview of modelling methodology

A7.23 In Annex 8 we give a detailed description of the model. However a high level description is as follows:

i) A synthetic base station macrocell network of a particular size (number of sites) is established covering the simulation area plus a buffer zone 10km deep surrounding the simulation area. As discussed in Annexes 8 and 10, our site placement algorithm attempts to place sites in an intelligent way by ensuring each site is placed optimally to serve an area with the greatest population density based on a seed network of approximately 9,000 sites[6]. In contrast, an operator might choose a different approach, based on maximising a coverage footprint, capacity, or focus on particular areas of population.

A confidential respondent criticised our approach to generating synthetic networks in their response to the January 2012 consultation as generating an unusually high proportion of sites in relatively built-up areas like our 'West London' area and too few in less densely populated areas. This impression of an unusually high proportion of sites in built-up areas was created by a typographic error in paragraph A7.54 of that consultation where we erroneously stated that a network with the equivalent of 10,000 sites nationally had a total of 2,651 sites in our 'West London' area. The 2,651 sites in our 'West London' area were actually for a network with the equivalent of 18,000 sites nationally.

ii) An SINR distribution is calculated for a hypothetical test terminal (UE) positioned at the geographic location of a randomly selected sample[7] of postcode units[8] within the simulation area. SINR is calculated taking into account signals from sites within the base station network within a certain distance (10km) of the each sample postcode unit location up to a maximum of the 20 closest sites.

iii) Using the SINR distribution generated in step ii) above together with an appropriate SINR to throughput mapping function (based on the function in Annex A.1 of 3GPP TR 36.942[9]), and taking into account system overheads, the average downlink single-user throughput distribution for the sample of postcode unit locations is established.

iv) Steps i), ii) and iii) above are repeated to establish SINR and single-user throughput distributions for a range of base station network sizes, network loadings, carrier bandwidths and building penetration depths for the frequencies under consideration (e.g. 800 MHz, 1800 MHz and 2600 MHz).

v) From the single-user throughput distribution statistics within the simulation area, the three metrics of performance are calculated:

[6] This is taken from an existing operator's site location information, data for a significantly larger seed network was not available to us

[7] 10,000 sample points

[8] A postcode unit is a sub-area of a postcode sector as extracted from Code-Point® data.

[9] 3GPP TR 36.942 V9.3.0 "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios", Annex A, Section A.1: http://www.3gpp.org/ftp/Specs/html-info/36942.htm

- *Coverage* – the percentage of the residential population (i.e. when at home)[10] within the simulation area to which it is technically possible to deliver a downlink service capable of providing basic connectivity[11] (if 85% of the resource blocks of the serving cell, including system overheads, were dedicated to a single customer[12]), as a function of the number of network sites and the loading on the wider network.

- *Speed* – for a network with a given number of sites and loading, the downlink data-rate (if 85% of the resource blocks of the serving cell, including system overheads, were dedicated to a single customer) attained or exceeded by a particular percentage of residential population within the simulation area.

- *Capacity* – for a network with a given number of sites and loading, the percentage of the residential population within the simulation area that can be simultaneously served with a given downlink speed and number of sites.

Propagation model

A7.24 The outdoor propagation model we are using for 800 MHz and 1800 MHz is the Extended Hata model and we use the implementation given in CEPT's SEAMCAT documentation[13].

A7.25 As a consequence of comments made by Vodafone in their response to the January 2012 consultation (see Annex 10), we have conducted a review of propagation for 2.6 GHz. Vodafone made the point that, due to an error in the implementation of the Extended Hata model (for frequencies above 2 GHz), we overestimated the propagation losses for frequencies in this band and hence under-estimated the performance of LTE network operating at 2.6 GHz. There are two versions of the SEAMCAT documentation which describe the Extended Hata propagation model (from the ECO's SEAMCAT manual). Version 1 contains the formula we implemented for the March 2011 and January 2012 consultations whereas version 2 (published about a year ago) contains a revised implementation. Analysis of both the versions shows that neither provides a particularly good fit to published measurement data for frequencies above about 2 GHz and we have confirmed with the European Communications Office that the origins of the extension above 2GHz is unknown. We have therefore adapted our 2.6 GHz propagation modelling algorithm to align it better with the published measurement data which shows a range of propagation path loss difference between 1800 MHz

[10] Each postcode unit has associated with it a number of domestic delivery points: each delivery point will generally correspond to one residential address. The residential population at each location is obtained by multiplying the number of domestic delivery addresses at each postcode unit by a weighting factor derived from the population of the census output area (from the 2001 Census) within which the postcode unit location falls

[11] See paragraph A7.47 below for a description of what we interpret basic connectivity to mean.

[12] 85% is considered, for the purposes of this analysis, to be a practical upper bound to loading on average

[13] ERC Report 68, "Monte-Carlo Radio Simulation Methodology for the use in sharing and compatibility studies between different radio services or systems": http://www.erodocdb.dk/Docs/doc98/official/pdf/REP068.PDF
and "SEAMCAT implementation of Extended Hata and Extended Hata SRD models": http://tractool.seamcat.org/raw-attachment/wiki/Manual/PropagationModels/ExtendedHata/Hata-and-Hata-SRD-implementation_v2.pdf

and 2.6 GHz with a central value of approximately 4dB[14] (see Annex 8 and Annex 10 for details).

Variability in our results

A7.26 In the January 2012 consultation we presented results where we modelled a range of key parameters values which we grouped into two cases:

- '**Min var'**: which grouped the set of key parameter values that tended, in most circumstances, to **minimise** the relative performance variation between frequencies; and

- '**Max var**': which grouped the set of key parameter values that tended, in most circumstances, to **maximise** the relative performance variation between frequencies.

A7.27 The parameters which made up the 'Min var' and 'Max var' cases were as follows:

- Resource allocation algorithm

- Parameters associated with BPL; and

- SINR cut-off.

A7.28 Our new versions of 'Minvar' and 'Maxvar' do not include variation in the resource allocation algorithm or SINR cut-off and the values of mean BPL and its associated standard deviation also differ from those assumed in the January 2012 consultation. We say something about each of these in the sub-sections that follow. We start with the resource allocation algorithm, then BPL assumptions (mean and standard deviation) together with our approach to depth in buildings, and finally SINR cut-off.

A7.29 Given our view, explained in paragraph A7.39 below, that our 'Maxvar' values are more aligned with the evidence available to us and (as we explain in paragraph A7.2) and as explained in Annex 2, given the importance of the performance of different frequency spectrum holdings in the coverage and capacity dimensions, we consider it appropriate to concentrate on the 'Maxvar' case which illustrates results that emphasise the differences between different frequencies while still being credible assumptions.

A7.30 For these reasons, and apart from a few cases where specifically identified, we concentrate on results based on 'Maxvar' values. Consequently, unless explicitly indicated otherwise, all results shown are for our 'Maxvar' parameters.

Resource allocation algorithm

A7.31 In the January 2012 consultation we used a random allocation algorithm for the 'Min var' case and a more intelligent allocation algorithm for the 'Max var' case. Our understanding, at the time was that the practicality of the use of intelligent resource allocation and efficacy of any particular scheduling algorithm used was not totally clear. Since publication of the January 2012 consultation we have looked at this further and have had further research carried out by Real Wireless on our behalf[15].

[14] This lies between the version 1 and version 2 implementations of SEAMCAT
[15] See Annex F of the Real Wireless report on technical investigations in support of the combined award that they have undertaken and is published alongside this statement

Real Wireless has confirmed with various equipment vendors, that they are implementing intelligent resource allocation as supported in release 8 of the LTE standards and further enhancements are expected in release 10 (e.g. dynamic Inter Cell Interference Cancellation (ICIC) and Co-ordinated Multi-pint (CoMP) techniques). The intelligent algorithm we implemented, whilst not identical to those used in real LTE deployments, is a reasonable proxy for modelling their performance. Additionally, we had support from one confidential respondent for the use of an intelligent resource allocation algorithm and no other respondents commented on this aspect of our modelling.

A7.32 We have therefore decided to implement our intelligent scheduling algorithm for all the results presented in this statement. Note however that this provides little or no benefit over random scheduling for higher network loadings.

BPL assumptions and approach to depth in buildings

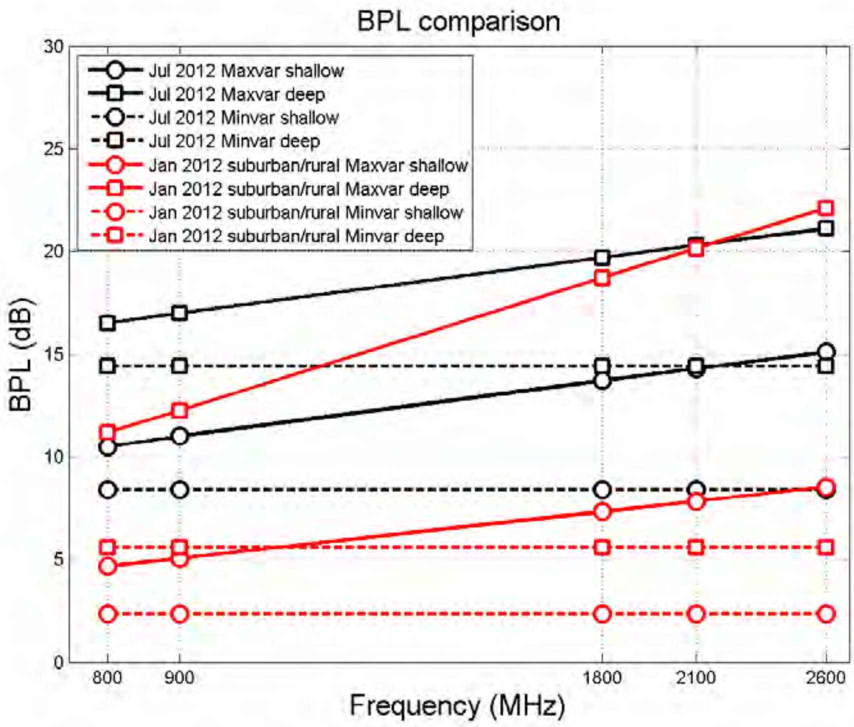
A7.33 As a consequence of comments made by several stakeholders in their responses to the January 2012 consultation, we have conducted a review of our BPL assumptions against measurement data in open literature and information from existing mobile operators and have made a number of changes:

- our 'Minvar' BPL losses have been increased (i.e. we are now assuming greater losses at all depths within buildings);
- our deep 'Maxvar' BPL losses now vary less with frequency than they did in the January 2012 consultation, as a result losses are greater at lower frequencies.
- our 'Maxvar' BPL losses have been increased for shallow in-building depths for all frequencies;
- we have also adjusted our BPL standard deviation assumptions; and
- we now model a single set of BPL parameters applicable to all clutter environments rather than different parameters for different clutter environments.

A7.34 Another change to our modelling approach is that we no longer show results for four different in-building depths (i.e. 1, 5, 10 and 15m from the January 2012 consultation), just 'shallow' and 'deep'. This is because the underlying data available is not sufficiently accurate to justify a highly granular presentation of depth. As stated in our January consultation, paragraph 3.86, we exercised caution in interpreting depth literally, noting for example a depth of 15 metres could be taken to represent a user physically very deep within a relatively low loss building but could also represent a user who is at a shallower physical depth but in a building subject to greater propagation losses. The revised 'shallow' and 'deep' illustrations better reflect this position.

A7.35 For a comparison of our old and new BPL assumptions please see Figure A7.2 below.

Figure A7.2: Mean BPL assumptions



A7.36 The comparison above is against the suburban/rural BPL values from January 2012.

A7.37 The full justification for our BPL assumptions and approach to depth in buildings is detailed in Annex 8. The parameters are summarised in Table A7.2 and Table A7.3 below:

Table A7.2: Mean BPL values

Mean BPL, L_{BPL} (dB)	'Minvar'		'Maxvar'	
	Shallow	Deep	Shallow	Deep
800 MHz	8.4	14.4	10.5	16.5
900 MHz	8.4	14.4	11.0	17.0
1800 MHz	8.4	14.4	13.7	19.7
2100 MHz	8.4	14.4	14.3	20.3
2600 MHz	8.4	14.4	15.1	21.1

Table A7.3: Standard deviation of BPL values

SD of building penetration loss, $\sigma_{BPL}\sigma$ (dB)	'Minvar'	'Maxvar'
800 MHz	5.4	6.8
900 MHz	5.4	6.9
1800 MHz	5.4	7.2
2100 MHz	5.4	7.2
2600 MHz	5.4	7.3

A7.38 As detailed in Annex 8, the two sets of BPL values included within our 'Minvar' and 'Maxvar' cases capture reasonable lower and upper estimates of the BPL mean and standard deviation values, and their frequency dependence, based on the results reported in a number of key sources from the literature, the COST 231 model and responses from current national wholesalers. They account for the large uncertainty in the BPL parameter values observed in practice.

A7.39 Following receipt of responses to the January 2012 consultation we asked the operators for details of BPL parameters they use in their coverage checkers. We received more complete information from some operators than others, however the information provided indicated that the operators' own BPL assumptions lay, in general, closer to 'Maxvar' than 'Minvar'. This evidence together with our own engineering judgement leads us to believe that the 'Maxvar' case is likely to be a credible representation of BPL parameters applicable to residential premises in the UK. Much greater losses than our 'Maxvar' case are unlikely to be credible and losses towards our 'Minvar' case are less likely to be credible.

SINR Cut-off

A7.40 The SINR cut-off represents the lowest SINR value for which a viable downlink service can be received (based on the performance of the most sensitive control channels). In the January 2012 consultation we explored two values for this cut-off as part of our 'Min var' and 'Max var' parameters sets. The more stringent of our values (i.e. -5dB) represented a situation where operators took no special steps to improve performance and was incorporated into our 'Max var' case. Whereas the less stringent of our values (i.e. -10dB) represented a situation where operators took specific steps to improve decoding of control channels at low SINR (by techniques such as power boosting or puncturing) and was incorporated into our 'Minvar' case.

A7.41 It's not clear whether operators are likely to employ techniques such as power boosting or puncturing to improve decoding of control channels at low SINR as it's their choice and mature networks aren't yet rolled out.

A7.42 What is clear is that the higher of our two cut-offs (-5dB) represents a more straightforward implementation than is required to achieve the lower cut-off (-10dB). Therefore, we believe that use of the higher cut-off seems more likely to representative of real LTE macrocell networks deployed in the UK.

A7.43 Using the higher SINR cut-off tends to increase the coverage difference predicted by our model for different frequencies. Most of the results presented are based on 'Maxvar' BPL values which also assume the higher of our SINR cut-offs (-5dB). We have produced a limited set of results that show their sensitivity to the lower assumption (-10dB).

A7.44 Unless explicitly indicated otherwise, all results are based on an SINR cut-off of -5 dB.

Performance metrics

A7.45 Similarly to the January 2012 consultation we explore three key performance metrics:

- Coverage;
- Speed; and
- Capacity

Coverage

A7.46 Unlike for the January 2012 consultation, our approach to modelling coverage looks, for the most part, at basic connectivity which we define as any location which has an SINR greater than or equal to the SINR cut-off. As indicated above, we now assess coverage for just two in building depths, 'shallow' and 'deep'. We interpret 'shallow' as typical of a location in a room with at least one external wall and window within a residential property. We interpret 'deep' as typical of a location without an external wall or window within a residential property. 'shallow' and 'deep' are characterised by specific mean and standard deviation values for BPL. We recognise that building stock in the UK will have a very wide range of BPL characteristics and that our 'shallow' BPL values could equally well represent a relatively deep location within a building with a relatively low BPL. Likewise, our 'deep' BPL values could equally well represent a relatively shallow location within a building with a relatively high BPL.

A7.47 We interpret basic connectivity as the ability to provide low data-rate services such as basic internet connectivity (e.g. email, non-media rich web browsing, etc) and data-rates capable of supporting voice traffic[16]. For a single user this might require speeds typically in the range 100 to 500kbit/s. During relatively busy periods a network is very likely to have multiple users accessing services in a cell simultaneously and these users will have to share the available network resources between them. For users who are at the very edge of cell it is likely that only a small number of these could simultaneously access services characteristic of basic connectivity per cell. On the other hand, for users who are close to the centre of the cell, the network may support many simultaneous users even where those users are accessing higher data-rate services (e.g. streaming video). Note that larger bandwidth carriers will be able to support a larger number of simultaneous users, and where bandwidths are restricted (e.g. 2x5 MHz) they may not be able to support as many.

[16] Note, release 8 of the 3GPP standards does not standardise LTE voice and voice services are unlikely to be central to early LTE deployments.

A7.48 We note that other solutions are available to complement macrocell coverage such as femtocells and offload via Wi-Fi.

Speed

A7.49 Speed in our analysis is modelled as single-user throughput. Single-user throughput represents the maximum theoretical downlink data-rate that a single user could receive if they were the only user in a cell at any instant in time and the maximum available resources of the cell were dedicated to them. For the purposes of our simulation we assume that a maximum of 85% of total cell resources are available to a single user. This metric is the same as used in the March 2011 and January 2012 consultations.

Capacity

A7.50 In general terms, the capacity of a network is a measure of how much offered traffic can be served whilst maintaining key quality of service metrics. Such metrics might include the number of connection request failures, the number of dropped connections, the ability to maintain a minimum throughput to users, the number of lost data packets, latency, etc. Different users demanding different services from the network will need different combinations of these metrics. For instance, for a user who is streaming video, maintaining an acceptable minimum guaranteed data-rate is important to avoid interrupts; for an online gamer, latency might be the most important metric; for someone surfing the web, both latency and minimum data rate might be key. A network operator will try to balance all the competing demands of its users. Moreover, if the traffic profile of the users of one network is different from the traffic profile of the users of another, even if they have the same number of subscribers and the same network size and spectrum resources, they might in practice perform very differently with one network struggling to meet demand whilst the other doesn't.

A7.51 Consequently, it is very difficult to derive a single capacity metric that adequately addresses all of the important network quality metrics that an operator is likely to feel are important.

A7.52 Unlike for the January 2012 consultation where we produced specific capacity results. For this statement we rely on an interpretation of single-user throughput results as a proxy for capacity (see paragraph A7.57 below).

The graphs

A7.53 We use three types of graphs to display the results of our analysis:

- Coverage comparison bar charts;
- Single-user throughput as a function of population covered; and
- Capacity as a function of number of sites.

Coverage comparison bar charts

A7.54 For these graphs, coverage (i.e. percentage of the residential population) is represented by the height of the bars. There are two variants used. The first variant compares coverage results for the West London simulation area from the January 2012 consultation and results generated for this statement (see Figure A7.3 for an example). The second variant compares current results for the West London simulation area with those from the 0-50%, 50-80% and 80-90% areas (see Figure A7.5 for an example).

Single-user throughput as a function of population covered

A7.55 The x-axis on these figures represents the percentage of the residential population (i.e. when users are indoors at home) that our model predicts could receive a single-user throughput of at least the corresponding value indicated on the y-axis (see Figure A7.7 for an example).

A7.56 These graphs can be used to illustrate the extent of coverage for basic connectivity for each network: the intercept of each line with the x-axis. This indicates basic connectivity but does not guarantee that higher data-rates will be available to all users in coverage.

A7.57 These graphs can also be used as a proxy for comparing the capacity of one frequency/bandwidth combination with another but only when dealing with equal site counts and equal network loadings. So, for example, if a graph shows the single-user throughput line for a 2x10 MHz carrier at 800 MHz sits above the single-user throughput line for a 2x15 MHz carrier at 1800 MHz and both are for networks with the equivalent of 18,000 sites nationally loaded to 85% then it is reasonable to interpret this as the carrier at 800 MHz having greater capacity than the carrier at 1800 MHz. On the other hand, if the carrier at 800 MHz was for a network with fewer sites and/or was more lightly loaded than the corresponding carrier at 1800 MHz then it would not be appropriate to draw conclusions about the relative capacity of the two carriers from these graphs.

Capacity as a function of number of sites

A7.58 These graphs plot the number of sites (of an equivalent national network) on the y-axis verses capacity on the x-axis. Capacity on these graphs has been displayed on a normalised scale that allows the comparison of different spectrum holdings. This scale represents a ratio of the total resources available to the network to the resources needed to serve all users with a specified guaranteed data-rate service (see Figure A7.41 for an example).

A7.59 The number of sites displayed on the y-axis represents the size of an equivalent national network rather than the actual number of sites included in the simulation area. For instance, a network with the equivalent of 12,000 sites nationally has a total of 4,820 sites in our 0-50% simulation area (see Table A7.9 below).

Impact of modelling changes for the West London simulation area

A7.60 Figure A7.3 and Figure A7.4 below show the impact the changes described above on our West London coverage results. They compare the coverage results for a 1Mbit/s service for a network with the equivalent of 12,000 sites nationally[17] loaded to 85% for the West London simulation area based on assumptions from January 2012 to those based on our current assumptions for both the ‘Maxvar’ and ‘Minvar’ cases.

[17] A network with an equivalent of a national 12,000 site network was used for this comparison with January 2012 results in January 2012 it showed the largest differences between frequencies.

Figure A7.3: Illustration of the impact of modelling assumptions – 'Maxvar'

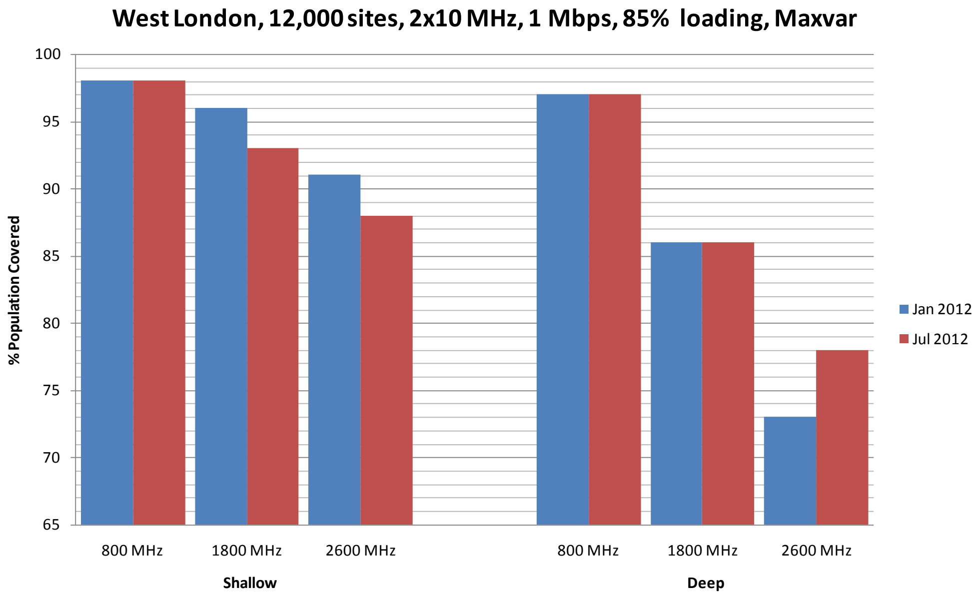
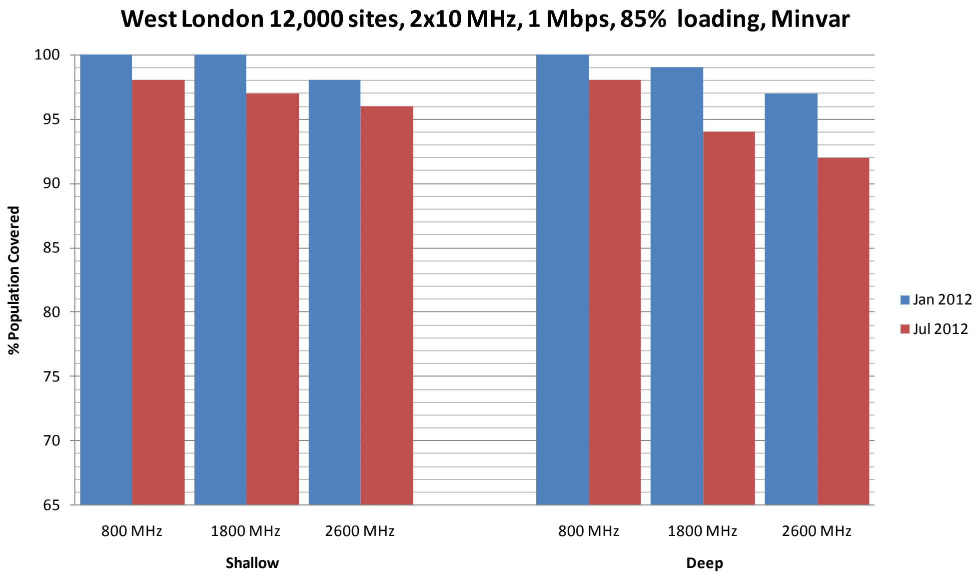


Figure A7.4: Illustration of the impact of modelling assumptions – 'Minvar'



A7.61 The consequences of the changes to our results are that our model now predicts bigger differences between frequencies at shallow depths (for both the 'Minvar' and 'Maxvar' cases) and that for the 'Minvar' case our model predicts bigger differences with frequency at deep depths. The increased coverage for 2.6 GHz in the 'Maxvar' case is mainly due to the change in propagation model for this frequency band.

Comparison of simulation areas

A7.62 Figure A7.5 and Figure A7.6 below show how the West London area used in our January 2012 consultation compares with our new population density based simulation areas. They compare coverage for basic connectivity for networks with 2x10 MHz and 12,000 sites and 85% loading.

Figure A7.5: Comparison of simulation areas – 'Maxvar'

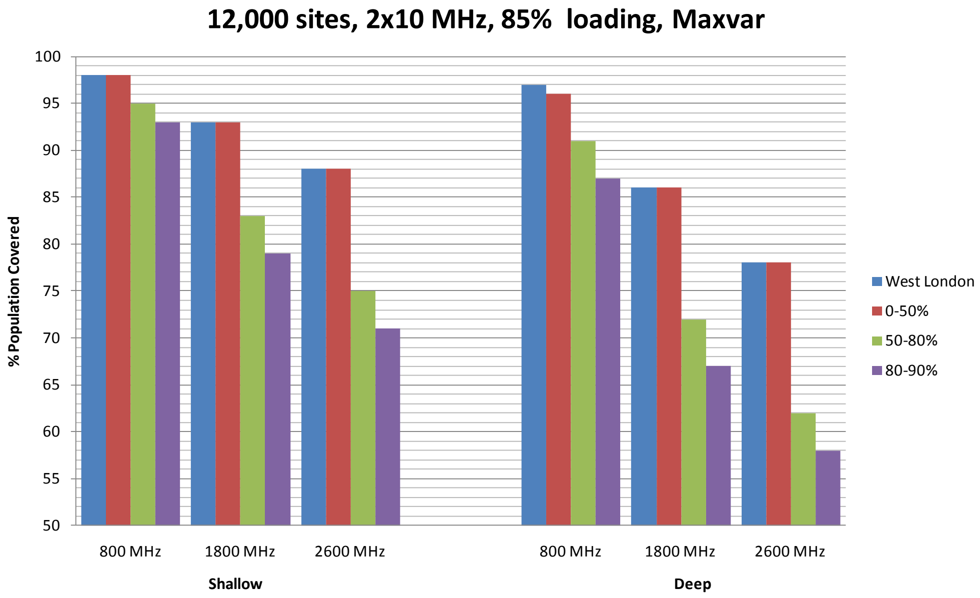
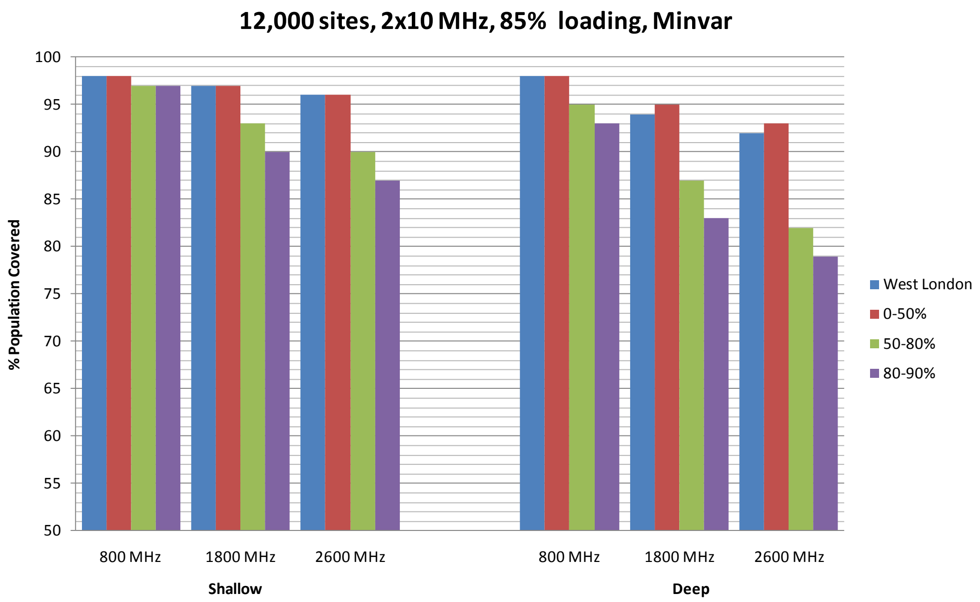


Figure A7.6: Comparison of simulation areas – 'Minvar'



A7.63 As can be seen, results for the West London area (the blue bar) used in the January 2012 consultation are very close to our new 0-50% area (red bar) results.

Sensitivity of our results to BPL assumptions

A7.64 Figure A7.7 to Figure A7.8 below look at the sensitivity of our results to BPL assumptions, they plot downlink single-user throughput as a function of population (percentile) for networks with 2x10 MHz and 12,000 sites and 85% loading for the 50-80% simulation area. We have plotted results obtained using both 'Minvar' and 'Maxvar' BPL values: 'Minvar' represented by the dotted lines and 'Maxvar' by the solid lines.

Figure A7.7: 'Minvar'/'Maxvar' comparison – Single-user throughput, shallow

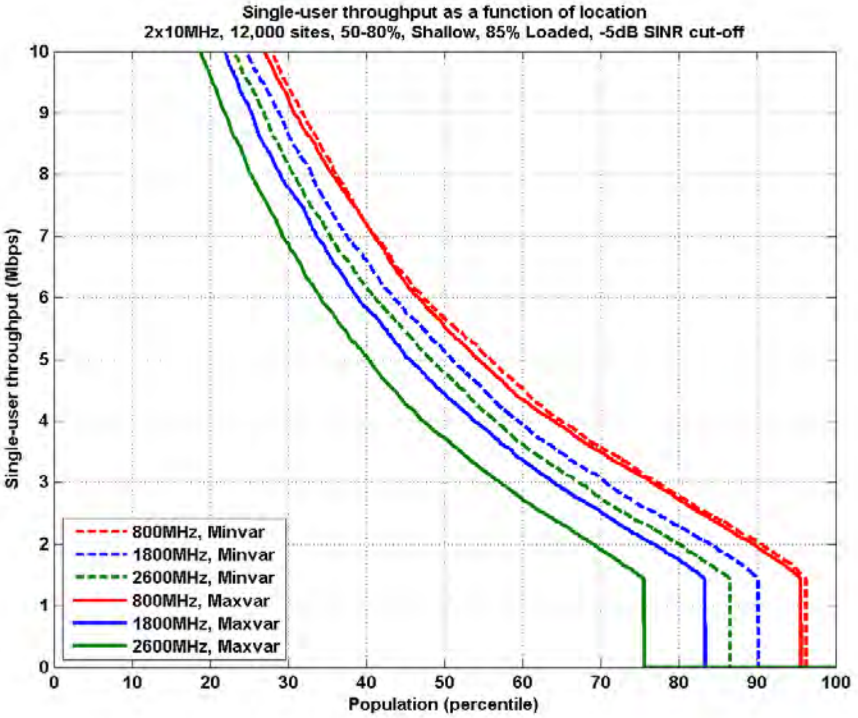
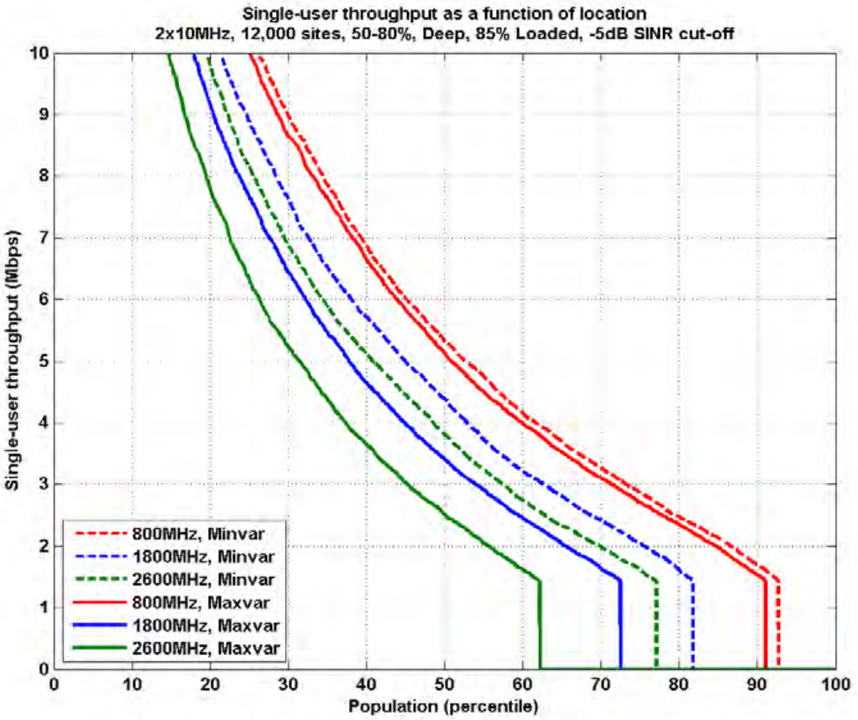


Figure A7.8: 'Minvar'/'Maxvar' comparison – Single-user throughput, deep



A7.65 As expected, the performance of networks our model predicts for the 'Minvar' case is better than the corresponding 'Maxvar' case for all frequencies. However the difference in performance is relatively small for 800 MHz and gets larger with increasing frequency. The performance difference also increases when going from shallow (Figure A7.7) to deep (Figure A7.8) indoor locations.

A7.66 Though we have only shown results for the 50-80% simulation area, a similar picture holds for the 0-50% and 80-90% areas: with the 0-50% area showing slightly smaller differences between the 'Minvar' and 'Maxvar' cases and the 80-90% area showing slightly greater differences between the 'Minvar' and 'Maxvar' cases.

A7.67 For the reasons outlined in paragraphs A7.29 and A7.39 we only display results for 'Maxvar' BPL assumptions in all graphs shown in the remainder of this annex.

Sensitivity of our results to SINR cut-off

A7.68 Figure A7.9 to Figure A7.10 below look at the sensitivity of our results to SINR cut-off, they plot downlink single-user throughput as a function of population (percentile) for networks with 2x10 MHz and 12,000 sites and 85% loading for the 50-80% simulation area. We have plotted results obtained using both a -5dB cut-off (represented by the solid lines) and a -10dB cut-off (represented by the dashed lines) using 'Maxvar' BPL assumptions.

Figure A7.9: SINR cut-off comparison – Single-user throughput, shallow

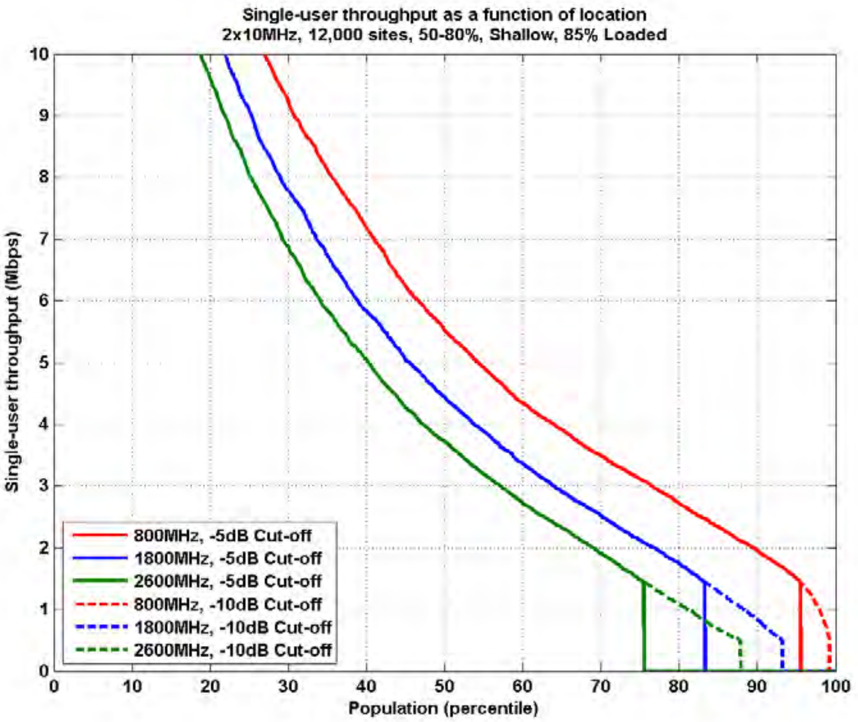
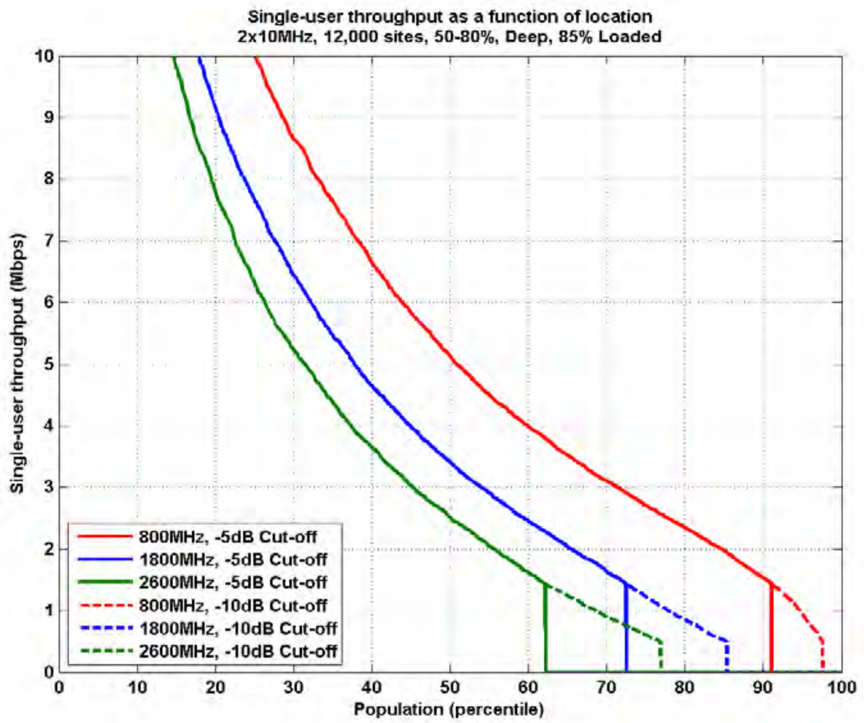


Figure A7.10: SINR cut-off comparison – Single-user throughput, deep



A7.69 As can be seen, coverage is improved for a -10dB cut-off in comparison to -5dB with higher frequencies being affected relatively more than lower ones.

A7.70 Though we have only shown results for the 50-80% simulation area, a similar picture holds for the 0-50% and 80-90% areas: with the 0-50% area showing slightly smaller differences between the -5dB and -10dB cases and the 80-90% area showing slightly greater differences between the -5dB and -10dB cases.

A7.71 For the reasons outlined in paragraphs A7.40 to A7.44 we only display results for an SINR cut-off of -5dB in all graphs shown in the remainder of this annex.

Performance difference between frequencies

A7.72 All the figures in this section show downlink single-user throughput as a function of population that our model predicts for LTE networks with 2x10 MHz of spectrum. As indicated above, all results are based on ‘Maxvar’ BPL values and an SINR cut-off of -5 dB.

A7.73 We start by looking at networks with the equivalent of 12,000 sites nationally[18] and illustrate the performance differences predicted between the frequencies. We then look at the impact of reducing network loading at higher frequencies and conclude that this gives a relatively small improvement in coverage when loading is reduced to 50% from 85%. Next we look at the impact of increasing the site count for the higher frequency networks (18,000 sites as opposed to 12,000) and conclude that this is a more effective strategy for reducing the coverage gap with 800 MHz than

[18] Networks with the equivalent of 12,000 sites have been chosen as the starting point for this analysis because in the January 2012 consultation (at that time) we considered this a reasonable expectation for the size of macrocell LTE network a national wholesaler might deploy in the medium term.

reducing loading. Finally we look at the situation where networks at all frequencies deploy networks with the equivalent of 18,000 sites nationally[19].

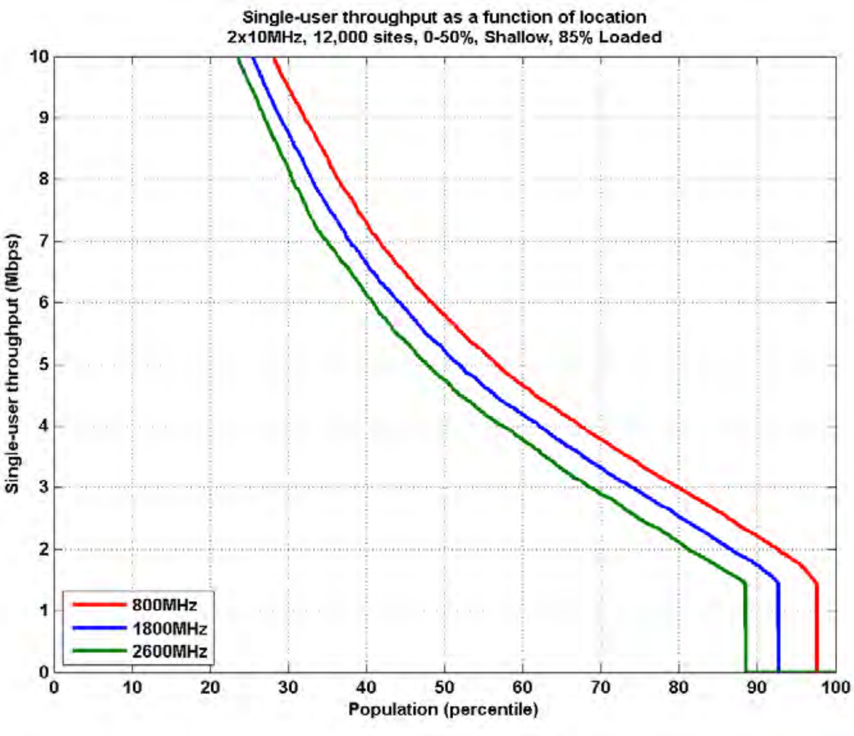
A7.74 For the first and last cases above we show results for all three simulation areas (0-50%, 50-80% and 80-90%) for both shallow and deep indoor locations. For the intermediate cases we only show results for the 50-80% area at the two indoor depths on the grounds that this is sufficient to show the general trends.

Performance of networks with 12,000 sites

A7.75 We first look at the difference in the performance that our model predicts for LTE networks operating in the three different frequency bands, 800 MHz, 1800 MHz and 2600 MHz, when each network has the same bandwidth, number of sites and loading. And where each network has the equivalent of 12,000 sites nationally.

A7.76 Figure A7.11 to Figure A7.16 show downlink single-user throughput as a function of population (percentile) for networks with 2x10 MHz and 12,000 sites and 85% loading.

Figure A7.11: Single-user throughput, 12,000 sites, 0-50% area, shallow and 85% loading

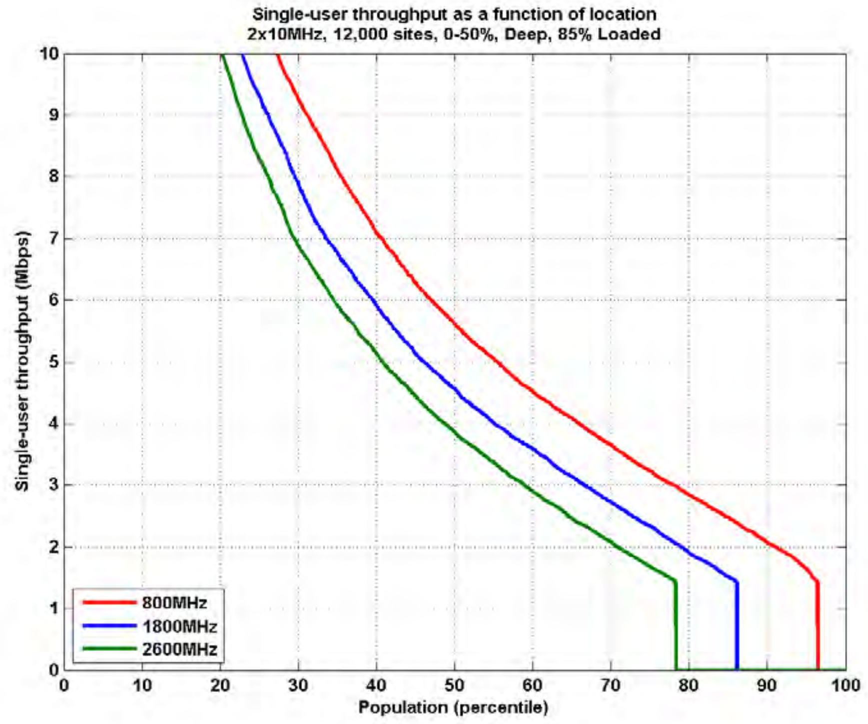


A7.77 Figure A7.11 above illustrates the difference in single-user throughput performance in the densest of our three simulation areas, the **0-50%** area, for users in **shallow** indoor locations. This demonstrates that, as expected, the 800 MHz network has better single-user performance than the 1800 MHz network (red lines are above the blue) and that 1800 MHz network as better single-user performance than the 2600 MHz (blue lines are above the green).

[19] Networks with the equivalent of 18,000 sites have been chosen because (as set out in Annex 2 paragraph A1.20) our revised view is that this a reasonable expectation for the size of macrocell LTE network a national wholesaler might deploy in the medium term.

A7.78 Coverage, for basic connectivity, is indicated where the lines intersect the x-axis. Our model predicts that there is a difference in coverage between the frequencies and that for networks operating at higher frequencies coverage is less than for those operating at lower frequencies (800 MHz = 97%, 1800 MHz = 93%, 2600 MHz = 88%).

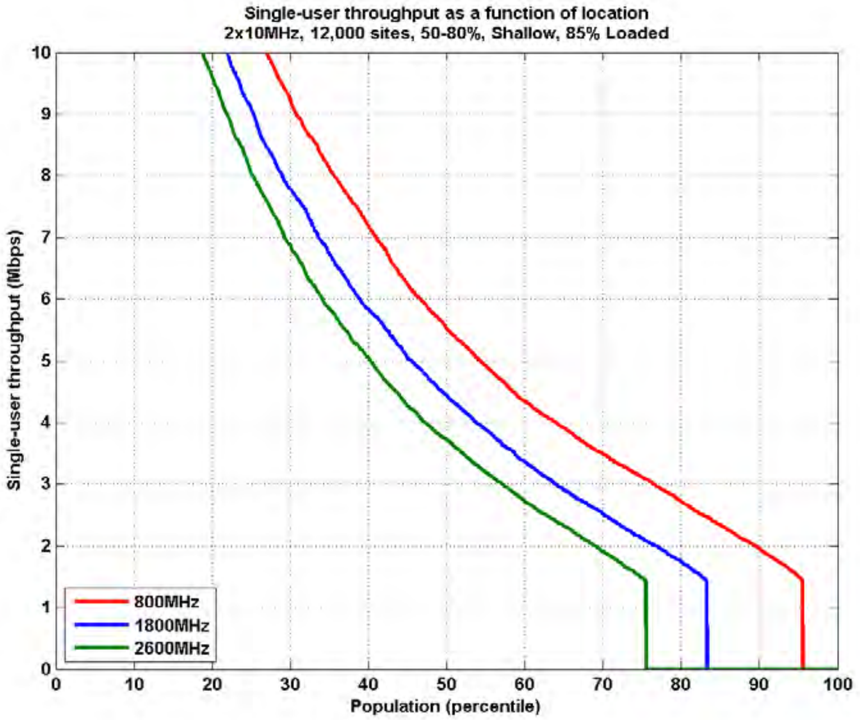
Figure A7.12: Single-user throughput, 12,000 sites, 0-50% area, deep and 85% loading



A7.79 Figure A7.12 above illustrates the difference in single-user throughput performance in the **0-50%** area but this time for users in **deep** indoor locations. Comparing Figure A7.12 with Figure A7.11 performance has degraded for all frequencies. However, the degradation in performance at 800 MHz is slight whereas the degradation in performance in performance is greater for higher frequencies.

A7.80 As expected, coverage for basic connectivity is also poorer at deep indoor locations and the gap in coverage between lower and higher frequencies is wider that it was at shallow indoor locations. For instance for 800 MHz coverage is still in the high 90s at about 96%, whereas for 1800 MHz it has dropped to about 86% and for 2600 MHz to about 78%.

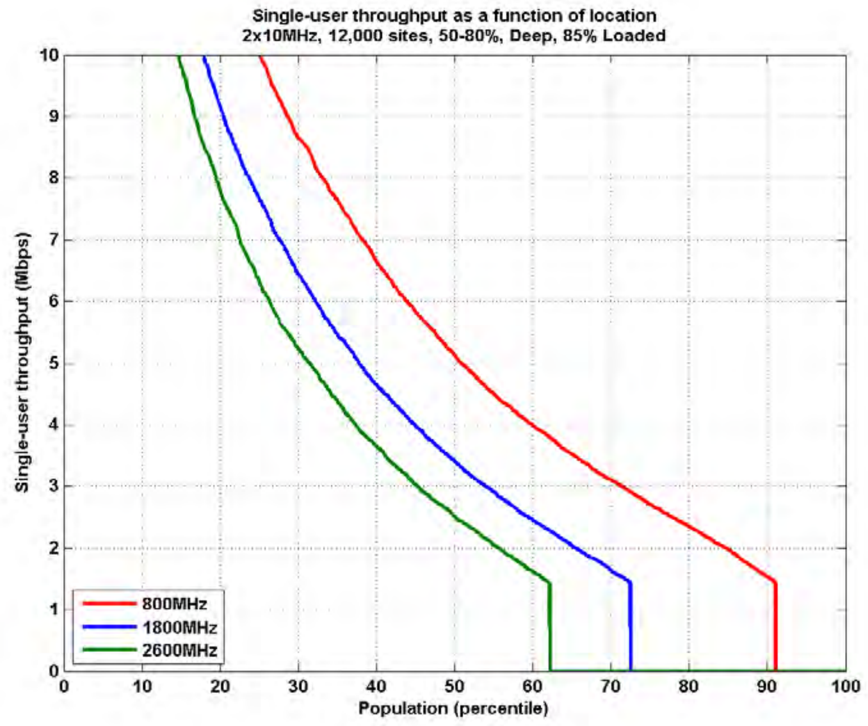
Figure A7.13: Single-user throughput, 12,000 sites, 50-80% area, shallow and 85% loading



A7.81 Figure A7.13 above illustrates the difference in single-user throughput performance in the next densest of our three simulation areas, the **50-80%** area, for users in **shallow** indoor locations. Comparing Figure A7.13 with Figure A7.11 performance has degraded for all frequencies. However, the degradation in performance at 800 MHz is slight whereas the degradation in performance is greater for higher frequencies. The change in performance in going from the 0-50% area to the 50-80% area has a similar but slightly greater impact on network performance than going from shallow to deep indoor locations in the 0-50% area.

A7.82 As expected, coverage for basic connectivity is poorer in the 50-80% area than the 0-50% area and the gap in coverage between lower and higher frequencies is wider that it was in the 0-50% area. For instance for 800 MHz coverage is approximately 95%, whereas for 1800 MHz it has dropped to approximately 83% and for 2600 MHz to approximately 76%.

Figure A7.14: Single-user throughput, 12,000 sites, 50-80% area, deep and 85% loading



A7.83 Figure A7.14 above illustrates the difference in single-user throughput performance in the **50-80%** area, for users in **deep** indoor locations. Comparing Figure A7.14 with Figure A7.13 performance has degraded for all frequencies.

A7.84 These results show a similar picture to those for the 0-50% area in that going from shallow to deep locations results in poorer performance both in terms of single-user throughput and coverage for basic connectivity.

A7.85 The next two graphs (Figure A7.15 and Figure A7.16) illustrate the difference in single user throughput performance of the **80-90%** area for **shallow** and **deep** indoor locations. These show how the basic trends in performance differences continue for these less densely populated locations.

Figure A7.15: Single-user throughput, 12,000 sites, 80-90% area, shallow and 85% loading

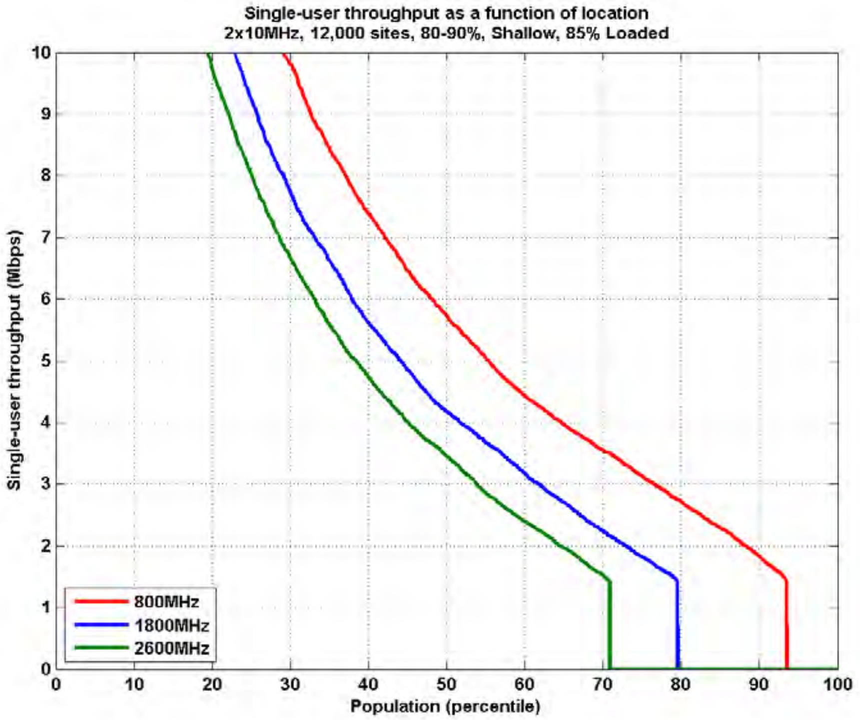
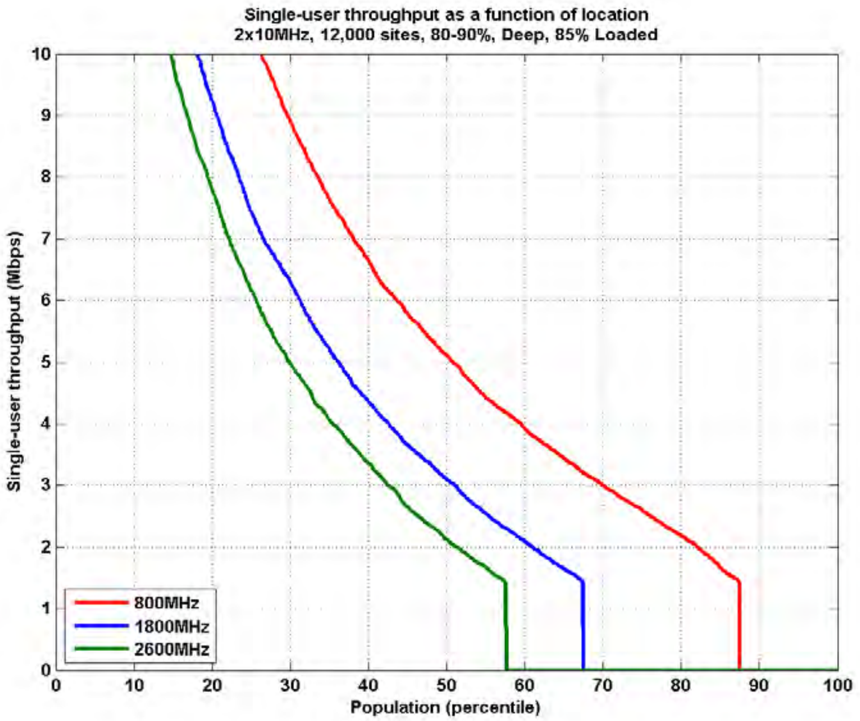


Figure A7.16: Single-user throughput, 12,000 sites, 80-90% area, deep and 85% loading



A7.86 In summary, Figure A7.11 to Figure A7.16 show that single-user throughput performance and coverage is better at lower frequencies and both degrade when going from shallow to deep indoor locations and from more dense to less densely populated areas.

A7.87 It is noticeable from the graphs that coverage for basic connectivity for each frequency is entirely a function of the SINR cut-off. This is shown by the point where the curves drop vertically to intersect the x-axis. This means that coverage for basic connectivity is effectively independent of bandwidth. Though coverage to achieve a specific data-rate target may not be (e.g. a 2 Mbit/s service would have greater coverage for a 2x20 MHz carrier than for a 2x10 MHz one).

Table A7.4: Coverage, 12,000 sites

Area	Popn	Shallow			Deep		
		800	1800	2600	800	1800	2600
0-50%	50%	98%	93%	89%	96%	86%	78%
50-80%	30%	96%	83%	76%	91%	73%	62%
80-90%	10%	94%	80%	71%	87%	67%	58%
0-80%	80%	97%	89%	84%	94%	81%	72%
0-90%	90%	96%	88%	82%	94%	80%	71%

A7.88 Table A7.4 summarises the coverage data from the graphs above. The final two rows are calculated as a weighted sum from the rows above, they give the total coverage (for basic connectivity) that our model predicts for each frequency at each depth for the combined 0-80% and 0-90% areas.

Table A7.5: Households without 1800 MHz coverage but with 800 MHz coverage, 12,000 sites, 'Maxvar'

Area	Popn	Shallow	Deep
0-50%	50%	600,000	1,200,000
50-80%	30%	900,000	1,300,000
80-90%	10%	300,000	500,000
0-80%	80%	1,500,000	2,500,000
0-90%	90%	1,800,000	3,000,000

A7.89 Table A7.5 gives an estimate of the number of households in each of the three simulation areas which our model predicts would not have coverage at 1800 MHz but who would at 800 MHz.

Mitigating coverage differences by reducing network loading

A7.90 One approach to reducing the coverage gap between an operator with spectrum at 800 MHz and one with spectrum at 1800 MHz or 2600 MHz may be for the 1800 MHz and 2600 MHz operators to manage their carriers so that they ran at a lower maximum load, for instance at 50% rather than at 85% loading. This might be possible particularly where the 1800 MHz or 2600 MHz operator had a large bandwidth available to them. For instance if an operator had 2x40 MHz of 1800 MHz spectrum they could in theory run two 2x20 MHz carriers, one they limited to 50% load and the other which they allowed to run at full load, though there may be other practical reasons not to do this.

A7.91 To illustrate the impact of reducing load on 1800 MHz and 2600 MHz networks would have on their coverage compared to a 800 MHz network, Figure A7.17 and Figure A7.18 show the single-user throughput results our model predicts for both shallow and deep indoor locations for our 50-80% simulation area when comparing an 800 MHz network with the equivalent of 12,000 sites nationally loaded to 85% with 1800 MHz and 2600 MHz networks with the equivalent of 12,000 sites nationally loaded to 50%.

Figure A7.17: Single-user throughput, 12,000 sites, 50-80% area, shallow

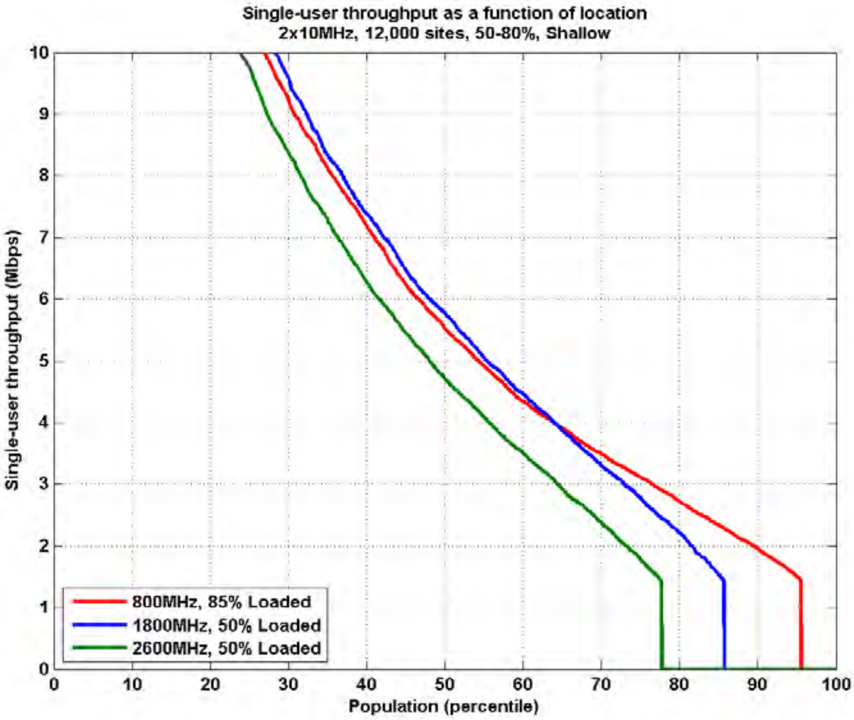
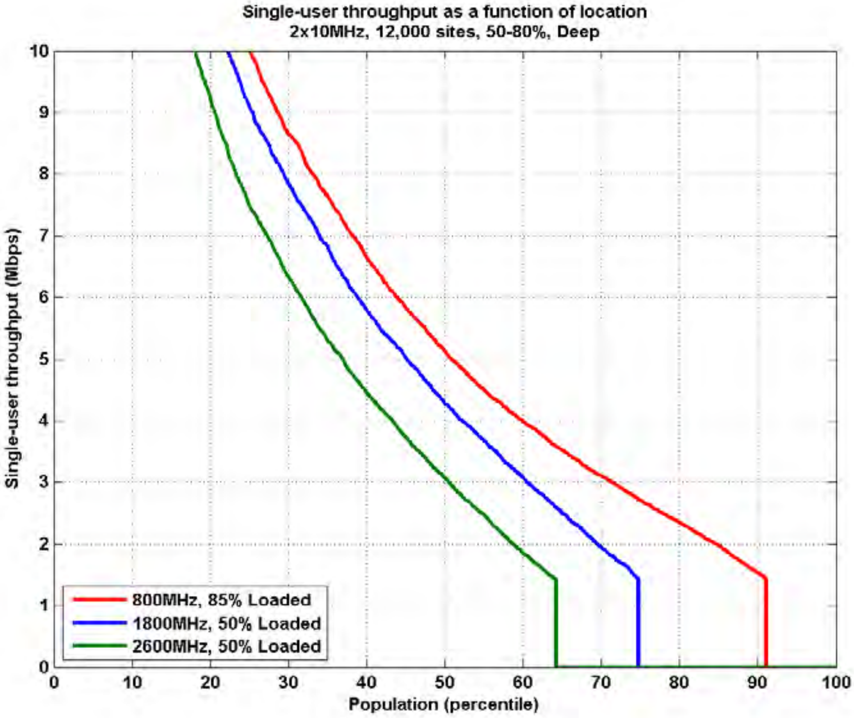


Figure A7.18: Single-user throughput, 12,000 sites, 50-80% area, deep



A7.92 Figure A7.17 to Figure A7.18 show that, though coverage of the 1800 MHz and 2600 MHz networks are improved, the improvement is relatively small (2 to 3%). To utilise this strategy effectively, the 1800 MHz and 2600 MHz operators would need to run their carriers at a loading significantly lighter than 50%. However, we have seen no evidence of this being a strategy used in real networks and are therefore uncertain of the practicality of such a strategy.

A7.93 Though reducing loading has only limited effect on coverage it does improve the single-user throughput performance of the networks. This is most noticeable for shallow indoor locations e.g. in Figure A7.17 the 800 MHz throughput performance (red line) is below the 1800 MHz and 2600 MHz performance for a significant proportion of the population. For deep indoor locations the relative difference in throughput performance is less (see Figure A7.18). The improvement in single-user throughput performance results from the fact that in a more lightly loaded network there is less interference and hence SINR and consequently throughput is better. On the other hand, keeping the network lightly loaded will inevitably mean that overall network capacity is reduced.

Mitigating coverage differences by increasing site density of the higher frequency networks

A7.94 An alternative mitigation strategy that an 1800 MHz or 2600 MHz operator could employ to reduce the coverage gap with an 800 MHz network would be to deploy more sites. In Figure A7.19 and Figure A7.20 below, we show the single-user throughput results for the both shallow and deep indoor locations for our 50-80% simulation area when comparing an 800 MHz network with the equivalent of 12,000 sites nationally with 1800 MHz and 2600 MHz networks with the equivalent of 18,000 sites, all networks loaded to 85%.

A7.95 These results demonstrate that adding additional sites to the 1800 MHz network is a more effective strategy to reduce the coverage gap between it and 800 MHz than reducing network loading.

Figure A7.19: Single-user throughput, mixed site count, 50-80% area, shallow

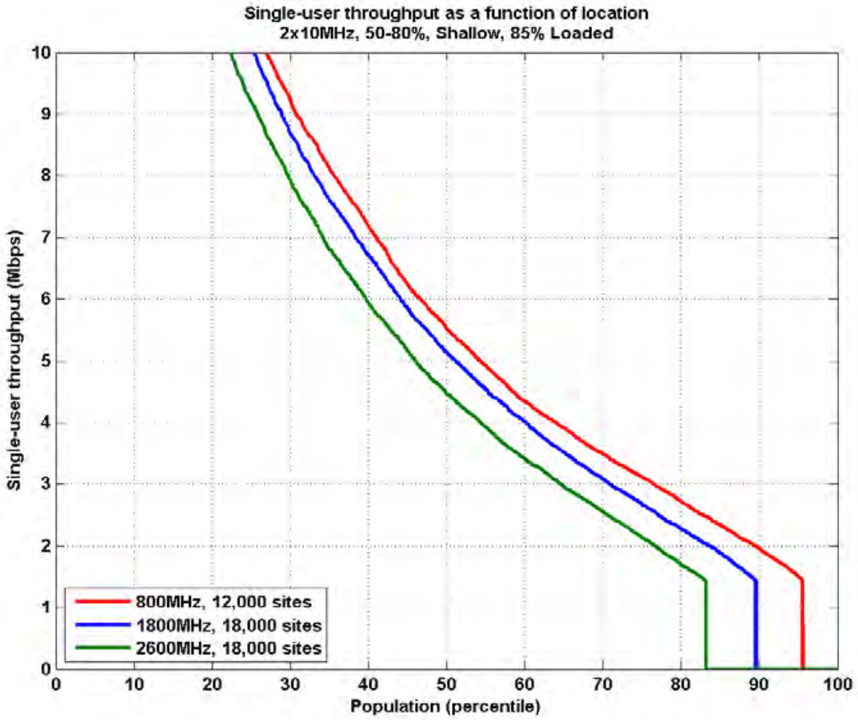
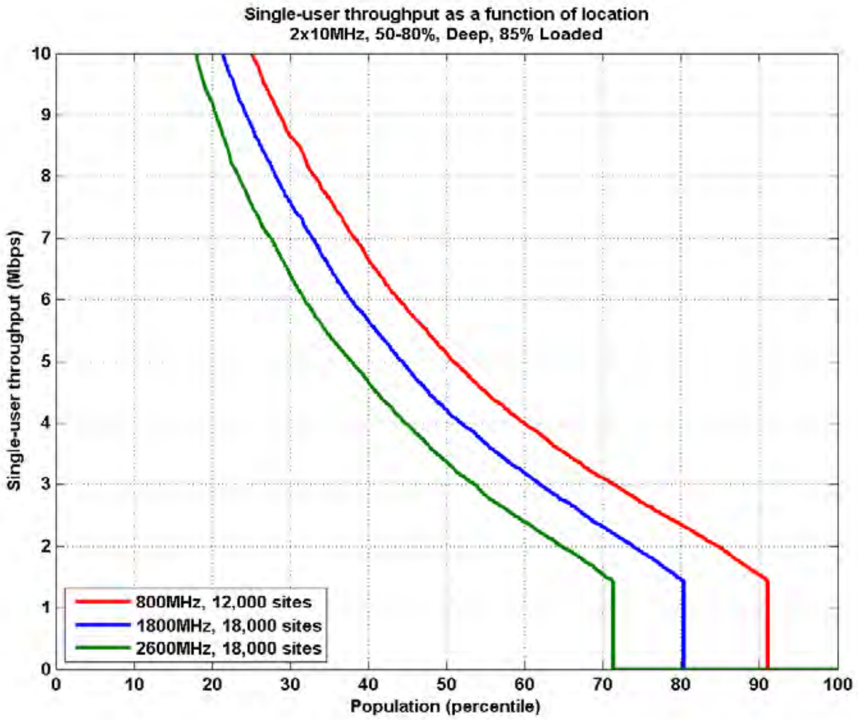


Figure A7.20: Single-user throughput, mixed site count, 50-80% area, deep



A7.96 Whilst coverage of the 1800 MHz and 2600 MHz networks are improved, 800 MHz still offers better coverage in all cases.

What if the 800 MHz operator also deploys more sites?

A7.97 In Figure A7.21 to Figure A7.26 below, we show downlink single-user throughput as a function of population for networks with 2x10 MHz, 18,000 sites and 85% loading.

Figure A7.21: Single-user throughput, 18,000 sites 0-50% area, shallow

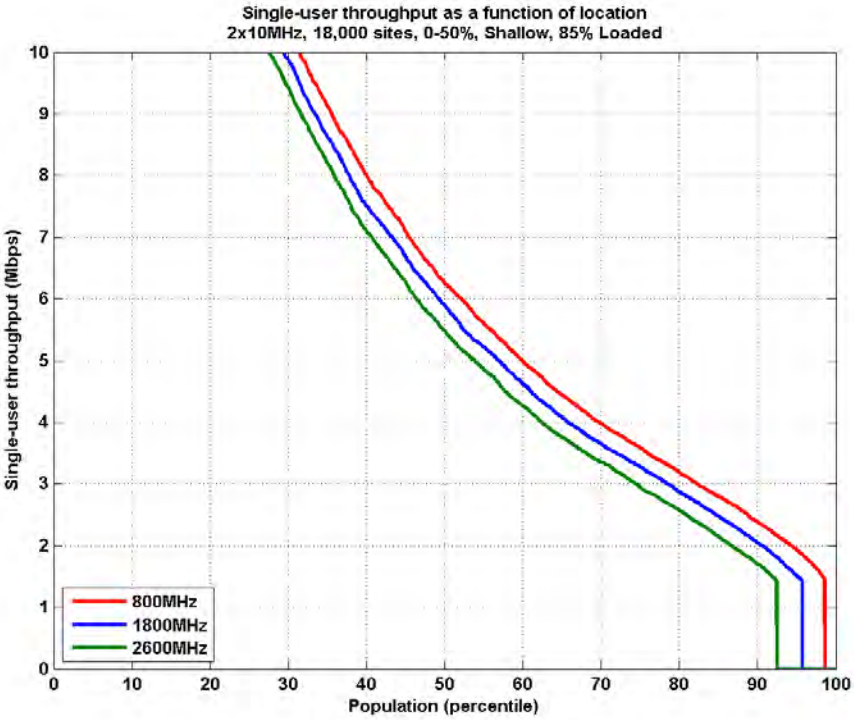


Figure A7.22: Single-user throughput, 18,000 sites 0-50% area, deep

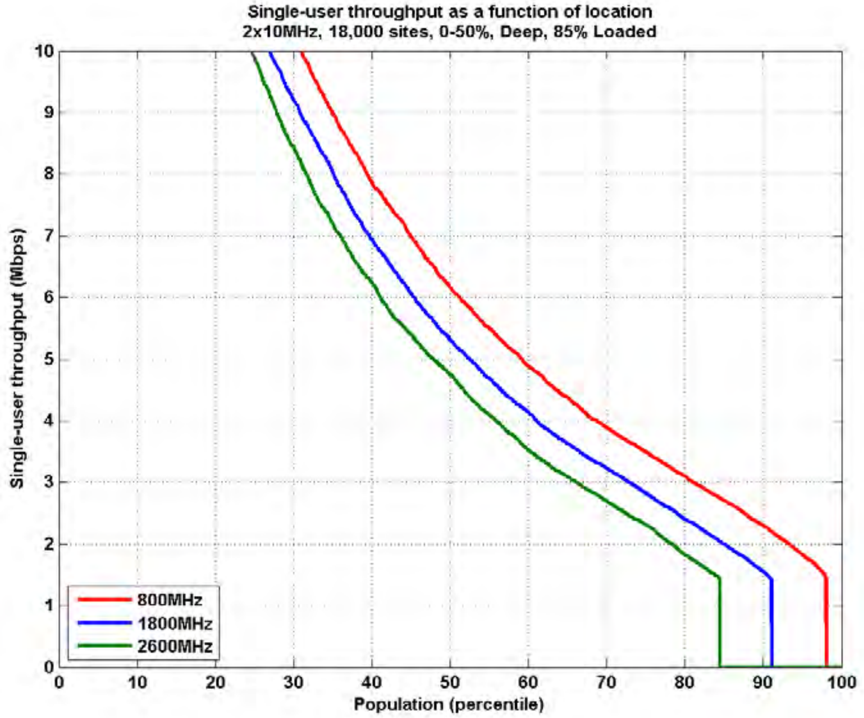


Figure A7.23: Single-user throughput, 18,000 sites 50-80% area, shallow

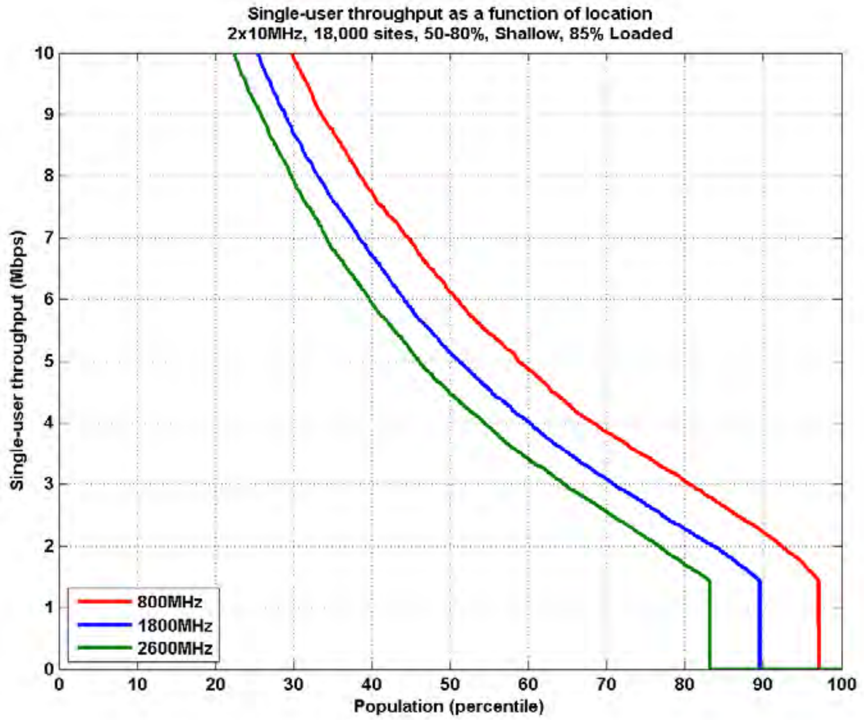


Figure A7.24: Single-user throughput, 18,000 sites 50-80% area, deep

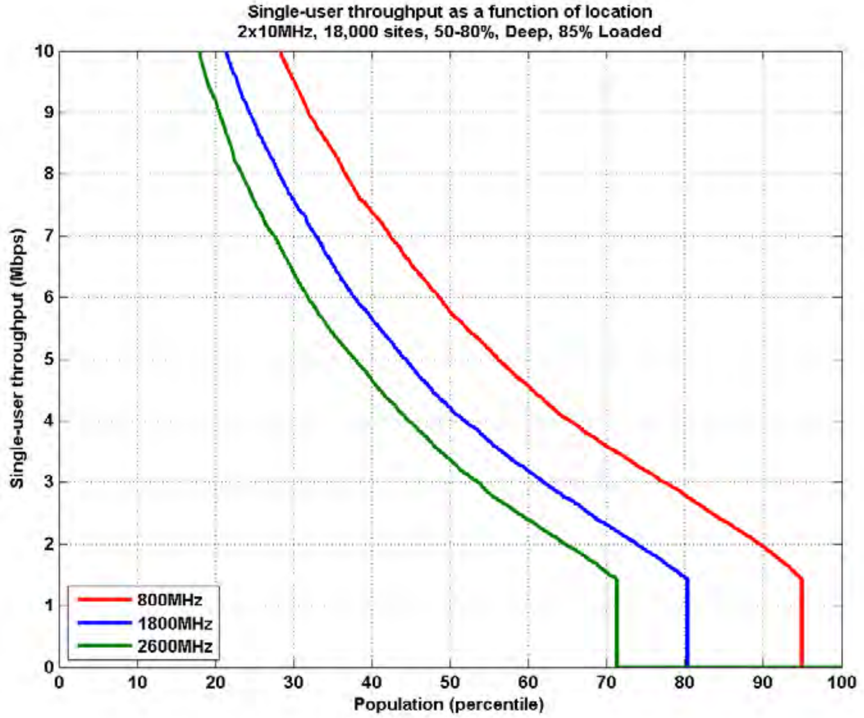


Figure A7.25: Single-user throughput, 18,000 sites 80-90% area, shallow

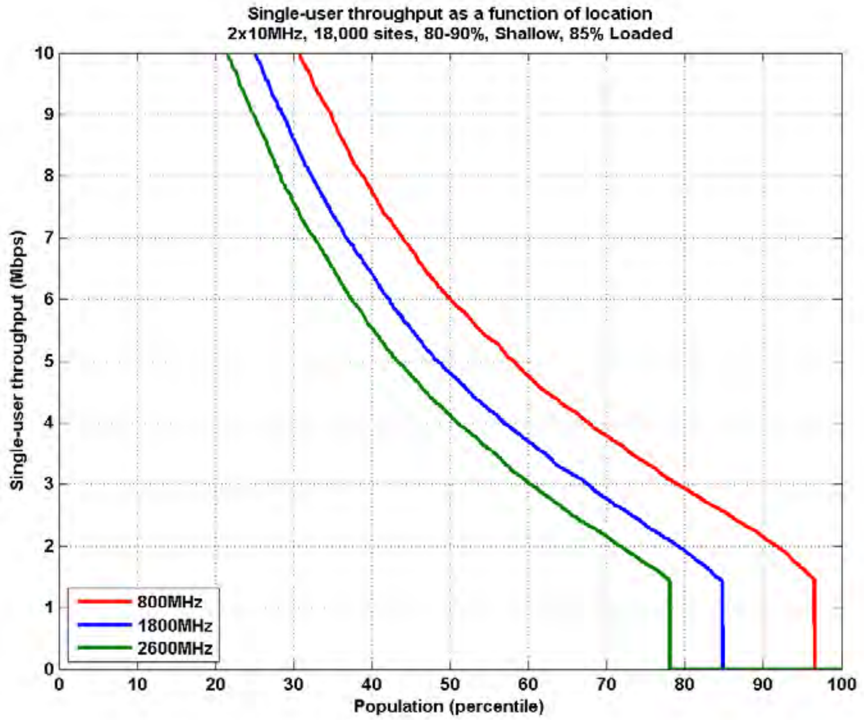
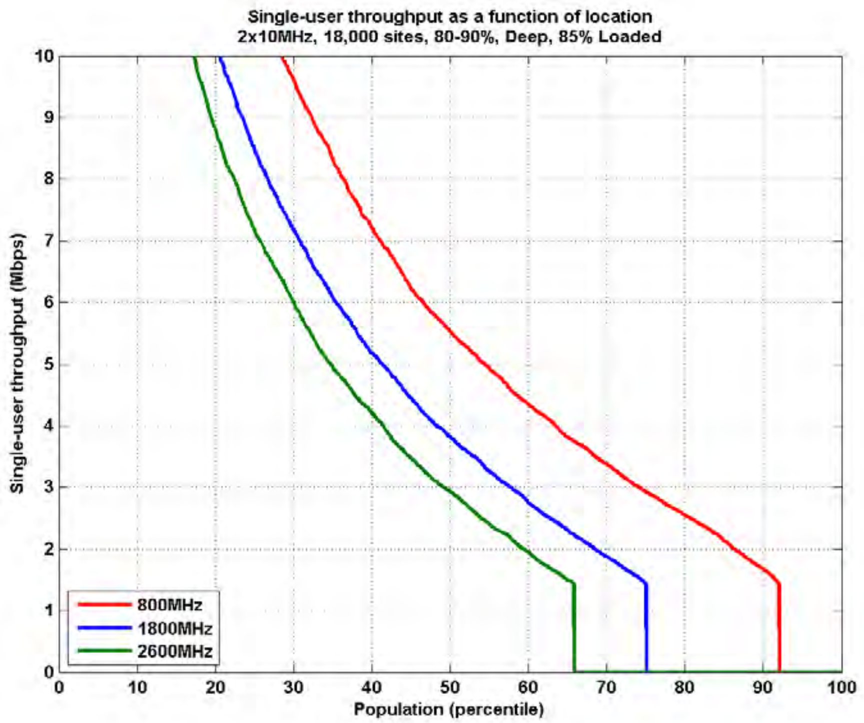


Figure A7.26: Single-user throughput, 18,000 sites 80-90% area, deep



A7.98 Figure A7.21 to Figure A7.26 (for 18,000 sites) tell a similar story to Figure A7.11 to Figure A7.16 (for 12,000 sites). Single user throughput performance and coverage is better for lower frequencies and degrades when going from shallow to deep indoor locations and from more dense to less densely populated areas. However, this degradation is less pronounced for a network with more sites.

Table A7.6: Coverage, 18,000 sites

Area	Popn	Shallow			Deep		
		800	1800	2600	800	1800	2600
0-50%	50%	99%	96%	93%	98%	91%	84%
50-80%	30%	97%	90%	83%	95%	80%	71%
80-90%	10%	97%	85%	78%	92%	75%	66%
0-80%	80%	98%	93%	89%	97%	87%	79%
0-90%	90%	98%	92%	88%	96%	86%	78%

A7.99 Table A7.6 summarises the coverage data from the Figure A7.21 to Figure A7.26 above. The final two rows are calculated as weighted sum from the rows above and give the total coverage (for basic connectivity) that our model predicts for each frequency at each depth for the combined 0-80% and 0-90% areas.

Table A7.7: Households without 1800 MHz coverage but with 800 MHz coverage, 18,000 sites

Area	Popn	Shallow	Deep
0-50%	50%	300,000	900,000
50-80%	30%	500,000	1,000,000

80-90%	10%	300,000	400,000
0-80%	80%	800,000	1,900,000
0-90%	90%	1,100,000	2,300,000

A7.100 Table A7.7 gives an estimate of the number of households in each of the three simulation areas which our model predicts would not have coverage at 1800 MHz but who would at 800 MHz for a network with the equivalent of 18,000 sites nationally.

Impact of bandwidth

A7.101 In this section we look at the impact of bandwidth on the performance of networks operating at different frequencies.

A7.102 In Figure A7.27 to Figure A7.30 below, we show downlink single-user throughput as a function of population for networks with:

- 2x10 MHz @ 800 MHz;
- 2x15 MHz @ 1800 MHz; and
- 2x20 MHz @ 2600 MHz.

A7.103 Each network has the equivalent of 18,000 sites nationally and is loaded to 85%.

Figure A7.27: Single-user throughput, 18,000 sites 0-50% area, shallow

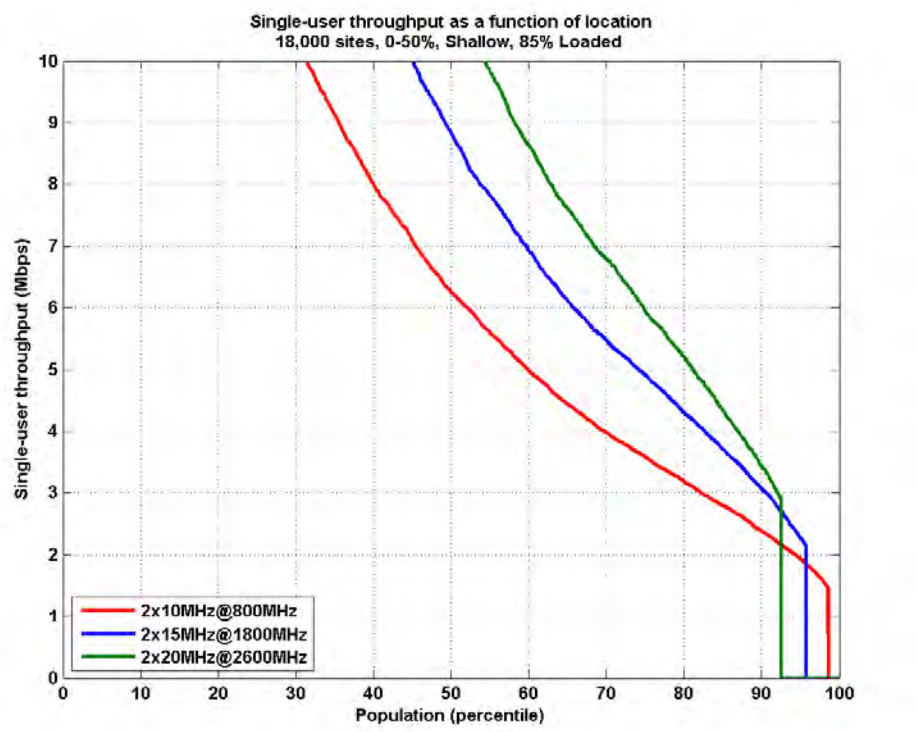


Figure A7.28: Single-user throughput, 18,000 sites 0-50% area, deep

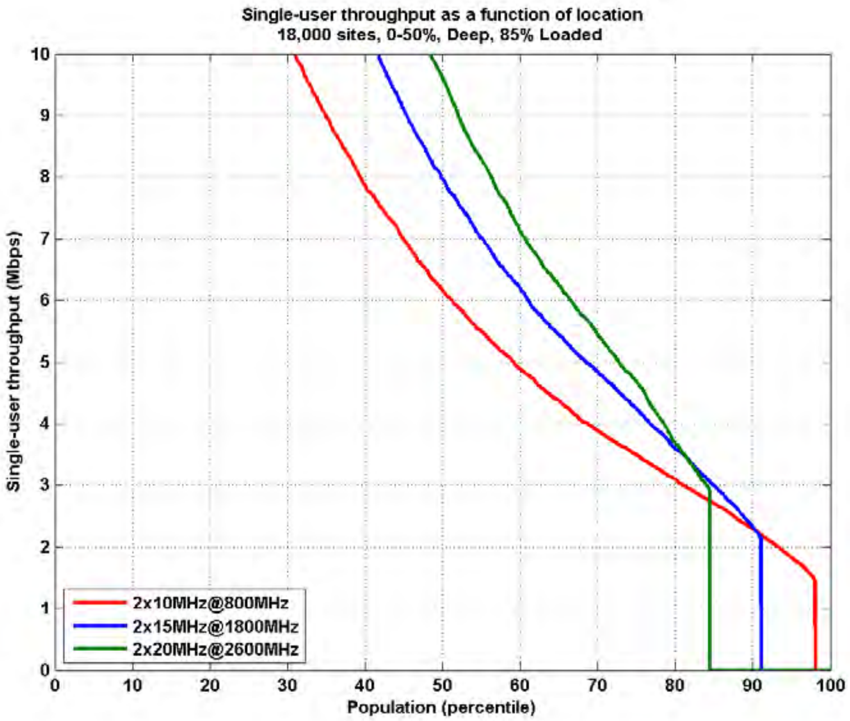


Figure A7.29: Single-user throughput, 18,000 sites 50-80% area, shallow

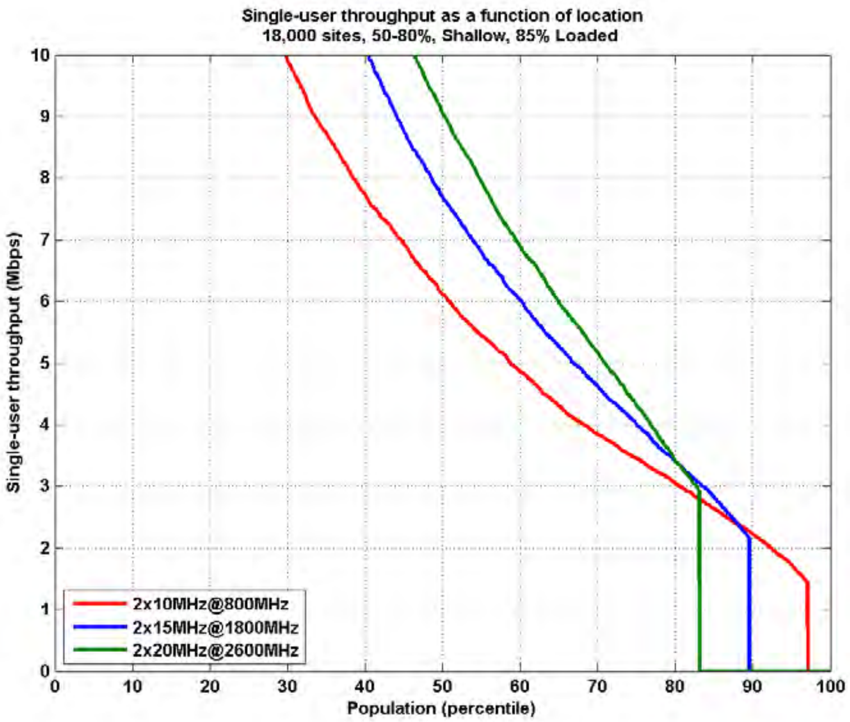
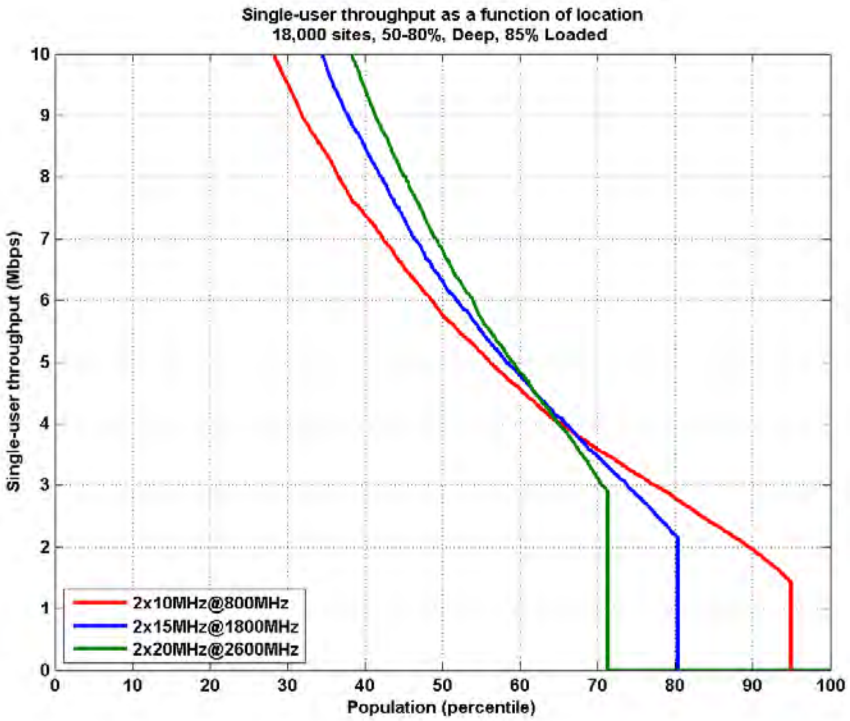


Figure A7.30: Single-user throughput, 18,000 sites 50-80% area, deep



A7.104 Figure A7.27 to Figure A7.30 above, show that our model predicts that larger bandwidth can, in certain circumstances, be more important than frequency in providing greater single-user throughput. This is shown in the graphs where, to the left of the crossover points (i.e. the points where the three lines cross each other), the 1800 MHz network with 2x15 MHz or spectrum has a larger single-user throughput than the 800 MHz network with 2x10 MHz and the 2600 MHz network with 2x20 MHz has a larger single-user throughput than the 1800 MHz network. This is most pronounced for users in shallow indoor locations in the 0-50% area where the crossovers are above the 90% population point (hence for the majority of the population covered, the wider bandwidths provide better single-user throughput than the narrower bandwidths at lower frequencies) and is least pronounced where the crossovers are at about the 65% population point (at deep locations in the 50-80% area).

Impact of uplink requirements to support downlink TCP traffic

A7.105 In this section we explore the potential impact of the requirement to support a minimum uplink data-rate that is a certain percentage of the downlink data-rate necessary to support TCP traffic.

A7.106 One confidential respondent to the January 2012 consultation raised the issue of uplink limitations in relation to downlink TCP traffic. TCP traffic requires receipt of acknowledgements and the respondent argued that just to cater for these acknowledgements an uplink data-rate equal to approximately 4% or the downlink TCP data-rate is required (see Annex 10 for more details).

A7.107 This requirement this could lead to situations where coverage is constrained by the uplink rather than the downlink. As the total power available in the uplink is fixed (to 23dBm), if a relatively high uplink data-rate is needed the available uplink power has to be shared over a number of resource blocks. This therefore limits the power per resource block and hence the range.

A7.108 So, for example, a downlink TCP service of 5Mbit/s would require 200kbit/s in the uplink for acknowledgements. A single uplink resource block might only give 50kbit/s so 4 uplink resource blocks would be needed. This means that the power available in the uplink per resource block would be a ¼ of that available if only one uplink resource block was needed (which is what our analysis for the January 2012 consultation assumed was all that would be needed).

A7.109 The analysis below shows results for the following:

- SU TP – the downlink single-user throughput with no limitations caused by the uplink (solid lines);
- TCP TP(i) – the maximum achievable downlink TCP data-rate consistent with maintaining 4% of that data-rate in the full bandwidth of the uplink channel (dashed lines);
- TCP TP(ii) – the maximum achievable downlink TCP data-rate consistent with maintaining 4% of that data-rate when the uplink channel is restricted to 5 MHz (dotted lines);
- TCP TP(iii) – n x TCP TP(ii), where n is the full channel bandwidth in MHz divided by 5 MHz (dot-dash-dot lines[20]);

A7.110 Results are presented for the 50-80% simulation area for shallow and deep indoor locations. Each network has the equivalent of 18,000 sites nationally and is loaded to 85%. We report results for a bandwidth of 2x20 MHz as this represents the worst case (as the uplink power is potentially spread over the widest bandwidth).

A7.111 As described more fully in Annex 8, we do not explicitly model the uplink interference from UEs other than the test UE, but instead perform a link budget style calculation for the uplink based on the received power in the downlink, to establish whether uplink limitations exist for any particular location. Interference is accounted for by use of an interference margin (noise rise). The interference margin we have used is 2dB which is consistent with values provided by several operators in their responses to information requests.

[20] Note: In the case of Figure A7.31 these lines are hidden by the solid lines of SU TP

Figure A7.31: TCP uplink limitation, 2x20MHz, 50-80%, shallow

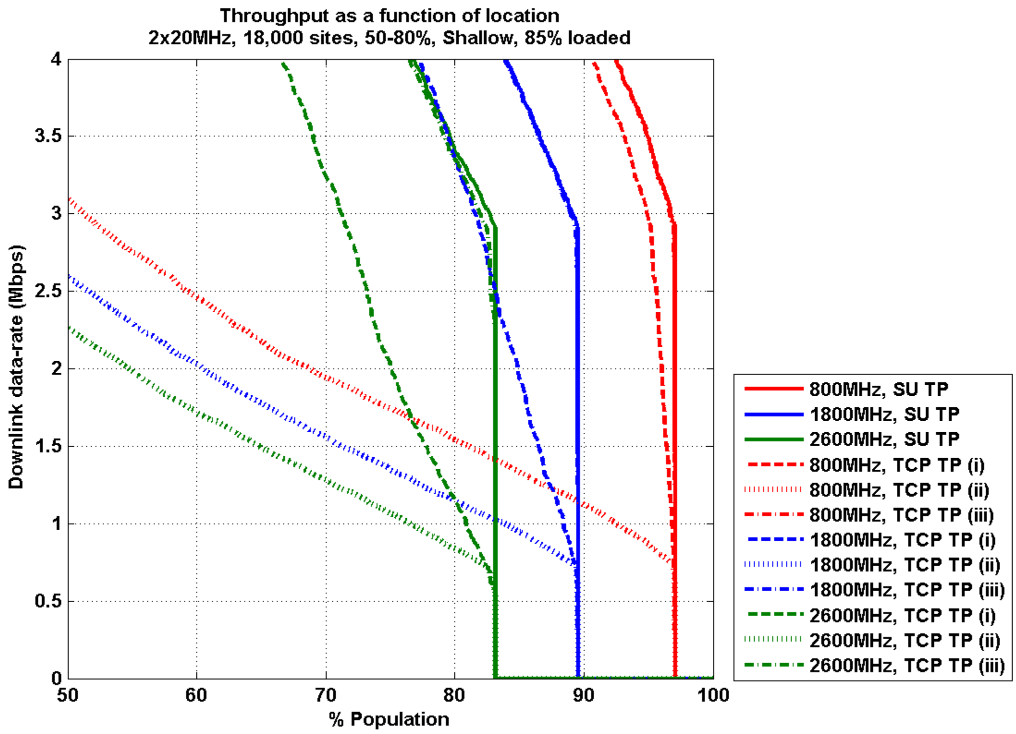
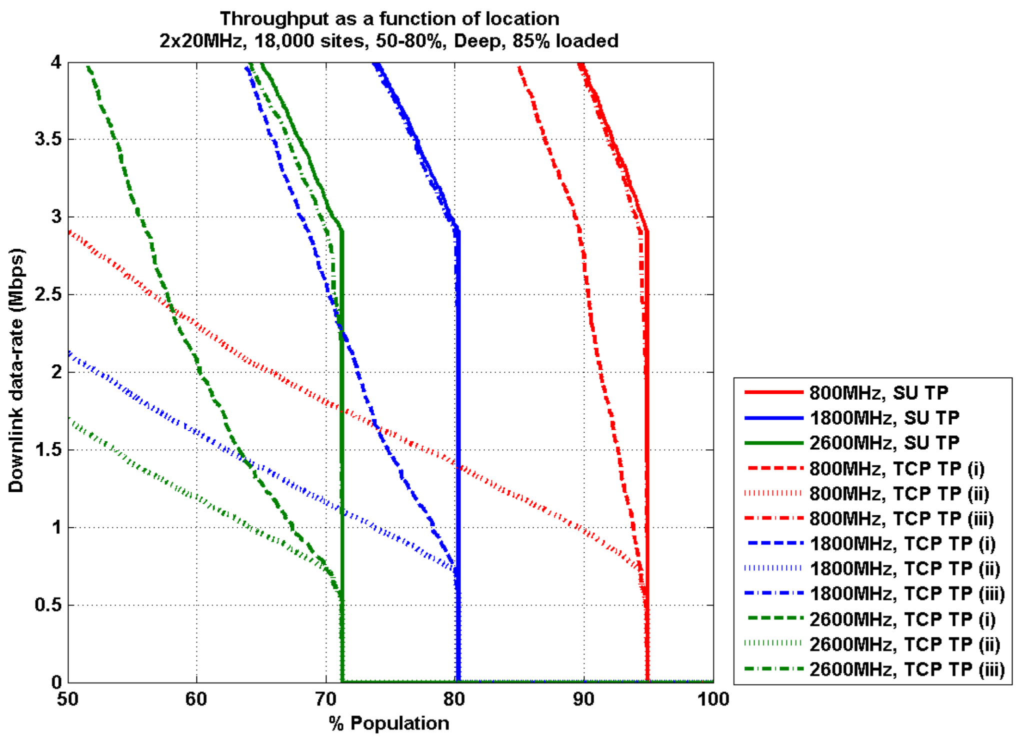


Figure A7.32: TCP uplink limitation, 2x20MHz, 50-80%, deep



A7.112 Figure A7.31 and Figure A7.32 show that our model predicts that coverage for basic connectivity is not affected if uplink constraints consequential to TCP acknowledgements are taken into account. However, these constraints do limit the maximum achievable downlink data-rate for TCP traffic. Wider bandwidths are more affected than narrower ones (as the power in the uplink may be spread over more resource blocks). Lower frequencies are affected less that higher ones. Deep locations are affected more than shallow ones. Less densely populated areas are affected less than more densely populated ones.

A7.113 However, if the uplink channel is restricted to 5 MHz of the available bandwidth then the total combined downlink data-rate for TCP traffic is almost identical to the single-user throughput e.g. the TCP TP(iii) lines are almost identical to the SU TP lines in the graphs above (which is why they can't be seen in certain cases). This indicates that, the need to ensure TCP uplink traffic is at least 4% of the downlink, only impacts achievable downlink data-rates where there is a single user in the cell. In cases where there are multiple users in the cell then it is unlikely that TCP will impose a significant constraint on achievable downlink data-rates (i.e. TCP may impose a constraint on individual users but this is not, in general, a system wide constraint).

A7.114 It should be stressed that our approach to investigating uplink constraints consequential to TCP traffic is less sophisticated that our unconstrained downlink analysis and therefore these results are more uncertain than our unconstrained single-user throughput results.

A7.115 The analysis above is limited to situations where the uplink is used to provide TCP acknowledgements, i.e. data traffic is highly asymmetric. This is reasonable approximation for a range of usage types such as streaming video, web browsing and file downloads.

A7.116 In cases where a higher uplink data rate is required (e.g. live video conferencing) then uplink constraints are more likely to be significant as, LTE is designed for asymmetric traffic; for example Holma and Toskala[21] demonstrate uplink and downlink budgets that are balanced for data-rates of 64kbit/s and 1024kbit/s respectively. Thus higher uplink data-rate traffic is inevitably going to be more difficult to support, for example providing symmetric services such as video-conferencing over wide coverage areas.

RSRP

A7.117 In this section we explore the potential impact if LTE handsets are unable decode signals where the RSRP is low as suggested by one confidential respondent to our January 2012 consultation.

A7.118 In Annex 10 we explain why we do not agree with the claim by the confidential respondent that for RSRP values below -122dBm, handsets will no longer be detected by the network and hence this metric should be used to set the limit of coverage for basic connectivity rather than the SINR cut-off (-5dB) we have used.

A7.119 It should be stressed that an SINR cut-off of -5dB, as required to maintain the Physical Downlink Control Channel for LTE, is equivalent to an RSRP of -127dBm

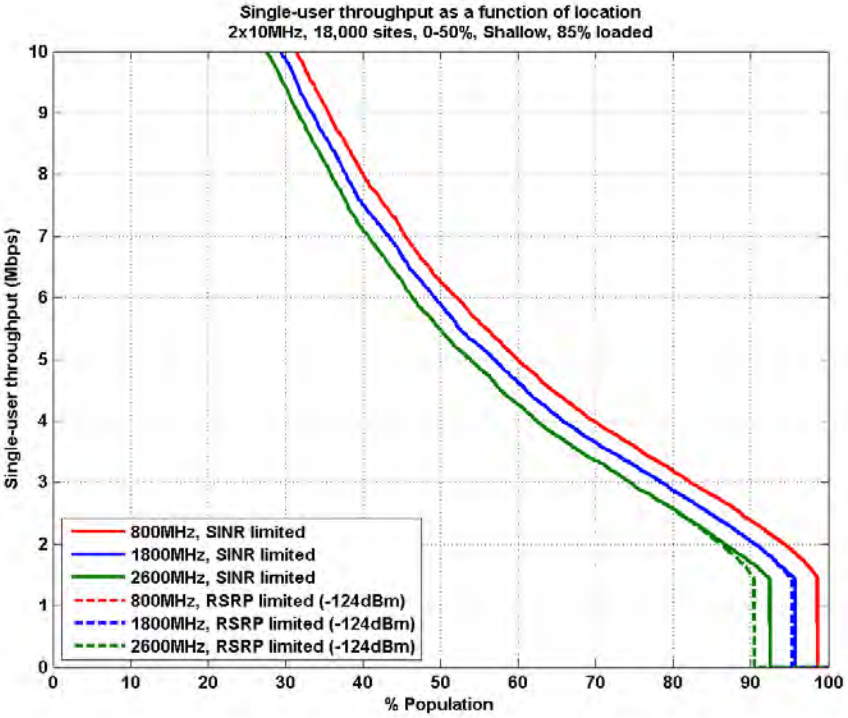
[21] H.Holma & A.Toskala, "LTE for UMTS: Evolution to LTE-Advanced", 2nd Ed, Wiley 2011, p267 & p269

and we have seen evidence[22] from early LTE networks that for RSRP values as low as -124dBm throughput can be delivered to current user equipment.

A7.120 Results are presented for the 0-50%, 50-80% and 80-90% simulation areas for 'shallow' and 'deep' indoor locations. Each network has the equivalent of 18,000 sites nationally, 2x10 MHz of spectrum and is loaded to 85%.

A7.121 See Annex 8 for details of how we have included an RSRP limitation in our modelling for the purposes of this sensitivity analysis.

Figure A7.33: RSRP constraint comparison, 18,000 sites, 0-50% area, shallow



[22] In confidential responses to requests for information.

Figure A7.34: RSRP constraint comparison, 18,000 sites, 0-50% area, deep

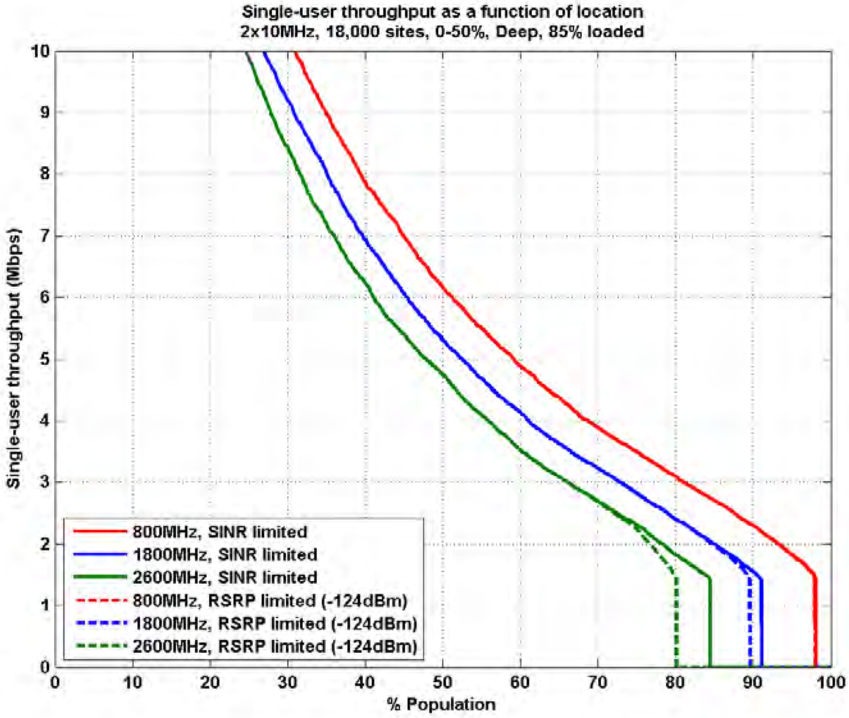


Figure A7.35: RSRP constraint comparison, 18,000 sites, 50-80% area, shallow

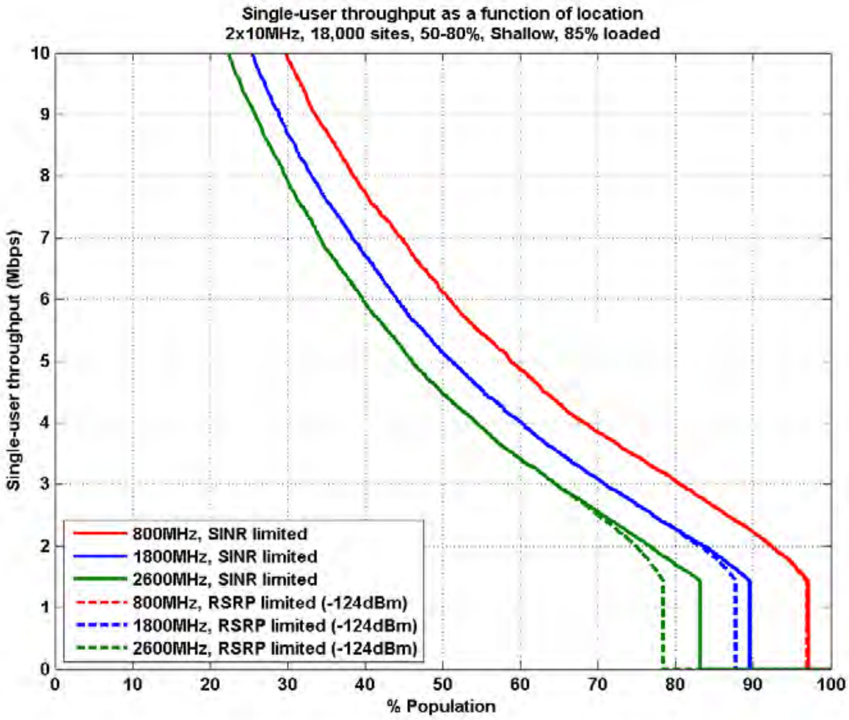


Figure A7.36: RSRP constraint comparison, 18,000 sites, 50-80% area, deep

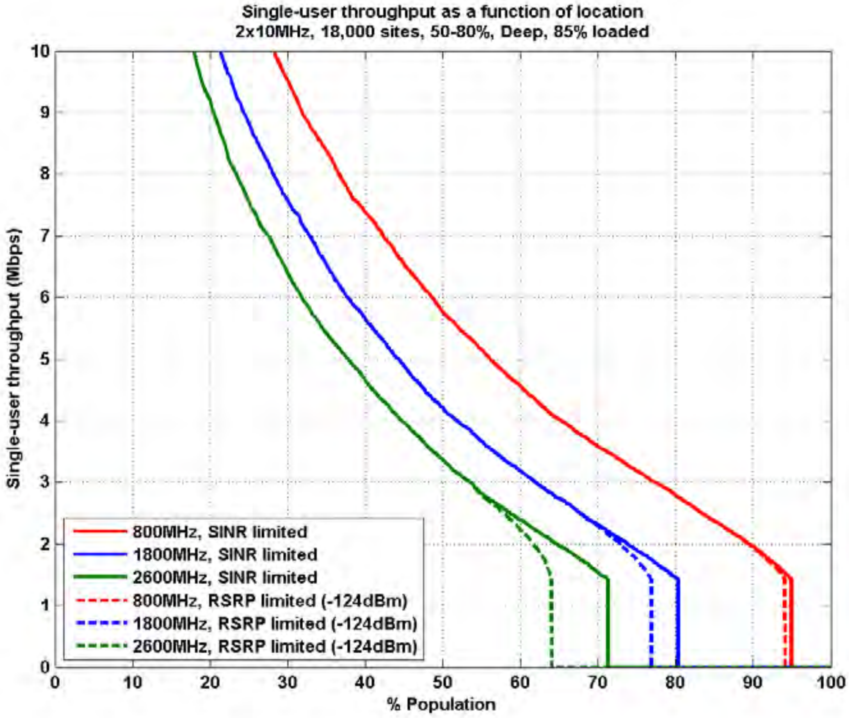


Figure A7.37: RSRP constraint comparison, 18,000 sites, 80-90% area, shallow

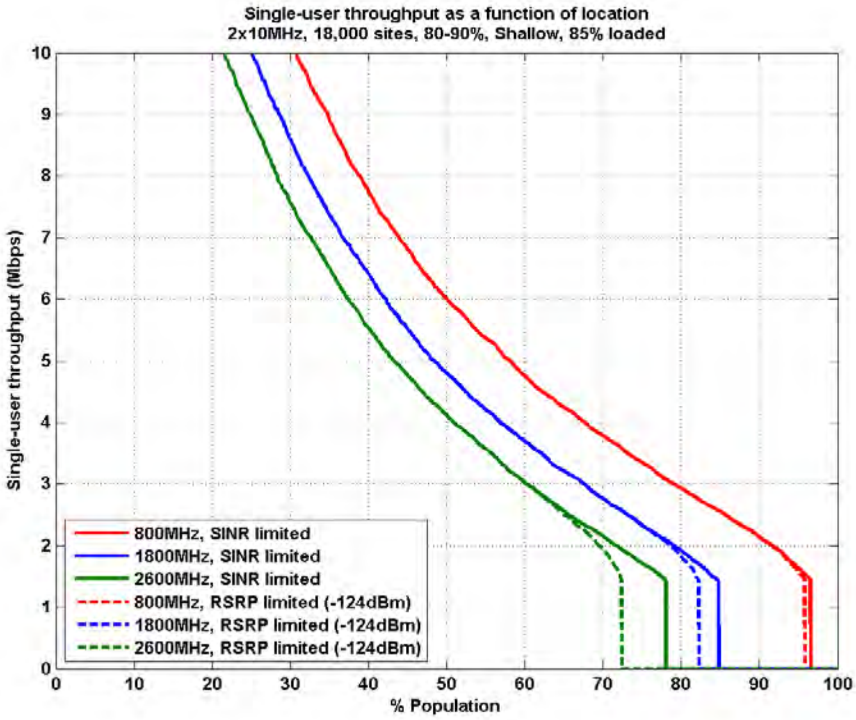
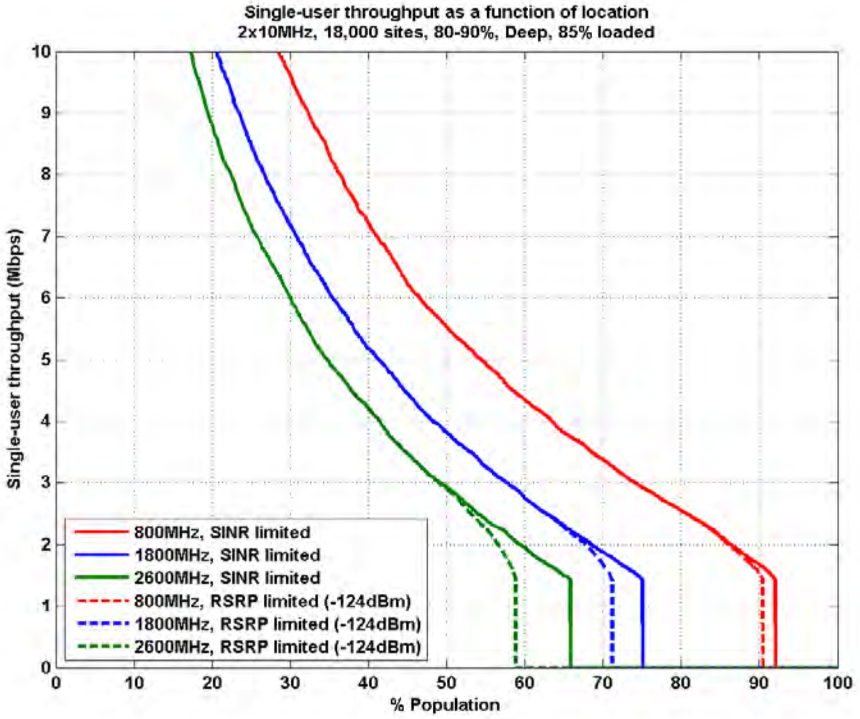


Figure A7.38: RSRP constraint comparison, 18,000 sites, 80-90% area, deep



A7.122 The results in Figure A7.33 to Figure A7.38 show our model predicts that an RSRP limit of -124dBm could restrict coverage.

Table A7.8: RSRP constrained coverage (-124dBm), 18,000 sites

Area	Popn	Shallow			Deep		
		800	1800	2600	800	1800	2600
0-50%	50%	99%	95%	90%	98%	90%	80%
50-80%	30%	97%	88%	78%	94%	77%	64%
80-90%	10%	96%	82%	72%	90%	71%	59%
0-80%	80%	98%	92%	86%	96%	85%	74%
0-90%	90%	98%	91%	84%	96%	83%	72%

A7.123 Table A7.8 summarises the RSRP constrained coverage data from the Figure A7.33 to Figure A7.38 above. The final two rows are calculated as weighted sum from the rows above and give the total coverage (for basic connectivity) that our model predicts for each frequency at each depth for the combined 0-80% and 0-90% areas.

A7.124 Comparing the results in Table A7.8 to those in Table A7.6 for the 0-90% area it can be seen that networks operating at 800 MHz are relatively insensitive to an RSRP limitation of -124 dBm with coverage for basic connectivity reduced by less than about 1% even for deep indoor locations. However, for higher frequencies, an RSRP limit of -124dBm does noticeably restrict coverage. For networks operating at 1800 MHz for shallow indoor locations the impact on coverage is relatively small at about 1%. For deep indoor locations coverage is reduced by about 3% for network operating at 1800 MHz. For networks operating at 2600 MHz the RSRP limit of

-124dBm restricts coverage even more, for shallow indoor location by about 4% and for deep indoor locations by about 6%.

A7.125 These results are provided to illustrate the potential sensitivity of coverage to a RSRP level that is higher than is implicit in our SINR cut-off (but for which we have seen evidence). However, for the reasons set out is Annex 10, we feel that our approach based on an SINR cut-off of -5dB (with an implicit RSRP limit of -127dBm) is reasonable for the purposes of our assessment of the performance of LTE macrocell networks operating at different frequencies.

Comparison of 800 MHz with 900 MHz and 1800 MHz with 2100 MHz

A7.126 In Figure A7.39 and Figure A7.40 below we show the results of a comparison of single-user throughput results for 800 MHz vs 900 MHz and 1800 MHz vs 2100 MHz. These are for the case of a network with the equivalent of 12,000 sites nationally, loaded to 85% for shallow and deep in-building coverage. Generally the model shows a similar picture regardless of site count, loading and depth.

Figure A7.39: Single-user throughput - comparison of frequencies, shallow

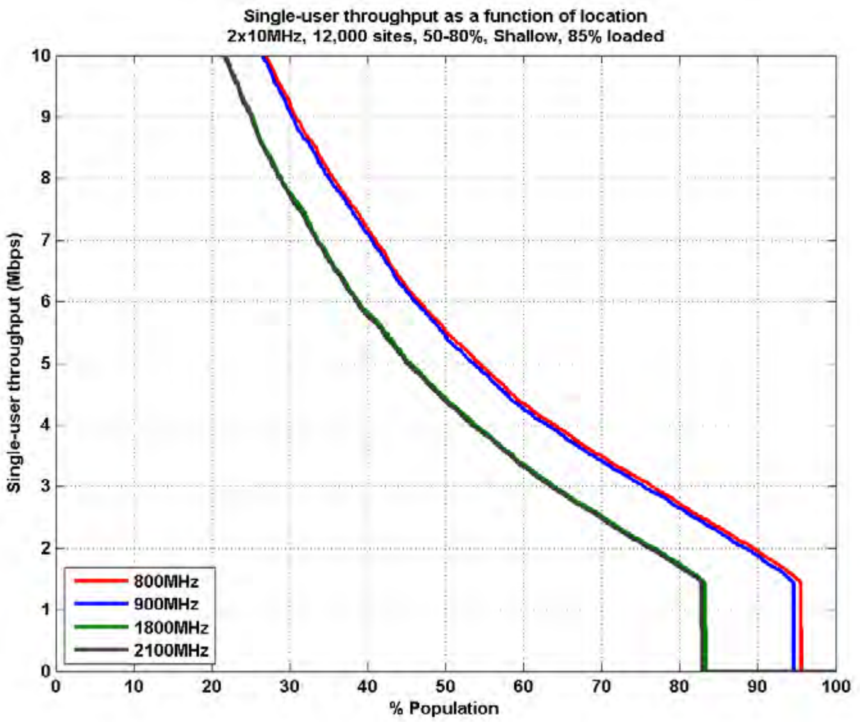
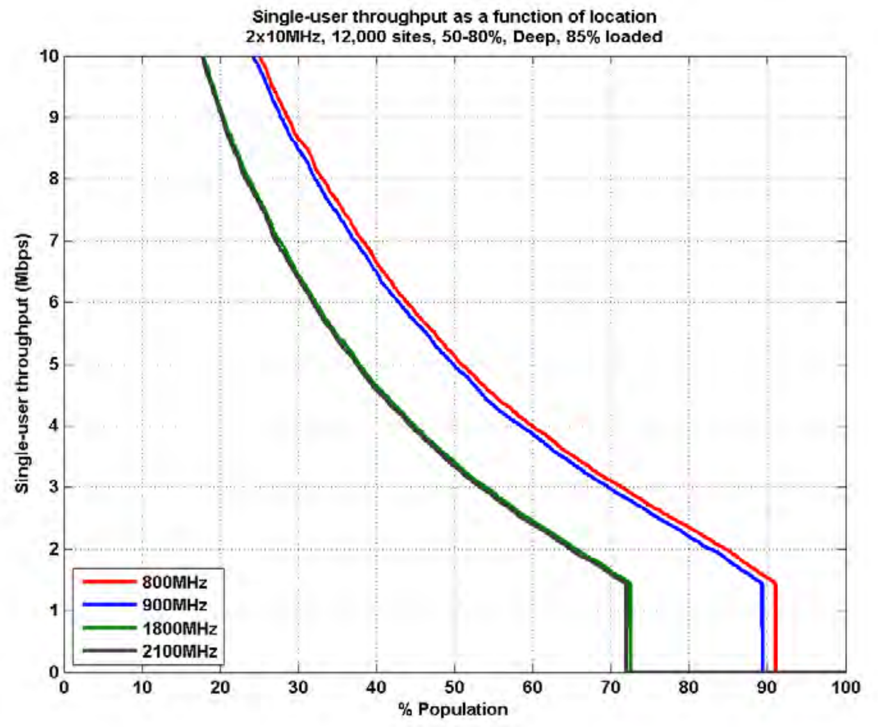


Figure A7.40: Single-user throughput - comparison of frequencies, deep



A7.127 For the 800 MHz vs 900 MHz case the model shows little difference in the performance of networks at the two frequencies. As would be expected, 800 MHz performs very slightly better than 900 MHz but the difference is not significant.

A7.128 Similarly, the model results for 1800 MHz and 2100 MHz show close alignment with no significant difference in coverage in the above figures.

A7.129 We would expect results for the case of a network with the equivalent of 18,000 sites nationally to show even smaller differences between 800 MHz and 900 MHz and between 1800 MHz and 2100 MHz.

Capacity as a function of network size

A7.130 Figure A7.41 to Figure A7.43 illustrate our model's prediction that the relative capacity of networks varies with site count for networks with the equivalent of 4,000, 8,000, 12,000 and 18,000 sites nationally and with bandwidth. The y-axis on these graphs represents the number of sites for the equivalent national network (see Table A7.9). The relative capacity in these graphs is based on offering a downlink data-rate of 1Mbit/s to 90% of the population within the area. All users are assumed to be in shallow indoor locations whereas in practice users will be distributed outdoors and indoors at a range of depths.

Table A7.9: Site numbers

	Number of sites per equivalent national network size			
Area	**4,000**	**8,000**	**12,000**	**18,000**
0-50%	1,589	3,214	4,820	7,181

50-80%	1,226	2,420	3,655	5,473
80-90%	436	895	1,359	2,094

A7.131 Table A7.9 above shown the number of sites within each of our three main simulation areas that our synthetic networks with the equivalent of 4,000, 8,000, 12,000 and 18,000 sites nationally have. It should be noted that for any particular synthetic network the sum of the sites in the three areas is less than the total sites in the equivalent national network. This is because our site placement algorithm does not just concentrate on the three areas but builds up a site base to simulate a nationwide network. A description of the site placement algorithm is given in Annex 8.

A7.132 It should also be noted that the profile of sites within each of the simulation areas in Table A7.9 is unlikely to match closely the roll-out profile of a new entrant operator starting from scratch.

Figure A7.41: Capacity vs sites, 800 MHz, 0-50%, shallow

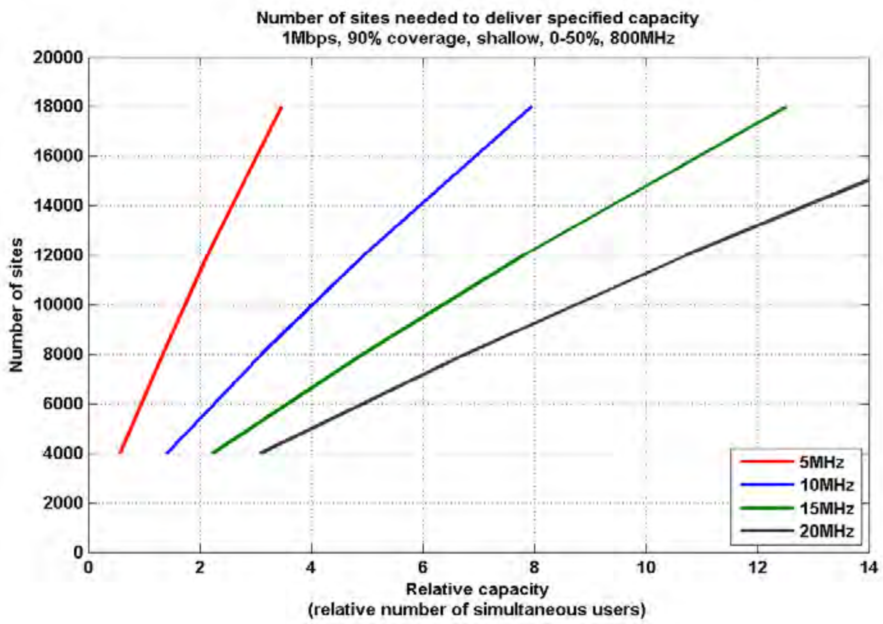


Figure A7.42: Capacity vs sites, 1800 MHz, 0-50%, shallow

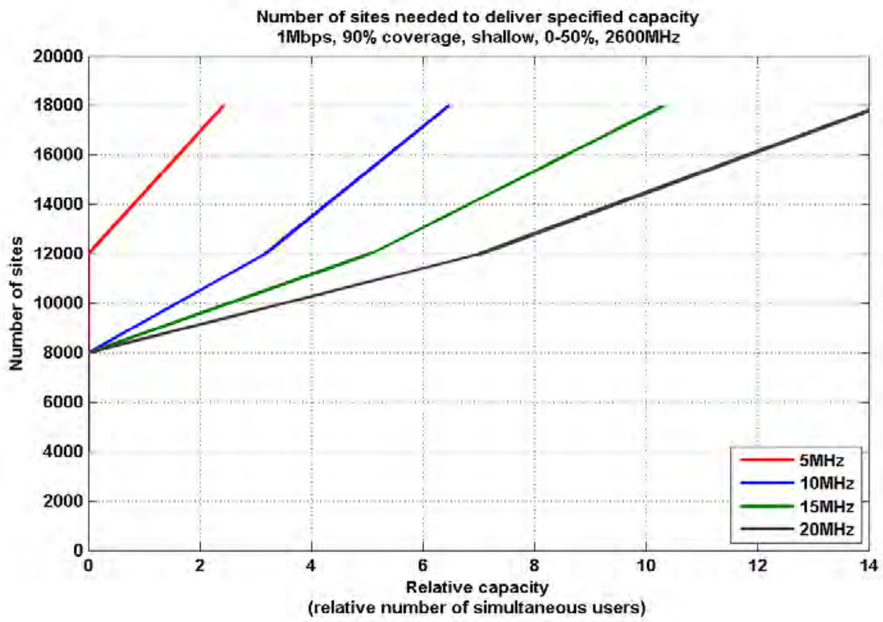
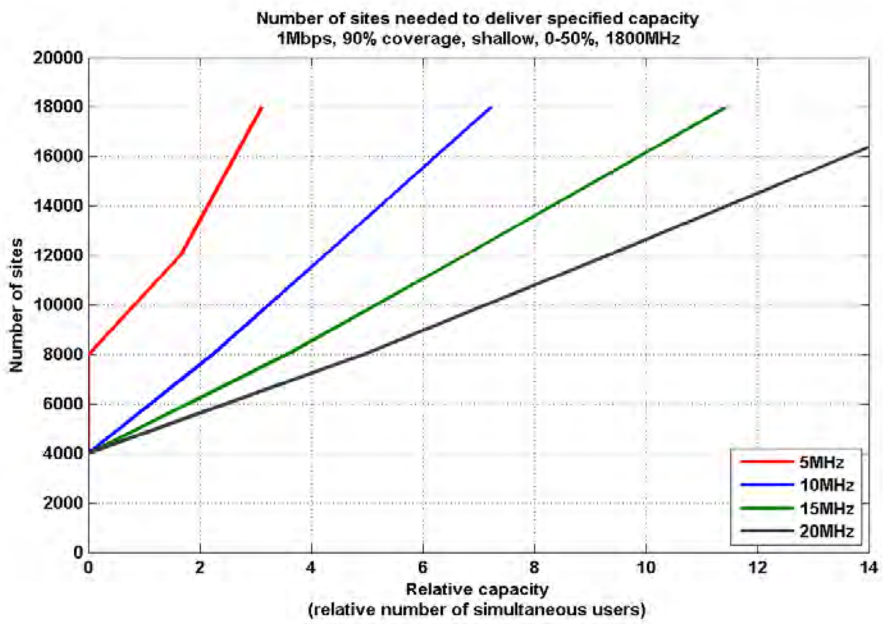


Figure A7.43: Capacity vs sites, 2600 MHz, 0-50%, shallow



A7.133 As expected, Figure A7.41 to Figure A7.43 demonstrate that (provided the networks are capable of providing the required coverage at the specified data-rate) capacity is a linear function of site number over the range of network sizes investigated (e.g. if you double the number of sites in the network you double its capacity). They also demonstrate that, for the same size network, capacity is also a linear function of bandwidth (e.g. if you double the bandwidth you double the capacity).

Single-user throughput comparisons of different spectrum holdings

A7.134 The figures in this section show downlink single-user throughput as a function of population that our model predicts for LTE networks. The figures enable illustration of predicted performance variation of networks operating using some different example spectrum holdings.

A7.135 As we did for the section dealing with capacity vs coverage above, the results in this section are presented for the 0-50% and 50-80% simulation areas for both shallow and deep indoor locations.

A7.136 The particular example spectrum holdings shown have been chosen to help illustrate the choice of minimum spectrum portfolios necessary to be a credible national wholesaler.

Comparison 1: 2x15 MHz of 800 MHz against alternatives

A7.137 In this subsection we look at the performance of a spectrum portfolio of 2x15 MHz of 800 MHz and compare it with two alternatives, one with a smaller amount of 800 MHz spectrum and another with the same amount of spectrum in a higher frequency band. The combinations investigated are as follows:

- 2x15 MHz @ 800 MHz;
- 2x15 MHz @ 1800 MHz; and
- 2x10 MHz @ 800 MHz

Figure A7.44: Single-user throughput, 18,000 sites, 0-50% area, shallow

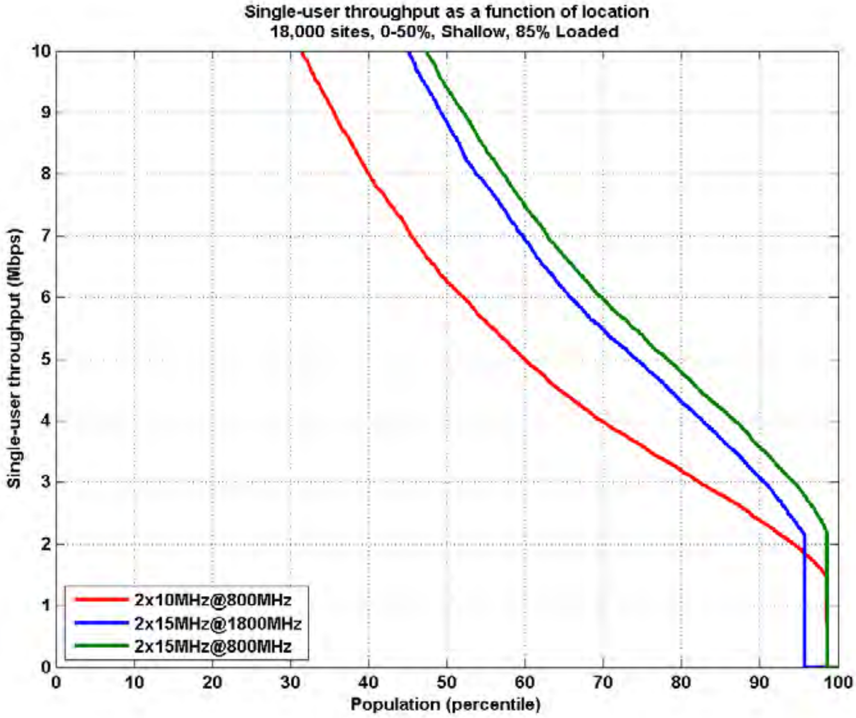


Figure A7.45: Single-user throughput, 18,000 sites, 0-50% area, deep

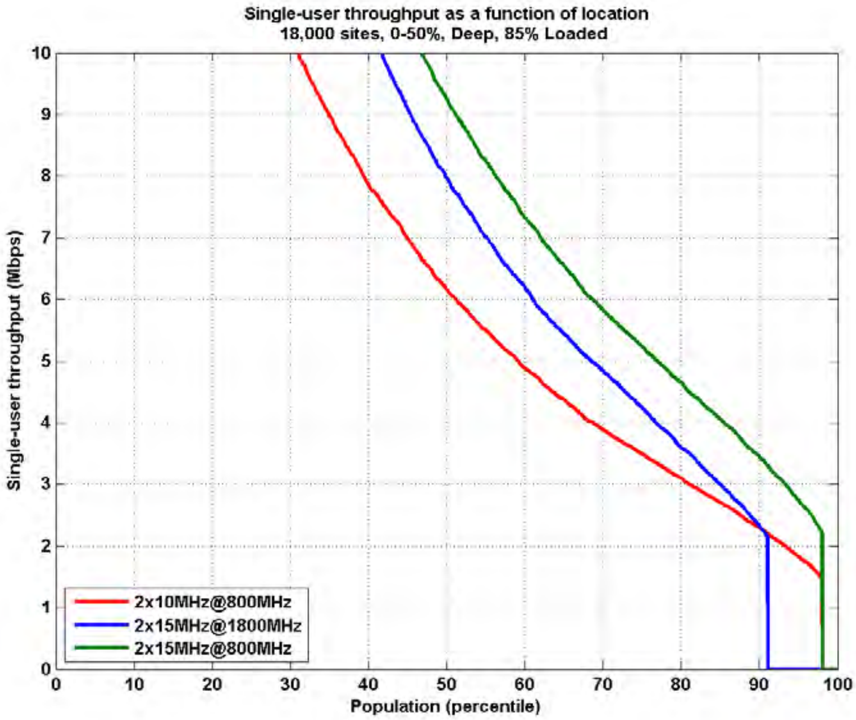


Figure A7.46: Single-user throughput, 18,000 sites, 50-80% area, shallow

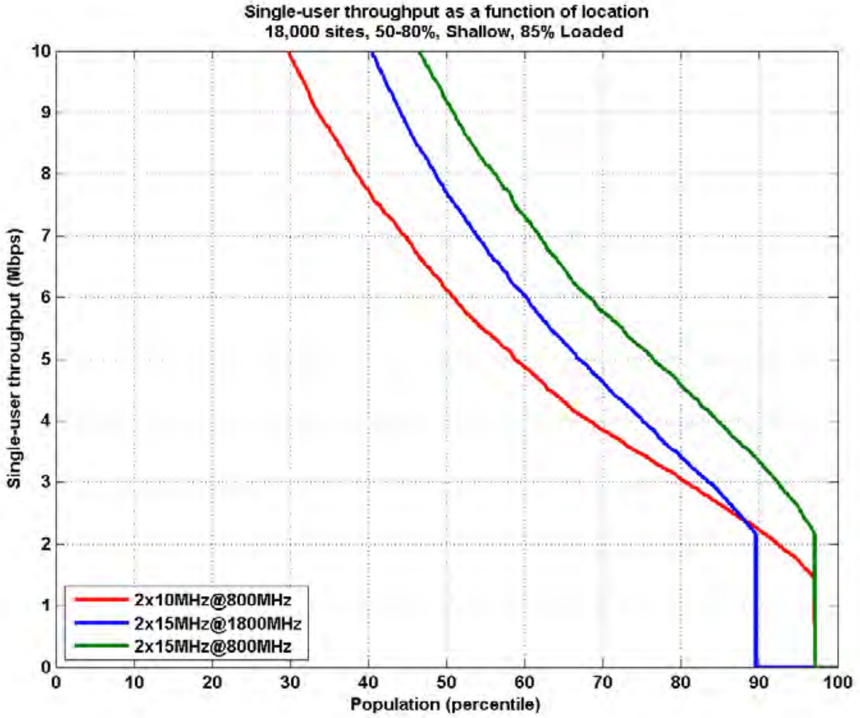
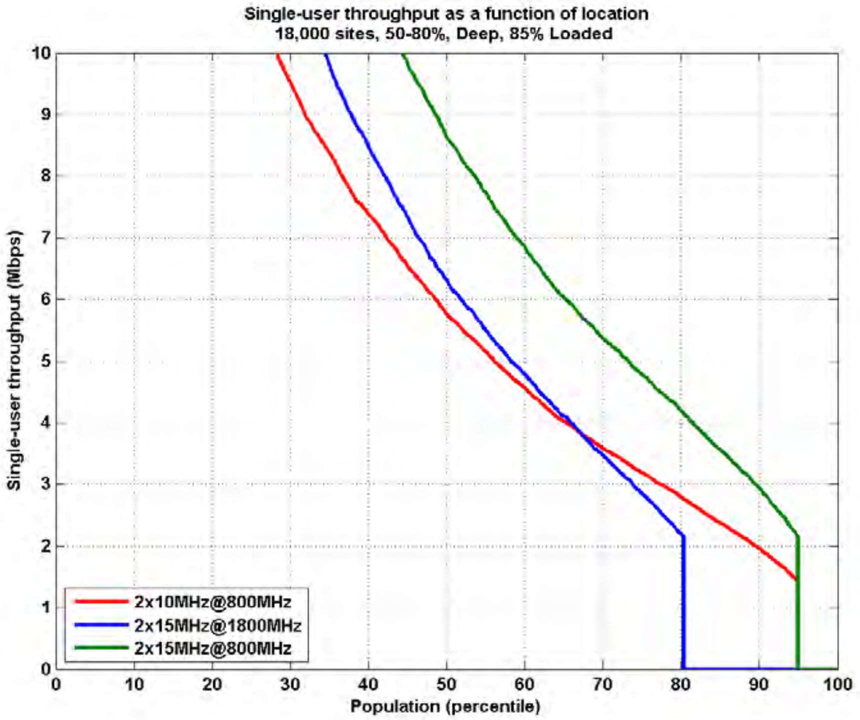


Figure A7.47: Single-user throughput, 18,000 sites, 50-80% area, deep



A7.138 Figure A7.44 to Figure A7.47 show that our model predicts that 2x15 MHz of 800 MHz has consistently better performance than either 2x10 MHz of 800 MHz or 2x15 MHz of 1800 MHz. It is better than 2x10 MHz of 800 MHz in terms of single user throughput but has the same coverage for basic connectivity. And it is better than 2x15 MHz of 1800 MHz in terms of both single user throughput and coverage.

Comparison 2: 2x15 MHz of 1800 MHz plus 2x20 MHz of 2600 MHz against alternatives

A7.139 In this subsection we look at the performance of a spectrum portfolio 2x15 MHz of 1800 MHz plus 2x20 MHz of 2600 MHz and compare an alternative with the same quantity of 1800 MHz spectrum but with a smaller quantity of 2600 MHz. The combinations investigated are as follows:

- 2x15 MHz @ 1800 MHz plus 2x20 MHz @ 2600 MHz;
- 2x15 MHz @ 1800 MHz plus 2x10 MHz @ 2600 MHz.

A7.140 When looking at Figure A7.48 to Figure A7.51 below it should be remembered that 2x15 MHz of 1800 MHz (the red line) is common to both portfolios.

Figure A7.48: Single-user throughput, 18,000 sites, 0-50% area, shallow

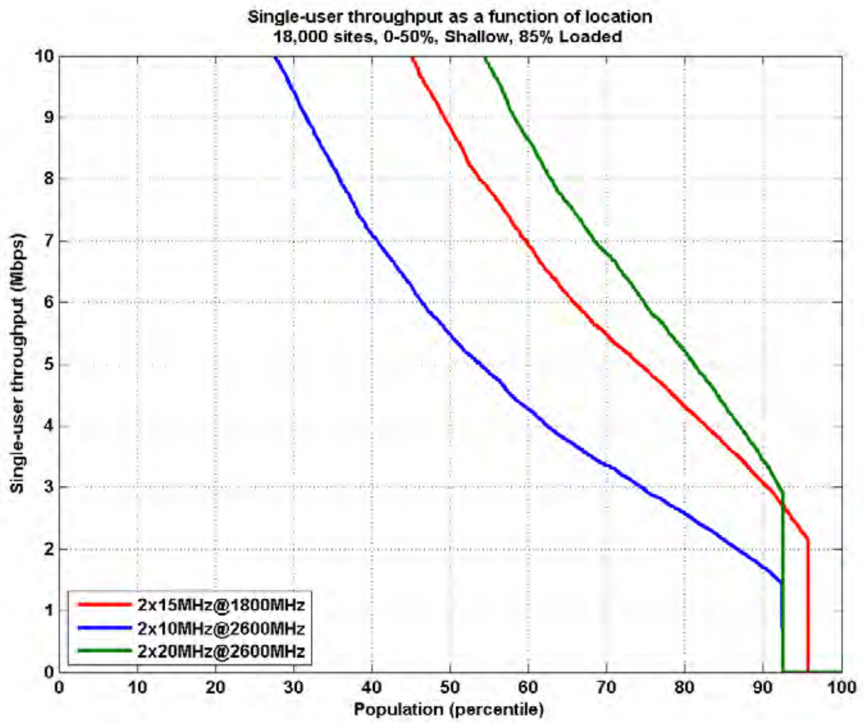


Figure A7.49: Single-user throughput, 18,000 sites, 0-50% area, deep

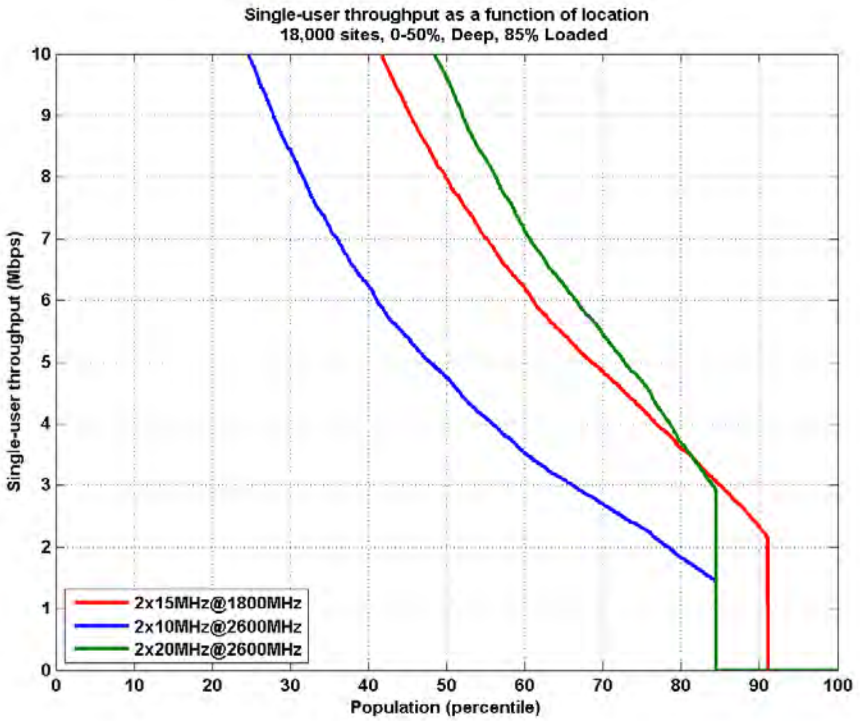


Figure A7.50: Single-user throughput, 18,000 sites, 50-80% area, shallow

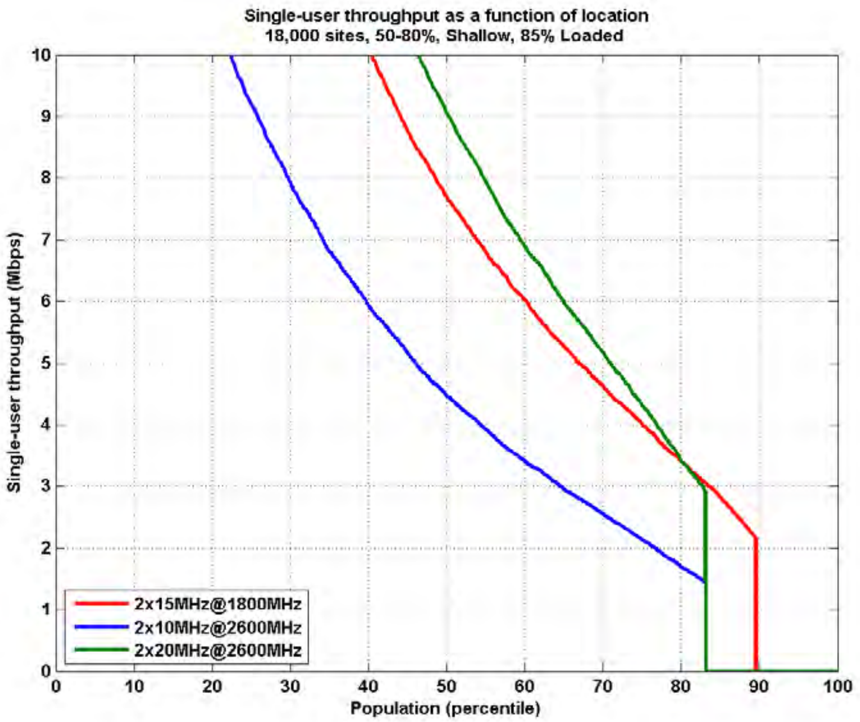
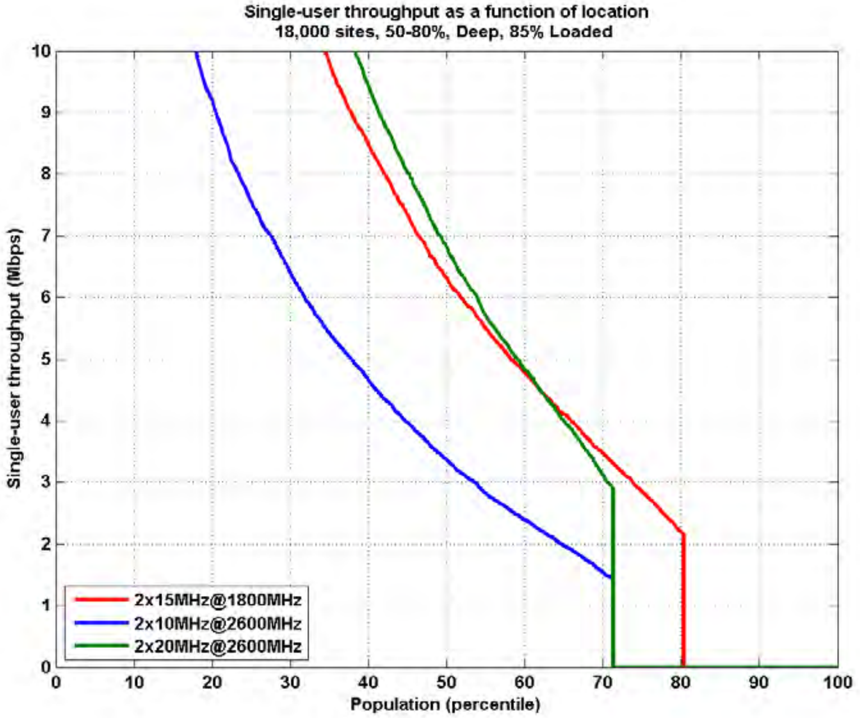


Figure A7.51: Single-user throughput, 18,000 sites, 50-80% area, deep



A7.141 Figure A7.48 to Figure A7.51 demonstrate that the key difference between these portfolios is the higher single-user throughput (and consequently the higher capacity) provided by the extra bandwidth at 2600 MHz provided by the first. They have identical coverage.

Comparison 3: 2x5 MHz of 800 MHz plus 2x15 MHz of 1800 MHz against alternatives

A7.142 In this subsection we look at the performance of a spectrum portfolio with 2x5 MHz of 800 MHz plus 2x15 MHz of 1800 MHz and compare alternatives with the same quantity of 800 MHz spectrum but with a larger quantity at 2600 MHz. The combinations investigated are as follows:

- 2x5 MHz @ 800 MHz plus 2x15 MHz @ 1800 MHz;
- 2x5 MHz @ 800 MHz plus 2x20 MHz @ 2600MHz ; and
- 2x5 MHz @ 800 MHz plus 2x40 MHz @ 2600 MHz.

A7.143 We caution what conclusions can be drawn from these results since we do not take any account of load-balancing within our modelling. The complexity and performance issues associated with balancing multi-frequency spectrum portfolios are likely to be particularly important in this case.

A7.144 When looking at Figure A7.52 to Figure A7.55 below it should be remembered that 2x5 MHz of 800 MHz (the red line) is common to all three portfolios.

Figure A7.52: Single-user throughput, 18,000 sites, 0-50% area, shallow

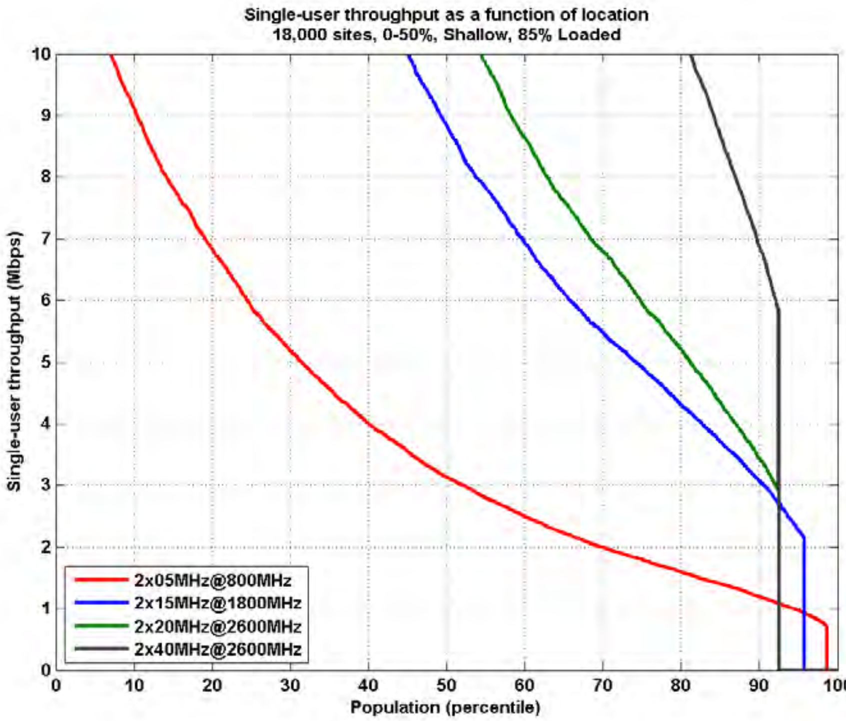


Figure A7.53: Single-user throughput, 18,000 sites, 0-50% area, deep

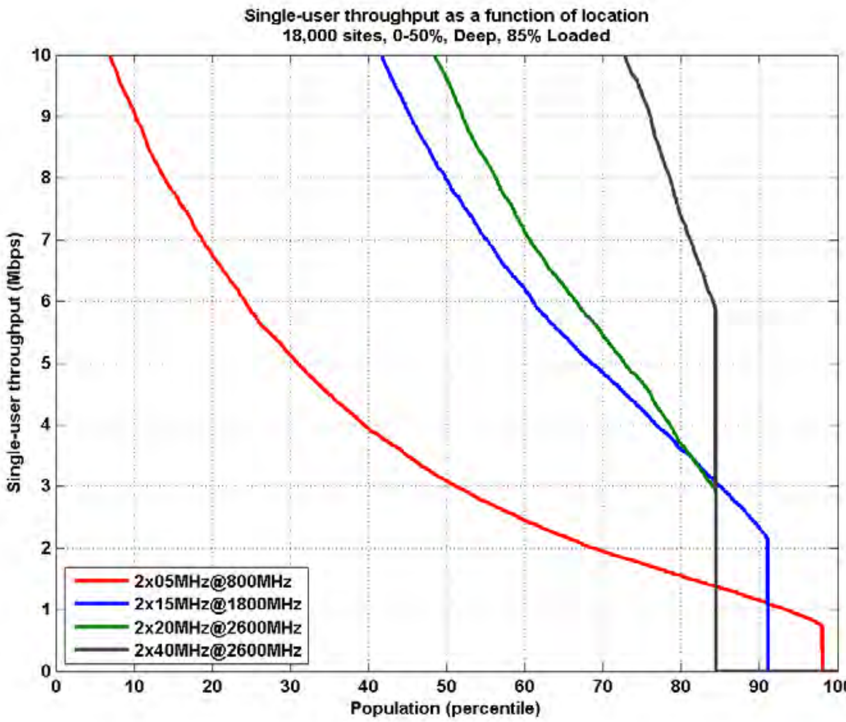


Figure A7.54: Single-user throughput, 18,000 sites, 50-80% area, shallow

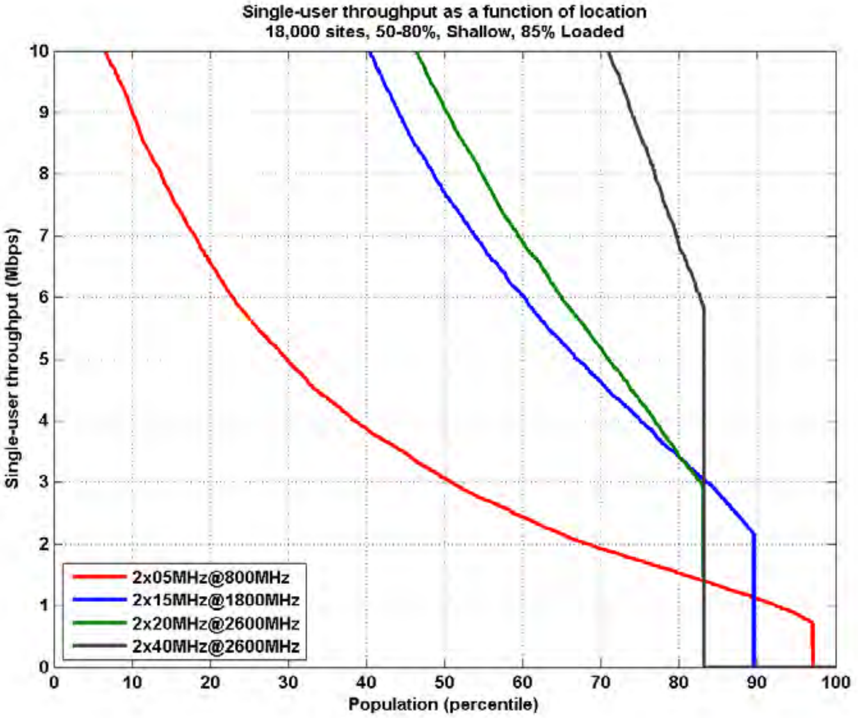
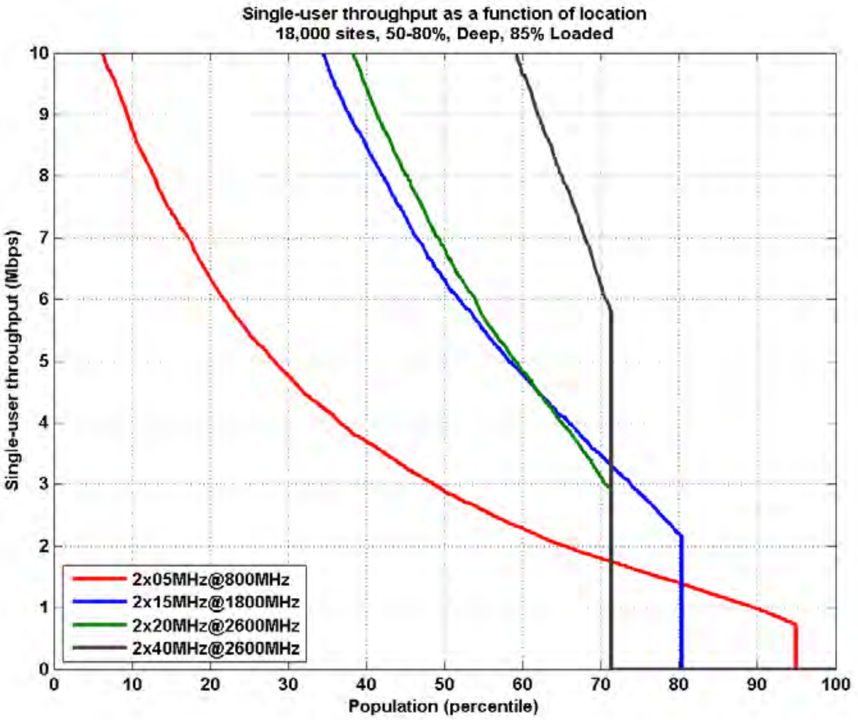


Figure A7.55: Single-user throughput, 18,000 sites, 50-80% area, deep



A7.145 Figure A7.52 to Figure A7.55 show that the model predicts the 1800 MHz spectrum in the first portfolio can provide additional capacity for a small proportion of users but is comparable in capacity terms to 2x20MHz of 2600 MHz. 2x40 MHz of 2600 MHz gives greater capacity.

Annex 8

LTE Technical Modelling Revised Methodology

Summary

A8.1 This Annex describes how we have modelled the downlink performance of LTE macrocell networks using paired spectrum for the purposes of our competition analysis. The main results from this model are presented in Annex 7. In addition to this summary, the annex comprises the following sections:

- *Modelling approach*, which describes the technical model we have used for generating the results reported in this consultation document;
- *Approach for modelling building penetration loss,* which sets out how we have derived our assumptions used to model in-building coverage;
- *Presentation of results,* which sets out how we present results;
- *Variability in our modelling,* which provides details of the various sources of variability and uncertainty we have considered in our modelling and how we have chosen to include these in our results;
- *Parameters and assumptions*, which tabulates our parameter choices and assumptions

A8.2 We are particularly concerned with comparing the performance achieved by networks using different portfolios of spectrum with a range of frequency bands and bandwidths. As such our technical model has been developed and parameters selected with this in mind.

A8.3 The technical model has been developed using the MATLAB numerical computing language. It is essentially the same as the model published alongside the January 2012 consultation. Following a detailed review of responses to the January 2012 consultation and further internal analysis, a number of the parameters and assumptions have been changed.

A8.4 The heart of the model is the generation of signal to interference plus noise ratio (SINR) and single-user throughput distributions for one or more simulation areas. A high level description of the model is as follows:

i) A synthetic base station network of a particular size (number of sites) is established covering the chosen simulation area plus a buffer zone 10 km deep surrounding the simulation area. The base station network is constructed, as far as is possible, to have similar characteristics (in terms of site density vs. population density, antenna heights, etc.) as current or potential future mobile macrocell networks.

ii) A SINR distribution is calculated for a hypothetical test terminal (which we refer to as a UE, or user equipment, in line with 3GPP) positioned at the geographic location of a randomly selected sample[23] of postcode units[24] within the simulation area. SINR is calculated taking into account signals from up to a maximum of the 20 closest base station sites within 10 km of each sample postcode unit.

iii) Using the SINR distribution generated in step ii) above together with an appropriate SINR to throughput mapping function, and taking into account system overheads, the average downlink single-user throughput distribution for the sample of postcode unit locations is established.

iv) Steps i), ii) and iii) above are repeated to establish SINR and single-user throughput distributions for a range of base station network sizes, network loadings, carrier bandwidths and building penetration depths for the frequencies under consideration (800 MHz, 1800 MHz and 2600 MHz).

v) From the single-user throughput distribution within the chosen simulation area, three metrics of performance are calculated:

- *Coverage* – the percentage of the residential population (i.e. when at home)[25] within the simulation area to which it is technically possible to deliver a downlink service capable of providing basic connectivity[26] (if 85% of the resource blocks of the serving cell, including system overheads, were dedicated to a single customer[27]), as a function of the number of network sites and the loading on the wider network.

- *Speed* – for a network with a given number of sites and loading, the downlink data-rate (if 85% of the resource blocks of the serving cell, including system overheads, were dedicated to a single customer) attained or exceeded by a particular percentage of residential population within the simulation area.

- *Capacity* – for a network with a given number of sites and loading, the percentage of the residential population within the simulation area that can be simultaneously served with a given downlink speed and number of sites.

A8.5 As with all technical modelling, decisions have to be made about the details of the methodology adopted and the value of every technical parameter used. In this statement we have formed our best judgement with respect to all aspects of the model and parameters. We accept that there will be considerable uncertainty around many of the parameter values and assumptions.

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[23] We have used 10,000 sample points in our analysis

[24] A postcode unit is a sub-area of a postcode sector as extracted from Code-Point® data.

[25] Each postcode unit has associated with it a number of domestic delivery points: each delivery point will generally correspond to one residential address. The residential population at each location is obtained by multiplying the number of domestic delivery addresses at each postcode unit by a weighting factor derived from the population of the census output area (from the 2001 Census) within which the postcode unit location falls

[26] See paragraph A7.45 in Annex 7 for a description of what we interpret basic connectivity to mean. Due to the influence of the SINR cut-off this is essentially the point at which single-user throughput falls to zero.

[27] 85% is considered, for the purposes of this analysis, to be a practical upper bound to loading on average

A8.6 In order to address uncertainty in certain parameters and aspects of the methodology we have performed a sensitivity analysis for a limited range of scenarios.

Modelling Approach

A8.7 This section describes the Monte Carlo modelling approach we have adopted to analyse and compare the downlink performance of LTE macrocell networks operating in the 800 MHz, 1800 MHz and 2600 MHz bands.

A8.8 In the text below the following definitions apply:

- base station network: a network of base stations being simulated, each base station being characterised by its location and the height of its antenna array above ground level;
- site: a base station site consisting of three antenna sectors with each sector pointing in azimuth directions 0, 120 and -120 degrees relative to North;
- serving site: the site, one of whose sectors is assumed to be providing a data service to the UE during each Monte Carlo simulation snapshot;
- sector: one of the three antenna sectors of any site in the base station array (sectors are often referred to as cells). Any reference to a cell in the text below can be assumed to have the same meaning as a reference to a sector;
- serving sector: the sector (or cell) of the serving site that is assumed to be providing a data service to the UE during a simulation snapshot;
- non-serving sector: a sector of any site in the base station network that is not the serving sector.
- network loading: the fraction of the total number of resource blocks utilised for both data and overheads. The serving cell may have a different loading to cells of the wider network. Note that, throughout this statement, network loading (or loading) is always with reference to the wider network unless explicitly stated otherwise.

A8.9 The main parameters and assumptions used to generate the key results in this statement are as follows:

- base station network distributions (locations and antenna heights) representative of existing national wholesaler's macro networks
- base stations are assumed to be 3-sectored macro sites
- base station antenna patterns are based on theoretical equations from 3GPP TR 36.814[28] with each of the horizontal and vertical 3dB beam-widths the same for all frequencies, and downtilt values optimised according to the distance to nearby sites

[28] 3GPP TR 36.814 V9.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects", March 2010: http://www.3gpp.org/ftp/specs/html-INFO/36814.htm

- 2x2 MIMO is assumed
- loading of the serving cell: 85%
- loading of cells in the wider network: 50% to 85% (85% for the majority of results)
- clutter type for each UK postcode unit location (i.e. UE location) extracted from the Infoterra 50m × 50m clutter database
- building penetration depth: shallow in-building, deep in-building

A8.10 The overall approach is unchanged from that used in the January 2012 consultation, with the exception of the building penetration depth assumptions, an adjustment to the propagation model for 2.6GHz, and the inclusion of new simulation areas. These revisions are outlined in detailed below.

Simulation Areas

A8.11 Underlying all the results presented in this statement are SINR distributions generated across 3 specific simulation areas based on population density as follows:

i) the zero to 50% most densely populated area;

ii) the 50% to 80% most densely populated area; and

iii) the 80% to 90% most densely populated area

A8.12 As set out in Annex 10, a number of respondents to the January 2012 consultation were concerned that the simulation areas used in the analysis were not representative of the wider population, and did not consider coverage to a range of different geo-types. In response to this feedback, and to gain a better view of coverage and capacity across the population as a whole, we adopted a set of three areas which consider different population density percentiles as listed above. The majority of results in Annex 7 are for these areas. We have also included a limited set of results which consider the 'West London' area (a 100km square area to the west of London), as used in the January 2012 consultation, for the purposes of direct comparison of parameter changes for the results in the revised analysis presented in this document.

A8.13 The new simulation areas are derived by ranking the population of the UK into a set of regions which can be ranked according to population density. They need to be of a suitable size in order to generate distinct regions of an appropriate size for considering mobile coverage. Local Authority district boundaries have been found to give a reasonable size of output area on this basis[29].

A8.14 We have not modelled the 90% to 100% area (i.e. the least densely populated regions) because, whilst important, differences in the performance of LTE networks

[29] Local Authority data for Northern Ireland was not available for the purposes of this exercise. Thus Northern Ireland is not included in the modelling, with the total population adjusted accordingly. It is reasonable to assume that Northern Ireland follows a similar population distribution to other areas in the UK and therefore would not significantly alter the results.

operating at different frequencies and providing service in this area are unlikely to affect competition.

A8.15 The full process for deriving each area is as follows:

i) The total population[30] in each Local Authority district region is summed and divided by the area of the district to obtain the population density.

ii) Districts are ranked according from highest to lowest population density, and the cumulative percentage of population is calculated.

iii) Districts corresponding to the following population percentile ranges are extracted from this cumulative sum:

a. 0-50%

b. 50-80%

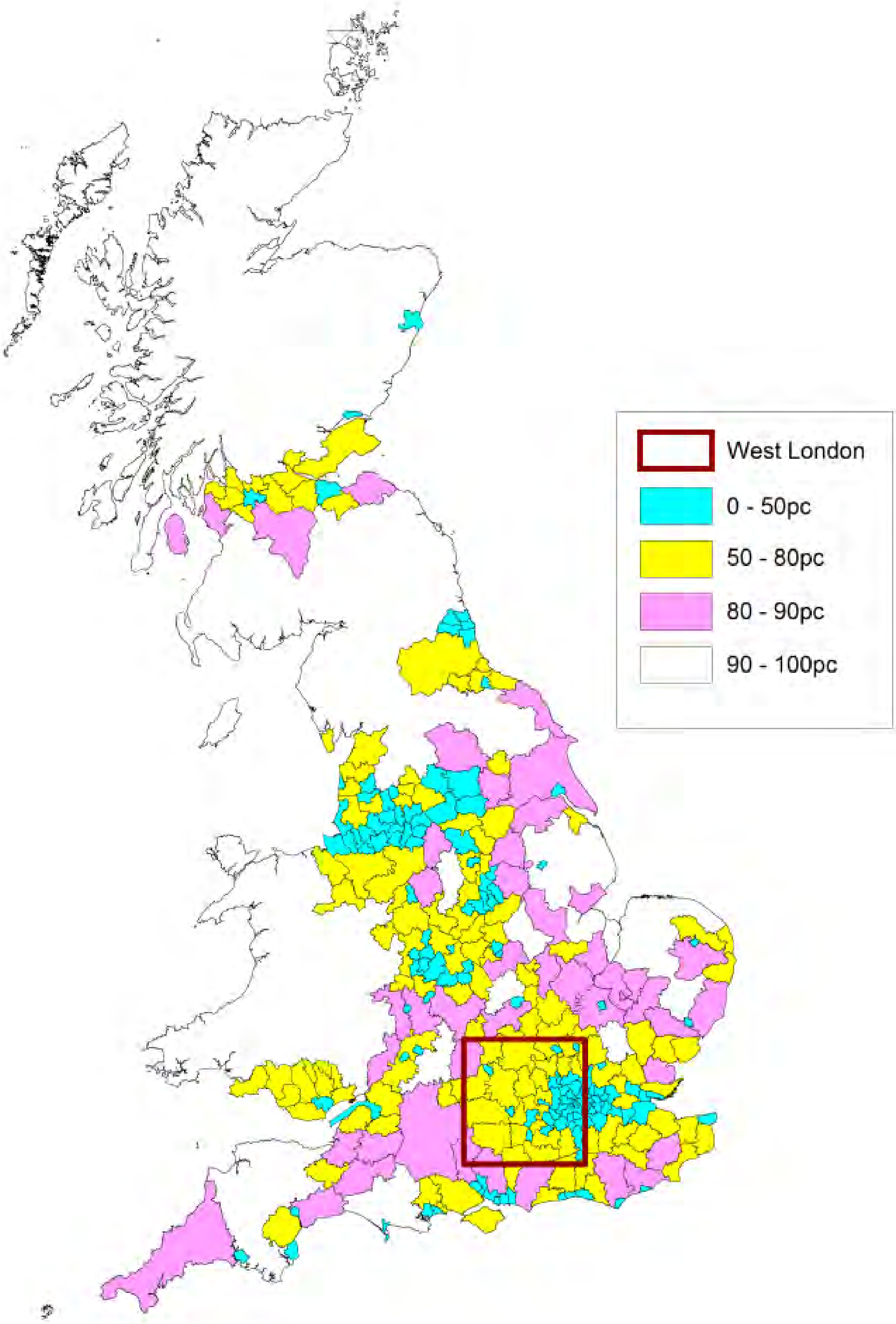
c. 80-90%

iv) A randomly selected set of 200,000 postcode delivery points from the Code-Point® database is extracted from each area for use in the analysis (this does not apply to the 80-90% area which only contains a total of ~180,000 points, which are all included in the analysis). As noted in footnote 23, we have used 10,000 sample points in our analysis, these points are sub-sampled from the set of postcode delivery points described here.

A8.16 The three simulation areas and the West London area used in the previous analysis are highlighted in the map in Figure A8.56 below:

[30] Population is considered at a postcode level, using the Code-Point® database in conjunction with the 2001 Census. This is consistent with the dataset used elsewhere in the analysis.

Figure A8.56: Simulation areas



A8.17 Table A8.10 below gives a breakdown of the population, the number of households and the average population per household for each of the three simulation areas (excluding West London).

Table A8.10: Population and household statistics

Area	HHs	Total	Pop per

		Population	HH
0-50%	11,992,771	28,588,215	2.38
50-80%	7,100,905	17,162,838	2.42
80-90%	2,355,925	5,648,553	2.40
National	24,485,625	58,791,867	2.40

A8.18 Table A8.11 gives the breakdown of the simulation areas in terms of population per clutter type and compares this with the corresponding breakdown for each of the nations (England, Wales, Scotland and Northern Ireland) and to the UK as a whole.

Table A8.11: Population by clutter type in each simulation area

	Dense urban	Urban	Suburban	Rural
West London	54,731	736,781	6,796,476	854,880
0-50%	187,092	1,864,007	24,254,503	2,284,306
50-80%	13,968	442,869	13,892,081	2,812,639
80-90%	3,828	131,327	4,125,524	1,387,949
England	155,390	2,019,711	40,183,836	6,755,127
Scotland	45,477	435,146	3,539,654	876,772
Wales	715	111,277	2,181,829	606,691
Northern Ireland	1,014	20,708	1,106,066	555,047
UK	206,290	2,616,588	47,146,166	8,822,605

A8.19 Table A8.12 gives a similar breakdown but this time the population in each clutter type is given as a percentage of the total population within the relevant area.

Table A8.12 : Population percentage per clutter type in each simulation area

	Dense urban	Urban	Suburban	Rural
West London	0.65%	8.73%	80.50%	10.13%
0-50%	0.65%	6.52%	84.84%	7.99%
50-80%	0.08%	2.58%	80.95%	16.39%
80-90%	0.07%	2.32%	73.04%	24.57%
England	0.32%	4.11%	81.82%	13.75%
Scotland	0.93%	8.89%	72.28%	17.90%
Wales	0.02%	3.84%	75.22%	20.92%
Northern Ireland	0.06%	1.23%	65.73%	32.98%
UK	0.35%	4.45%	80.19%	15.01%

A8.20 The breakdown shows that suburban clutter dominates the breakdown of population in all simulation areas, which is consistent with the trend in each Nation and in the

UK as a whole. As would be expected, the proportion of population in urban and suburban decreases when moving to less densely populated areas.

A8.21 The 0-50% and West London areas show a similar proportion of population in each clutter type.

Synthetic Networks

A8.22 A number of synthetic networks were generated from a 'real' seed macrocell network[31]. This seed network had a national site count of approximately 9,000 macro sites with site parameters based on an existing macro cell network[32]. The synthetic networks generated have been scaled to represent national networks with site counts of 4,000, 8,000, 12,000 and 18,000. A detailed description of the process used to create these synthetic networks follows:

i) Sites from a seed network (having similar characteristics in terms of site density, antenna heights etc. as current mobile networks) were selected within the selected simulation area and buffer zone.

   a. The seed network was scaled up to create a 20,000 site national network. The scaling up process was as follows:

   b. All the sites in the UK were connected to their nearest neighbours using a Delaunay triangulation such that a closed polygon consisting of unique triangles was formed.

   c. The triangle containing the highest number of delivery addresses (associated with postcode unit locations in Code-Point® data) was selected and, a new artificial site was placed at its geometric centroid. The new site was given an antenna height (for each of its three sectors) which was the mean of the antenna heights of the three sites forming the triangle.

ii) Steps b. and c. were repeated, each time picking the triangle containing the next highest number of delivery points until sufficient sites were added to form a 20,000 site network.

A8.23 To generate the full set of synthetic networks, the 20,000 site network was sub-sampled by removing sites one by one at random until the target number of sites (representing equivalent national site counts of 4,000, 8,000, 12,000 and 18,000 sites) in the simulation area plus buffer zone was reached. The synthetic networks were created only once and were used for every modelling run at all frequencies.

A8.24 It should be noted that our algorithm is designed to maintain the same relative proportion of sites to population density as the seed network as we feel that this is a reasonable approach to take for the purposes of assessing the difference in performance between networks operating at different frequencies. However, we have had to make a number of compromises with the choice of algorithm. It is not specifically designed to lead to optimal coverage for any particular network size. It does not account for practical difficulties that operators might have in finding sites. It does not attempt maintain the same relative coverage of road and rail networks that an operator might also deem important when rolling out a network.

[31] The seed network was taken from an existing mobile operator's macrocell data.
[32] Data for significantly larger networks was not available to us

A8.25 The number of sites from each network which lie within each simulation area are provided in the following table:

Table A8.13: Number of sites in each area, by synthetic network size

	Synthetic network size			
Simulation area	**4,000**	**8,000**	**12,000**	**18,000**
West London	575	1,138	1,777	2,603
0-50%	1,589	3,214	4,820	7,181
50-80%	1,226	2,420	3,655	5,473
80-90%	436	895	1,359	2,094

A8.26 The method used to generate synthetic networks is unchanged from our January 2012 consultation.

A8.27 It should also be noted that the profile of sites within each of the simulation areas in Table A8.13 is unlikely to match closely the roll-out profile of a new entrant operator starting from scratch. For instance, comparing the coverage achieved by H3G as their 2100 MHz 3G site base grew over a number of years from 2003 onwards would not be a fair comparison as they would have been interested in providing a balance of both coverage and capacity in order to optimise investment costs with generating revenue.

SINR Distribution Model

A8.28 We use a Monte Carlo method to generate a set of SINR distributions for each combination of frequency, in-building depth, network size, network loading, BPL case and simulation area considered.

A8.29 An overview of the steps involved in each simulation run to generate an SINR distribution is as follows:

i) Establish a set of 10,000 sample locations within the simulation area. These are taken from a random sample of Code-Point® postcode unit locations within the simulation area, with clutter for each postcode unit location taken from the Infoterra clutter database with 50 metre resolution[33].

ii) Using simple geometry, calculate the median outdoor path loss at each sample location from each of the three sectors of the 20 closest surrounding base stations (including base stations from the buffer zone) using the Extended Hata propagation model[34] (as outlined in paragraphs A8.35 to A8.40 below) accounting for horizontal and vertical base station antenna patterns, antenna heights and the clutter at the sample location. Any base stations further than 10km from the sample location are omitted.

[33] The same set of random locations is used for each and every SINR distribution generated in the same sample area. Analysis has shown that using a different randomly selected set of points produces equivalent results.

[34] For frequencies above 2 GHz we use a modified version of Extended Hata. This is explained in detail in paragraphs A8.35 to A8.40.

iii) Determine the mean building penetration loss (BPL) for the particular in-building depth under consideration (the mean BPL at the sample location is assumed to be the same for transmissions from all surrounding base stations).

iv) For each sample location, generate a set of shadow fading values for each of the 20 closest surrounding base stations (assuming 50% shadow fading correlation). Shadow fading is assumed to have a log normal distribution with a zero mean and characteristic standard deviation σ_S.

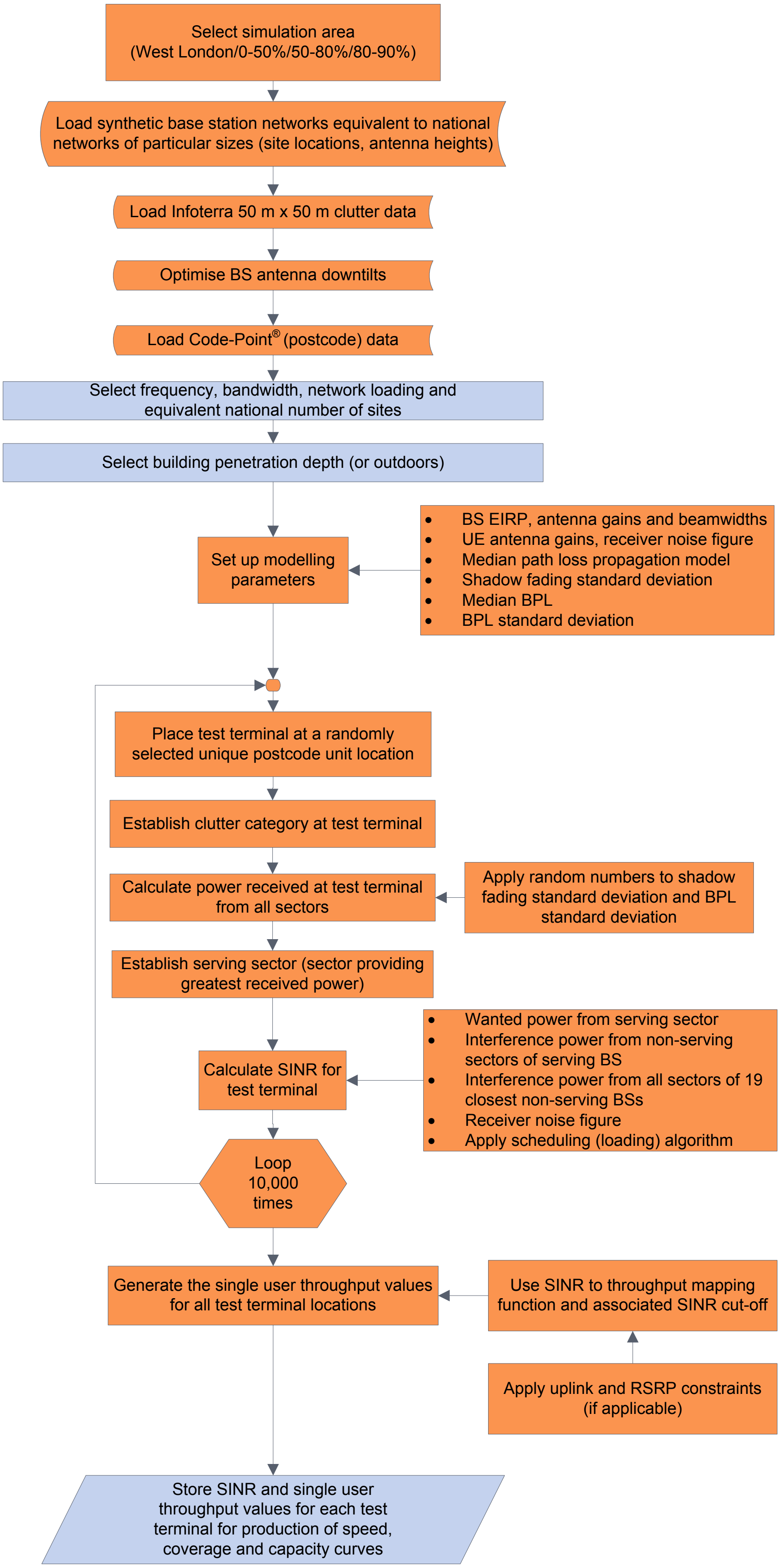
v) For each sample location, generate a set of BPL variability values for each of the 20 closest surrounding base stations (assuming 50% correlation). BPL variability is assumed to have a log normal distribution with a zero mean and characteristic standard deviation σ_{BPL}.

vi) Combine the mean BPL and median outdoor path loss figures together with the shadow fading and BPL variability figures to derive an overall path loss to each sample location from each of the three sectors of the 20 closest surrounding base stations.

vii) From the above, find the sector that provides the greatest received power at the sample location and designate this as the serving sector.

A8.30 The SINR at the sample location for a single resource block is calculated from the wanted power of the serving sector, the interference power from all of the other sectors of the 20 closest surrounding base stations and the UE receiver noise. This calculation assumes that the resource blocks from the serving sector transmit at 47dBm EIRP per resource block (i.e. the maximum allowed by our proposed technical licence conditions). Interference power from non-serving sectors is taken into account by weighting the calculated interference power by the probability that the interference is received during the same time period and at the same frequency as the wanted power from the serving sector. The probability is dependent upon the network loading and scheduling algorithm used for the allocation of resource blocks. This is illustrated in the flow chart below (Figure A8.57).

Figure A8.57: Model flow chart



A8.31 The overall approach remains unchanged from the January 2012 consultation; however individual parameters and assumptions have been revised, as noted in the following sections.

A8.32 A detailed description of individual steps in the generation of the SINR distributions is given in the following sections.

Sample locations

A8.33 For each sample location (Code-Point® postcode unit location) within the simulation area:

- its clutter category (Dense Urban, Urban, Suburban or Rural) is established from the Infoterra clutter database with 50 metre resolution;

- a set of 21 random variables is generated. These values are drawn from the normal distribution with a zero mean and standard deviation σ_S. The first value in the set represents the local shadow fading component for the sample location and the next 20 represent the shadow fading component for the 20 base station sites closest to that location; and

- a further set of 21 random variables is also generated. These values are similarly drawn from the normal distribution with a zero mean and standard deviation σ_{BPL}. The first value in the set represents the local building penetration loss variability component for the sample location and the next 20 represent the building penetration loss variability component for the 20 base station sites closest to that location.

A8.34 This approach remains unchanged from the January 2012 consultation.

Propagation model

A8.35 In the January 2012 consultation, we used the Extended Hata propagation model to calculate the path loss from the base station to the UE, as described in CEPT's SEAMCAT documentation[35].

A8.36 Vodafone, in their response to the January 2012 consultation, raised the issue of an error in this implementation of the model, which resulted in an overestimate of the path loss at 2.6 GHz (implying an underestimate in coverage/throughput at this frequency).

A8.37 This was found to be due to an error in an earlier version of the SEAMCAT documentation (version 1), which was used as the basis for the implementation contained in our original analysis published in March 2011. A revised version (version 2) includes a correction to one of the terms for frequencies from 2 - 3 GHz. In the January 2012 consultation we incorrectly stated version 2 as the reference, when in fact version 1 was the implementation used in the model.

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[35] ERC Report 68, "Monte-Carlo Radio Simulation Methodology for the use in sharing and compatibility studies between different radio services or systems":
http://www.erodocdb.dk/Docs/doc98/official/pdf/REP068.PDF
and "SEAMCAT implementation of Extended Hata and Extended Hata SRD models":
http://tractool.seamcat.org/raw-attachment/wiki/Manual/PropagationModels/ExtendedHata/Hata-and-Hata-SRD-implementation_v2.pdf

A8.38 Further analysis carried out on our behalf by Real Wireless[36] of both versions has shown that neither provides a particularly good fit to published measurement data for frequencies above about 2 GHz. We have therefore adapted our 2.6 GHz propagation modelling algorithm to align it better with the published measurement data which shows a range of propagation path loss differences between 1800 MHz and 2.6 GHz with a central value of approximately 4dB. The amended equation[37] is as follows:

$$L_{urban} = 46.3 + 33.9\log_{10}(2000) + 25\log_{10}(f/2000) + \beta - a - b \qquad (1)$$

A8.39 It should be noted that this equation is a single part of the wider model. The rest of the model is unchanged from the SEAMCAT documentation (see footnote 35).

A8.40 Full details of our response to comments raised by Vodafone in connection with this issue are outlined in Annex 10.

Shadow fading

A8.41 The shadow fading standard deviation σ_S (in decibels) is derived from equation 32 in Annex 5 of Recommendation ITU-R P.1546-4[38]:

$$\sigma_S = K + 1.3 \cdot \log_{10}(f) \qquad (2)$$

where we have adopted a value of $K = 4.2$dB for Dense Urban and Urban clutter and $K = 3.5$dB otherwise. Frequency (f), is in MHz.

A8.42 The choise of K factors is based on maintaining the shadow fading value for 800 MHz that we had in the March 2011 consultation where we were using a different formula based on an empirical relationship fitted to curves from Okumura[39].

A8.43 This remains unchanged from our January 2012 consultation.

Building penetration loss

A8.44 The assumed values for mean[40] building penetration loss and standard deviation are outlined in the following tables:

Table A8.14: Mean BPL values

Frequency (MHz)	Mean BPL, L_{BPL} (dB)	
	Shallow	Deep
800	10.5	16.5

[36] Real Wireless, Annex D of their technical analysis in support of the 800 MHz and 2.6GHz award published with this statement.

[37] The original version of this equation can be found in the table in section 1.3 of the SEAMCAT documentation (see previous footnote)

[38] ITU-R Recommendation P.1546-4, “Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3,000 MHz”, Oct 2009: http://www.itu.int/rec/R-REC-P.1546/en

[39] Y. Okumura, E. Ohmori, T. Kawano, K. Fukuda, “Field strength and its variability in VHF and UHF land mobile service”, Review of the Electrical Communications Laboratories, 16, 8250873, 1968.

[40] The variability of building penetration loss is assumed to follow a log-normal distribution, thus mean and median are equivalent, and these terms are used interchangeably in this document

900	11.0	17.0
1800	13.7	19.7
2100	14.3	20.3
2600	15.1	21.1

Table A8.15: Standard deviation of BPL values

Frequency (MHz)	σ_{BPL} (dB)
800	6.8
900	6.9
1800	7.2
2100	7.2
2600	7.3

A8.45 The BPL values and underlying modelling approach have been revised in order to take account of feedback from respondents to the January 2012 consultation.

A8.46 The full derivation of these assumptions is outlined in a later section in paragraphs A8.103 to A8.136.

Geometry and antenna patterns

A8.47 For each simulation snapshot a UE is placed at a sample location (Code-Point® postcode unit location) within the simulation area.

A8.48 Simple geometry is used to calculate the distances and angles between each transmitter of each sector of the closest 20 base station sites and the UE location.

A8.49 Using the angle information, the relative gain of every antenna in the direction of the UE location is calculated by combining the azimuth and elevation radiation patterns of each antenna. The theoretical radiation patterns (in decibels) are obtained from equations (3) and (4) below which are taken from 3GPP TR 36.814[41]:

Azimuth pattern:
$$A_{\mathrm{H}}(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3\mathrm{dB}}}\right)^2, \mathrm{A_m}\right] \quad (3)$$

Elevation pattern:
$$A_{\mathrm{V}}(\theta) = -\min\left[12\left(\frac{\theta - \theta_{\mathrm{tilt}}}{\theta_{3\mathrm{dB}}}\right)^2, \mathrm{SLA_v}\right] \quad (4)$$

A8.50 The values of $\varphi_{3\mathrm{dB}}$ and $\theta_{3\mathrm{dB}}$ are 65° and 7.5°, respectively for all frequencies; θ_{tilt} is the down-tilt; $\mathrm{A_m} = 25\mathrm{dB}$; and $\mathrm{SLA_v} = 20\mathrm{dB}$.

A8.51 Down-tilt is optimised in response to variation of two parameters, u and v, used in calculations of down-tilt:

$$\theta_{\mathrm{tilt}} = \tan^{-1}(h_{\mathrm{BS}}/(\mathrm{u} * ISD_{\mathrm{m}})) + \mathrm{v} * \theta_{3\mathrm{dB}} \quad (5)$$

[41] 3GPP TR 36.814 V9.0.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects", March 2010: http://www.3gpp.org/ftp/specs/html-INFO/36814.htm

A8.52 Where h_{BS} is the antenna height of the particular base station and ISD_{m} is the mean distance between the base station under consideration and the next six closest base stations. The value of v was established by trial and error with a value of 2.5 found to be reasonably optimal for all sites of all synthetic networks considered. The best value of u for all sites of each synthetic network is found by iterating over a small number of trial values (with u ranging from 0.2 to 2). From these trials the best value of u is considered to be the one that maximises the average of the throughputs for the three frequencies 800 MHz, 1800 MHz and 2600 MHz for the particular synthetic network being considered.

A8.53 In the January 2012 consultation, simulation results were found to be relatively insensitive to down-tilt, and though not perfectly optimal for all combinations of network size and frequency band under consideration, equation (5) was found to provide a reasonable compromise for the calculation of down-tilts across the simulation areas. We believe it is reasonable to assume that this is also the case for the new simulation areas used in this document, though we have not revisited the full analysis.

Determination of serving sector

A8.54 Shadow fading and building penetration loss values for each base station site at the UE location are calculated using relevant random variables generated for the postcode unit location (as described in paragraph A8.33), assuming shadow fading and building penetration cross correlation coefficients of 0.5 used according to the method outlined in section 3.2.4 of IEEE 802.16m-08/004r5[42].

A8.55 The coupling loss to the UE location from each sector of the closest 20 base station sites is calculated accounting for path-loss using the Extended Hata model[43] (the dense urban path loss being set to the urban path loss + 3dB), relative antenna gain in the direction of the UE, shadow fading and building penetration loss. Note that for the calculation of the rural path loss we use the ‘Open’ Extended Hata loss.

A8.56 The sector that provides the greatest receive power at the UE location is designated as the ‘serving’ sector and its site is designated as the ‘serving’ site.

Serving cell power at UE locations

A8.57 The wanted power (P_{wanted}) at the UE location is calculated from the power received (radiated power multiplied by coupling loss) from the ‘serving’ sector. In calculating P_{wanted}, shadow fading and building penetration losses are accounted for as in paragraph A8.33

Calculation of other cell interference power

A8.58 The other-cell interference power (P_{other}) at the UE location is calculated from the sum of the interference power received (radiated power multiplied by coupling loss) from each sector of the closest 20 base station sites (including from non-serving sectors of the ‘serving’ site but excluding the ‘serving’ sector). In calculating other-cell interference, shadow fading and building penetration losses from sites other

[42] R. Srinivasan et. al, “IEEE 802.16m Evaluation Methodology Document (EMD)”, IEEE 802.16m-08/004r5, Jan 2009, section 3.2.4: http://ieee802.org/16/tgm/core.html

[43] Revised for 2.6GHz as described in paragraphs A8.35 to A8.38

than the ‘serving’ site are assumed to be cross-correlated with a coefficient of 0.5 (A8.33). Shadow fading and building penetration losses for different sectors of the ‘serving’ site are assumed to be fully correlated, consistent with the method described in footnote 42.

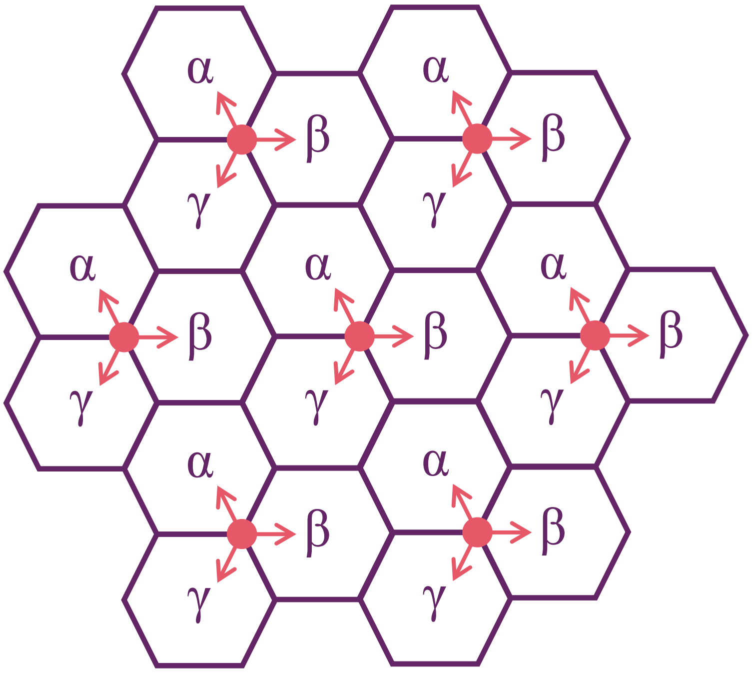
A8.59 Network or system loading is accounted for, when calculating P_{other}, by multiplying the interference power from each sector by an interference probability. The interference probability is calculated using intelligent scheduling where the resource blocks in each sector of the serving cell are allocated on a basis that accounts for the scheduling of the corresponding resource blocks on other sectors of the serving cell in order to minimise inter cell interference, as explained in the following section. A transmitter will only cause interference to a receiver if it is operating on the same resource blocks as the wanted signal. Resource blocks occupy discrete frequencies and time slots. A frequency re-use pattern of 1x1 is assumed and each resource block may be used only once in any given sector (cell) at a particular time. It is therefore assumed that, in a given cell, users will be on *orthogonal* channels and there will be no intra-cell interference.

Scheduling algorithm

A8.60 We do not have detailed knowledge of the scheduling algorithms that operators will use, as these are likely to be proprietary. We therefore use our own algorithm to approximate the likely effect when calculating the probability that the interference from a non-serving sector is on the same resource block as the wanted signal. We refer to this as the “interference probability” and multiply the interference power from non-serving sectors by this factor when calculating the SINR.

A8.61 The scheduling algorithm we use assumes that resource blocks are allocated in an *intelligent* way. By intelligent scheduling we mean that the radio resource algorithm is assumed to allocate resource blocks in a manner that minimises interference between sectors of the same site (i.e. where possible the site seeks to avoid allocating the same resource block in more than one sector). Between sites it is assumed that there is no explicit coordination, and that sites allocate their resource blocks in the same fashion as each other (i.e. all sectors with the same azimuth orientation schedule resource blocks in exactly the same way). This is achieved by the placing the sectors into three sets (referred to here as types α, β and γ), with each sector type preferentially using a primary sub-group of resource blocks. Figure A8.58 illustrates this arrangement.

Figure A8.58: Illustration of sector arrangement in intelligent loading

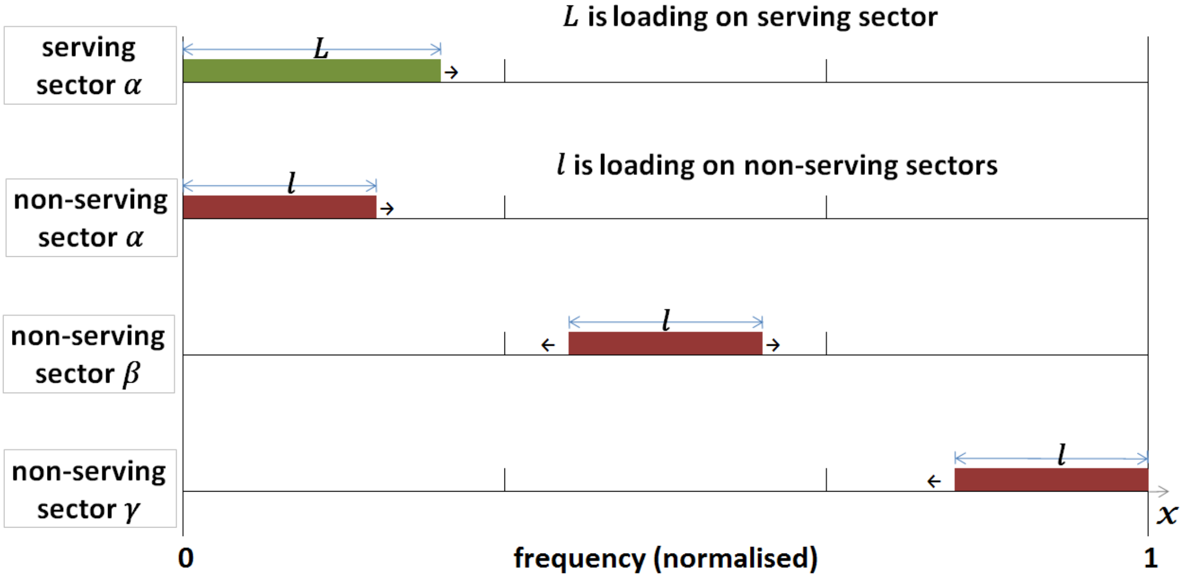


.

A8.62 As loading increases, corresponding sectors allocate resource blocks from the same primary *sub-group* first before moving on to allocate resource blocks from the other sectors' primary sub-groups. This means that, if each sector is loaded to no more than 1/3 (i.e. uses no more than 1/3 of the total available resource blocks), interference between sectors of the same site is eliminated. It also means that, if each sector (including the serving sector) is loaded to no more than 1/3, the serving sector will only experience interference from 1/3 of the sectors from the rest of the network (those assigned the same primary sub-group of resource blocks).

A8.63 The intelligent algorithm adopted here is not intended to represent any particular algorithm that might be implemented in real LTE networks. Rather it is an abstraction designed to illustrate the impact that such algorithms can have on network performance. It is designed to minimise interference from those sectors that are not in the same set as the serving sector. Accordingly, sectors with the same azimuth preferentially use resource blocks from the same primary sub-group and each sector is loaded in the manner shown in Figure A8.59, where we illustrate the case in which the serving sector is a sector of set α and the other non-serving sectors are in sets α, β and γ.

Figure A8.59: Intelligent scheduling of sectors



A8.64 For the purposes of this illustration (Figure A8.59) the bandwidth is normalised to unity, meaning that the frequency (denoted x) lies between 0 and 1, and the sectors α, β and γ are arranged relative to frequency as shown in the diagram.

A8.65 In our modelling we have assumed that the serving sector is in set α and the other (non-serving) sectors are in sets α, β and γ, and the occupancy of spectrum in the band is as illustrated in the diagram. We use the following notation in this description:

- $L = Loading_{own}$ (i.e. loading on serving sector);
- $l = \ Loading_{other}$ (i.e. loading on non-serving sector); and
- $H()$ is the Heaviside (or unit step) function)[44]:

A8.66 Based on the above assumptions, it can be shown that:

i) Probability that a serving sector resource block in set α is interfered with by a non-serving resource block in set α is:

$$P(\alpha_l|\alpha_L) = [l - (l - L)H(l - L)]/L \tag{6}$$

$$= \min(l, L)/L \tag{7}$$

ii) Probability that a serving sector resource block in set α is interfered with by a non-serving resource block in set β is:

$$P(\beta_l|\alpha_L) = \left[\frac{1}{2}\{(2\mathrm{L} - 1 + l)\mathrm{H}(2\mathrm{L} - 1 + l) - (2\mathrm{L} - 1 - l)\mathrm{H}(2\mathrm{L} - 1 - l)\}\right]/L \tag{8}$$

iii)

[44] For this approximation we have not taken account of individual resource blocks.

$$= \min(\max(L - 0.5 + \frac{l}{2}, 0), l)\ /L \qquad (9)$$

iv) Probability that a serving sector resource block in set α is interfered with by a non- serving resource block in set γ is:

$$P(\gamma_l|\alpha_L) = [(L + l - 1)H(L + l - 1)]/L \qquad (10)$$

$$= \max(L + l - 1, 0)\ /L) \qquad (11)$$

v)

A8.67 The intelligent scheduling algorithm remains unchanged from the January 2012 consultation. However, in our previous analysis we additionally included a random scheduling algorithm for certain scenarios. We no longer consider random scheduling for the reasons discussed in Annex 7 and Annex 10. Further detail on the comparison between random and intelligent loading can be found in Annex 14 of our January 2012 consultation.

Generation of SINR distributions

A8.68 The SINR at the UE location is calculated according to the following equation:

$$SINR = \frac{P_{\text{wanted}}}{P_{\text{other}} + P_{\text{noise}}} \qquad (12)$$

where:

- The wanted power, P_{wanted}, at the UE location is the calculated power (in watts) received per resource block from the serving sector
- The other power, P_{other}, is the total other cell interference power (in watts) received during the same time period and at the same frequency as P_{wanted}.
- The noise power, P_{noise}, is the noise power (in watts) at the UE given by kTB multiplied by the UE noise figure where k is Boltzmann's constant, T is the temperature in kelvin (290 K) and B the bandwidth in hertz (i.e. 180 kHz for one resource block):

$$P_{\text{noise}} = k * T * B * NF \qquad (13)$$

A8.69 The UE noise figure values are derived from 3GPP TS 36.101[45], and are outlined in the following table:

Table A8.16: UE Noise figure values

Frequency (MHz)	NF (dB)
800	10
1800	10
2600	9

[45] 3GPP TS 36.101 V9.12.0. "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception", July 2012: http://www.3gpp.org/ftp/Specs/html-info/36101.htm

A8.70 The steps in paragraph A8.29 are repeated for each test UE location within the simulation area (10,000 sample locations) to build up an SINR distribution which is unique to the particular combination of frequency, base station network size, network loading and building penetration depth chosen for that run of the model.

A8.71 A series of different SINR distributions are generated covering each particular combination of frequency, base station network size, network loading and building penetration depth required.

Throughput calculations

A8.72 For the purposes of this statement we have adopted the same ‘realistic’, function used for the main results in January 2012 (see Annex 14 from the January 2012 consultation). This function is an attenuated and truncated form of the Shannon bound and is taken from 3GPP TR 36.942[46].

A8.73 Our mapping function is expressed (in bit/s/Hz) as follows:

$$Thr_{real} = \begin{cases} 0, & \text{for } SINR < \mathrm{SINR_{min}} \\ \alpha \,.\, \mathrm{S}(SINR), & \text{for } \mathrm{SINR_{min}} < SINR < \mathrm{SINR_{max}} \\ \mathrm{Thr_{max}}, & \text{for } SINR > \mathrm{SINR_{max}} \end{cases} \tag{14}$$

where $S(SINR)$ is the Shannon bound (in bps/Hz) given by:

$$\mathrm{S}(SINR) = \log_2(1 + 10^{SINR/10}) \tag{15}$$

where: α is an attenuation factor, representing implementation losses

- $\mathrm{SINR_{min}}$ is the minimum SINR of the codeset, dB
- $\mathrm{Thr_{max}}$ is the maximum throughput of the codeset, bps/Hz
- $\mathrm{SINR_{max}}$ is the SINR at which max throughput is reached, dB

A8.74 The values of these parameters for a 1x2 LTE downlink, in a typical urban fast fading channel at 10km/h, from 3GPP TR 36.942, are given in Table A8.17 below:

Table A8.17: Parameters from the attenuated and truncated form of the Shannon bound as used in modelling

Parameter	Value	Unit	Notes
α	0.6	-	Represents implementation losses
$\mathrm{SINR_{min}}$	-5	dB	TR 36.942 assumes -10dB, based on QPSK, 1/8 rate. We assume -5dB for the reasons outlined in the following section
$\mathrm{Thr_{max}}$	8.8	bps/Hz	TR 36.942 assumes 4.4bps/Hz, based on 64QAM 4/5 rate for SIMO, which implies 8.8bps/Hz for 2x2 MIMO

[46] 3GPP TR 36.942 V9.3.0 “Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios”, Annex A, Section A.1: http://www.3gpp.org/ftp/Specs/html-info/36942.htm

A8.75 We have benchmarked the performance given by this mapping function against a number of real world results. See, for example, the Rysavy Research and 3G Americas paper[47] which highlights some work by Ericsson[48]. These indicate that the performance given by this function is fairly close to that seen in current implementations of LTE with a 2x2 antenna configuration (even though it is modelled as a 1x2 implementation).

A8.76 We consider that our mapping function is a lower bound to likely LTE performance. Early LTE deployments are likely to have similar performance and it may be some time before performance significantly improves upon that given by this function.

SINR cut-off

A8.77 The mapping function of 3GPP TR 36.942 (as used above) quotes a value of $\mathrm{SINR}_{\mathrm{min}}$ of -10dB. However, the work of 3GPP TR 36.942 pre-dated later 3GPP work on control channel design, and so was an early approximation. Later work[[49]] has concluded that system coverage is limited by the PDCCH, and that the 36 bit payload format (needed to carry DL grants) requires -5.3dB E_S/N_0, a similar figure to that given by Laselva et al[50].

A8.78 The coverage analysis in [[49]] describes how control channel coverage can be extended by power boosting or puncturing, suggesting a 3dB power boost is feasible. Such a boost would mean the PDCCH could have an SINR of -5.3dB whilst wideband SINR could be 3dB lower at -8.3dB, which is the same as that needed to support the most robust channel, the PBCH. Other suggested wideband SINR cut off figures from coverage analyses are -8.3dB [[51]] and -9dB [[52]].

A8.79 Since it is not yet known whether power boosting and puncturing techniques can and will be used in practice, and as there is particular sensitivity of the coverage results to the choice of SINR cut-off, we have made a decision to adopt a value of SINR cut-off of -5dB. A limited set of sensitivity results which assume a value of -10dB will also be presented. This issue is explored further in Annex 7 and Annex 10.

A8.80 In our January 2012 consultation values of both -10dB and -5dB were considered in the main results.

[47] Rysavy Research & 3G Americas, "Transition to 4G, 3GPP Broadband Evolution to IMT-Advanced (4G)", September 2010, Figure 17, p49: http://www.rysavy.com/Articles/2010_09_HSPA_LTE_Advanced.pdf

[48] Jonas Karlsson and Mathias Riback, "Initial field performance measurements of LTE", Ericcson Review No. 3, 2008, pp. 22 – 28: http://www.ericsson.com/ericsson/corpinfo/publications/review/2008_03/files/LTE.pdf

[49] Motorola, "E-UTRA Coverage", 3GPP RAN1#50 document R1-073371,August 2007: http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_50/Docs/

[50] D. Laselva et al, "On the Impact of Realistic Control Channel Constraints on QoS Provisioning in UTRAN LTE", IEEE Vehicular Technology Conference (VTC 2009-Fall), 20 - 23 Sept 2009: http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5378830&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5378830

[51] S. Sesia, I. Toufik, M. Baker, "LTE: The UMTS Long Term Evolution", Wiley 2009, p417

[52] H. Holma & A.Toskala, "LTE for UMTS: Evolution to LTE-Advanced", 2nd Ed, Wiley 2011, p269

Minimum RSRP level

A8.81 A respondent to the January 2012 consultation was concerned that the throughput achieved by a UE was based on a minimum SINR (i.e. a relative level), and did not take into account any absolute levels - specifically the RSRP (reference signal received power). The respondent claimed that a UE would not achieve coverage if the RSRP was below a threshold of -122dBm per 15 kHz subcarrier.

A8.82 Therefore we have included a sensitivity analysis for a limited set of scenarios which show the effect of introducing a minimum RSRP level into the model, for the purposes of comparison with unconstrained results. The main results continue to assume no additional RSRP constraint. It should be noted that a SINR cut-off of -5dB is equivalent to an RSRP constraint of -127dBm/(15 kHz) which is implied by the noise figure of the receiver.

A8.83 For the reasons outlined in Annex 10, a threshold of -124dBm/(15 kHz) is considered for the sensitivity analysis. UEs which do not achieve this power level in the downlink (per resource block) are assumed to have zero throughput.

System overheads

A8.84 Our mapping function does not take account of system overhead. We therefore account for the following overheads when calculating throughput:

- Reference Signals
- Physical Downlink Control Channel (PDCCH)
- Primary and Secondary Synchronisation Channels (PSCH/SSCH)
- Physical Broadcast Channels (PBCH)

A8.85 We have adopted a single figure of 20% to account for the overall effect of overheads in our main results. This remains unchanged from our January 2012 analysis and is consistent with the additional analysis on overhead allocations undertaken by Real Wireless on our behalf[53].

A8.86 A limited additional set of sensitivity results which consider a figure of 30% are also presented in Annex 7, based on feedback from responses to the January 2012 consultation, which are explored in Annex 10.

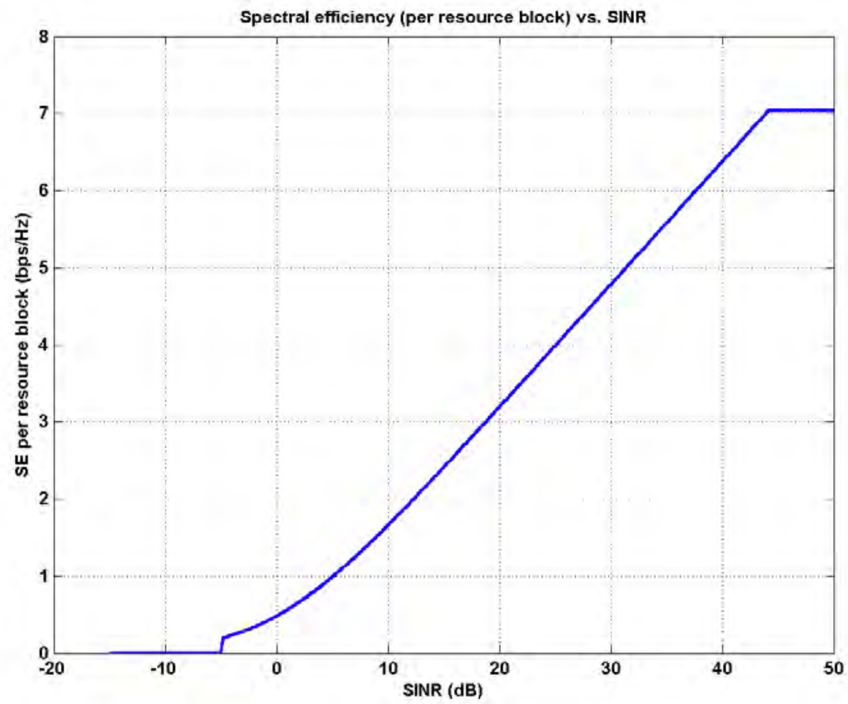
Throughput per resource block

A8.87 The use of the mapping function, combined with a reduction of 20% to account for overheads, gives a net spectral efficiency (bit/s/Hz) vs SINR for the user data in a resource block.

A8.88 The resulting spectral efficiency is plotted in Figure A8.60 below (assuming an SINR cut-off of -5dB and 85% loading).

[53] Real Wireless Annex E: Analysis of Stakeholder Comment Regarding Loading and Overhead assumptions

Figure A8.60: Spectral efficiency used in the modelling



A8.89 For the generation of the single-user throughput (speed) curves, the available user bit rate per resource block is calculated by multiplying the spectral efficiency by 180 kHz (the occupied bandwidth of an LTE resource block).

A8.90 For the generation of the capacity results the data-rate available per resource block is enhanced by including an approximation for the effect of frequency domain packet scheduling, as detailed below.

Frequency domain packet scheduling

A8.91 Frequency domain packet scheduling (FDPS) exploits the fact that an LTE carrier is split into multiple sub-carriers and that these sub-carriers are grouped together in frequency and split by time to form individual physical resource blocks (a 5 MHz carrier has 25 resource blocks whilst a 20 MHz carrier has 100). At any instant in time different users can be allocated a different number of physical resource blocks depending on their instantaneous demand and their signal quality. If the channel quality is significantly different for different physical resource blocks (which is typically the case for macro cellular networks with bandwidths equal or greater than about 5 MHz) then LTE can exploit this by optimally scheduling users on physical resource blocks with the best channel quality at their location. This can lead to a FDPS gain which for pedestrian users can be of the order of 40% for a 10 MHz system bandwidth. To achieve this level of gain however there needs to be multiple users all demanding a service that requires a relatively small proportion of the resources available in the cell at any instant of time. If there are just a few users requiring a large proportion of resources then the gain is reduced.

A8.92 We have included the effect of FDPS in our capacity results. For all other results presented in this consultation FDPS gain is not applied.

A8.93 FDPS gain is applied to the calculated single-user throughput results to account for improved performance from sharing that throughput between multiple users and scheduling those users on groups of resource blocks whose SINR is highest for that user.

A8.94 The calculation is in three steps as follows:

a) Calculate a factor between 1 and 1.4 using the following equation[54]:

$$\gamma = 1.4 - 0.729 \times e^{-0.599U} \tag{16}$$

where U is the number of simultaneous users (for a given guaranteed data-rate service) who could be supported at a particular location if the single-user throughput was shared equally between them.

b) Obtain an additional bandwidth dependent factor (δ)[55]. The value of (δ) for each carrier bandwidth is given in Table A8.18 below:

Table A8.18: FDPS gain bandwidth factors

Bandwidth	5 MHz	10 MHz	15 MHz	20 MHz
δ	0.9643	1.000	1.0179	1.357

c) The single-user throughput per resource block with FDPS applied is calculated according to:

$$TP_{RB\_FDPS} = TP_{RB} * \gamma * \delta \tag{17}$$

where TP_{RB} is the single-user throughput per resource block in the absence of FDPS.

Uplink limitations

A8.95 The main results presented are for downlink performance only, and do not consider if sufficient uplink throughput can be achieved for control and acknowledgement data. A simple link budget analysis assuming a UE transmitting at maximum power (23dBm) over one resource block suggests that the vast majority of cases should not be impaired by uplink limitations. Supplementary information on this issue was published at the end of the January 2012 consultation period[56].

A8.96 A respondent to the January 2012 consultation questioned the assumption that uplink limitations are not relevant, with specific reference to TCP acknowledgements which can require 4% of the available downlink throughput in the uplink for proper operation.

[54] This equation above is an approximate curve fit to the curves shown in H. Holma & A. Toskala, “HSDPA/HSUPA for UMTS”, Wiley 2006, Figure 7.13, -139

[55] The value of δ is derived from H. Holma & A.Toskala, “LTE for UMTS: Evolution to LTE-Advanced“, 2nd Ed, Wiley 2011, Table 10.18; having been normalised to the 10 MHz bandwidth

[56] Ofcom, “800 MHz & 2.6 GHz Combined Award – Additional technical information and simulation results”, Feb 2012, Section 4 - Uplink Limitations: http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/annexes/Additional_technical_inform1.pdf

A8.97 We have additionally conducted a sensitivity analysis which considers uplink limitations for a limited set of scenarios. In this sensitivity analysis, we derive the uplink throughput based on the downlink received power according to the following procedure:

i) The uplink received power is derived from downlink received power using the difference in EIRP (for a single resource block) and antenna gain:

$$P_{Rx\_UL} = P_{Rx\_DL} + (EIRP_{UE} - EIRP_{BS}) + (G_{BS} - G_{UE}) \tag{18}$$

ii) The uplink SINR is then calculated according to:

$$SINR_{UL} = P_{Rx\_UL} - (10\log_{10}(kTB) + NF_{BS} + NR_{UL}) \tag{19}$$

where: BS noise figure: NF_{BS} = 2dB [57]
Uplink noise rise: NR_{UL} = 2dB [58]

A minimum SINR cut-off of -7.5dB is assumed in the uplink.[59]

iii) Uplink throughput per resource block is calculated based on the spectral efficiency:

$$S_{eff} = \min\left(S_{eff\_max}, BW_{eff} * \log_2\left(1 + 10^{(SINR_{UL}/10SINR_{eff})}\right)\right) \tag{20}$$

$$TP_{UL\_RB} = S_{eff} * BW_{RB} * (1 - Overhead) \tag{21}$$

where:

BW_{eff}	=	0.4	(3GPP 36.942)
$SINR_{eff}$	=	1	(3GPP 36.942)
S_{eff_max}	=	2bit/s/Hz	(3GPP 36.942)
$Overhead$	=	0.2	(as assumed in downlink)
BW_{RB}	=	180 kHz	

Steps i) to iii) are repeated for all possible numbers of resource blocks (N_{RB}) up to the maximum (depending on bandwidth and loading). The maximum EIRP is spread over the number of resource blocks in each iteration. The optimum value of N_{RB} which gives the maximum value of throughput is calculated according to:

$$TP_{UL} = TP_{UL\_RB} * N_{RB} \tag{22}$$

The optimum value of N_{RB} may be lower than the maximum due to the spreading of the maximum EIRP over multiple resource blocks – i.e. the throughput will become increasingly noise limited.

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57 H. Holma & A.Toskala, "LTE for UMTS: Evolution to LTE-Advanced", 2nd Ed, Wiley 2011, Table10.8, p267, and supported by confidential data supplied from operators in response to specific information requests.

58 H. Holma & A.Toskala, "LTE for UMTS: Evolution to LTE-Advanced", 2nd Ed, Wiley 2011, Figure 10.14, p277. Derived from Figure 10.14 from for an ISD of 1.5km at 50% probability, and supported by confidential data supplied from operators in response to specific information requests

59 S. Sesia, I. Toufik, M. Baker, "LTE: The UMTS Long Term Evolution", Wiley 2009, p416

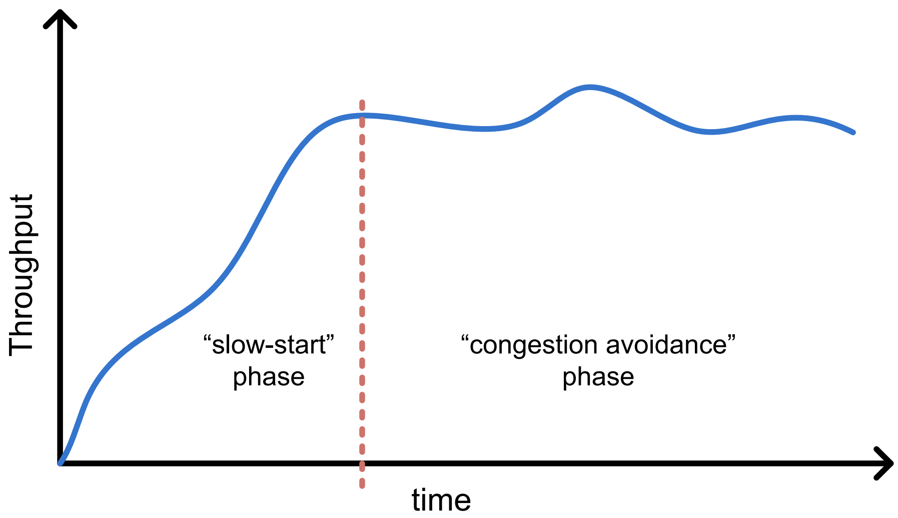
iv) A modified downlink throughput is calculated by considering the maximum possible downlink that meets the 4% uplink constraint (i.e. the downlink speed needs to be at least 25 times the uplink speed):

$$TP_{DL}' = \min\left(25 * TP_{UL}, TP_{DL}\right) \tag{23}$$

where TP_{DL}' is the uplink constrained downlink single user throughout available to the UE.

A8.98 This approach is a simplistic simulation of the “slow-start” and “congestion-avoidance” TCP connection phases[60], where the throughput is gradually increased until TCP acknowledgements can no longer be received. This effect is illustrated below:

Figure A8.61: Illustration of TCP connection phases



A8.99 The above approach considers the case of a single user in the cell. It is reasonable to assume that if one user can’t achieve the maximum due to TCP uplink limitations then there will be additional capacity available to other users in the cell.

A8.100 We therefore consider the case where each user is restricted to 5 MHz in the uplink (i.e. 21 resource blocks when 85% loading is taken into account). While this restricts the downlink available to each user it is possible that the overall available downlink to all users may be restored to the equivalent level as the non-uplink limited case.

A8.101 It should be noted that the outlined approach is a simplistic approximation designed to estimate uplink throughput based on the available downlink throughput. We believe that this is appropriate for the purposes of providing indicative results to determine if uplink is the limiting factor in coverage of LTE, but have not performed a full Monte Carlo analysis to simulate multiple users in the uplink.

A8.102 The approach to uplink limitations is explored further in Annex 10. The results of the sensitivity analysis are presented in Annex 7.

[60] IETF RFC 5681, “TCP Congestion Control”, Sept 2009: http://tools.ietf.org/html/rfc5681

Approach for modelling building penetration loss

A8.103 As presented in our consultation of January 2012, the building penetration loss (BPL) is typically modelled as a log-normal random variable, with a mean of L_{BPL} (dB), and a standard deviation of σ_{BPL} (dB). Specifically, the mean BPL is modelled as:

$$L_{BPL} = L_W + \alpha d \qquad (24)$$

where L_W, the mean penetration loss (in dB) through an external wall d, is the depth (in metres) within the building at the point of reception, and α represents the dependence (in dB per metre) of the BPL on the depth of penetration. In short, the product αd is indicative of the mean *additional* loss experienced at specific depths inside a building.

A8.104 The standard deviation, σ_{BPL}, represents the uncertainty of BPL around the mean value. It is a function of the variation in wall loss and variation within the building, and is modelled as:

$$\sigma_{BPL} = \sqrt{\sigma_W^2 + \sigma_I^2} \qquad (25)$$

where σ_W is the standard deviation of the penetration loss through an external wall, and σ_I σ_{I} is the standard deviation of the additional indoor loss.

A8.105 In the following sections, we describe our approach in ascribing appropriate values to the above BPL parameters for the purpose of our technical modelling.

A8.106 Ideally, we would rely upon an internationally recognised standard or recommendation for describing BPL parameters. COST 231 is an industry formulated and recognised approach to modelling, however we note that it does not specify enough detail in BPL parameter sets for the wide range of frequencies that we are considering.

A8.107 In order to supplement the information in COST 231, we have performed an extensive survey of published literature in this field and requested information from the UK national wholesalers[61].

A8.108 In the literature we have found that a great deal of variability in the methodologies used, types of buildings and frequencies examined exists in the various publications. Consequently, the spread of BPL values reported in the literature is large; the frequency dependency of BPL is extremely variable; the methodologies are variable and not always clear; and we are hesitant to draw average conclusions from, and make comparisons between, the detailed results from the widespread sources often with differing objectives and focus.

[61] The literature surveyed and comparisons with the information provided by the UK mobile national operators is contained in a confidential report by Real Wireless on “Propagation losses into and within buildings in the 800, 900, 1800, 2100 and 2600 MHz bands” A non-confidential version is published as Annex A of the Real Wireless technical work in support of the 800MHz and 2.6GHz award, published alongside this statement.

A8.109 For the above reasons, the approach we have taken is to focus on studies in addition to COST 231 which involve real measurements of whole buildings (as opposed to penetration loss of materials or theoretical studies) at multiple frequencies in the frequency range of interest, studies which we have used in our work previously and therefore included within our consultations, and studies which respondents to our previous consultations have quoted. Specifically, we have focused on the following four sources of data:

- COST 231 Final Report on “Digital Mobile Radio Towards Future Generation Systems”
- Qualcomm, “UMTS900 lessons learned,” engineering service note 80-W1115-1 Rev E, May 2008.
- P. Tar and G. Cser, “Indoor and/or outdoor cells for overall indoor solution,” Magyar Telekom/T-Mobile Hungary, IIR Indoor Conference, Barcelona, Spain, April 2009.
- H. Okamoto; K. Kitao and S. Ichitsubo, “Outdoor-to-indoor propagation loss prediction in 800-MHz to 8-GHz band for an urban area,” *IEEE Transactions on Vehicular Technology, Vol. 58, No.3*, March 2009, pp. 1059-1067.

A8.110 Subsequent to our consultation in January 2012, we made information requests and subsequently received additional data from four national wholesalers with regard to their assumptions around building penetration losses for either their current networks or those they may use for LTE rollout.

A8.111 It is difficult to make accurate comparisons with the data supplied by all national wholesalers because of a number of uncertainties for example around the assumptions of depth within a building, dependencies on the way individual wholesalers plan their networks and parameters associated with their outdoor prediction models.

A8.112 In order to account for the large uncertainty in the BPL parameter values observed we have used the above sources to infer upper and lower ends of the range encountered within those studies and adopted these within our ‘*Minvar’* and ‘*Maxvar’* parameter sets. We have defined two scenarios, called *shallow* and *deep*, as a way of illustrating building penetration losses and expected performance inside buildings. These parameter sets aim to model building penetration into residential buildings at ground floor level.

A8.113 In what follows, we elaborate further on the definitions of the above terms, and we present the values we have adopted for the various BPL parameters. We first focus on the mean BPL, and the contributions of external walls and the depth of penetration indoor, before addressing the respective standard deviations. We finally compare the adopted values with the relevant data which we have received from a number of stakeholders subsequent to our January 2012 consultation.

Mean building penetration loss

Mean external wall loss

A8.114 Table A8.19 shows the values of mean external wall loss and standard deviation based on the material reported by the four key references identified above.

A8.115 The level of detail in COST 231 is sparse; it suggests between 4 and 10dB for 900 MHz to 1800 MHz line of sight external wall losses (4dB wood, 7dB concrete with normal sized window). It suggests an angle-dependent loss of 3–5dB (900 MHz) and 5–7dB (1800 MHz).Therefore we have inferred that COST 231 suggests an external wall loss of 7 to 15dB at 900 MHz, and 9 to 17dB at 2100 MHz. This would suggest a range of building types from which a mean and standard deviation could be derived. However no information is provided as to the distribution of values within the ranges, therefore we have taken the midpoint of the range to be the mean value and assumed that the quoted upper and lower limits cover the entire range.

A8.116 The mean values of 9.5dB and 12.8dB and associated standard deviation values of 5.6dB and 6.0dB reported by Qualcomm correspond to measurements of building penetration loss at 900 MHz and 2100 MHz, respectively, based on the distribution from 12 different buildings. The buildings examined are described as cement buildings, mixture of glass/brick/cement buildings, and mainly glass buildings. The measurements are reported to have been made just inside an external wall, and are described as "loss at the first wall". For this reason, we treat the reported BPL values as suitable proxies for external wall loss.

A8.117 Tar and Cser report measured mean BPL values of 12.7, 3.9, 8.2, and 8.6dB at 2100 MHz, for four types of building characterised as "downtown", "housing estate", "suburbs", and "village", respectively. The measurements are for an indoor depth that is characterised as corresponding to "daylight". The value of 6.9dB for the mean external wall loss and 3.6dB for the standard deviation in Table A8.19 below, we have calculated from the four reported mean BPL values, minus 1.5dB to account for additional indoor losses[62].

A8.118 Okomoto et. al. propose a BPL model which has a frequency-independent external wall loss of 10dB. It does not provide any information on standard deviation.

Table A8.19: Values of external wall loss parameters suggested by various sources.

	COST 231	Qualcomm		Tar and Cser		Okomoto et. al.
	Mean	Mean	Std Dev	Mean	Std Dev	Mean
800 MHz	10.7*	9.0*	5.5*	-	-	10
900 MHz	11.00	9.5	5.6	-	-	10
1800 MHz	13.00	12.2*	5.9*	-	-	10
2100 MHz	13.4*	12.8	6.0	6.9	3.6	10
2600 MHz	14.1*	13.6*	6.1*	-	-	10

Frequency dependence (dB/decade)	6.6**	8.8**		-		0.00

* Derived via linear interpolation and extrapolation of reported loss values (in dB) with respect to the logarithm of frequency.
**Derived from the loss values reported at the relevant two frequencies.

A8.119 Broadly there is agreement between the COST 231 and Qualcomm mean external wall losses (differing by 1-2dB). However the Qualcomm report suggests a wider distribution of external wall losses than inferred from COST 231, meaning there will be a significant number of cases within the Qualcomm distribution with greater wall

[62] Consistent with our definition of "shallow" in-building penetration, we treat daylight as a depth of 2.5 metres. Coupled with a 0.6dB/m increase in loss with increasing depth (see subsequent sections), this implies that the mean external wall loss is 1.5dB lower than the reported mean BPL values.

losses. This suggests that a distribution based on the Qualcomm results will include buildings of a higher loss than one based on the range quoted in COST 231. Results based on the Qualcomm parameters also have the largest frequency dependence[63]. For these reasons we have adopted the Qualcomm figures as a basis for our 'Maxvar' profile.

A8.120 As can be seen, the results from Tar and Cser suggest the lowest value of mean external wall loss at 2100 MHz, while Okomoto et. al. suggest the lowest frequency dependence of the external wall loss. For this reason, we use these as a basis for our 'Minvar' profile with a mean based on Tar and Cser and zero frequency dependence, taken from Okomoto[64].

Dependence of mean BPL on indoor depth

A8.121 Table A8.20 shows the values of the depth-dependence factor, α, as reported by the four key references.

A8.122 The value of α cannot be readily inferred from the measurement results by Qualcomm as there is no distance from the external wall shown on the relevant graph, however the results do suggest that there is a greater frequency dependency at larger depths.

A8.123 The measurements by Tar and Cser do not explicitly address the parameter α. However, α can be inferred from measurements of building penetration loss at penetration depths labelled as "daylight" and "deep", respectively. Associating "daylight" and "deep" with indoor depths of 2.5 metres and 12.5 metres respectively (consistent with our definitions of *shallow* and *deep*, see next section), then the measurements suggest that $\alpha = 0.63$.

A8.124 Both Okomoto et. al. and COST 231 suggest a value of α = 0.6dB/m that is independent of frequency.

Table A8.20: Depth dependence of BPL suggested by various sources.

		COST 231	Qualcomm	T-Mob Hungary	Okomoto et. al.
Indoor depth dependence, α	dB/m	0.6	?	0.63*	0.6
Frequency dependence of α	dB/dec	0	>0	-	0

* Inferred from measurements.

[63] We have undertaken some analysis with our model and confirmed that BPL parameters based on Qualcomm show a greater difference in performance between different frequency bands compared to those based on using values in the range quoted in COST 231. For the purposes of this comparison our model was adapted to consider a uniform distribution of BPL variability of ±4dB (based on the quoted range) when the COST 231 parameters were considered. In all other cases the variability assumes a log-normal distribution with the appropriate standard deviation as in Table A8.22Table A8.21

[64] We note the Okomoto paper concludes a zero frequency dependence of alpha, but notes that measurements did register a small dependence prior to concluding it was not significant in comparison to the wide distribution of other building penetration losses.

A8.125 Based on the above evidence, we use a value of $\alpha = 0.6$dB/m for the depth dependency of BPL at all frequencies examined, and for both the 'Minvar' and 'Maxvar' profiles.

Calculation of mean building penetration loss

A8.126 The mean BPL, L_{BPL}, can now be derived by appropriately combining the values of mean external wall loss, L_W , and the depth dependency, α, of the building penetration loss.

A8.127 For the purposes of modelling, we define two scenarios relating to the depth of indoor coverage, which we refer to as *shallow* and *deep*. We associate "shallow" with depths of 0 to 5 metres inside a building (e.g., within a room with an external wall and perhaps a window). Whereas we associate "deep" with depths of 10 to 15 metres inside a building (e.g., deep inside a large house). In order to avoid unnecessary and artificially high granularities in our mapping to physical distances, we quantify shallow and deep indoor depths as distances of 2.5 and 12.5 metres, respectively. Coupled with a distance dependence factor of α = 0.6dB/m, this implies a 6dB difference in BPL between our defined shallow and deep scenarios.

A8.128 Based on the above arguments, and the values in Table A8.19 for mean external wall loss, Table A8.21 shows the adopted values of mean BPL for the 'Minvar' and 'Maxvar' profiles for the defined scenarios of shallow and deep indoor penetration.

Table A8.21: Adopted values of mean BPL.

Mean BPL, L_{BPL} (dB)	'Minvar'		Maxvar'	
	Shallow	Deep	Shallow	Deep
800 MHz	8.4	14.4	10.5	16.5
900 MHz	8.4	14.4	11.0	17.0
1800 MHz	8.4	14.4	13.7	19.7
2100 MHZ	8.4	14.4	14.3	20.3
2600 MHz	8.4	14.4	15.1	21.1

Standard deviation of building penetration loss

A8.129 The standard deviation values for external wall loss derived from our four references are given in Table A8.19. As there is little information about standard deviation in COST 231 and Okomoto, we have used the values derived from the Qualcomm measurements as the external wall loss component of our 'Maxvar' profile. While these standard deviation values do suggest a small element of frequency dependency, the variation across the frequency range of interest is only 0.6dB. Based on this observation, and in the absence of additional data, we use the lower standard deviation value derived from the Tar and Cser measurements for our 'Minvar' profile, and have applied this at all frequencies of interest.

A8.130 The other component of our formulation of BPL standard deviation is the variation around additional indoor loss. COST 231 suggests a standard deviation of between 2.7 and 5.3dB for the indoor penetration loss. Our other main references do not provide sufficient information to allow this parameter to be quantified.

A8.131 Given the information from COST 231, it is not possible to assess whether the larger standard deviations necessarily correspond to larger penetration depths[65], and whether a significant frequency dependency exists. For this reason, and in the absence of additional information, we use the mid-point standard deviation of 4dB for both shallow and deep indoor penetration, and both the 'Minvar' and 'Maxvar' profiles, at all frequencies. Combining the standard deviations of external wall loss and additional indoor loss via Equation (25), the total BPL standard deviation is given in Table A8.22 below.

Table A8.22: Adopted values of BPL standard deviation.

SD of building penetration loss, σ_{BPL} (dB)	'Minvar'	'Maxvar'
800 MHz	5.4	6.8
900 MHz	5.4	6.9
1800 MHz	5.4	7.2
2100 MHZ	5.4	7.2
2600 MHz	5.4	7.3

Information from stakeholders

A8.132 As mentioned in A8.110 we made information requests to the four national wholesalers for information on assumptions underlying their public coverage checkers which included the values they use for indoor losses.

A8.133 Whilst their specific values are confidential, we have cross-checked our values for 'Minvar' and 'Maxvar' with the relevant suburban data provided and they generally lie within our 'Maxvar' range. However, one national wholesaler assumes slightly higher losses than our 'Maxvar' case for both deep and shallow.

Variation of parameters with clutter type

A8.134 In responses to our information request and our last consultation we received differing views from the mobile operators. One suggested no variation of BPL parameters with clutter type was appropriate, where two others gave BPL values which did vary significantly with clutter type.

A8.135 The four sources (Qualcomm, Tar and Cser, Okamota and COST 231) considered above do not put forward any strong evidence for variation of BPL parameters within different clutter categories such as "urban", "suburban" etc. other than an inference that particular types of buildings may be more common within particular clutter types, however there is insufficient evidence to determine how any variation might relate to the residential building stock in the UK. Whilst physically and intuitively we would expect losses to be greater in dense urban environments than say rural, this is difficult to quantify. Given that approximately 80% of the UK population is resident in suburban clutter (Table A8.12), we have concluded that our

[65] Measurements by Tar and Cser regarding the standard deviations of BPL (not additional indoor loss) at 2100 MHz are somewhat helpful in this respect. These indicate standard deviations of between 3.7 and 4.9 dB for "daylight" penetration, and 3.6 to 4.9 dB for "deep" penetration, for buildings characterised as "downtown", "housing estate", "suburbs", and "village". These suggest that the standard deviation of BPL is not a strong function of the depth of penetration.

values for BPL should not vary with clutter type.We have observed in the information provided by national wholesalers, that where values are provided explicitly for urban and dense urban environments that these appear to have slightly higher losses than we have assumed in our profiles. This is not a significant issue in the context of our modelling because our modelling is based on investigation of residential premises, approximately 80% of which are located in suburban clutter. Whilst these assumptions are valid for residential properties, we recognise that certain urban or dense urban business premises may experience somewhat greater levels of BPL values.

Conclusions on BPL

A8.136 We have described our revised approach in selecting appropriate values for building penetration loss parameters used in our technical modelling. These values assumed in the 'Minvar' and 'Maxvar' profiles account for the large uncertainty in the penetration loss observed in practice and represent reasonable lower and upper data sets for the various parameters, as well as their dependencies on frequency. We have checked that the relevant values provided by the national wholesalers (corresponding to suburban clutter) and these are consistent with the values corresponding to the 'Maxvar' profile.

A8.137 We have run our model using the COST 231 assumptions in order to compare results with our 'Maxvar' parameters[66]. The results of this comparison show a wider variation between frequencies for the 'Maxvar' profile.

Presentation of results

A8.138 In this section we introduce the types of plots which are used in Annex 7 to present results for coverage, speed (single-user throughput), and capacity.

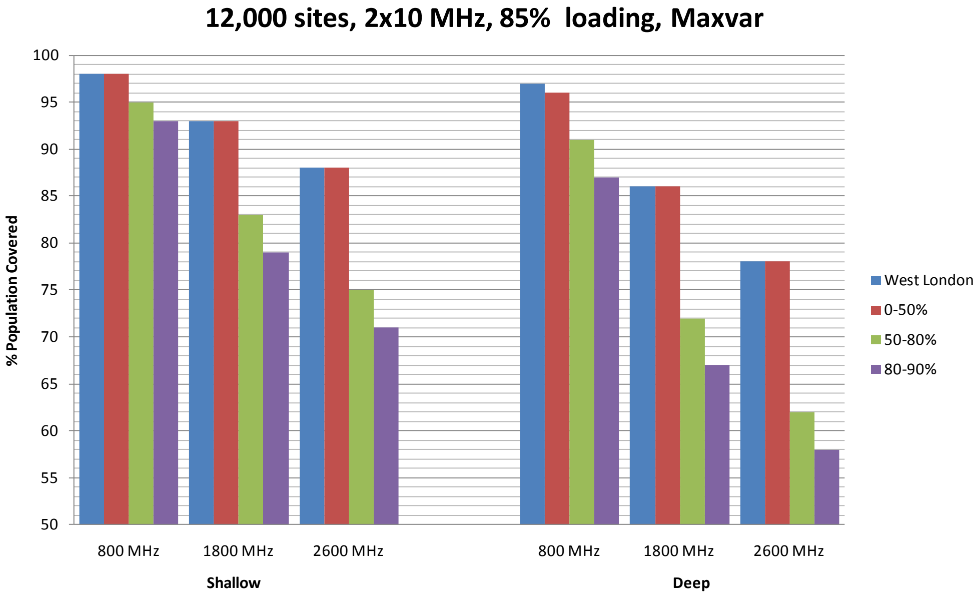
Coverage

A8.139 It should be stressed that coverage results are not a prediction of the nationwide coverage. Rather they indicate the coverage achievable within the particular simulation area.

A8.140 Figure A8.62 below illustrates the coverage results for shallow and deep indoor users in each of the simulation areas.

[66] As explained in paragraph A8.115, COST 231 quotes a range of values for external wall loss. Thus the mean wall loss figures provided in Table A8.19 are the mid-point of the range of quoted values of ±4dB. For the purposes of this comparison our model was adapted to consider a uniform distribution of BPL variability of ±4dB when the COST 231 parameters were considered. In all other cases the variability assumes a log-normal distribution with the appropriate standard deviation as in Table A8.21.

Figure A8.62: Variation of coverage with depth in building, 10 MHz, 85% loading, 12,000 sites, various frequencies, all simulation areas

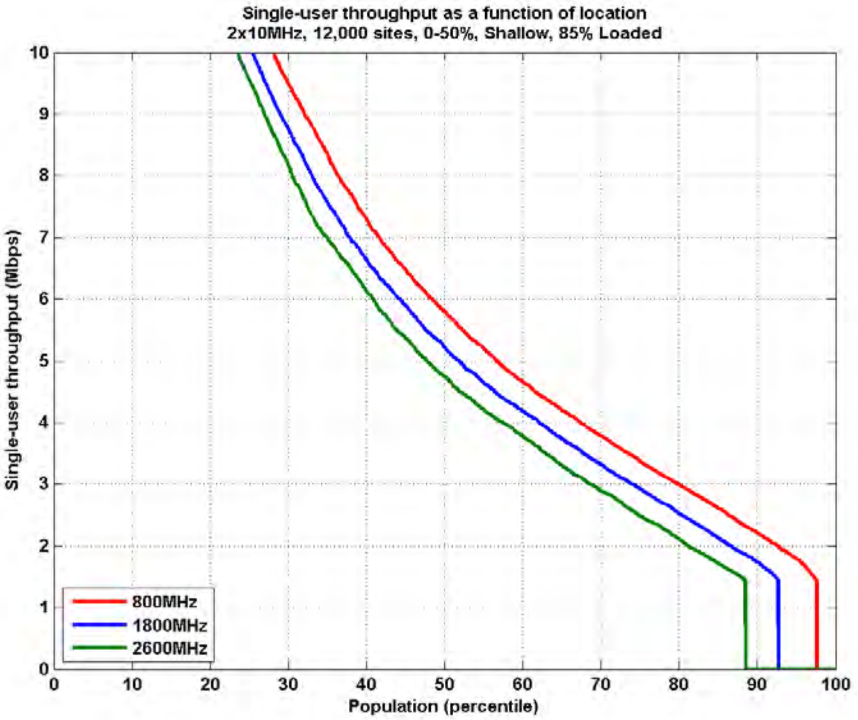


Speed

A8.141 The speed of a network, for a particular combination of frequency, channel bandwidth, base station network size and network loading is obtained directly from the single-user throughput distribution for the relevant channel bandwidth. This distribution is sorted in descending order. Each throughput value from the distribution is then plotted against the population that can receive at least that throughput.

A8.142 Figure A8.63 below illustrates the speed results for shallow users for a network with the equivalent of 12,000 sites nationally for a 10 MHz carrier at 85% loading in the 0-50% simulation area.

Figure A8.63: Single-user throughput as a function of location, 10 MHz carrier, 85% loading, various frequencies, 0-50%, shallow



A8.143 Figure A8.63 should be interpreted as follows: the x-axis indicates the percentage of population within the simulation area ordered such that those having the best signal conditions are to the left, and those with the worst to the right. So "50%" in Figure A8.63 represents the 50% of population which are in locations with the best signal conditions and hence highest throughput for each of the 800 MHz, 1800 MHz and 2600 MHz networks (these are not necessarily the same 50% of locations). The y-axis shows the single-user throughput attained or exceeded at each of these locations when a single user consumes the full capacity of the serving cell.

Capacity

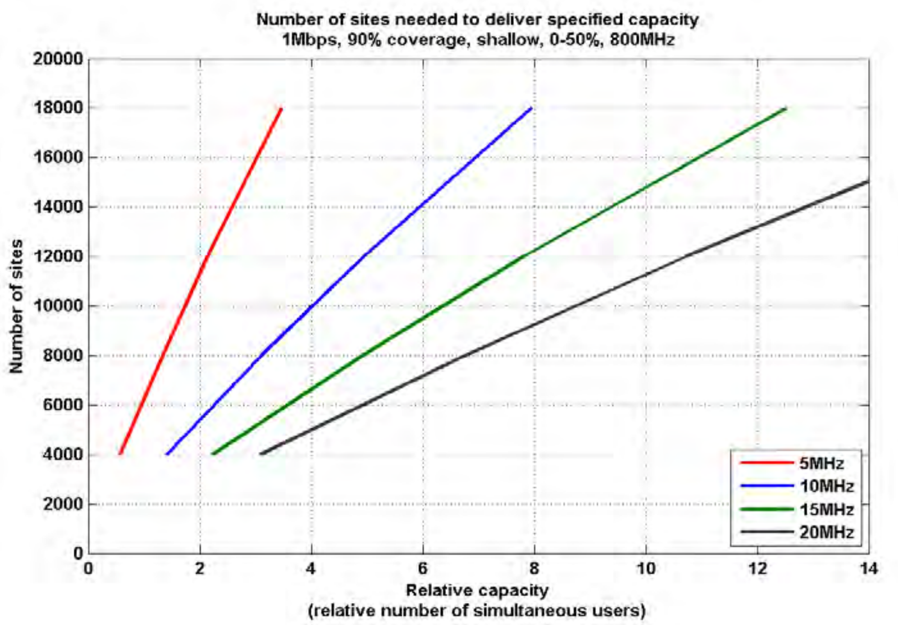
A8.144 In general terms, the capacity of a network is a measure of how much offered traffic it is able to serve whilst maintaining key quality of service metrics. Such metrics might include the number of connection request failures, the number of dropped connections, the ability to maintain a minimum throughput to users, the number of lost data packets, latency, etc. Different users demanding different services from the network will need a different combination of these metrics. For instance, for a streaming video user maintaining an acceptable minimum guaranteed data-rate is important to avoid interrupts; for an online gamer latency might be the most important feature; for someone surfing the web both latency and data-rate may be key. A network will try and balance all of the competing demands of its users. Moreover, if the traffic profile of the users of one network is different from the traffic profile of another network, even if they have the same number of customers and the same network and spectrum resources they might, in practice perform very differently with one network struggling to meet demand whilst the other does not.

A8.145 As a consequence of the above, it is very difficult to derive a single capacity metric that adequately addresses all of the important network quality features that an operator is likely to feel are important. However, as many of these network quality features are likely to be independent of the frequency band they have not all been addressed in this analysis.

A8.146 For the purposes of our analysis we have assumed all users are to be provided with the same service – a guaranteed data-rate service of a specified speed – and that users are uniformly distributed over all modelled locations. We then calculate the relative number of such users per cell that could simultaneously be served by the network, taking account of the resources available to the network and the resources required to serve each user with the specified service. This is a simple scenario, but allows an illustration of relative capacity without having to make a lot of detailed assumptions about the specifics of the services that will be demanded by different users.

A8.147 Figure A8.64 below illustrates the number of sites required to deliver the specified capacity for a fixed coverage level of 90% at 800 MHz, and for a 1Mbit/s guaranteed data-rate.

Figure A8.64: Capacity vs number of sites, 1Mbit/s, 18,000 sites, 0-50% area, 90% coverage, 800 MHz, shallow

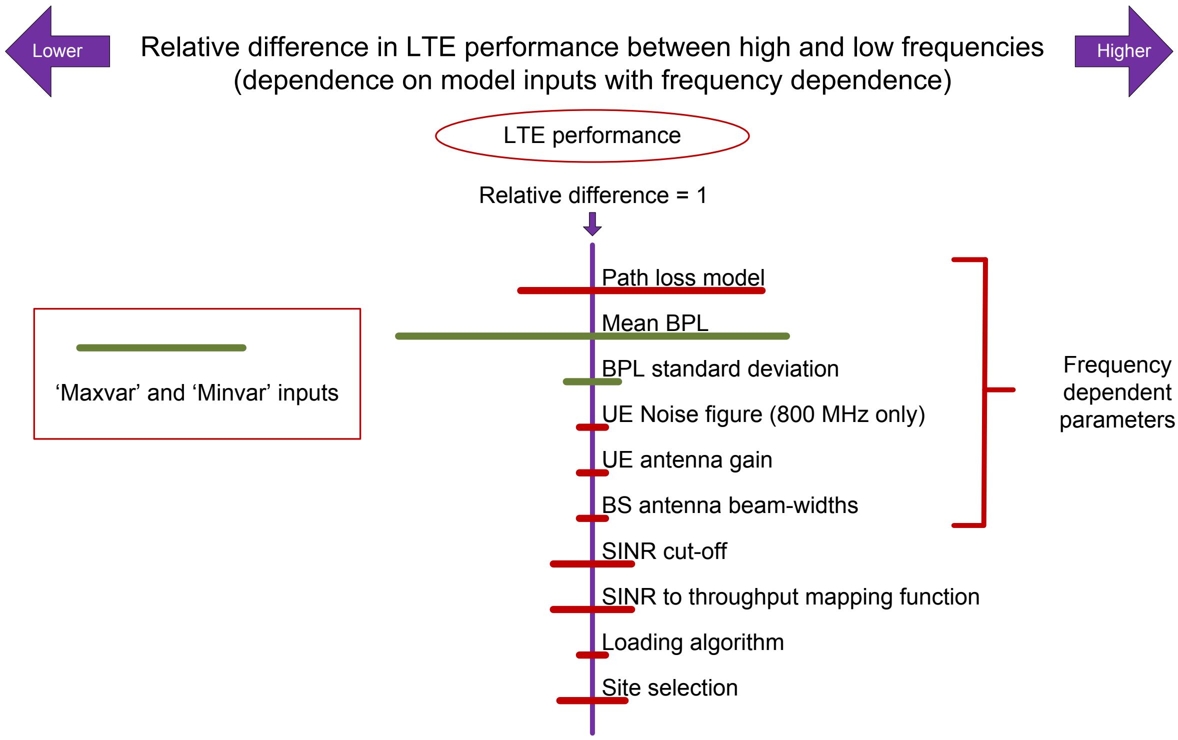


Variability in our modelling

A8.148 As discussed in paragraph A8.5 above, there is considerable uncertainty around many of the parameter values and assumptions we have used in our modelling.

A8.149 Figure A8.65 below provides an illustration of the wide range of uncertainties that we have considered in relation to our model, particularly those likely to affect the relative performance between frequencies. This illustration by no means includes every single source of uncertainty that might be applicable to the model but it does show those that we believe are likely to have the greatest impact on the interpretation of our results.

Figure A8.65: Illustration of uncertainties



A8.150 The length of the horizontal bars is indicative of our current view of the size of the relative performance difference between 800 MHz and 2600 MHz as a function of the uncertainty associated with each input parameter (or input algorithm). The length of each bar to the right means a higher relative difference in performance in response to a change in the relevant input parameter and the length of the bar to the left means a lower relative difference in performance. Note that the diagram should be interpreted in a qualitative manner - it is not to scale.

A8.151 Some uncertainties in our choice of parameter values (or ranges) will always remain, simply because they fall into a category where a wide range of values are considered reasonable. Other uncertainties arise because we are required to make an assessment of the performance of current implementations or likely improvements in performance over the lifetime of the technology. Overall, there are many sources of uncertainty and, and we consider the uncertainties associated with a number of these parameters below.

BPL assumptions

A8.152 As illustrated in Figure A8.65, mean BPL is an important uncertainty in the relative difference between frequencies, and there is additional uncertainty associated with the standard deviation of BPL.

A8.153 The ranges for BPL standard deviation and mean BPL represent the current uncertainty around the nature of propagation into buildings due to the myriad of different paths, locations, building types, construction materials, internal layouts and the relative importance of those locations for customers who are sensitive to differences in service quality etc. Even with perfect knowledge of every possible parameter we could never build a practical model that would eliminate these uncertainties (though, potentially, with better knowledge it could be reduced somewhat).

A8.154 As outlined in A8.126 to A8.136 above, in order to illustrate these uncertainties we have chosen to group the parameter values into two cases: those that minimise the relative performance variation between frequencies (our ‘Minvar’ case) and those that tend, in most circumstances, to maximise the relative performance variation (our ‘Maxvar’ case). The model is then run twice to produce results for these two cases.

A8.155 As explained in Annex 7, evidence from operators together with our own engineering judgement leads to believe the ‘Maxvar’ case is a credible representation of BPL parameters applicable to residential premises in the UK and that our ‘Minvar’ case is likely to be less credible.

A8.156 Given the above paragraph and (as we explain in paragraph A8.2) the fact that we are particularly concerned with comparing the performance achieved by networks using different portfolios of spectrum with a range of frequency bands and bandwidths, we consider it appropriate to concentrate on results using the ‘Maxvar’ case.

A8.157 Therefore the majority of results presented in Annex 7 are for the ‘Maxvar’ case. An additional set of sensitivity results which consider the ‘Minvar’ case are also presented in Annex 7.

Path loss model

A8.158 As outlined in earlier sections, we have used the Extended Hata model for calculation of path loss. The Extended Hata Model is based upon a range of path loss measurements and has been subject to extensive peer review both within academia and industry. It is widely accepted and has been used by regulatory bodies, CEPT and ITU in the conduct of various studies. We consider it the best model available to Ofcom to model performance for this consultation, with an additional correction applied for frequencies above 2 GHz, as outlined above in paragraphs A8.35 to A8.40 and in Annex 10.

SINR to throughput mapping function

A8.159 In Annex 14 of the January 2012 consultation we presented an analysis of the sensitivity of the results to the choice of SINR to throughput mapping function. This showed that in absolute terms the mapping function has a significant impact on the single-user throughput mapping function. However, the effect on the relative performance is more moderate as reflected in Figure A8.65.

Additional uncertainties

A8.160 We additionally consider sensitivity analyses which take into account the following parameters:

a) SINR cut-off

b) RSRP constraints

c) Uplink limitations

d) Overhead (20% vs 30%)

e) Loading of other cells (50% vs 85%)

A8.161 These are explored in Annexes 7 and 10.

Parameters and assumptions

A8.162 Our parameters and assumptions are given in Table A8.23.

Table A8.23: Parameters and assumptions

Ref.	Parameter/ Assumption	Value or range modelled	Units	Comment
Simulation area				
0	Geographic extents of simulation areas	1: 0-50% most densely populated area 2: 50-80% most densely populated area 3: 80-90% most densely populated area 4: 100km square area west of London	(eastings , northings)	See map in Figure A8.56. Areas 1-3 are generated based on Census population data grouped by Local Authority Districts. Area 4 is a 100km x 100km square centred on (482300, 180,500)
Synthetic base station networks				
1	Base station locations	Based on random selection from a generated super-set of sites equivalent to a UK national network of 20,000 sites.	(eastings, northings)	Representative of national networks of various site counts - see paragraph A8.22
UE test points				
2	UE locations	Postcode unit locations extracted from Code-Point® data	(eastings, northings)	The Postcode unit locations have a local density commensurate with user density
3	User weighting applied to UE test points	Number of domestic delivery points associated with the Postcode unit location.		Applying a weighting of the number of domestic delivery points to the results for each UE test point provides a weighting that to a first approximation takes into account population density.
Base station parameters				
4	Sectors per site	3		Industry practice

Ref.	Parameter/ Assumption	Value or range modelled	Units	Comment
5	Radiated power (EIRP) per 180 kHz LTE resource block	47	dBm	Derived from the maximum value permitted by the proposed technical licence conditions for 800 MHz and 2600 MHz[67]
6	Antenna gain	-		Not explicitly used as we are assuming a fixed EIRP for the downlink modelling.
7	Antenna horizontal 3dB beam-width	65	degrees	A fixed value for all frequencies based on the Kathrein 742 265 multi-band antenna[68] – interpolated to the mid-point between 800 MHz and 2600 MHz
8	Antenna vertical 3dB beam-width	7.5	degrees	A fixed value for all frequencies based on the Kathrein 742 265 multi-band antenna[68] – interpolated to the mid-point between 800 MHz and 2600 MHz
9	Antenna down-tilt	variable	degrees	Optimised for frequency and average distance to nearest neighbouring sites
10	Antenna height	variable	m	Distribution representative of existing mobile operators networks - see paragraph A8.22
UE parameters				
11	Antenna gain (mean effective gain)	-1.1dBi @800MHz 0.0dBi @ 1800 MHz +0.5dBi @ 2600 MHz	dBi	Takes into account antenna efficiency increasing with frequency as suggested by Vodafone in their response to our March 2011 consultation
12	Antenna height	1.5	m	Standard assumption
13	Body loss (relative to free space)	5.0	dB	See para A13.289-a13.300 of [[69]]

67 Annex 11 of the statement.
68 Kathrein Scala 742 265V02 datasheet: http://www.kathrein-scala.com/catalog/742265V02.pdf
69 Ofcom, "Application of spectrum liberalisation and trading to the mobile sector", Feb 2009, Annex 13, pp. 72 - 75: http://stakeholders.ofcom.org.uk/binaries/consultations/spectrumlib/annexes/annex13.pdf

Ref.	Parameter/ Assumption	Value or range modelled	Units	Comment
14	Receiver noise figure	10 (800 MHz) 10 (1800 MHz) 9 (2600 MHz)	dB	Derived from 3GPP TS 36.101[70]
Propagation				
15	Location variability (outdoor)	Varies dependent on frequency and clutter	dB	See paragraph A8.41.
16	Location variability (outdoor) cross-correlation coefficient	1.0 (inter-sector) 0.5 (inter-site)		See section 3.2.4 of [71]
17	Building penetration loss variability	Building penetration loss standard deviation values as given in Table A8.15	dB	See paragraphs A8.103 to A8.136
18	Building penetration loss cross-correlation coefficient	1.0 (inter-sector) 0.5 (inter-site)		See [71]
19	Mean building penetration loss	Varies according to frequency and BPL scenario. See Table A8.14	dB	See paragraphs A8.103 to A8.136
20	Propagation path loss model	Revised Extended Hata		From [72] , and updated for frequencies above 2 GHz as set out in A8.35 to A8.40
21	Clutter definitions	Infoterra clutter database	50m x 50m resolution	
Calculation of throughput				
22	Network loading as applied to non-serving sector interference power in calculation of SINR.	Intelligent allocation of resource blocks - see paragraphs A8.57 to A8.67		The network loading scheme is taken into account in estimating the probability of interference due to usage of interfering resource blocks in non-serving sectors.

[70] 3GPP TS 36.101 V9.12.0. "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception", July 2012: http://www.3gpp.org/ftp/Specs/html-info/36101.htm
[71] R. Srinivasan et. al, "IEEE 802.16m Evaluation Methodology Document (EMD)", IEEE 802.16m-08/004r5, Jan 2009, section 3.2.4: http://ieee802.org/16/tgm/core.html
[72] ERC Report 68, "Monte-Carlo Radio Simulation Methodology for the use in sharing and compatibility studies between different radio services or systems": http://www.erodocdb.dk/Docs/doc98/official/pdf/REP068.PDF
and "SEAMCAT implementation of Extended Hata and Extended Hata SRD models": http://tractool.seamcat.org/raw-attachment/wiki/Manual/PropagationModels/ExtendedHata/Hata-and-Hata-SRD-implementation_v2.pdf

Ref.	Parameter/ Assumption	Value or range modelled	Units	Comment
22	SINR to throughput mapping function	Mapping function as given in paragraphs A8.73 to A8.76	Throughput units of bps/Hz	Derived from 3GPP TR36.942[73]
23	SINR cut-off	-5	dB	See paragraphs A8.77 to A8.80
24	System overheads	20%		The mapping function used does not include system overheads and these are accounted for separately in the calculation of the available throughputs.
Calculation of capacity				
25	Inclusion of frequency domain packet scheduling	FDPS is only included in the calculation of capacity		See paragraphs A8.91 to A8.94
RSRP constraint (sensitivity analysis)				
26	RSRP limit	-124	dBm / (15 kHz)	See paragraph A10.57 of Annex 10
Uplink limitations (sensitivity analysis)				
27	UE EIRP	23	dBm	See comment on ref. 5 above
28	UE Noise Rise	2	dB	See [74]
29	BS Gain	15.4 (800 MHz) 17.9 (1800 MHz) 19.0 (2600 MHz)	dBi	$G = 7.023\log_{10}(f) - 5$
30	BS Noise figure	2	dB	See [75]
31	Bandwidth efficiency	0.4		From 3GPP TR36.942[73]
32	SINR efficiency	1		From 3GPP TR36.942[73]
33	Peak spectral efficiency	2	bit/s/Hz	From 3GPP TR36.942[73]
34	Uplink SINR cut-off	-7.5	dB	See [76]
35	Maximum Uplink bandwidth	5	MHz	Applies if multiple users are being considered

[73] 3GPP TR 36.942 V9.3.0 “Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios”, Annex A, Section A.1: http://www.3gpp.org/ftp/Specs/html-info/36942.htm

[74] H. Holma & A.Toskala, “LTE for UMTS: Evolution to LTE-Advanced“, 2nd Ed, Wiley 2011, Figure 10.14, p277. Derived from Figure 10.14 from for an ISD of 1.5km at 50% probability, and supported by confidential data supplied from operators in response to specific information requests

[75] H. Holma & A.Toskala, “LTE for UMTS: Evolution to LTE-Advanced“, 2nd Ed, Wiley 2011, Table10.8, p267, and supported by confidential data supplied from operators in response to specific information requests.

[76] S. Sesia, I. Toufik, M. Baker, “LTE: The UMTS Long Term Evolution”, Wiley 2009, p416

Annex 9

Technical analysis and detail of the coverage obligation

Introduction

A9.1 This annex sets out:

9.1.1 the further technical analysis that Real Wireless has undertaken on Ofcom's behalf in support of our decision making described in Section 5 of this Statement.

9.1.2 the details of the obligation and the way in which we will verify compliance.

A9.2 It is supported by the following additional documentation:

9.2.1 Real Wireless has provided a report on its analysis methodology.[77] Its results are included in a confidential annex to that report which we have not published as it contains commercially sensitive information relating to the current National Wholesaler's networks and businesses. However, a high level summary is provided in the following paragraphs.

9.2.2 Our compliance verification methodology for meeting the coverage obligation with LTE technology.[78]

Technical Analysis

Introduction

A9.3 Real Wireless has used information on existing network coverage and site portfolios provided by the existing 2G and 3G national wholesalers in order to assess the level of UK and nations coverage that might be achieved by different national wholesalers predominantly using existing network infrastructure.

A9.4 The analysis has taken two approaches with results provided to us for each approach. Further details on the steps associated with each methodology and their respective limitations can be found in the Real Wireless report.

A9.5 The Real Wireless analysis was undertaken using all UK premises as a proxy for population.

Results

A9.6 Results from approach 1 – based on supplied signal strength data for existing 2G and 3G networks – suggested that at least one portfolio of existing sites would be able to achieve some indoor coverage close to 98% of the UK, 95% in Scotland and Wales, and around 90% in Northern Ireland.

[77] See Real Wireless report on technical analysis in support of the 800 MHz and 2.6GHz award published alongside the statement.
[78] See compliance verification document for LTE published alongside the statement.

A9.7 The level of coverage predicted under approach 2 for one set of existing sites is shown in Table A9.24. This shows that almost 98% of the UK population is predicted to be served with coverage sufficient to enable a 2Mbps service to at least some indoor locations within the vast majority of premises. The table also provides an indicative estimate of the equivalent outdoor coverage for a 2Mbps service. Indoor locations are determined using a BPL of 10.5dB with associated standard deviation of 6.8dB[79].

A9.8 The analysis also provides the levels of coverage in each nation based on the selected set of sites. The number of sites and therefore coverage experienced by residents in Northern Ireland is currently more limited than in the other nations and consistent with this analysis, which is based on these existing sites, shows that only 86% of the premises would achieve 2Mbps shallow indoor coverage. However we understand at least two national wholesalers are currently deploying additional sites in order to improve coverage in Northern Ireland[80]

Table A9.24: Estimated LTE 800 coverage achieved from a set of existing sites

Max Coverage by Nation	Shallow Indoor	Outdoor
England	98.4%	99.97%
Scotland	95.1%	99.0%
Wales	95.1%	99.7%
Northern Ireland	86.0%	97.5%
UK	97.6%	99.8%

A9.9 The methodology provides a high level view of the coverage that might be achievable from particular sets of sites and it is likely that the coverage in practice will differ from this simplified analysis. As the results in Table A9.24 show that the UK coverage of premises with some indoor coverage is just below 98%, we also expect that the national wholesalers may need to build some additional sites in order to achieve the levels of coverage required by the obligation.

A9.10 The analysis also gives an indication of the costs of expanding coverage. Figure A9.66 below shows that the cost per premises starts to increase significantly towards the maximum of achievable coverage from a set of sites. The set of sites used in this example could achieve 98% UK coverage but on a somewhat lower level of assumed building penetration loss than that in our formulation of the coverage obligation. At higher levels of building penetration loss, the modelling suggests a cost curve of a similar shape, but lower overall levels of population coverage for a given cost per premises. Recognising the inherent limitations of our (high level) modelling methodology, we have compared our results with our understanding of the position of the existing national wholesalers and we therefore believe that the cost estimates of £2,000 to £3,000 per additional premises broadly correlate to a 98% coverage with the characteristics specified in the relevant licence condition.

A9.11 As the limits of achievable coverage from an existing site base are realised, each additional site will cover only a few premises that are not already covered by a more

[79] These values are identical to those used for MaxVar shallow in our other technical analysis.
[80] http://www.telegeography.com/products/commsupdate/articles/2012/02/15/mbnl-to-spend-gbp25-million-boosting-3g-coverage-in-northern-ireland/

cost effective site. These will often be in rural areas where the cost of backhaul may be particularly high and there is a very sparse distribution of premises.

A9.12 We also recognise that the use of existing sites may not always be the most cost effective solution and that in some circumstances, it may be more economic to deploy services from new site locations even though these may have a greater initial cost. However costs also rise rapidly with new sites as was demonstrated in the study undertaken by Real Wireless on the cost of extending 800 MHz mobile broadband coverage which we published as part of our consultation in January 2012[81]

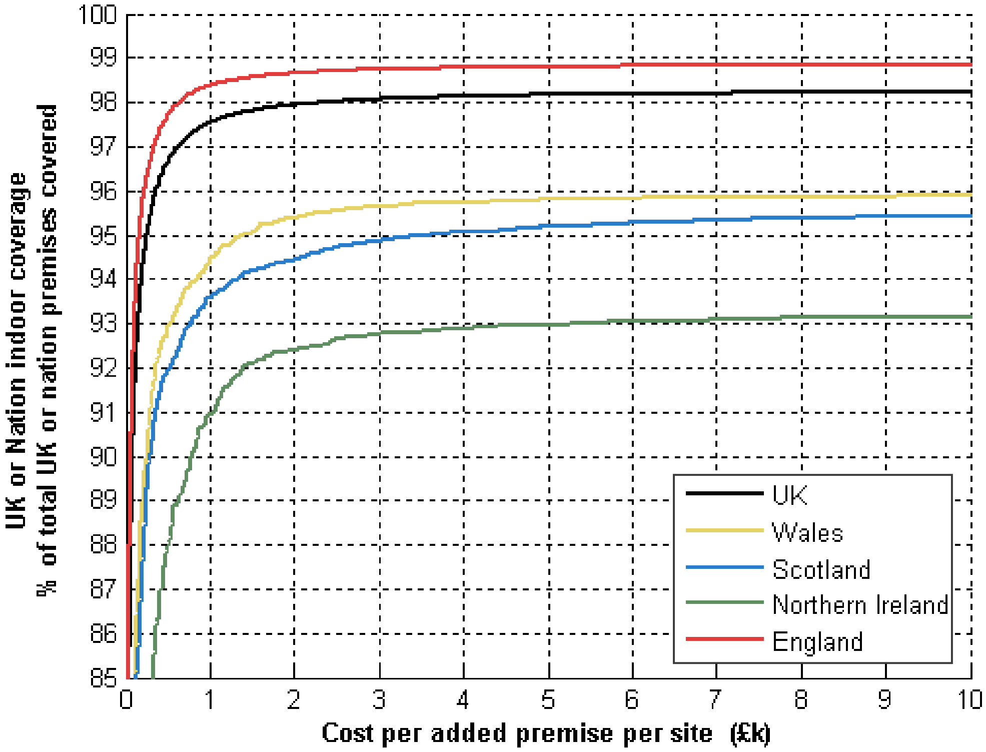


Figure A9.66: Cost per premises curves of upgrading a set of existing sites[82]

A9.13 Figure A9.66 shows that at 98% UK coverage the incremental cost is approximately £2k per additional premises For Wales and Scotland, the model estimates 95% coverage is delivered at an estimated incremental cost of broadly within the range of £1.5k to £3k per additional premises covered. Beyond that level, costs rise very quickly – achieving 96% coverage in either Wales or Scotland would require an incremental cost in excess of £10k per additional premises.

A9.14 In Northern Ireland the model predicts that at an incremental cost of £3k per additional premises, coverage would remain below 93%. The incremental costs of exceeding this level of coverage from an existing site portfolio rise very sharply indeed. However as stated above, we understand that the number of sites and

[81] "Technical analysis of the cost of extending an 800 MHz mobile broadband coverage obligation for the United Kingdom" http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/annexes/real-wireless-cost-analysis.pdf

[82] The chart shows the coverage that can be achieved by upgrading a representative site portfolio without construction of any new sites. The underlying analysis assumes a slightly lower value of building penetration loss than assumed in the formulation of the coverage obligation, reflecting our view that an operator may need to construct a small number of additional sites to meet the obligation.

therefore coverage in Northern Ireland is currently increasing and therefore upgrading to 4G based on this increased site base is likely to be more cost effective and lead to higher coverage than our model currently predicts.

The licence condition and compliance monitoring

A9.15 The licence condition in the relevant Schedule for the coverage obligation is as follows:

"6. Coverage Obligation

(a) The Licensee shall by no later than 31 December 2017 provide, and thereafter maintain, an electronic communications network that is capable of providing, with 90% confidence, a mobile telecommunications service with a sustained downlink speed of not less than 2 Mbps when that network is lightly loaded, to users:

(i) in an area within which at least:
a. 98% of the population of the United Kingdom lives, and
b. 95% of the population of each of England, Wales, Scotland and Northern Ireland lives; and

(ii) at indoor locations that meets the condition specified in paragraph 6(b)(ii) of this Schedule, which are within any residential premises within the area specified in paragraph 6(a)(i).

(b) For the purposes of paragraph 6(a)(ii) of this Schedule:

(iii) the service must be provided using radio equipment which is not situated inside the relevant residential premises;

(i) the condition referred to is that the radio signal propagation loss from the outside of the building to the location inside the building does not exceed:
a. 13.2dB for radio signals in the frequency ranges 791MHz – 821MHz and 832MHz – 862MHz;
b. 13.7dB for radio signals in the frequency ranges 880MHz – 915MHz and 925MHz – 960MHz;
c. 16.5dB for radio signals in the frequency ranges 1710MHz – 1785MHz and 1805MHz – 1880MHz;
d. 17.0dB for radio signals in the frequency ranges 1900MHz – 1980MHz and 2110MHz – 2170MHz;
e. 17.9dB for radio signals in the frequency range 2500MHz – 2690MHz;
f. Any other propagation loss notified to the Licensee by Ofcom in respect of radio signals in any other frequency band."

A9.16 We will calculate "an area within which at least 95/98% of population of the UK/of each of England, Wales, Scotland and Northern Ireland lives" by reference to the unit postcode areas covering the residential delivery point addresses in which the relevant percentage of the population lives. This is based on a population distribution, which we will create by uniformly distributing the population from the latest census data across all residential delivery point addresses within each census output area. The centroid of the unit postcode area will be used as the relevant test points.

A9.17 We will interpret a "network that is lightly loaded' as meaning a network having a single user demanding the service within the serving cell and surrounding cells of the network loaded to a light level (e.g. the common channels only transmitting at 22% of the maximum cell power).

A9.18 In determining the values that should be used to describe the condition for indoor locations, we have considered available literature as well as confidential information provided by the national wholesalers on the parameters that they currently use in deploying their networks or that they tell us that they have used in modelling the likely performance of LTE.

A9.19 As we explain further in Annex 8 of this Statement, there is significant variability and uncertainty in published literature on the radio propagation losses associated with buildings. There is no set of values that perfectly describes the entire residential building stock of the UK and therefore we cannot be certain we have used exactly representative figures. However, we believe the values we have chosen are a reasonable judgement based on the available evidence. The values for the indoor condition have been derived by taking the difference between an outdoor 90% confidence limit and an indoor one based on the combination of variance for shadow fading as defined in ITU-R 1812-2 and our definition of 'Maxvar' shallow BPL used in the competition assessment analysis and described in Annex 8. We consider that it will be possible that within most residential buildings there will be locations which satisfy the relevant condition.

A9.20 The values are consistent with those used in the technical analysis undertaken by Real Wireless and we also consider that they are consistent with the values that the national wholesalers have given us – taking into account the differences in the way that they plan their networks.

A9.21 In the January 2012 consultation we suggested we might monitor compliance with the coverage obligation in a way consistent with how we propose to measure compliance with the 3G coverage obligation[83]. We also suggested technical assessment of compliance might be complemented by some testing of actual experience and invited views on the value of such an approach.

A9.22 Taking into account the responses we received to our consultation, we propose to test compliance using a method consistent with the 3G verification methodology, but adapted to reflect 4G technology, the indoor requirements and the level of the obligation. We will assess outdoor coverage but take account of the additional losses that might be experienced by users within their homes. Inevitably, any approach based on modelling is an approximation of the performance encountered in reality. However, given the complexity and practical limitations of verifying compliance, particularly at indoor locations we believe this is the most appropriate method.

A9.23 Our approach to monitoring compliance will be to calculate the signal to interference plus noise ratio (SINR) for the appropriate downlink data channel for a hypothetical test terminal located at each outdoor population point, taking into account signals from the 20 closest base sites operating in the same spectrum band and applying the additional radio propagation losses for the indoor condition to the signals received from the serving and surrounding cells.

A9.24 In approaching compliance with regard to the Radio Access Network only, we make the reasonable assumption that to comply with the obligation the rest of the elements of the network are provisioned such that they are able to support at least 2Mbps data traffic to every sector simultaneously.

[83] The 3G verification methodology can be found at http://stakeholders.ofcom.org.uk/binaries/consultations/2100-MHz-Third-Generation-Mobile/annexes/methodology.pdf

A9.25 The coverage obligation will be attached to a 2x10 MHz lot within the 800 MHz band. Specifically, this will be for 811 to 821 MHz paired with 852 to 862 MHz. However, the licensee holding these frequencies will be able to meet the obligation with any frequencies it is permitted to use. It may also use other mobile broadband technologies in addition to, or instead of, LTE. Although we have specified a detailed compliance verification methodology for current generation LTE technology alongside this statement[84], it will be open to the licensee with the obligation to meet the obligation with alternative mobile broadband technologies: we are simply concerned to ensure that a service as specified above is provided, regardless of the technology that the licensee decides to use to do so. Should the licensee decide to use a technology other than LTE to provide the service – or if the LTE specification changes – we will consider the need to revise our approach or define an alternative methodology, always ensuring that the approach is consistent with the service characteristics encapsulated in the current methodology. The key elements are described in the following paragraphs.

A9.26 We have defined the relevant SINR thresholds for a 2x2 (MIMO) system based on the throughput mapping function in Annex A, Section A.1 of 3GPP TR 36.942[85]. Whilst we note that this is typically applied to a 1x2 (SIMO) system, we have benchmarked the performance given by this mapping function against a number of real world results. See, for example, Rysavy Research and 3G Americas paper[86] which highlights some work by Ericsson[87]. These indicate that the performance given by this function is fairly close to that seen in current implementations of LTE with a 2x2 antenna configuration.

A9.27 The mapping function does not take account of system overhead. We therefore accounted for the following overheads when calculating the required SINR:

- Reference Signals
- Physical Downlink Control Channel (PDCCH)
- Primary and Secondary Synchronisation Channels (PSCH/SSCH)
- Physical Broadcast Channels (PBCH)

A9.28 The size of these overheads on a per-channel basis is illustrated in Table 9.25. The number of resource blocks (50, 75, 100) corresponds to the various bandwidths of 10, 15, 20 MHz respectively. It is apparent that the proportion of overheads varies slightly with bandwidth, so that the peak throughput for a 10 MHz channel is not exactly half that of a 20 MHz channel. However, the difference is only slight and we have adopted of a single figure of 22% to account for the overall effect of overheads.

[84] See paragraph 1.4 in 4G Coverage Obligation Verification Methodology: LTE
[85] "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
[86] Transition to 4G, 3GPP Broadband Evolution to IMT-Advanced (4G), Rysavy Research & 3G Americas, September 2010, p. 49, Figure 17. http://www.rysavy.com/Articles/2010_09_HSPA_LTE_Advanced.pdf
[87] Initial field performance measurements of LTE, Jonas Karlsson and Mathias Riback, Ericcson Review No. 3, 2008, pp. 22 – 28. http://www.ericsson.com/ericsson/corpinfo/publications/review/2008_03/files/LTE.pdf

Table 9.25: Calculation of overheads

	Overheads (%)			
	Number of MIMO streams (s = 2)	Number of resource blocks (n)		
		50	75	100
Reference signals	4s/84	9.52	9.52	9.52
Physical Downlink Control Channels (PDCCH) [*l* = 2]	(2 x 12 – 2s) / (2 x 84)	11.90	11.90	11.90
Primary and Secondary Synchronisation Channels (PSCH/SSCH)	(2 x 2 x 12 x 6) / (20 x 84n)	0.34	0.23	0.17
Physical Broadcast Channels (PBCH)	(4 x 12 – 2s) x 6 / (20 x 84n)	0.31	0.21	0.16
Total		22.07	21.86	21.75

A9.29 In order to take the condition for relevant indoor locations into account in the SINR calculation, the maximum additional radio propagation loss for the relevant band associated with these locations is applied to the outdoor signal levels received from the serving and surrounding cells prior to determining the SINR calculation.

A9.30 We have chosen ITU-R Recommendation P.1812-2 “A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands” as the most appropriate propagation model to assess the coverage obligation[88]. This is because it directly takes into account terrain which will have a greater effect on the network coverage footprint at the locations in the UK that will be required to meet a 98% coverage obligation as specified above..

A9.31 ITU-R Rec. P.1812-2 describes a propagation prediction method suitable for terrestrial point-to-area services in the frequency range 30 MHz to 3 GHz and is therefore applicable for 4G services in any of the bands between 800 MHz and 2.6 GHz. To assess the coverage obligation, this recommendation will be used in a point to point mode to calculate the median path loss (i.e. for 50% time and 50% locations) and the location variation will be applied in the SINR calculation.

A9.32 We will use the default parameters for representative clutter heights as defined in P.1812-2. These are given in Table 9.26.

[88] http://www.itu.int/rec/R-REC-P.1812-2-201202-I/en

Table 9.26: Default information for clutter-loss modelling in P.1812-2

Clutter type	Representative clutter height (m)	
	Use in profile equation[89]	Use in Terminal clutter losses[90]
Water/sea	0	10
Open/rural	0	10
Suburban	10	10
Urban/trees/forest	15	15
Dense urban	20	20

A9.33 Within the determination of the SINR, we assume a relevant Body Loss of 2.5dB, consistent with the 3G verification methodology.

A9.34 In setting out the compliance verification methodology we have made some assumptions as to the likely performance and network setup of LTE within the required timeframe of the obligation. In particular this affects our SINR cutoff and throughput mapping functions used to determine the required SINR values. If the licensee is able to provide sufficient evidence to satisfy us that these assumptions are incorrect then we may consider making changes to these elements of the compliance verification methodology.

[89] Equation 1c in P.1812-2

[90] Section 4.7 in P.1812-2 applicable to Equation 64b for water/sea/open and rural categories and Equation 64a for the other categories

Annex 10

Ofcom's comments on responses to the January 2012 technical analysis

Introduction

A10.1 In the January 2012 consultation we provided a set of results on technical performance modelling for deployment of networks in various quantities of spectrum in the 800 MHz, 900 MHz, 1800 MHz, 2.1 GHz and 2.6 GHz bands, and we received a number of comments from stakeholders on the technical analysis. This annex considers the comments that we received on various aspects of the technical modelling and the assumptions that lay behind it, and provides our analysis of the points raised. We have provided new technical modelling results in Annex 7 and set out any changes to the methodology in Annex 8 of this Statement.

Building penetration loss

Comments to the January 2012 consultation

A10.2 There was a range of views on the building penetration loss that we had assumed in our technical modelling and the respondents were not all of the same view in relation to our assumptions.

A10.3 We received critical comments on the relative attribution of loss between external and internal walls and on the variation of building penetration loss with frequency. One confidential response was of the view that the building penetration loss values in our 'Min var' case were too low across all depths of coverage; the respondent thought that for deep indoor locations the 'Max var' building penetration loss values were not too unreasonable but they were too low to be realistic for shallow indoor locations. Another confidential response suggested that the weight of evidence supported a correlation between building penetration loss and increasing frequency, and therefore had a preference for the 'Max var' assumptions on the grounds that the 'Min var' assumptions on the relation between building penetration loss and frequency were not sustainable.

A10.4 Vodafone stated that it did not agree with the increased frequency dependence of building penetration loss in the 'Max var' assumptions, compared to the March 2011 consultation. It suggested that the March 2011 values were an overestimate of the frequency dependence and the January 2012 'Max var' assumptions increase the overestimate. Overall, Vodafone believed that the situation would be closer to the 'Min var' assumption.

A10.5 In addition, Vodafone commented on the assumptions on standard deviation of building penetration loss. In particular it was concerned that the upper bound in our assumptions could give rise to results that showed negative building penetration loss. Vodafone acknowledged that there was evidence for these values in published papers but was concerned that some of the variation could be due to the range of heights where the signals were measured, and therefore there was a risk that we had overestimated the building penetration loss standard deviation. A separate comment in a confidential response suggested that the building penetration loss values in our 'Min var' case were too low across all depths of coverage. It considered the ‘Max var’ building penetration loss values to be not too unreasonable for the deep indoor locations but much too low to be realistic for the shallow indoor locations, while also noting support for the ‘Max var’ assumption of an increase in the building penetration loss standard deviation with frequency.

Our analysis and response

A10.6 We have reviewed our assumptions in light of these comments. We have revised our assumptions for the modelling that we have included in this Statement. In summary, our new values of BPL for ‘Minvar’ have increased and whilst there remains a frequency dependency for ‘Maxvar’, the magnitude of this frequency dependency is reduced. We have also reduced considerably the standard deviation associated with Maxvar in some cases The new modelling results are in Annex 7 and the revised methodology is set out in Annex 8.

Distribution of users inside buildings

Comments to the January 2012 consultation

A10.7 We received a confidential response which contained comments on our assumptions on the numbers of users at different depths within buildings. In the January 2012 consultation we had modelled a distribution of users at four in-building depths plus outdoors, i.e. a total of five depths, and had assigned 20% of users to each notional depth. The confidential response commented that although this appeared to reasonably reflect current mobile voice and smart phone usage patterns, future data usage patterns were expected to increase the proportion of indoor consumption.

A10.8 The same response also questioned the model assumption that the 40% of users at the first two in-building depths (1m and 5m depths) are close to a wall that is well illuminated by a nearby base station. It was suggested that many locations near windows could be on the side of the building that does not face the best serving site, and for a number of locations the windows could be at an oblique angle to the propagation from the serving site. In such locations, propagation from the serving site into the building could be via multiple diffractions or reflections and the comment indicated that the building penetration losses would be equivalent to locations deeper in the interior of the building. We were told that a significant majority of users would experience the equivalent of the deep indoor building penetration losses, rather than the 40% assumed in our January 2012 modelling.

A10.9 Three recommended in its response that we should conclude that there is a high prevalence of deep indoor and hard to serve locations.

Our analysis and response

A10.10 We did not receive any direct evidence in support of the comments on distribution of users. However, we recognise this is an area where there is little detailed evidence.

A10.11 In paragraph A14.28 of the January 2012 consultation we explained that although these depths are presented as actual physical distances from the external wall, we exercise caution in interpreting this literally. For instance, we said that whilst our results for a depth of 1 metre may represent someone very close to the external wall where the major influence is the external wall loss, our results for a depth of 15m could be taken to represent a user physically very deep within a relatively low loss building but could also represent a user who is at a shallower physical depth but subject to greater propagation losses e.g. behind several internal walls or in a building with a very thick external wall etc. So our interpretation of the analysis was one of ability to serve a distribution of easier and harder to reach locations, rather than one of serving users at absolute depths in a building.

A10.12 In our revised modelling, we no longer show results for four in-building depths; our modelling now includes two in-building depths: “shallow” and “deep”. In addition, our revised modelling is now presented as separate sets of results, for parameters that are representative of users in shallow locations, and parameters that are representative of users in deep locations. This allows us to interpret the data as representative of those locations and avoids us having to make assumptions on their relative importance or on how users are distributed in practice. The new modelling results are in Annex 7 and the revised methodology is set out in Annex 8.

Simulation areas

Comments to the January 2012 consultation

A10.13 In the January 2012 consultation our technical modelling used two areas around West London and Cambridge. We received two confidential responses in relation to these simulation areas. One confidential response expressed concerns that we had focussed on the West London results and that this approach would reduce the probability of noise-limited operation in our results, due to the focus on capacity in this area. The response suggested that other parts of the country were better represented by the Cambridge simulation area, characterised by greater areas of noise limited operation. Three stated that our use of two sample areas to draw conclusions at a national level is unsound.

Our analysis and response

A10.14 We chose ‘West London’ because we believed it reasonably representative of the more populous areas of the country where competition between operators will be predominantly focused. We believe that this was a valid approach to support a competition assessment that was considering the ability of networks to be credible national wholesalers. We have, however, revised our modelling and moved to an approach based on population density, which avoids the problem of selecting “typical” areas and makes it much clearer what the exact criteria are for the selection of modelling areas. The simulation areas that we have used in our revised modelling are:

- the zero to 50% most densely populated;
- the 50% to 80% next most densely populated; and
- the 80% to 90% densely populated area .

A10.15 These areas are defined on the basis of local authority district boundaries but they exclude Northern Ireland due to lack of appropriate data. Hence the zero to 50% area is comprised of the most densely populated local authority districts in England, Scotland and Wales where 50% of the population live (from the 2001 census).

A10.16 Having undertaken the new modelling, we have observed that the ‘West London’ results match reasonably well the results based on the zero to 50% most densely populated areas of the country. The description of the areas used in the new modelling is in the results annex (Annex 7).

The synthetic network

Comments to the January 2012 consultation

A10.17 In response to the January 2012 consultation, Three said that our synthetic modelling process predicts extremely unrealistic site numbers for an equivalent national network. In its view, the site numbers that we had calculated, both within our chosen sample areas and in the extrapolated UK network, were not close to accurately reflecting a real UK network.

A10.18 Three specifically commented on the method we had used to scale up the seed network to generate additional sites for larger national site numbers, and our sub-sampling approach to generate a range of networks with smaller site numbers. The comment suggested that our method results in a disproportionate number of sites in key urban and suburban areas, and use of such a synthetic model can never be as good as a national modelling approach based on a real mobile network. Our analysis and response

Our analysis and response

A10.19 We acknowledge that there are inevitable limitations in any modelling approach but we did not intend the model to replicate how a network might be rolled out. Our site placement algorithm (see Annex 8) attempts to place sites in an intelligent way by ensuring each site is placed optimally to serve an area with the greatest population density based on a 'real' seed network of approximately 9,000 sites[91]. In contrast, an operator might choose a different approach, based on maximising a coverage footprint, capacity, or focus on particular areas of population. Inevitably the profile of sites generated by our site placement algorithm is unlikely to match closely the roll-out profile of a new entrant operator starting from scratch. For instance, comparing the coverage achieved by H3G as their 2100 MHz 3G site base grew over a number of years from 2003 onwards would not be a fair comparison as they would have been interested providing a balance of both coverage and capacity in order to optimise investment costs with generating revenue.

A10.20 The impression of an unusually high proportion of sites in the 'West London' area may have been created by a typographic error in paragraph A7.54 of the consultation where we erroneously stated that a network with the equivalent of 10,000 sites nationally had a total of 2,651 sites in our 'West London' area. The 2,651 sites in our 'West London' area were actually for a network with the equivalent of 18,000 sites nationally.

Potential limitations due to uplink performance

Comments to the January 2012 consultation

A10.21 Following the January 2012 consultation, we received comments from one confidential respondent that suggested that uplink limitations in 4G networks are significant and should be considered in the Ofcom analysis. This issue was not raised by other respondents.

A10.22 The confidential respondent was concerned about uplink limitations that could restrict the data-rates that can be achieved in noise limited environments, and

[91] Data for significantly larger seed network was not available to us

which it stated are more prevalent in high frequency than low frequency networks. The respondent highlighted that a downlink link budget analysis for a particular example suggests that out to a particular range in a suburban noise limited deep indoor environment a 2Mbit/s downlink service is feasible, but that the link would fail at a shorter range than the particular range under consideration because of failure of the uplink due to loss of control channel synchronisation. In the example the respondent stated that the uplink will fail when it drops below around 80kbit/s whilst the downlink could still operate at around 2.5Mbit/s, and at these data rates the respondent concluded that with the uplink providing less than 4% of downlink speeds this would be barely sufficient to service Transport Control Protocol (TCP) acknowledgements. Doubling the bandwidth, in this example, resulted in an uplink to downlink data-rate ratio of less than 2%, which the respondent claimed is insufficient to support acknowledgements of a downlink TCP stream. The respondent also stated that the uploading performance in such areas will be highly unsatisfactory for many applications.

Comments in response to Ofcom's request for clarification

A10.23 Ofcom sought clarification from the confidential respondent who had supplied the comments in paragraph A10.22. In its confidential response to our request the respondent further commented that the requirement for a minimum data-rate of 80kbit/s to be achieved in the uplink to ensure service is possible may not be a fixed data-rate value, but seems to depend upon deployment scenario. A specific point we asked the respondent for comment upon was the number of resource blocks (12x15 kHz) required in the uplink to achieve the minimum uplink throughput for a viable downlink, and it indicated that more than one resource block is required for a throughput of 64kbits/s. In connection with the requirement for the uplink to provide a minimum of 4% of the downlink data-rate in support of adequate TCP performance, it indicated that the percentage has a dependence upon implementation. The respondent also provided evidence to indicate that a high single-user downlink performance was achieved at an SINR which is some way above the "minimum SINRs" adopted in Ofcom's consultation. It stated that this is because the uplink failed, though evidence was not provided showing uplink failure.

Comments in response to Ofcom's published supplementary information

A10.24 In response to confidential comments raised in response to the March 2011 consultation, Ofcom had considered the impact of potential uplink limitations and supplementary information[92] was published at the end of the consultation period for the January 2012 consultation. Our investigation was based on a link budget analysis, and one of the assumptions was that, in the uplink, 23dBm EIRP over one resource block would be sufficient to sustain the downlink. We requested comments on the supplementary information from a number of respondents and confidential feedback from one respondent stated that they believe the LTE link budget to be uplink limited by 0.5dB when the downlink is unloaded and downlink limited by 2dB once load is applied to downlink. Another confidential respondent stated with reference to their own link budget that the uplink and downlink are shown to be finely balanced for the user bit rates chosen. They also stated that, while there are some detailed differences between their parameters and those used by Ofcom, their link budgets indicate that the downlink is the limiting link for the user bit rates in their link budgets. They commented that this is consistent with Ofcom's analysis.

[92] 800 MHz & 2.6 GHz Combined Award – Additional technical information and simulation results, Feb 2012, Section 4 Uplink Limitations, http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/annexes/Additional_technical_inform1.pdf

Assuming higher downlink user bit rates, they stated that they expect the downlink to continue to be the limiting link.

Our understanding of the points raised by these comments

A10.25 In response to the points raised, we addressed the following technical issues reported in paragraph A10.22:

i) A minimum data-rate is required in the uplink to maintain connectivity of the uplink. The respondent assumed this to be 80kbit/s in its analysis.

ii) The uplink data-rate needs to be a minimum percentage of the downlink data-rate in order to sustain adequate TCP performance. The respondent assumed this to be 4% in its analysis.

iii) More than one resource block is required in the uplink to achieve a throughput of 64kbit/s.

Technical investigation by Real Wireless

A10.26 We asked Real Wireless to analyse the points reported in paragraph A10.22. Their conclusions are summarised below and supporting evidence is provided in their report published alongside this statement[93].

Minimum data-rate in the uplink

A10.27 Within the Ofcom LTE model the calculation of results for a given simulation area is focused on modelling the downlink SINR distribution in the simulated area and do not explicitly consider uplink limitations. The assumption is that the SINR cut-off used to ensure maintenance of the downlink control channels will be sufficient (indirectly) to maintain uplink control channel connectivity also.

A10.28 We have found no evidence to support the respondents' claim that 80kbit/s is the minimum supported data-rate to maintain connectivity of an LTE uplink. The respondent refers to loss of control channel synchronisation, which we assume to mean that at certain downlink ranges examined by the Ofcom LTE model the uplink SINR would not be good enough to maintain the uplink control channels which consist of the Physical Uplink Control Channel (PUCCH), Physical Random Access Channel (PRACH) and sounding reference signals.

A10.29 Discussions of uplink coverage and link budgets from standard LTE texts from Sesia[94] and Holma and Toskala[95] include Physical Uplink Shared Channel (PUSCH) rates of 5kbit/s and 64kbit/s, respectively, showing that 80kbit/s is not an absolute minimum for uplink connectivity. The discussion of uplink coverage in Holma and Toskala makes the assumption that two uplink resource blocks would be used to support a 64kbit/s uplink data-rate and that this would require an SINR of -7dB.

[93] See the report for Ofcom by Real Wireless: Investigations of technical issues related to the combined award of 800MHz and 2.6GHz spectrum (Section 4 and Annex C) published alongside this statement
[94] S. Sesia, I Toufik, M. Baker, "LTE the UMTS Long Term Evolution", Wiley 2009
[95] H. Holma and A Toskala (eds), "LTE for UMTS: Evolution to LTE Advanced", 2nd ed., Wiley, 2010

A10.30 A comparison of cell range across uplink channels in Sesia[94] also implies that in the 2x5 MHz frequency division duplex scenario examined that the required uplink control channels (including the PRACH and ACK/NACK[96] and Channel Quality Indicator (CQI) information on the PUCCH) can achieve similar ranges to a 5kbit/s PUSCH. This further supports the view that the equivalent minimum uplink data-rate at which uplink control channels would start to fail could be much lower than the suggested 80kbit/s.

A10.31 We have also found no evidence that there is any requirement in the 3GPP LTE standards[97,98,99] that a minimum data-rate must be maintained on the PUSCH to maintain the uplink connectivity required to support a purely downlink service level as targeted by our LTE model. Given that uplink control information such as CQIs and ACK/NACKs can be sent on the PUCCH when the PUSCH is not in use[99], it is possible that a purely downlink service would only require PRACH, PUCCH and sounding reference signals to be available at the cell edge as the minimum uplink connectivity to support the downlink connection.

A10.32 Therefore uplink connectivity would be maintained in Ofcom's LTE model providing that the maximum path loss at the cell edge is within the required level to meet the SINR targets for the uplink control channels composing of the PRACH, PUCCH and sounding reference signals to be maintained.

A10.33 3GPP simulations[100] and the discussion of uplink coverage in Sesia[94] implies that there is a range balance built into the design of the uplink and downlink control channels and that the PUCCH will have similar range to the Physical Broadcast Channel (PBCH). These sources also highlight that any uplink/downlink coverage gaps can be closed by techniques such as using a repetition factor. In the case of the PRACH a repeated preamble burst may be required to achieve similar coverage to the PBCH in the 2x5 MHz frequency division duplex scenario examined in these sources, but it is concluded that it should be feasible to maintain the uplink downlink control channel range balance with these adaptations.

Minimum data-rate in the uplink needed to support downlink TCP traffic

A10.34 It is likely that a large proportion of LTE data traffic will use TCP. Various sources suggest uplink acknowledgement traffic might be between 0.5%[101] and 11%[102] of the TCP traffic on the downlink, depending on the implementation. The 4% figure suggested by the confidential respondent seems a reasonable proportion, and so for 2Mbps of DL TCP traffic, we might expect 80kbps of uplink acknowledgements.

Resource block requirements in the uplink

A10.35 The uplink data-rate depends upon:

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[96] ACK is a positive ACKnowledgement and NACK is a Negative ACKnowledgement. It is used in a hybrid automatic repeat request.

[97] 3GPP TS 36.211, E-UTRA Physical Channels and Modulation, Release 10, V10.4.0, December 2011

[98] 3GPP TS 36.212, E-UTRA Multiplexing and channel coding, Release 10, V10.5.0, March 2012

[99] 3GPP TS 36.213, E-UTRA Physical layer procedures, Release 10, V10.5.0, March 2012

[100] Motorola, R1-073371 – E-UTRA Coverage, 3GPP TSG RAN1, August 2007

[101] "Performance evaluation of HTTP/TCP on asymmetric networks", Go Hasegawa, Masayuki Murata and Hideo Miyahara, http://goo.gl/nMPr8

[102] Riikka Susitaival, Henning Wiemann, Jessica Östergaard, Anna Larmo: "Internet access performance in LTE TDD". IEEE Vehicular Technology Conference (VTC 2010-Spring), 2010

- the number of simultaneous resource blocks in the frequency domain over which the UE transmit power is spread
- the number of resource blocks per second in the time domain (one every transmit time interval or a particular number every transmit time interval)
- number of information bits per resource block (which depends upon the modulation and coding rate, and thus the SINR)

A10.36 Reference to 3GPP TS 36.211 and [[103]] shows that one resource block allocations are possible. In addition, a 3GPP document[104] considers concentrating full power into one resource block. More resource blocks can be used to provide more throughput, but more simultaneous resource blocks means less power per resource block and thus reduces the path loss than can be tolerated. We note that Holma and Toskala[105] indicate in their uplink link budget that two resource blocks are required to provide 64kbit/s in the uplink.

Our analysis and response

Minimum data-rate in the uplink

A10.37 Given the evidence provided by Real Wireless and our own engineering judgement we think that it is valid to assume in our model that provided we meet the SINR cut-off to maintain downlink control channel connectivity that this is likely to also ensure that the minimum required uplink control channel connectivity is maintained and that a minimum uplink data-rate of 80kbit/s does not need to be explicitly considered in our modelling.

A10.38 However, we have conducted a sensitivity analysis to explore the potential impact of TCP requirements in the uplink (to support acknowledgements) and for this analysis we explicitly use an uplink SINR cut-off of -7.5 dB to ensure uplink control channel connectivity is maintained (see Annex 7 for details of these results and Annex 8 for details of the methodology used).

Minimum data-rate in the uplink needed to support downlink TCP traffic

A10.39 We have not previously addressed uplink performance in connection with TCP traffic. However, this protocol is likely to be widely used for the majority of LTE data traffic. We do not have sufficiently solid information at this early stage of LTE deployments to determine exactly what percentage of the downlink data-rate is required as an uplink data-rate to ensure support of TCP acknowledgement traffic in the uplink.

A10.40 Given the lack of firm evidence to the contrary we are content to use 4%, as suggested by the confidential respondent who raised the issue, in our own sensitivity analysis. This implies that to maintain a 2Mbit/s downlink TCP data-rate would require an uplink data-rate of 80kbit/s just for acknowledgements. However,

[103] *"Uplink Power Control in UTRAN LTE Networks",* R. Müllner, C. Ball, K. Ivanov, J. Lienhart and P. Hric, Proceedings from the 7th International Workshop on Multi-Carrier Systems & Solutions, pp 175, May 2009, Herrsching, Germany.

[104] *"Spectrum Emissions Mask considerations for LTE UE",* Ericsson, 3GPP Tdoc R4-070382, April 2007

[105] "LTE for UMTS: Evolution to LTE-Advanced", Holma H and Toskala A, John Wiley and Sons, 2011.

our understanding of TCP is that the protocol adapts the transmission data-rate in response to feedback from receipt of acknowledgements in the reverse direction. In cases where acknowledgements are constrained TCP will reduce the transmission data-rate to a point which can be supported by the acknowledgements. Hence downlink data-rates will degrade in cases where the achievable uplink data-rate is the limiting factor but coverage. Links are unlikely to fail completely but users in hard to serve locations are likely to receive limited data-rates (below what they could expect absent the TCP acknowledgement constraint). In our sensitivity analysis we explore the impact of TCP acknowledgements by estimating the uplink data-rate achievable at each sample point in our simulation and calculating the downlink TCP data-rate that this could support based on the requirement that the uplink data-rate needs to be at least 4% of the downlink data-rate (see Annex 7 for details of these results and Annex 8 for details of the methodology used).

Resource block requirements in the uplink

A10.41 We do not think that there is evidence to support a claim that the minimum number of resource blocks that can be scheduled in the uplink is more than one.

Downlink SINR cut-off.

A10.42 The confidential respondent who had supplied the comments in paragraph A10.22 and clarification comments in paragraph A10.23 indicated that a high single-user downlink performance was achieved at an SINR which is some way above the “minimum SINRs” adopted in Ofcom’s consultation. By “minimum SINRs” we assume that the respondent is referring to the SINR cut-off. However, we note that to achieve high downlink target throughputs a higher target SINR than the SINR cut-off of -5 dB will generally be required.

Views on the use of RSRP as the relevant metric for assessing performance, in addition to SINR

Comments to the January 2012 consultation

A10.43 One confidential response disagreed with our use of SINR alone to make a decision as to whether or not user equipment (UE) can access the network. The respondent said that our assumption was that a user communicates with the network if SINR is greater than -10dB and -5dB for the ‘Min var’ and ‘Max var’ scenarios respectively, but in reality no user will be able to communicate with the network if the signal level falls below -122dB for a 15kHz subcarrier, irrespective of the level of interference.

A10.44 The respondent stated that cell selection cannot be determined by SINR alone and that 3GPP states that Reference Signal Received Power (RSRP) should be used to determine serving cell selection decisions. The respondent quoted 3GPP TS 36.133:

> “After a UE is switched on the Cell selection process takes place, as described in TS36.304. This process allows the UE to select a suitable cell where to camp on in order to access available services. In this process the UE can use stored information (Stored information cell selection) or not (Initial cell selection). A cell shall be considered detectable provided following conditions are fulfilled:

RSRP >= -122dBm for Bands 3, 8, 12, 13, 14, 20 and
RSRP Ês/Iot >= -4 dB”

A10.45 The respondent’s understanding was that statement above clearly recommends an RSRP approach to estimating coverage.

A10.46 The respondent said that RSRP is in effect a measure of the wanted signal strength whilst SINR looks at the relative strength of the signal compared to the level of interference, and that a user can only connect to the network if signal strength is above a minimum wanted level, which must be achieved regardless of interference, therefore considering SINR in isolation to determine coverage is not appropriate.

A10.47 The respondent said that using an SINR only approach, as we had done, will result in predicting coverage for some UE which does not satisfy the minimum signal strength requirements which are needed for communication to take place. Hence the respondent concluded that our modelling would produce overly optimistic coverage results. The respondent said that by use of SINR alone we had failed to follow an industry standard approach to modelling coverage.

Comments in response to Ofcom’s request for clarification

A10.48 In a further clarification of their consultation response the respondent has commented that the receiver noise floor of a LTE UE within a 15 kHz sub-carrier is approximately -122dBm and implies that this is the theoretical limit of the minimum RSRP level that can be measured.

A10.49 In a further clarification to their consultation response the respondent has commented that if the measured RSRP level goes below -122dBm an idle mode UE will reselect another cell or suffer unacceptably poor performance.

Our analysis and response

A10.50 We asked Real Wireless to analyse the points reported above on RSRP, their findings can be found in a separate report published alongside this statement[106].

A10.51 Our approach of using a minimum SINR cut-off level of -5dB to determine if LTE coverage is achievable at a particular location implicitly applies a minimum RSRP threshold of -127dBm (see Table A10.27 for details). We therefore disagree with the comment that we have neglected to consider the minimum signal strength requirement in our coverage analysis.

[106] See the report for Ofcom by Real Wireless: Investigations of technical issues related to the combined award of 800MHz and 2.6GHz spectrum (Section 3 and Annex B) published alongside this statement

Table A10.27: Equivalent RSRP level implied by an SINR cut-off of -5dB

Description	Value	Comments
UE reference sensitivity (10MHz bandwidth)	-94dBm	From 3GPP TS 36.101[107]
SINR cut-off	-5dB	The SINR threshold cut-off used in the 'Maxvar' case of our assumptions -see Annexes 7 and 8
Minimum wideband target RSSI (assumes 10MHz system bandwidth)	-99dBm	This combines the UE reference sensitivity and SINR cut-off from the previous two rows to give the minimum target wideband RSSI that must be achieved at the receiver to meet the SINR cut-off requirement in a noise limited scenario. In an interference limited scenario the implied target wideband RSSI level will be higher than this.
Equivalent minimum RSRP (RSSI per 15 kHz sub-carrier)	-127dBm[108]	This converts the minimum wideband 10MHz target RSSI to the equivalent target RSRP level per 15 kHz sub-carrier assuming that power is equally divided across all 600 resource elements.

A10.52 In both the March 2011 and January 2012 consultations we based our technical analysis on the SINR approach, which implicitly includes RSRP. Only one respondent has suggested this is not appropriate.

A10.53 The RSRP level of -122dBm is applicable to one aspect of the 3GPP specification, namely cell re-selection, however there are other references in the specification in relation to conformance testing[109] that explicitly mention measuring RSRP at lower values than -122dBm.

A10.54 The reference to 3GPP TS 36.133 that the confidential respondent referred to appears to be a combination of two different parts of the standard:

- The first part: "*After a UE is switched on the Cell selection process takes place, as described in TS36.304. This process allows the UE to select a suitable cell where to camp on in order to access available services. In this process the UE can use stored information (Stored information cell selection) or not (Initial cell selection)*", is taken from **section 4.1 on Cell Selection**.

- The second part: "*A cell shall be considered detectable provided following conditions are fulfilled: RSRP >= -122dBm for Bands 3, 8, 12, 13, 14, 20 and RSRP Ês/Iot >= 4 dB*", is taken from **section 4.2 on Cell Re-selection**.

[107] Table 7.3.1-1 in 3GPP TS 36.101 V11.1.0, "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception", June 2012
[108] This figure is the same regardless of bandwidth: a bandwidth of 10 MHz was used for illustrative purposes.
[109] See Table B.3.1-1 in 3GPP TS 36.133 V11.1.0, "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management", June 2012

A10.55 These two parts of the standard[110] referred to, namely **Cell Selection** and **Cell – Re-selection,** relate to different procedures and it is therefore not appropriate to mix the requirements in the way suggested. Cell selection applies to the procedure a UE undergoes when it is first switched on and is looking for a suitable cell to camp on to. This procedure requires the UE to measure RSRP but there is no minimum threshold requirement. Cell re-selection is the procedure the UE applies when it is not in an active session (idle mode) and is looking to see if there is another cell within its vicinity which would provide a better connection. For the cell re-selection procedure the UE measures the RSRP of neighbouring cells but if below -122 dBm it will not re-select to that particular cell. However, the standard does not state the UE will drop from its currently connected cell when the RSRP from that cell falls below -122 dBm. It should also be noted that when a UE is in an active session (connected mode) the handover procedure to neighbouring cells does not include a minimum RSRP threshold.

A10.56 In terms of the required RSRP threshold that would be appropriate to apply in a LTE network we have no grounds to believe that the level of -122dBm suggested in the confidential response is the minimum practical threshold. We have seen evidence from one operator in confidential material supplied in response to an information request that data throughput is achievable at corresponding RSRP values down to at least -124dBm. In informal discussion with another operator we have also seen evidence that data throughput is achievable at corresponding RSRP values down to at least -124dBm. We also note that the evidence of operation down to -124dBm is from early LTE deployments. In addition (as noted in paragraph A10.51) an SINR cut-off of -5dB, as required to maintain the Physical Downlink Control Channel for LTE, is equivalent to an RSRP of -127dBm. As the technology matures we would expect equipment performance to improve over time and therefore we believe that operation below and RSRP level of -124dBm (down to at least -127dBm implicit in our SINR cut-off) is a reasonable expectation.

A10.57 In summary, we have implicitly included an RSRP threshold in our simulations (-127 dBm) and there is no ground to believe that we should have used an explicit threshold of -122 dBm instead. We believe that the approach used in our LTE model is appropriate, given the objectives of our simulations, as it considers coverage in both noise and interference limited scenarios. However, we have conducted a sensitivity analysis to explore the potential impact of using and alternative RSRP threshold as an limit on coverage. For this sensitivity analysis we have use an RSRP value of -124dB as supported by the evidence from the early LTE deployments we have seen (see Annex 7 for details of these results and Annex 8 for details of the methodology used).

Propagation model

Comments to the January 2012 consultation

A10.58 Vodafone commented on our implementation of the Extended Hata model for our analysis of the 800 MHz, 1800 MHz and 2600 MHz bands. Vodafone stated that our MATLAB implementation of path loss for the urban clutter type at frequencies in the range 2000 MHz to 3000 MHz did not match the definition in the CEPT SEAMCAT implementation of Extended Hata. In particular, Vodafone indicated that a specific term in one equation should have been a constant, rather than being dependent on frequency. Vodafone calculated that this would result in 3.9dB overestimate of path

[110] 3GPP TS 36.133 V8.18.0, “LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management”, June 2012

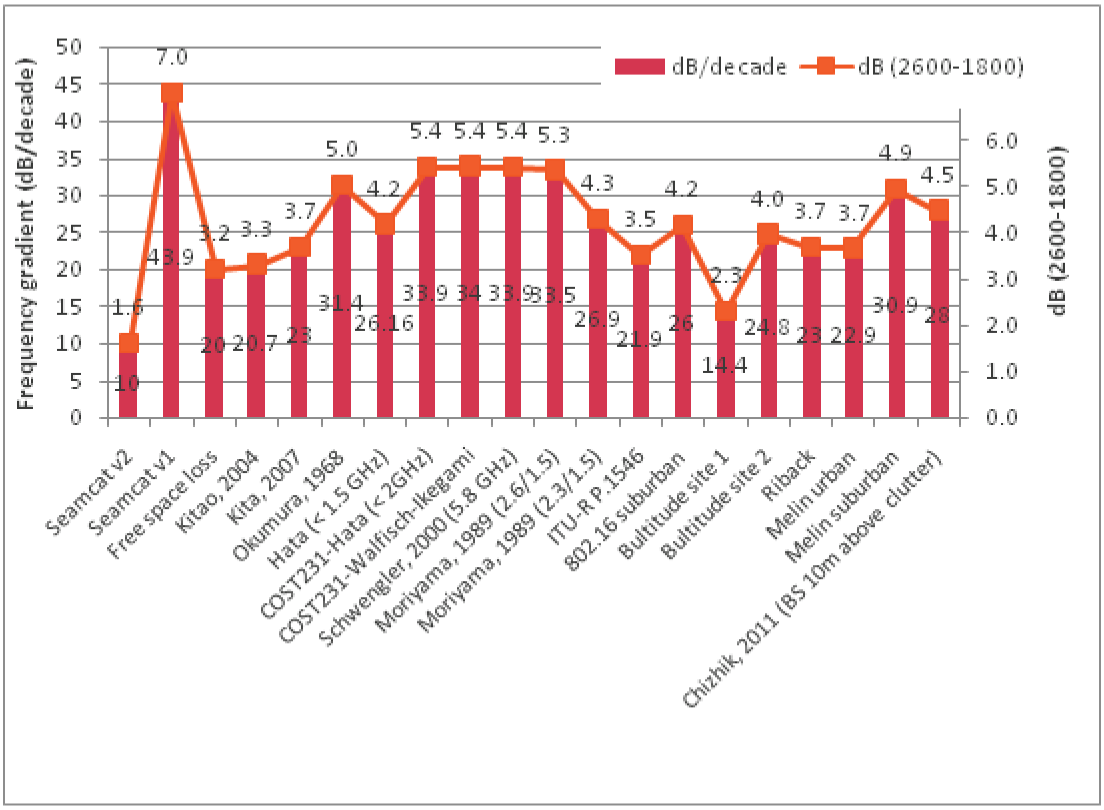
loss at 2.6 GHz and would cause an underestimate of cell radii at that frequency to around 60% of the size predicted by the Extended Hata model. This underestimate would apply to noise limited cells; interference limited cells would be less affected.

Our analysis and response

A10.59 We identified the reason for the discrepancy between our implementation of Extended Hata and the CEPT SEAMCAT documentation which arose through a (now corrected) error in some ECO documentation for Extended-Hata in their SEAMCAT modelling tool[111], even though, as recently established with ECO, SEAMCAT has always had "33.9 × log 2000" in the implementation. Nevertheless, we observed that the results curves for 1800 MHz and 2.6 GHz lay very close together and we had some concerns that the results might not be physically valid.

A10.60 We asked Real Wireless to review the validity of the propagation model, particularly the extension above 2000 MHz and make recommendations. Real Wireless compared a number of studies and propagation models and compared them on the basis of the frequency gradient (in various frequency ranges) and the implied differences in mean path loss between 2600 MHz and 1800 MHz. Figure A10.67 shows this comparison.

Figure A10.67: Summary of frequency gradients and mean path loss difference between 2600 MHz and 1800 MHz from studies considered by Real Wireless



A10.61 Real Wireless's findings were:

[111] "SEAMCAT implementation of Extended Hata and Extended Hata-SRD models", http://tractool.seamcat.org/raw-attachment/wiki/Manual/PropagationModels/ExtendedHata/Hata-and-Hata-SRD-implementation_v1.pdf

- The SEAMCAT v2 model has substantially lower frequency dependence (10dB/decade) above 2 GHz than the v1 model (43.9dB/decade) which was used by Ofcom in the January consultation.

- The precise origin of the frequency dependence in the SEAMCAT v2 model above 2 GHz is obscure and does not align with the measurement or modelling studies reported in the Real Wireless analysis. Ofcom contacted the SEAMCAT administrator at the European Communications Office who confirmed that the origin of the extension above 2 GHz is unknown.

- Comparing both approaches with measurements reveals that neither SEAMCAT approach taken alone is representative and frequency dependence in measurements occupies an intermediate value between the two SEAMCAT cases.

- Measurements vary significantly in the range 15 to 35dB/decade over the relevant frequency range, with 25dB/decade being somewhat typical.

- Further, consideration of the relevant physical mechanisms suggests that the dependence on frequency should:

  - Reduce with increasing frequency

  - Reduce with reducing base station antenna height relative to the clutter

  These features are not included in any of the Hata-based models. While SEAMCAT v2 incorporates the first of these features to some extent, it does not incorporate the second feature.

- These findings suggest Ofcom should modify the propagation model employed at 2.6 GHz to have approximately between 2.3 and 5.5dB (central value around 4dB) greater loss at 2.6 GHz than 1.8 GHz, but should not place too much weight on the specific value adopted, given the variabilities which are not captured by the standard models.

A10.62 We have accepted the Real Wireless recommendations and adapted our implementation of the Extended Hata model above 2000 MHz so that it gives a 4dB increase in loss for 2.6 GHz when compared to 1800 MHz. The new modelling results are in Annex 7 and the revised methodology is set out in Annex 8. The analysis by Real Wireless is published in a separate report, published alongside this statement[112] .

Comments on our network loading assumptions

Comments to the January 2012 consultation

A10.63 One confidential respondent was concerned that the use of an average 85% network loading would increase the probability of locations being interference limited, and this would make the modelled difference between low band and high band networks appear lower than would be expected for a well-designed network. The respondent was of the view that our network loading assumptions were too

[112] See the report for Ofcom by Real Wireless: Investigations of technical issues related to the combined award of 800MHz and 2.6GHz spectrum (Section 5 and Annex D) published alongside this statement

high; it suggested that in any given cell a maximum utilisation of around 70% is needed in order to keep user data-rates at a reasonable fraction of the single-user data-rate, to support video services with an acceptable grade of service and to maintain a good overall latency performance. The respondent also indicated that the unequal loading of cells in any given area and the geographic distribution of traffic would tend to reduce the average load for a network to closer to 50%.

Comments in response to Ofcom's request for clarification

A10.64 Ofcom sought clarification from the confidential respondent who had supplied the comments in paragraph A10.63, and in its confidential response to our request the respondent referred to queuing theory and the level of loading to ensure smooth operation in terms of latency performance.

Our analysis and response

A10.65 While there is a link between loading and user experience, the focus of our LTE modelling is upon achievable throughputs at different frequencies rather than latency targets. However we note that there are quality of service (QoS) mechanisms within LTE to ensure that delay sensitive traffic is prioritised during periods of congestion.

A10.66 We have conducted a sensitivity analysis to demonstrate the effect of a lower network loading than 85% upon single-user throughputs. The results for the 'Maxvar' case are shown in Figure A10.68 and Figure A10.69, where the results include a network loading of 50%. As expected the reduction in loading generally lifts the throughput curves for all frequencies, though there is only a modest effect on the coverage, the difference between the frequencies remaining approximately the same. We also note that the effect of the change in network loading only has a weak dependence on user depth.

A10.67 The effect upon the difference in single-user throughputs for the different frequencies is modest, and given it is common to assume 75 – 80% loading in 3G, with the methodology for 3GPP co-existence simulations[113] assuming 100%, we consider that adopting 85% loading for our simulations is reasonable.

[113] "*Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios; (Release 8)*", 3GPP document TR 36.942 8.3.0, 2010-10-01

Figure A10.68: Loading comparison, shallow

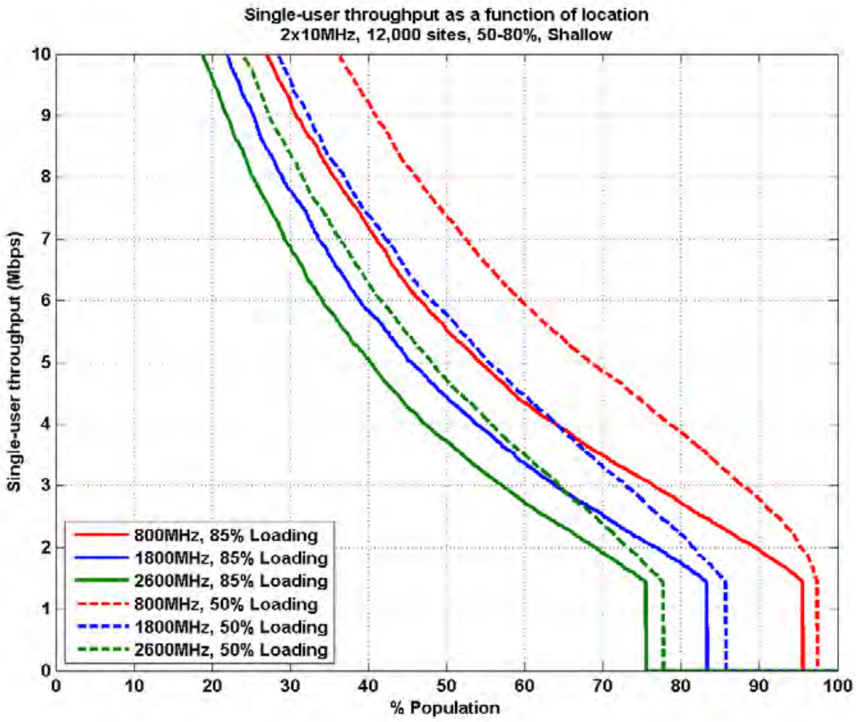
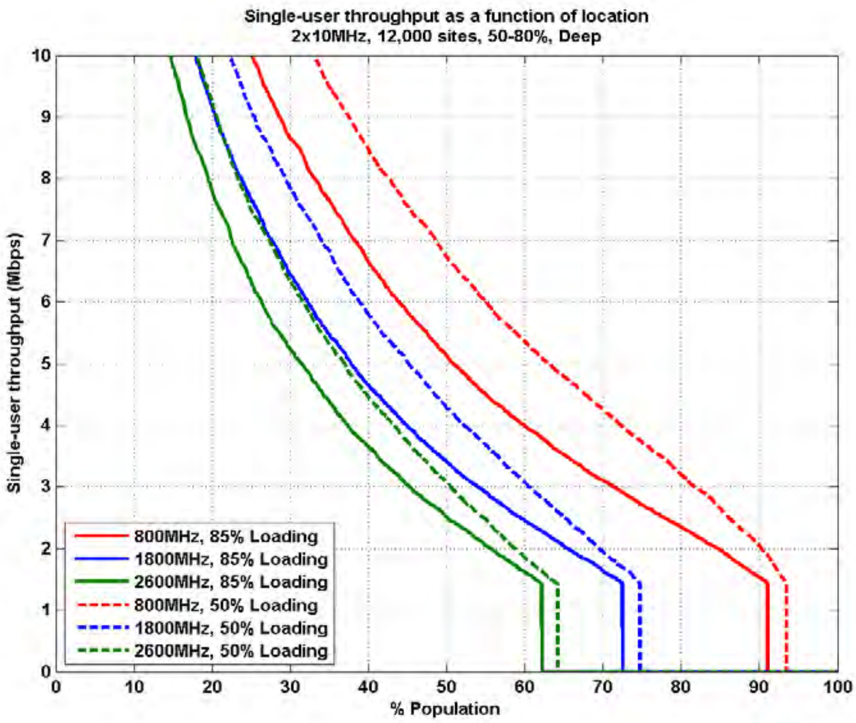


Figure A10.69: Loading comparison, deep



Comments on our resource scheduling assumptions

Comments to the January 2012 consultation

A10.68 One confidential response observed that the 'Min var' and 'Max var' parameter sets used random scheduling and intelligent scheduling algorithms respectively for resource allocation. The respondent believed that LTE would use a similar algorithm to 'max var' as defined in 3GPP specifications regarding X2 interface and was therefore of the view that that the 'Max var' scenario results were much more realistic than 'Min var' results.

Our analysis and response

A10.69 In the January 2012 consultation we had implemented an "intelligent scheduling" algorithm for the 'Max var' case and a random scheduling algorithm for the 'Min var' case. We had not been confident that intelligent scheduling would be available in all cases. Following the consultation, we had asked Real Wireless to look into this assumption. Real Wireless confirmed[114], based on conversations with various equipment vendors, that they are implementing intelligent resource allocation as supported in release 8 of the 3GPP LTE specifications. Further enhancements are expected in release 10 (e.g. dynamic Inter Cell Interference Cancellation (ICIC) and Co-ordinated Multi-point (CoMP) techniques..

A10.70 We considered our approach to the scheduling algorithm and, in view of the comments and the information, we have revised our modelling to use our intelligent scheduling algorithm in both the 'Minvar' and 'Maxvar' cases. Note however that this provides little or no benefit over random scheduling for higher network loadings.

Comments on our assumptions on overheads

Comments to the January 2012 consultation

A10.71 EE commented that our assumption of 20% overhead rate for LTE was too low. It indicated that 3GPP expects that for higher loads the overhead rate would be 30%, relating to a three symbol overhead for PDCCH, and that this higher overhead rate would have the effect of making the data-rates specified in the January 2012 consultation more difficult to achieve.

Our analysis and response

A10.72 To assess the impact of a loading of 30% rather than our adopted 20%, we generated the sensitivity results given in Figure A10.70 and Figure A10.71. The throughput curves are all depressed, though the effect is only modest. There is no impact on the coverage: this is because at the lower throughputs coverage will be limited by the SINR cut-off and not by system overheads. In addition, the impact on single-user throughput is similar for all frequencies and does not affect the relative performance between them.

A10.73 We asked Real Wireless to look further at the likelihood that overheads would be 30%[115]. Given that the overhead requirements are not directly a function of loading, but rather the number of users, the required overheads could be small in a heavily loaded cell if there are only a few users. Even though an overhead of 30% could be relevant in some scenarios, we consider that, for the more general case considered in our modelling, 20% is a reasonably representative value to adopt.

[114] See the report for Ofcom by Real Wireless: Investigations of technical issues related to the combined award of 800MHz and 2.6GHz spectrum (Section 7 and Annex F) published alongside this statement

[115] See the report for Ofcom by Real Wireless: Investigations of technical issues related to the combined award of 800MHz and 2.6GHz spectrum (Section 6 and Annex E) published alongside this statement

Figure A10.70: Overhead comparison, shallow

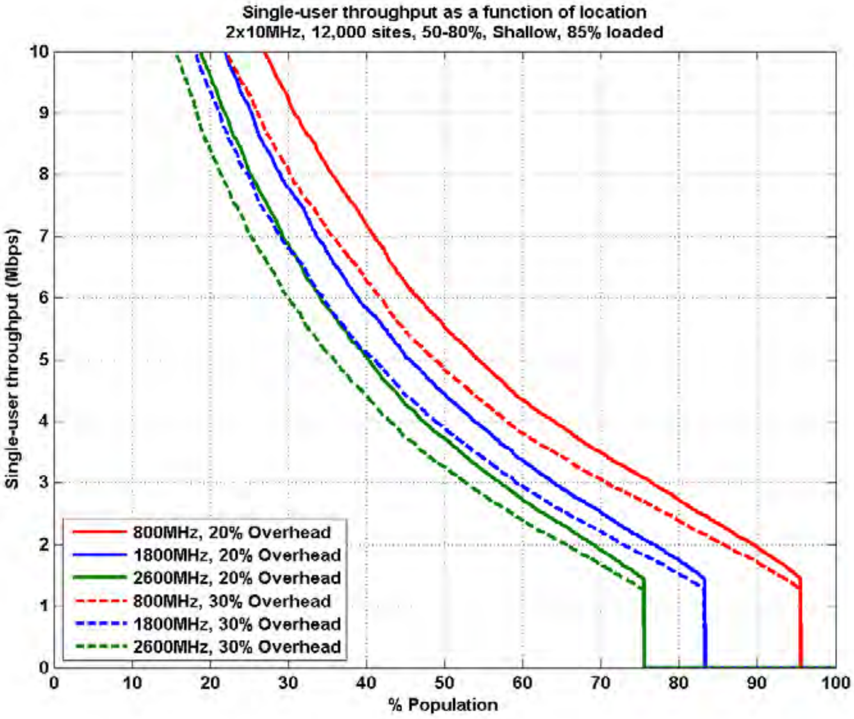
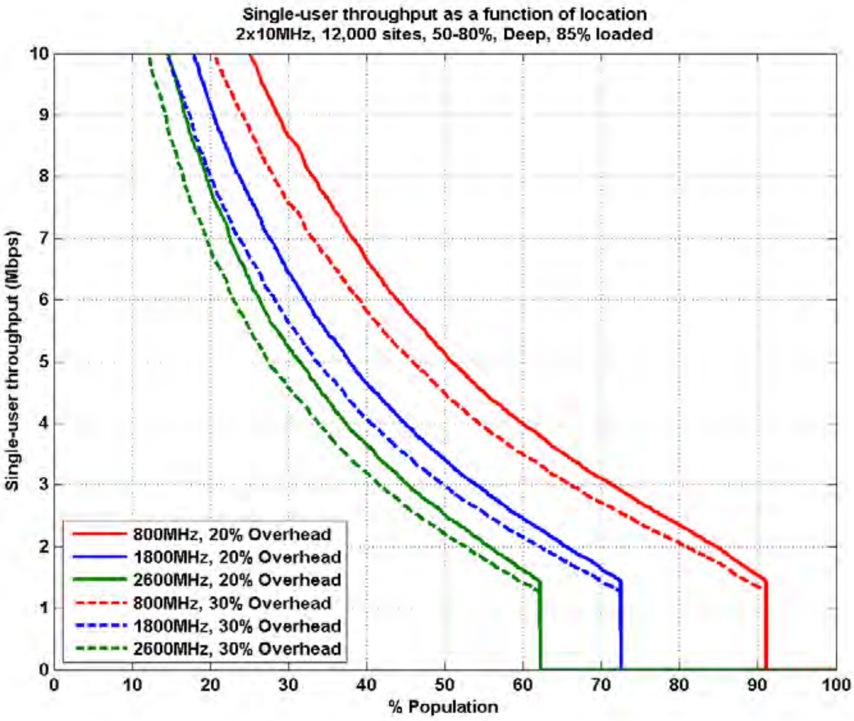


Figure A10.71: Overhead comparison, deep



Comments on spectrum capacity in the smaller portfolios

Comments to the January 2012 consultation

A10.74 Vodafone provided an example which showed that spectrum in the smaller portfolios augmented by either minimal (or manageable) site build in future years yields a network of sufficient capacity to be credible under reasonable demand forecasts for a network with current access to 3G spectrum. In particular, it shows an operator today facing congested sites and a growth in data demand of 63% p.a. over ten years could handle this growth with the smaller portfolios (i.e. 2x15 MHz of 1800 MHz or 2x10 MHz at 800 MHz) provided existing site numbers are augmented with minimal (or easily manageable) additional site rollout over a number of years. As such it argued that 2.6 GHz is not a requirement for capacity to be credible as assumed by Ofcom in its medium portfolios.

Our analysis and response

A10.75 Ofcom consider that Vodafone's technical analysis based upon an operator today facing congested sites and a growth in data demand at 63% per annum may present an over-simplified picture of what can be achieved in terms of the anticipated future traffic and the ability of cells to serve that traffic.

A10.76 Sensitivities have been illustrated in the results through the use of lower and upper bound assumptions for average cell throughputs for both HSPA+ and LTE, but the biggest sensitivity is likely to be that due to the estimated annual growth rate figure applied to the traffic, which, as cited in Annex 6 of the January 2012 consultation, could be as high as 102% per annum. Moreover, the figures cited are for the period 2009 up to 2014, not up to 2022. We note that if an annual rate of 63% is applied over 10 years the effective "inflation factor" is 1.63^{10}= 132. If an annual inflation rate of 102% is applied over 10 years the "inflation factor" is 2.02^{10} = 1131, which is an order of magnitude higher, and our calculations indicate that after 10 years using the higher figure could lead to more than an order of magnitude increase in the calculated number of additional sites. Such considerations indicate that estimates of the required number of additional sites may be somewhat unreliable.

A10.77 In addition, the quoted cell throughputs for LTE may be too optimistic, lower figures implying a higher number of additional sites may be required to serve the excess traffic.

A10.78 The analysis also assumes that sites can be placed perfectly to serve the un-served traffic. This may be unrealistic, especially if some locations are deep indoors, and we anticipate that over time there will be in increasing demand for mobile coverage indoors as user expectations rise.

Comments on calibration of our results against real network results

Comments to the January 2012 consultation

A10.79 One confidential response commented that we had failed to check or calibrate our results against real network results. This had led to an inability to recognize that our model contains erroneous inputs and correct them, the result being a failure to rectify our clear overestimates of indoor coverage.

Our analysis and response

A10.80 In order to address this criticism of our model (that we failed to calibrate our own results based on those from a real network) we ran our model with a different set of parameters based on our understanding of how an operator might plan a network in the context of RSRP. The parameters used were based on those supplied by the confidential respondent. The key points to note for this analysis is that we used both and SINR and RSRP threshold for a coverage confidence of 90% (unlike our main results in Annex 7). We explored an RSRP thresholds of -124 dBm.

A10.81 The Ofcom model was run twice, first using our standard ('Maxvar') assumptions with our 12,000 site network, and then using the respondents BPL assumptions, with their site location information from their network. The parameters for the first run are outlined in the Table A10.28 below.

Table A10.28: Ofcom parameters

	Ofcom 'Maxvar'	
Parameter	**800 MHz**	**1800 MHz**
Shallow Mean BPL (dB)	10.5	13.7
Deep Mean BPL (dB)	16.5	19.7
BPL Std Dev (dB)	6.8	7.2
Shadow fading Std Dev (dB)	7.3	7.7
EIRP per RB (dBm)	47	47
90% confidence margin (dB)	6.7	7.1
RSRP Threshold (dBm)	-124	-124

A10.82 The Ofcom results from the first run are reproduced in Table A10.29 below. Note these are for our three combined simulation areas and therefore represent population coverage in the zero to 90% most densely populated areas of the country.

Table A10.29: Ofcom population coverage prediction for RSRP -124 dBm, coverage confidence of 90%, 12,000 sites

Network loading	Depth	Frequency (MHz)	Ofcom RSRP -124 (dBm)
85%	Shallow	800	93%
85%	Shallow	1800	75%
85%	Deep	800	86%
85%	Deep	1800	60%

A10.83 From these results we conclude that when we use our model in a manner similar to the way this mobile operator suggested as appropriate for network planning purposes and using similar assumptions our model produces results that are comparable to those produced for the confidential respondent themselves. Full details of this analysis have been redacted from the public version of this annex but will be made available on request to the stakeholder whose response we are responding to.

Annex 11

Technical licence conditions

Introduction

A11.1 Ofcom issued consultations on the award of 800 MHz and 2.6 GHz in March 2011, June 2011 and January 2012. These consultations included technical elements and we received a number of comments from stakeholders on those elements. The January 2012 consultation also contained an account of the responses that we had received from stakeholders on the March 2011 and June 2011 consultations, as well as our analysis and comments on those responses. In addition, we addressed the stakeholder responses on issues related to the potential impact on short range devices in an Information Update on *Use of Short Range Devices alongside mobile broadband services operating in the 800 MHz band*[116], which we published in November 2011.

A11.2 This annex sets out a summary of the technical licence conditions for the award of 800 MHz and 2.6 GHz spectrum, including our decisions on matters that were subjects of the consultations. In addition, we summarise the comments that we received from stakeholders in response to the January 2012 consultation, our analysis of the points raised and our conclusions on the technical licence conditions for the award of 800 MHz and 2.6 GHz spectrum. We have also included a further update in relation to our work on short range devices interference issues.

Technical licence conditions for the 800 MHz and 2.6 GHz bands

A11.3 Table A11.1 provides a summary of the technical conditions.

Table A11.1: Technical conditions for 800 MHz and 2.6 GHz

Downlink power limits	800 MHz	61dBm/(5 MHz) EIRP
	2.6 GHz paired standard-power	61dBm/(5 MHz) EIRP
	2.6 GHz unpaired	
	Unrestricted frequencies	61dBm/(5 MHz) EIRP
	Restricted frequencies	25dBm/(5 MHz) EIRP
	2.6 GHz paired low-power	30dBm/(5 MHz) EIRP

[116] http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/Update.pdf

Downlink unwanted emission limits

800 MHz

Out-of-block limits are aligned with the block edge mask parameters in Commission Decision 2010/267/EU.

The technical conditions on unwanted emissions in frequencies below 790 MHz are the Case A limits from Commission Decision 2010/267/EU.

2.6 GHz paired standard-power

Out-of-block limits are aligned with the block edge mask parameters in Commission Decision 2008/477/EC.

In addition, the following limits apply for emissions into the 2.7 GHz band:

Frequency range	Limit on unwanted emissions
2695 to 2700 MHz	4dBm/MHz EIRP
2700 to 3100 MHz	-45dBm/MHz EIRP

2.6 GHz unpaired

Out-of-block limits are aligned with the block edge mask parameters in Commission Decision 2008/477/EC:

Unrestricted frequencies

- The Commission Decision's block edge mask is defined from the boundary of the specific unrestricted block of frequencies in the licence

Restricted frequencies

- The Commission Decision's block edge mask is defined from the boundary of the specific restricted block of frequencies in the licence
- The alternative block edge mask in the Commission Decision is available for base stations on restricted frequencies with additional restrictions on antenna placement

In addition, the following limits apply for emissions into the 2.7 GHz band:

Frequency range	Limit on unwanted emissions
2695 to 2700 MHz	4dBm/MHz EIRP
2700 to 3100 MHz	-45dBm/MHz EIRP

<table>
<tr><td></td><td>
2.6 GHz low-power
Out-of-block limits are aligned with the block edge mask parameters in Commission Decision 2008/477/EC.
In addition, the following limits apply for emissions into the 2.7 GHz band:
<table>
<tr><td>Frequency range</td><td>Limit on unwanted emissions</td></tr>
<tr><td>2695 to 2700 MHz</td><td>4dBm/MHz EIRP</td></tr>
<tr><td>2700 to 3100 MHz</td><td>-45dBm/MHz EIRP</td></tr>
</table>
</td></tr>
<tr><td>Antenna placement</td><td>
2.6 GHz unpaired restricted frequencies
Use of the alternative block edge mask by base stations using restricted frequencies is limited to

indoor antennas; and
outdoor antennas not exceeding 12m above ground level

2.6 GHz low-power
All 2.6 GHz low-power licences are restricted to

indoor antennas; and
outdoor antennas not exceeding 12m above ground level

</td></tr>
<tr><td>Coordination</td><td>
The licences require that the radio equipment is operated in compliance with such coordination procedures as are notified to the Licensee by Ofcom.
800 MHz
The following coordination procedures will be notified to licensees:

Notice of Transitional Restrictions on Mobile Networks in the 800 MHz band for protection of DTT in channels 61 and 62
Notice of DTT coexistence procedures required under spectrum access licences for the 800 MHz band

2.6 GHz
The following coordination procedures will be notified to licensees:

Notice of Co-ordination Procedure required under spectrum access licences for the 2.6 GHz band (Radar);

</td></tr>
</table>

	and • *Notice of coordination procedure for the licences covering the 2.6 GHz band (Restricted blocks)*.
International cross-border coordination	The licences require that the radio equipment is operated in compliance with such cross-border coordination and sharing procedures as may be notified to the Licensee by Ofcom. **800 MHz** The following memorandum of understanding will be notified to licensees: • *Memorandum of Understanding on frequency coordination between the Republic of Ireland and the United Kingdom in the frequency band 790 - 862 MHz* At present, there is no equivalent Memorandum of Understanding with France for the 800 MHz band. When one is concluded it will be notified to licensees. **2.6 GHz** The following memoranda of understanding will be notified to licensees: • *Memorandum of Understanding on frequency co-ordination between France and the United Kingdom in the frequency bands 2500 - 2690 MHz* • *Memorandum of Understanding on frequency co-ordination between the Republic of Ireland and the United Kingdom in the frequency bands 2500 - 2690 MHz*
Uplink	**800 MHz** Ofcom intends to exempt 800 MHz terminals with power levels up to 23dBm from licensing by an amendment to the Wireless Telegraphy Act (Exemption) Regulations. We will be publishing the Notice of Ofcom's proposals for changes to the licence exemption of Wireless Telegraphy devices in the autumn, and this will contain the specific measures we propose for 800 MHz terminals. **2.6 GHz** Ofcom intends to exempt 2.6 GHz terminals with power levels up to 23dBm for paired spectrum and 26dBm for unpaired spectrum from licensing by an amendment to the Wireless Telegraphy Act (Exemption) Regulations. We will be publishing the Notice of Ofcom's proposals for changes to the licence exemption of Wireless Telegraphy devices in the autumn, and this will contain the specific measures we propose for 2.6 GHz terminals. Standard-power licences include

	• Mobile or nomadic Radio Equipment up to 31dBm/(5 MHz) TRP • Fixed or installed Radio Equipment up to 35dBm/(5 MHz) EIRP
Additional requirements	**2.6 GHz low-power: Code of Practice** Low-power licensees are required to use their best endeavours to agree a Code of Practice on engineering coordination, which is intended to manage their shared access to the low-power spectrum. Licensees must then use their best endeavours to adhere to the agreed Code of Practice. If a Code of Practice on engineering coordination is not agreed within six months of the date of issue of the licences, or, where the objectives set out by Ofcom in the licence are not being secured, Ofcom will impose a Code of Practice. This would become a licence condition and therefore a breach of a Code of Practice imposed by Ofcom would constitute a breach of licence.

Technical licence conditions for 800 MHz spectrum

Downlink power limit

A11.4 Commission Decision 2010/267/EU sets out the technical parameters that must apply to the use of the 800 MHz band for networks other than high-power broadcasting networks. The Commission Decision states that an in-block EIRP limit for base stations is not obligatory; however, Member States may set limits and, unless otherwise justified, such limits would normally lie within the range 56dBm/(5 MHz) to 64dBm/(5 MHz).

A11.5 In the June 2011 consultation we proposed an in-block EIRP limit of 61dBm/(5 MHz), which is within the range set out in the Commission Decision. At the time, we noted that this in-block limit does not take account of any specific additional technical restrictions that may be needed for the co-existence of new services in the 800 MHz band with adjacent DTT use.

A11.6 We received concerns from stakeholders that that the coexistence implications of our proposed in-band power had not been fully explored, because our proposed in-band power was higher than the value modelled in the June 2011 DTT coexistence consultation. We also received a separate proposal from Vodafone that we should consider increasing the in-block emission limit for base stations in areas where the top few TV channels are not used (it did not specify a precise number), provided that filters are provided for DTT reception. In paragraphs A15.69 to A15.72 (Annex 15) of the January 2012 consultation, we set out our analysis of the points made in the responses. We also informed readers that we had undertaken additional modelling to look at coexistence between DTT and base stations operating at 61dBm/(5 MHz), and that the outputs of this modelling work and further analysis of the DTT coexistence issues continued to support the proposals put forward in the June 2011 consultation that the maximum in-band power limit should be set at a level of 61dBm/(5 MHz). We also explained that we believed that there would be risks in the approach that had been proposed by one stakeholder of allowing higher power for areas where the top few channels are not used for DTT, and that we were not proposing to permit the use of power levels above 61dBm/(5 MHz) in any locations.

A11.7 We published the results of our additional modelling of DTT coexistence in a further technical report[117] alongside the second consultation[118] on coexistence of new services in the 800 MHz band with digital terrestrial television.

A11.8 We received no further stakeholder comments on the in-band power limit after the January 2012 consultation. We have therefore decided that the technical licence schedules for the 800 MHz licences will include a maximum mean in-block power limit of 61dBm/(5 MHz) EIRP. This condition will apply to all 800 MHz base stations.

Downlink unwanted emission limits

A11.9 Commission Decision 2010/267/EU provides the out-of-block limits for base stations in Table A11.2 to Table A11.4. In the Commission Decision, the limits are built up by combining the values listed in the tables in such a way that the limit at any frequency is given by the highest (least stringent) value of (a) the baseline requirements, (b) the transition requirements, and (c) the in-block requirements (where appropriate). Our licence conditions are aligned with these block edge mask parameters.

Table A11.2: Baseline requirements — BS BEM out-of-block EIRP limits

Frequency range of out-of-block emissions	Maximum mean out-of-block EIRP	Measurement bandwidth
832 to 862 MHz (frequencies used for uplink)	-49.5 dBm	5 MHz

Table A11.3: Transition requirements – base station out-of-block EIRP limits per antenna (for one to four antennas) over downlink frequencies (791 to 821 MHz)

Frequency range of out-of-block emissions	Maximum mean out-of-block EIRP	Measurement bandwidth
–10 to –5 MHz from lower block edge	18 dBm	5 MHz
–5 to 0 MHz from lower block edge	22 dBm	5 MHz
0 to +5 MHz from upper block edge	22 dBm	5 MHz
+5 to +10 MHz from upper block edge	18 dBm	5 MHz
Remaining downlink frequencies	11 dBm	1 MHz

[117] http://stakeholders.ofcom.org.uk/binaries/consultations/949731/annexes/DTTCo-existence.pdf
[118] http://stakeholders.ofcom.org.uk/consultations/second-coexistence-consultation/

Table A11.4: Transition requirements – base station out-of-block EIRP limits per antenna (for one to four antennas) over frequencies used as guard band

Frequency range of out-of-block emissions	Maximum mean out-of-block EIRP	Measurement Bandwidth
790 to 791 MHz	17.4 dBm	1 MHz
821 to 832 MHz	15 dBm	1 MHz

Limits on unwanted emissions below 790 MHz

A11.10 Commission Decision 2010/267/EU provides three possibilities for base station unwanted emission limits in the spectrum below 790 MHz. The June 2011 consultation on technical licence conditions proposed to adopt the lowest level of emissions (designated “Case A” in Decision 2010/267/EU) for all base stations. These limits are shown in Table A11.5.

Table A11.5: Case A limits for unwanted emissions below 790 MHz

Frequency range	In-block EIRP, P dBm/(10 MHz)	Maximum mean EIRP in frequency range	Measurement bandwidth
470 to 790 MHz	P ≥ 59	0 dBm	8 MHz
	36 ≤ P < 59	(P−59) dBm	8 MHz
	P < 36	−23 dBm	8 MHz

A11.11 Several stakeholder responses to the June 2011 consultation on technical licence conditions suggested that Case A limits were insufficient to protect DTT. In contrast to the above responses, Vodafone suggested that Case A limits are too stringent for areas where channels 59 and 60 are not used by DTT and stated that equipment costs would be higher for base stations that needed to meet the Case A limits.

A11.12 In paragraphs A15.63 to A15.68 (Annex 15) of the January 2012 consultation, we set out our analysis of the points made in the responses. We stated that we were not minded to make particular exceptions to the proposals for emission limits below 790 MHz. We also drew attention to our proposals in the DTT coexistence consultation that instances where the Case A limits do not provide adequate protection should be addressed with targeted measures aimed at resolving the particular coexistence scenario, rather than a blanket imposition of alternative emission limits. We said that the information provided in responses did not persuade us that there was evidence to justify deviation from the limits set out in the Commission Decision.

A11.13 Following the January 2012 consultation we received a proposal to clarify the definition of the limits on unwanted emissions below 790 MHz. Vodafone commented that the limits to be applied depend on the base station in-block EIRP which is defined in dBm/10 MHz. Vodafone noted that this formulation could be ambiguous since it could refer to power measured in a bandwidth of 10 MHz or to a power spectral density. Vodafone suggested that that the former was intended, because of the nature of the interference mechanisms and because 10 MHz would be a very unusual bandwidth in which to define a power spectral density. Vodafone therefore proposed that we add a clarifying note in the technical licence conditions. We agreed that there was potential for different interpretations of the expression in this instance and that a clarifying note in the table would be beneficial in that licensees would understand the intended parameter. We have therefore added this clarification in the licences.

A11.14 We did not receive further comments on the proposed power limits after the publication of the January 2012 consultation. We have therefore decided to use the "Case A" out-of band emission limits, as defined in Commission Decision 2010/267/EU, as a technical licence condition in the 800 MHz licences. This condition will apply to all 800 MHz base stations.

Transitional restrictions on mobile networks in the 800 MHz band for protection of DTT in channels 61 and 62

A11.15 Ofcom will notify to licensees the transitional requirements for ensuring the protection of DTT services broadcasting on channel 61 (790 to 798 MHz) and 62 (798 to 806 MHz) during 2013 from potential harmful interference from mobile services in the 800 MHz band. The protection requirements in the Notice must be met on an ongoing basis until DTT services are cleared from the 800 MHz band. Paragraphs A11.16 to A11.19 show the derivation of the maximum permitted cumulative co-channel and adjacent channel interfering field strengths used in the Notice.

A11.16 In the Notice, the maximum permitted cumulative co-channel and adjacent channel field strengths are specified over 1 MHz bandwidths as indicated in Table A11.6.

Table A11.6: Maximum cumulative field strength

DTT reception at test point	Licensee's in-block signal measured over 1 MHz	Maximum cumulative field strength from the licensee's in-block signal measured at a test point
Ch 61	Falls within ch 61 (790 - 798 MHz)	20 dBµV/m/MHz
	Falls outside ch 61 (798 – 821 MHz)	65 dBµV/m/MHz
Ch 62	Falls within ch 62 (798 – 806 MHz)	20 dBµV/m/MHz
	Falls outside ch 62 (790 – 798 MHz, 806 – 821 MHz)	65 dBµV/m/MHz
Ch 61 & 62[119]	Falls within ch 61 or 62 (790 – 806 MHz)	20 dBµV/m/MHz
	Falls outside ch 61 and 62 (806 – 821 MHz)	65 dBµV/m/MHz

A11.17 For example, an 800 MHz licensee whose block includes 1 MHz segments which fall within channel 61 must ensure that the cumulative field strength from all of the licensee's mobile base stations received at a test point where channel 61 is in use by DTT, and in a specific 1 MHz segment within channel 61, does not exceed 20dBµV/m.

[119] Applies to the Winter Hill DTT transmitter only

A11.18 The maximum permitted cumulative co-channel field strength is based on 29dBµV/m in 8 MHz at 10m above ground. The 29dBµV/m in 8 MHz figure is used as a threshold in bilateral negotiations between the UK and its neighbours for determining whether interference from another country's co-channel DTT station is generally acceptable. Note this is a relaxation on the 25dBµV/m in 8 MHz field strength, for the protection of the broadcasting service, cited in CEPT report 29[120] ("Guideline on cross border coordination issues between mobile services in one country and broadcasting services in another country", 26 June 2009). The 29dBµV/m in 8 MHz figure is converted to 1 MHz bandwidth as follows: $29 + 10\ \log_{10}(1/8) = 20$ dBµV/m/MHz.

A11.19 The maximum permitted cumulative adjacent channel field strength is based on 74dBµV/m in 8 MHz at 10m above ground level. The 74dBµV/m in 8 MHz figure is derived by adding the difference between the DTT co-channel (+20dB) and adjacent channel (-25dB) protection ratios (i.e. 45dB) to 29dBµV/m. The 74dBµV/m in 8 MHz figure is converted to 1 MHz bandwidth as follows: $74 + 10\ \log_{10}(1/8) = 65$ dBµV/m/MHz.

Interference to cable TV equipment

A11.20 Following the January 2012 consultation we received a confidential comment which contrasted our approach in regard to potential interference into cable services with our approach to mitigating interference into DTT. However, the response did not suggest any modification to the proposed technical licence conditions for 800 MHz.

A11.21 Ofcom's position in regard to potential interference to cable services from 800 MHz systems had been set out previously in the March 2011 "Consultation on assessment of future mobile competition and proposals for the award of 800 MHz and 2.6 GHz spectrum and related issues" and in the February 2012 "Second consultation on coexistence of new services in the 800 MHz band with digital terrestrial television". In the March 2011 consultation, we stated that:

> "Cable services, by definition, are not delivered by wireless but they can use frequencies up to and including frequencies in the 800 MHz band within the cabling and in set top boxes (STBs) and cable modems (i.e. customer premises equipment (CPE)). Interference into CPE may arise if a mobile handset operating in the top of the 800 MHz band (i.e. using frequencies 832 to 862 MHz) is used close to it.
>
> "During 2010 we worked with the Department for Business, Innovation and Skills (BIS), Virgin Media and technical consultants to understand the scale of the potential interference problem in the specific UK circumstances. We commissioned a series of practical tests on a Virgin Media cable network using independent consultants Cobham Technical Services (CTS). We published the results of their work on our website in December 2010[121].
>
> "Given that any significant deployment of two-way mobile services in the 800 MHz band is unlikely to occur before mid-2013 in the UK, we

[120] http://www.erodocdb.dk/docs/doc98/official/pdf/CEPTRep029.pdf
[121] http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-policy-area/projects/ddr/2010-0792_LTE_into_CATV.pdf

believe there is time to manage this issue. Virgin Media, and other cable operators, could do this by a combination of careful management of their frequency plans, replacement (if necessary) of older equipment with more resilient new equipment and basic information to customers on how to avoid interference when using LTE handsets."

A11.22 In the February 2012 consultation we indicated that other than information provision, support will generally not be offered in instances where the interference is in relation to cable TV equipment.

A11.23 Our position on interference to cable services remains as stated in these earlier consultations.

Short range devices in spectrum above 863 MHz

A11.24 We received responses to the June 2011 consultation on technical licence conditions relating to short range devices (SRDs) including alarm systems, using spectrum above 863 MHz, from approximately 15 different organisations or individuals. There were a number of common themes brought out in the responses. The matters raised in those responses, together with further work undertaken for Ofcom, were considered in an Information Update on *Use of Short Range Devices alongside mobile broadband services operating in the 800 MHz band*[122], published on 30 November 2011. In that document we addressed the comments that we received on the following issues:

- the 800 MHz emissions masks for LTE equipment, and their compliance with Decision ECC/DEC/(09)03;
- proposals for improvements in equipment standards;
- the potential impact of multiple LTE users located within the vicinity of SRD receivers;
- assumptions on LTE upload traffic in the technical analysis published with the June 2011 consultation;
- our proposals to exempt 800 MHz terminals from the requirement for individual licensing;
- concern about the potential for high-power fixed terminals
- concern about the impact of LTE base station emissions on SRDs;
- potential impacts on channel 69 users and other users of wireless audio systems;
- different views on measurements of SRD receiver sensitivity;
- potential impacts on SRD systems with repeaters or external antennas; and
- other possible reasons why interference to SRDs might be worse than we had modelled:

[122] http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/Update.pdf

- o suggestion that the impact of out of band emissions from LTE could be higher than in-band SRD emissions because of different geographical separation and usage scenarios;
- o concern that LTE emissions could cause localised blocking for several seconds, which would adversely affect SRDs based on one-way communication or SRDs with latency requirements;
- o concern that existing fade margins in installations could not be used to combat additional interference from LTE, and that additional interference margins might be needed in new system installations; and
- o concern that LTE terminals would operate at full power in the start-up phase.

A11.25 In the Information Update we indicated that use of both the 800 MHz band and the licence-exempt SRD band are harmonised[123] throughout Europe. We concluded that the issue of potential interference to SRDs was therefore an issue shared by all European Union member states. We indicated that we were engaging with key European bodies in ETSI and CEPT, and we continue to do so. We also reported that CEPT started studies in autumn 2011 (SE24 Work Items 41 and 42) to investigate whether the SRD and LTU device equipment standards have been developed in a way that ensures technical mutual compatibility. Since the publication of the Information Update, ETSI technical committees have also been discussing this same issue of the compatibility of both equipment standards.

Our position in the November 2011 Information Update

A11.26 In Section 5 of the Information Update we set out our position on the matters raised in the responses on SRD issues. We stated that we saw no reason to change our view that it is inappropriate to impose constraints on the 800 MHz award in order to protect SRDs. We indicated at that time that this was a provisional view and that we would take a final decision on this when we made decisions on the entirety of the award of the 800 MHz and 2.6 GHz bands.

A11.27 Our position, set out in the Information Update, was that the likelihood and extent of interference from LTE would be low and the imposition of licence conditions on users of 800 MHz spectrum was not likely to be justified. We noted that if a user or manufacturer was still concerned, there was a wide range of alternative approaches available for current users of the SRD band, including social and other alarms. The alternatives for manufacturers and users include migration to other frequency bands; changing the characteristics of signal transmission (such as ensuring social alarms send repeated signals until the call is acknowledged); alternative technologies; or providing advice or information (in the case of leisure or entertainment equipment).

A11.28 We also stated that in many cases, SRD users were likely to have some control over the interference e.g. they may choose to switch off mobile devices in close proximity or – at least – not upload data at the same time as using SRD equipment. In any event, our view was that interference was likely to be an issue over only very short periods when large amounts of data were being uploaded in close proximity to an SRD at the precise moment a signal is being sent to its receiver.

[123] Commission Decisions 2006/771/EC and 2010/267/EU; and Harmonised Standards EN 301 908, EN 300 220, EN 302 208, EN 300 422 and EN 301 357

Further comments following the January 2012 consultation

A11.29 In its response to the January 2012 consultation, BEIRG commented that out-of-band emissions from new services above 790 MHz would potentially have a severely damaging effect on the amount of useable interleaved spectrum for PMSE. It stated that it did not agree with Ofcom that interference in channels 59 or 60 would not have a material impact on the availability for spectrum for PMSE use and also sought Ofcom's reassurance that interference from new services would not affect channels further down the spectrum than 59 and 60. BEIRG requested information on licensing arrangements for channels 59 and 60 and wanted to know what compensation would be offered to PMSE users in the event that there was interference from the new 800 MHz band services.

A11.30 BEIRG reiterated its comment into the June 2011 consultation on Technical Licence Conditions that a significant number of PMSE users have moved from Channel 69 to Channel 70. It stated that it was extremely disappointed with Ofcom's decision not to impose licence restrictions on the use of any portions of the 832 to 862 MHz block to protect SRDs.

Our further investigation and decisions on issues raised in relation to short range devices

A11.31 Subsequent to the publication of the November 2011 Information Update, we published on 9 May 2012 a further report124 "Potential for LTE interference to wireless audio" and we have undertaken further testing with some example production LTE UE devices, looking at the characteristics of LTE mobile terminal transmissions in a live network. Following careful consideration of consultation responses and in light of our extensive engagement with key stakeholders (notably with manufacturers, trade associations and users' representatives), and taking into account the two further studies referred to in this paragraph, we have concluded that it is inappropriate to impose licensing constraints on the 800 MHz award in order to protect SRDs.

A11.32 Our conclusions are that the likelihood and extent of interference from LTE will be low and the imposition of licence conditions on users of 800 MHz spectrum is not justified. Accordingly, we have decided not to include specific technical licence conditions for this purpose.

The 821 to 832 MHz centre gap in the 800 MHz band

A11.33 JFMG's response to the consultation on technical licence conditions did not cover use of the 800 MHz centre gap. We acknowledge that ECC/DEC/(09)03 provides a set of technical conditions for administrations wishing to implement low-power applications and PMSE in the 821 to 832 MHz centre gap between the 800 MHz downlink and uplink spectrum. When we addressed this comment in Annex 15 (paragraph A15.75) of the January 2012 consultation we stated that we did not have any concrete plans for the centre gap at that point. This remains the case and the centre gap does not form part of this award.

[124] http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/Wireless_Audio_Testing.pdf

Technical licence conditions for 2.6 GHz spectrum (standard-power paired and unpaired licences)

Downlink power limit

A11.34 Commission Decision 2008/477/EC sets out the technical parameters that apply to the use of the 2.6 GHz band. For unrestricted frequencies, the maximum in-block EIRP is 61dBm/(5 MHz).

A11.35 In its response to the June 2011 consultation on technical licence conditions, Vodafone proposed that we increase the 2.6 GHz in-block EIRP limit to 62dBm/5 MHz for base stations equipped with MIMO. We considered Vodafone's proposal in Annex 15 of the January 2012 consultation at paragraphs A15.95 and A15.96.

A11.36 We received no further comments on this matter following publication of the January 2012 consultation and we have included the power limit from Decision 2008/477/EC in the standard-power licences, applicable to unrestricted frequencies.

A11.37 To manage interference between paired and unpaired use, restricted blocks are required at 2570 to 2575 MHz and at 2615 to 2620 MHz. A 5 MHz restricted block will also be required between unpaired licensees in adjacent frequency blocks unless the 2570 to 2620 MHz spectrum were awarded as a single block.

A11.38 The maximum in-block EIRP in Decision 2008/477/EC for restricted frequencies is 25dBm/(5 MHz). We have included this power limit in the unpaired licences.

Downlink unwanted emission limits

A11.39 In Commission Decision 2008/477/EC, for an unrestricted spectrum block the limit for each frequency is given by the higher value out of the baseline requirements, the block specific requirements and the in-block requirements.

A11.40 The baseline requirements in the Commission Decision set a maximum mean EIRP (integrated over 1 MHz bandwidth) of

i) 4dB/MHz for frequencies allocated to FDD down link and ±5 MHz outside the range of frequency blocks allocated to FDD down link.

ii) -45dBm/MHz for frequencies in the band 2500 to 2690 MHz not covered by the definition above.

A11.41 For protection of radar we have also applied the -45dBm/MHz limit in the 2700 to 3100 MHz frequency range. We have also applied the 4dBm/MHz limit across the whole of the 2690 to 2700 MHz band so that it applies up to the boundary with the radar band. The lower frequency boundary for the -45dBm/MHz limit is different from the value that we included in the June 2011 consultation. Since our plans do not include the use of base stations in the lower paired spectrum, there is no requirement to extend the lower limit below the 2500 MHz in the Commission Decision. Table A11.7 sets out the baseline requirements in the licence.

Table A11.7: Baseline requirements

Frequency range of out-of-block emissions	Maximum mean out-of-block EIRP	Measurement bandwidth
Frequencies allocated to FDD down link and 5 MHz below and 10 MHz above the range of frequency blocks allocated to FDD down link.	4dBm	1 MHz
Frequencies in the range 2500-3100 MHz not covered by the definition above.	-45dBm	1 MHz

A11.42 For unrestricted blocks we have included the block specific requirements from the Commission Decision, as shown in Table A11.8. For clarity we have defined the frequency range from the edges of the unrestricted frequencies, since the Commission Decision term “block” is not used or defined in the licences. This means that for an unpaired spectrum holding, comprising restricted and unrestricted frequencies, the baseline requirements apply at the external boundary of the unrestricted frequencies.

Table A11.8: Block specific requirements

Frequency range of out-of-block emissions	Maximum mean out-of-block EIRP	Measurement bandwidth
Start of band (2500 MHz) to -5 MHz from lower edge of unrestricted frequencies	Baseline requirement level	
-5 MHz to -1 MHz from lower edge of unrestricted frequencies	4 dBm	1 MHz
-1 MHz to -0.2 MHz from lower edge of unrestricted frequencies	$+ 3 + 15(\Delta_F + 0.2)$ dBm	30 kHz
-0.2 MHz to 0 MHz from lower edge of unrestricted frequencies	3 dBm	30 kHz
0 MHz to 0.2 MHz from upper edge of unrestricted frequencies	3 dBm	30 kHz
0.2 MHz to 1 MHz from upper edge of unrestricted frequencies	$+ 3 - 15(\Delta_F - 0.2)$ dBm	30 kHz
1 MHz to 5 MHz from upper edge of unrestricted frequencies	4 dBm	1 MHz
5 MHz from upper edge of unrestricted frequencies to end of band (2690 MHz)	Baseline requirement level	
Where: Δ_F is the frequency offset from the relevant edge of unrestricted frequencies (in MHz)		

2.6 GHz TDD restricted blocks

A11.43 In the Commission Decision 2008/477/EC, for a restricted spectrum block the limit for each frequency is given by the higher value out of the baseline requirements and the in-block requirements. The Commission Decision also provides alternative parameters for the use of restricted frequencies in cases where antennas are placed indoors or where the antenna is below a certain height, provided that at geographical borders to other Member States the baseline conditions apply. These parameters are shown in Table A11.9.

A11.44 For clarity in Table A11.9 we have defined the frequency range relative to the edges of the restricted frequencies for which rights of use are stipulated in the Licence, since the Commission Decision term "block" is not used or defined in the licences. This means that for an unpaired spectrum holding, comprising restricted and unrestricted blocks, the block specific requirements for a restricted block with additional restrictions on antenna placement apply relative to the external boundaries of the restricted block.

Table A11.9: Alternative block specific requirements

Frequency range of out-of-block emissions	Maximum mean out-of-block EIRP	Measurement bandwidth
Start of band (2500 MHz) to -5 MHz from lower edge of restricted frequencies	-22 dBm	1 MHz
-5 MHz to -1 MHz from lower block edge	-18 dBm	1 MHz
-1 MHz to -0.2 MHz from lower block edge	$-19 + 15(\Delta_F + 0.2)$ dBm	30 kHz
-0.2 MHz to 0 MHz from lower block edge	-19 dBm	30 kHz
0 MHz to 0.2 MHz from upper block edge	-19 dBm	30 kHz
0.2 MHz to 1 MHz from upper block edge	$-19 - 15(\Delta_F - 0.2)$ dBm	30 kHz
1 MHz to 5 MHz from upper block edge	-18 dBm	1 MHz
5 MHz from upper block edge to end of band (2690 MHz)	-22 dBm	1 MHz
Where: Δ_F is the frequency offset from the relevant block edge (in MHz)		

A11.45 In the June 2011 consultation we proposed that the alternative block edge mask could be used by TDD base stations in restricted blocks meeting the following conditions on base station antenna placement:

i) antennas placed indoors at a separation greater than 70m from the nearest base station that uses the frequency block immediately below the restricted block; where the nearest such base station has an EIRP of 30dBm or lower, this separation may be reduced to 20m; or

ii) antennas placed outdoors at a height which is no greater than 12m above ground level and at a separation greater than 160m from the nearest base station that uses the frequency block immediately below the restricted block; where the nearest such base station has an EIRP of 30dBm or lower, this separation may be reduced to 40m.

A11.46 We received comments in support of our proposals on the alternative parameters for the use of restricted frequencies from Arqiva, BT and Cable&Wireless. We also received a confidential comment that the conditions might not be sufficient to protect FDD operation in some deployment scenarios.

A11.47 There was general agreement from most of those who responded on this point to the approach of sharing base station location information for coordination between the FDD network and TDD base stations using the restricted block alternative mask. One confidential response did not support the proposals and raised doubts about the potential accuracy of location information. We also received two views on the matter of timing of deployment of restricted block base stations using the alternative mask. One stakeholder sought assurance that once a TDD alternative mask base station was deployed, the neighbouring operator could not subsequently require its removal when their FDD network expanded, i.e. if they installed a new FDD base station within 160m of the TDD base station. Another stakeholder was concerned that our proposals would mean that an area could become sterilised for the operator who doesn't deploy first.

A11.48 Our assessment of the comments that we received was set out in Annex 15 of the January 2012 consultation, in paragraphs A15.90 to A15.94. We took the view that the technical conditions that we proposed in the June 2011 consultation would provide a good basis for operators to understand where they stand when they came to install equipment. We also concluded that there were no technical reasons that would prevent two operators coordinating to ensure that their base station antennas are not placed closer than the minimum distance unless there is agreement to do so. We acknowledged the concern that an operator who deployed first could be forced to remove base stations following new deployments in the adjacent frequency block and at the time we proposed to clarify in the Information Memorandum that any standard-power base station could receive interference if it is installed closer than 160m to a restricted block TDD base station, installed at an earlier time, that uses the alternative block edge mask in an adjacent frequency block.

A11.49 We received no further comments on the alternative parameters for use of restricted blocks following the January 2012 consultation, and we have included the alternative EIRP limits and the requirement for the antenna to be outdoors at a height no greater than 12m above ground level, or indoors. We recognise that there is a need for licensees to understand how they may implement the separation distance requirements and we have set out a Notice of coordination procedure for the licences covering the 2.6 GHz band, which deals with deployment of mobile electronic communication networks in unpaired restricted blocks and in spectrum adjacent to unpaired restricted blocks. This describes the necessary procedures to ensure that licensees do not deploy restricted block alternative mask base stations within these minimum distances unless they have agreement from the licensee in the adjacent frequency block below the restricted block. It also includes the clarification that it does not preclude 2.6 GHz licensees that hold spectrum in the adjacent block below a restricted block from establishing and bringing into use base stations whose antennas are within the coordination distances in Annex 1 from antennas of successfully coordinated 2.6 GHz base stations in a restricted block. Any such deployment is at the 2.6 GHz licensee's own risk and there is no requirement on the Restricted Block Licensee to make any changes to their deployment in these circumstances

A11.50 A copy of the *Notice of coordination procedure for the licences covering the 2.6 GHz band (Restricted Blocks) :* is included in the Information Memorandum at Annex 4. Coexistence wi*th radar use of spectrum above 2700 MHz*

A11.51 *We received several stakeholder responses to the June 2011 consultation on technical licence conditions seeking more detail and information on the radar remediation programme. In particular, stakeh*olders wanted to understand what timing they should expect, since this would potentially impact on any plans for deployment or roll-out.

A11.52 In Annex 15 of the January 2012 consultation (paragraphs A15.76 to A15.89) we summarised the comments from stakeholders in response to radar issues in the March 2011 and June 2011 consultations. We also provided an update on the radar remediation programme and related matters raised in these comments. We held a stakeholder event on the radar issues on 20 January, when we indicated[125] an expected protection threshold of -136dBm/m^2/MHz.

A11.53 BT's response to the January 2012 consultation stated that it had looked at the likely constraints that the coordination requirements might place on 2.6 GHz mobile systems. BT noted that following the radar remediation programme, the limiting factor that may determine required separation distances between mobile systems and the radar installations is the proposed power flux density limit in the radar band at the radar sites of -136dBm/m^2/MHz. BT sought further clarification of how this value had been determined. BT suggested that in light of the potential constraints that the proposed coordination requirements could place on mobile systems in the 2.6 GHz band it was important that this matter was carefully considered and the consequences of the coordination requirements were clearly understood and were minimised to the extent possible.

A11.54 We held a further stakeholder event on radar issues on 17 May when we elaborated further on coordination procedures for deployment in the 2.6 GHz band[126].

Management of radar coexistence in the technical licence conditions

A11.55 The coexistence between usage of the 2.6 GHz band and radars above 2700 MHz will be managed by three elements:

a) the technical licence schedules contain a requirement on unwanted emissions from downlink transmissions from 2.6 GHz radio equipment, which we have set at -45dBm/MHz in the spectrum range 2700 to 3100 MHz;

b) the technical licence schedules include a requirement to operate the radio equipment in compliance with such co-ordination procedures as are notified to the Licensee by Ofcom; the necessary radar coordination provisions will be included in the relevant coordination procedure; and

c) licence exemption of consumer terminals will be limited to terminals with a rated power of 23dBm in paired spectrum and 26dBm in unpaired spectrum, which aligns with the European Harmonised Standards EN 301 908 and EN 302 544; the use of terminals at the higher power limits up to 31dBm/(5 MHz) TRP or 35dBm/(5 MHz) EIRP will be covered by the licence and this will bring them within the scope of the coordination procedure.

A11.56 A copy of the Notice on Coordination Procedure required under spectrum access licences for 2.6 GHz band (Radar) is annexed to the Information Memorandum at Annex 3.

Technical licence conditions for low-power 2.6 GHz

Downlink power limit

A11.57 In the June 2011 consultation on technical licence conditions, we proposed an in-block EIRP limit of 30dBm.

[125] http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/annexes/RADAR_Event_Presentation.pdf
[126] http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/annexes/co-ordination-procedures.pdf

A11.58 In the January 2012 consultation (paragraphs A15.114 to A15.116), we indicated that BT proposed to reduce the potential for interference between low-power networks by subdividing the low-power licences into two categories:

- Three licences with a maximum permitted base station power of 30dBm EIRP, proposed as suitable for outdoor or indoor coverage
- Seven licences with a maximum permitted base station power of 10dBm EIRP, proposed as suitable for indoor coverage.

A11.59 The January 2012 consultation considered the representations that we had received on the possibility to define two categories of concurrent low-power lots as a means to manage the coexistence between outdoor low-power networks. We reflected that we had envisaged in our proposals that co-existence between networks would be addressed through a Code of Practice between licensees (see paragraph A15.116). We had reviewed the independent technical research that we had published alongside the March 2011 consultation, we suggested that the reduced power licence category could restrict licensees' flexibility but at 10dBm it might not have significant impact in removing the incentive to install systems in those most popular locations. As such, we suggested that its effectiveness as a tool to improve the coexistence was unproven. Nevertheless, in paragraphs 6.83 to 6.85 we said that this was a potentially interesting approach and we would welcome feedback on it, including on the power levels for the two categories of licences, the number of categories and the number of licences per category for example.

A11.60 BT's response to the January 2012 consultation said that it continued to advocate subdividing the shared low-power licences into two power categories (with different number of licences available for each) as a preferred approach, as it believes that this would maximise the efficiency of use of the spectrum by encouraging investment in low-power solutions without diminishing the benefits to consumers.

A11.61 ZTE also responded to the January 2012 consultation and indicated that it considered that there would be potential for two types of in-building deployment scenarios at different power levels:

- 1 W for public spaces e.g. shopping centres, transport hubs
- 0.1 W for smaller private spaces e.g. office and home

A11.62 ZTE had the view that 0.1W (i.e.20dBm) would not provide sufficient coverage in a public space – or would require deployment of a greater number of small cells, which would increase deployment costs.

A11.63 In addition, the response from Intellect agreed that the proposals for two categories of power levels for low-power licences merited further consideration.

A11.64 One confidential respondent commented on BT's proposal for two categories of low-power licences, with 10dBm and 30dBm power levels, and indicated that it did not believe that this would represent the optimal approach. The respondent believed it unlikely that 10dBm was sufficient to satisfy the needs of all indoor usage applications, and was concerned about the potential interference from 30dBm systems into 10dBm systems. The respondent also suggested that 10dBm might be insufficient to meet the needs of residential users who require their service to work within the bounds of their property rather than just within the confines of the house, and for business users requiring coverage in large buildings or complex internal structures. The respondent therefore considered that low-power users should be able to utilise any spectrum that they were awarded at a common power level sufficient to support any application.

A11.65 One confidential respondent commented that in order to address the co-ordination issues, Ofcom should consider limiting the number of sharers that can use the reserved lower power spectrum. However, it did not specify what it considered to be a suitable limit on the number of sharers.

A11.66 We reviewed these new comments against the background of our interim conclusion in paragraph A15.116 of the January 2012 consultation. We observed that there were concerns expressed in some responses, while there was no new evidence to suggest why a single low-power category with a Code of Practice on engineering coordination would have fewer benefits than a two-category approach (with or without a Code of Practice).

A11.67 We have concluded that there should be a single category of low-power licence and that the power limit will be 30dBm. Additional measures for coexistence between low-power networks are matters that should be addressed by the Code of Practice.

Downlink unwanted emission limits

A11.68 In the June 2012 consultation we proposed that block-specific requirements on emission limits for low-power licences should be set at the levels provided in the Commission Decision 2008/477/EC (see Table A11.8). We also included the additional baseline limits in the range 2695 to 3100 MHz for protection of radar.

A11.69 We received a number of comments from stakeholders on these proposals, which we addressed in Annex 15 of the January 2012 consultation (paragraphs A15.124 to A.15.135). Vodafone had commented that it did not agree with use of the same block edge mask as standard-power licences. It suggested that these out-of-block power limits would be inadequate for the protection of adjacent networks from low-power base station interference. In the January 2012 consultation we stated that we were not convinced that the use of low-power base stations by low-power licensees or by standard-power licensees would invalidate the block edge mask in Commission Decision 2008/477/EC or require us to impose separate technical conditions.

A11.70 Following the January 2012 consultation, we received a further response in which Vodafone called attention to its earlier comments on the block edge mask.

A11.71 However, Vodafone did not provide any material that would help to quantify the impact on a network operating in a neighbouring block from the unwanted emissions of low-power base stations, and it did not propose a specific reduction in the block edge mask limits that would bring the emissions into adjacent frequencies to an acceptable level.

A11.72 We note that the harmonised standards applicable to base stations for the 2.6 GHz band all include requirements on adjacent channel leakage power ratio. Any low-power base station that is CE marked by compliance with the harmonised standard will have out of band emissions much lower than those required by the Commission Decision. 2.6 GHz femtocells and other low-power base stations placed on the European market could be deployed both by low-power networks and by standard-power licensees. Any concerns about the suitability of the block edge mask for non-macrocell deployments therefore apply equally to the use of such devices by standard-power licensees as they do to low-power licensees. In this respect, we observed that no respondent raised any concern about the technical conditions applicable to deployment of femtocells within standard-power networks.

A11.73 Following our review of the comments on this matter, we have decided not to develop a new set of block edge masks specifically for low-power deployments. We have therefore included the block edge mask from Commission Decision 2008/477/EC and the baseline requirements in Table A11.7 as technical conditions in the low-power licences.

Low-power base station antenna placement

A11.74 In the January 2012 consultation we proposed the conditions for low-power base station antenna placement in Table A11.10.

Table A11.10: Low-power base station antenna placement

Location	Maximum antenna height
Outdoor locations	12m
Indoor locations	No height restriction

A11.75 We received comments on this point from two stakeholders, which we summarised the Annex 15 of the January 2012 consultation (paragraphs A15.124 and A15.125). The comments suggested that it is not necessary to include a maximum outdoor height in the low-power licences. We concluded at the time that there remains a case for a backstop maximum antenna height that would serve to limit the interference impact of individual outdoor base stations.

A11.76 A confidential response to the January 2012 consultation proposed that the permitted low-power antenna height should take account of the local environment and impact of interference, rather than being set at absolute levels, and that licence conditions should be flexible on this point and take account of mitigation techniques. We reviewed the original technical analysis that had been published alongside the March 2011 consultation and observed that it concluded that interference ranges rise more rapidly as the base station antenna heights become significantly above the heights of surrounding buildings, and it therefore recommended that the maximum height is set at or a little above the typical height of residential buildings. The report noted that a height of 12m would be consistent with existing street furniture deployments by operators. Since the report had concluded that antenna height was a factor in the range of interference to other networks, we took the view that a clear and unambiguous condition had lower risk than a flexible condition that was dependent on judgements about local conditions and interference mitigation.

A11.77 We have therefore decided to impose a technical licence condition setting a maximum height for outdoor low-power base station antennas of 12m above ground level, as proposed in the consultation on technical licence conditions.

Code of Practice on engineering coordination for 2.6 GHz low-power licensees

A11.78 In the June 2011 consultation we proposed that sharing of low-power spectrum in locations where several licensees wished to provide service should be managed by a Code of Practice on engineering coordination, to be agreed amongst the low-power licensees. We considered the responses in Annex 15, paragraph A15.130 of the January 2012 consultation. We stated that where respondents commented on this point, they had agreed with our proposal that a Code of Practice is the appropriate approach to manage coexistence between low-power licensees. Following the January 2012 consultation, we received further comments on the Code of Practice proposals.

A11.79 Arqiva noted that coordination of the sharers will be a critical issue in making the lower power use successful and said that it would welcome further guidance on how that coordination might work.

A11.80 Everything Everywhere commented that the technical viability of managing interference between a large number of concurrent licensees who actively use their spectrum was unclear, and that the ability to agree a Code of Practice was not the same as this being workable in practice. It made a comparison with the Code of Practice in the 1781.7 to 1785 MHz and 1876.7-1880 MHz bands and suggested that there was a low level of use of these bands, so the Code of Practice for those bands has never been tested in practice. Everything Everywhere did not provide any evidence for unworkability, only a suggestion that there was absence of evidence for workability. In addition, Everything Everywhere did not propose an alternative approach that would be preferable to a Code of Practice.

A11.81 In the view of Federation of Communication Services (FCS), the engineering co-ordination Code of Practice has worked well with licensees in the 1781.7 to 1785 MHz and 1876.7-1880 MHz bands. FCS stated that several of these licensees are delivering services effectively to customers today, and they manage interference potential through their engineering Code of Practice.

A11.82 Our decision, following the review of responses, is that we will proceed with the approach of managing sharing in low-power spectrum by means of an industry Code of Practice on engineering coordination. We will impose an obligation on any low-power licensees to use best endeavours to agree an industry Code of Practice on Engineering Coordination with the Notified Licensees within six months of the date of first issue of the Licence. Licensees will be required to use their best endeavours to adhere to the agreed Code of Practice when establishing and using stations for wireless telegraphy and installing and using apparatus for wireless telegraphy.

A11.83 Ofcom will have the power to impose a Code of Practice where the six months' time period has passed without agreement or where the objectives set out in the licence are not being secured. Any breach of the Code of Practice imposed by Ofcom would constitute a breach of the licence.

Comments on the hybrid approach for low-power

A11.84 The March 2011 consultation set out the potential for 2×10 MHz or 2×20 MHz of dedicated low-power spectrum in the 2.6 GHz band, to be shared between several licensees for provision of low-power services. It also introduced the concept of hybrid spectrum: 2×10 MHz dedicated to low-power and a further 2×10 MHz shared with a standard-power licensee, subject to certain conditions to manage the potential interference into the standard-power network.

A11.85 The June 2011 consultation took this forward by seeking views on two particular questions:

i) Whether stakeholders preferred dedicated or hybrid spectrum for low-power licences; and

ii) Views of stakeholders on the following options for implanting hybrid spectrum.

- o a geolocation approach, in which we would set a minimum separation distance between low-power base stations and the nearest standard-power base station; and
- o a spectrum sensing approach that would use the capabilities of the low-power base stations and terminals to determine the usage of the spectrum by the standard-power network and then implement any necessary power back-off to avoid causing interference to the standard-power network.

A11.86 In Annex 15 of the January 2012 consultation (paragraphs A15.97 to A15.101) we summarised the views in the responses to question (i). We received a range of views, some in favour of hybrid spectrum as a possible means to increase the quantity of low-power spectrum and some against, with concerns about the feasibility of managing the sharing between low-power networks and a standard-power network. Only three stakeholders stated their outright support for hybrid over dedicated spectrum but they provided no additional information that would suggest to us where they saw the additional benefits.

A11.87 In Annex 15 of the January 2012 consultation (paragraphs A15.102 to A15.108) we summarised the views in the responses to question (ii). We indicated that most of the responses on this question expressed opposition to the potential spectrum sensing approach, although two responses were broadly supportive. We also acknowledged that BT proposed an alternative approach, in which it suggested that coexistence between low-power and standard-power should be managed by limiting low-power networks to 15dBm EIRP in the shared 10 MHz block.

A11.88 We stated in the January 2012 consultation in paragraph A15.109 that we were no longer proposing the geolocation or spectrum sensing options for hybrid low-power spectrum. We received no further comments on those options after that consultation.

Alternative hybrid approach based on a geographic split

A11.89 The January 2012 consultation identified a possible alternative hybrid approach in which one block of 2.6 GHz spectrum, for example 2x10 MHz, is dedicated for either the low-power networks or a standard-power network in predefined geographic areas. The model that we outlined was for a geographic division between rural and non-rural areas. The licences would define:

a) the set of rural areas where low-power networks may establish base stations using the shared 2×10 MHz block; and

b) the set of non-rural areas where the standard-power network may establish base stations using the shared 2×10 MHz block.

A11.90 One confidential response from an individual expressed a degree of qualified support for the geographical division approach, depending on who was administering the service, but without further elaborating on this condition. A separate confidential response from an individual was opposed due to concerns of an adverse impact on handover in different geographical areas.

A11.91 The response from David Hall Systems suggested that the geographic split option should result in additional benefits for the consumers, and it could allow innovative new offerings to be provided and encourage new entrants to enter the market. A geographic split was also supported by Mr Manoj Chawla.

A11.92 The Federation of Communication Services (FCS) stated that it preferred a bandwidth of 2×15 MHz to be available for low-power, rather than the alternative of different bandwidths in urban and rural locations.

A11.93 BT stated that the urban areas are more likely than rural areas to have multiple low-power operators, so it is in the urban areas that additional low-power spectrum would be more useful, not the rural areas. BT indicated that extra low-power spectrum in rural areas would be useful for serving customers as a broadband delivery solution. However, on balance it also preferred 2×15 MHz to be available for low-power on a national basis, and highlighted that avoiding the urban/rural split would prevent more complicated geographic sharing options, including the need to deal with boundary issues.

A11.94 Arqiva indicated that it had not seen any evidence that a rural/urban split for low-power would create significant additional benefits for consumers. A confidential response from an individual also did not believe that there would be any consumer benefits from an urban/rural split. Three also did not see any significant benefit to adopting the geographically split licences proposal.

A11.95 Vodafone commented that a geographically split licence would require further work to specify fully and would further complicate the licence award. Vodafone also had concerns that creating lots with unequal value could distort the award and it urged us not to pursue either geographically split licences or the hybrid approach.

A11.96 ZTE supported a nationwide reservation of spectrum for low-power. It suggested that a geographic split would create less value for citizens and consumers than nationwide coverage of a reserved block of low-power shared spectrum.

A11.97 Everything Everywhere had concerns that a geographical split would be very difficult to implement, and suggested that if somebody had a strong business case for a service based on establishing low-power networks in rural areas, they should approach the standard 2.6 GHz licences with a view to agree this kind of spectrum sharing, for example through spectrum leasing.

A11.98 In its response to Question 4.4 of the January 2012 consultation, the Department of Enterprise, Trade and Investment (DETI) referred back to its previous response to the March 2011 consultation, where it was supportive of the potential for sub-national Radio Access Network (RAN) operators to emerge and deliver localised solutions, and indicated that it remained of the opinion that measures to encourage the opportunity to deliver localised solutions were important. DETI was disappointed that limited assessment of the potential benefits had been undertaken by Ofcom.

Our conclusion on this matter

A11.99 We concluded that development of a hybrid approach based on geolocation, spectrum sensing or a geographic split would have required further development and there was a clear message that most stakeholders believed it would not bring significant consumer benefits. In view of these considerations, we decided not include the hybrid option in the 2.6 GHz award.

Frequency placement of low-power 2.6 GHz blocks

A11.100 In the June 2011 consultation we had asked for views on the preferred frequency placement for low-power licences. The January 2012 consultation summarised the responses that we received, in paragraphs A15.110 to A15.112. Following the January 2012 consultation, we received a further response from BT, which suggested that placement of low-power spectrum required further consideration, and one confidential response, which was concerned about the cost of implementing a network at the top of the 2.6 GHz band with reduced power or with interference mitigation measures in low-power base stations for protection of radar.

A11.101 As explained in Section 7 and Annex 5 placement of any low power licences is determined at the assignment stage, with mechanisms in place to ensure that they are not assigned in the lowest or the highest spectrum blocks.

Representations on licence-exemption of low-power networks

A11.102 In Annex 15 of the January 2012 consultation (paragraphs A15.117 to A15.121) we considered the representations we received from Skype and the Institution of Engineering and Technology (IET) on licence exemption of low-power networks. The Skype and IET comments had been received in response to the March 2011 consultation.

A11.103 We concluded in the January 2012 consultation that there would be a number of risks in a licence exemption or underlay approach as advocated in these responses and we stated that we were not minded to pursue exemption of low-power networks in a shared block. We received no further responses on this matter after the January 2012 consultation and we therefore developed technical conditions on the basis of a limited number of low-power licences.

Other general comments on low-power networks

A11.104 We received a number of comments on other matters, which we discussed in paragraphs A15.131 to A15.135 in Annex 15 of the January 2012 consultation. In that consultation we did not identify any particular changes that would be required to the technical licence conditions in response to these comments. However, we did acknowledge that Samsung’s comment on the need to avoid a requirement for UK-specific terminals was relevant to our considerations on the hybrid approaches.

A11.105 We received no further comments on these matters following the January 2012 consultation and we have concluded that there is no requirement to impose additional technical conditions in response to these comments.

Representations on the number of concurrent low-power licences

A11.106 Virgin Media, in their response to the January 2012 consultation indicated that, in their view to up to 10 concurrent users would be feasible should their preferred option of reserving 2 X 20 MHz spectrum for exclusive low-power use be adopted, if a smaller portion of spectrum was reserved for low-power use they considered that the number of licensees should be similarly reduced.

A11.107 We remain of the view that up to 10 concurrent users would be feasible for low-power licences of 2 x 10 MHz.

Exemption of terminal stations

A11.108 In the June 2011 consultation on technical licence conditions we proposed to proceed with the approach that terminal stations operating in the 800 MHz and 2.6 GHz bands should be exempt from a requirement for individual licensing provided that they comply with certain technical parameters which we outlined in Section 8 of the June 2011 consultation. As we indicated at the time, those parameters were consistent with the usage studied during the development of CEPT Reports 19, and 30 covering these bands and with the power limits in Commission Decision 2008/477/EC.

A11.109 In Annex 15 of the January 2012 consultation (paragraphs A15.136 to A15.140) we indicated that we had received supportive comments on this question from Arqiva, BT, Cable&Wireless, Intel, Samsung, Three, Vodafone and one confidential response, while the responses from APWPT, BEIRG, Mr B Copsey, Ei Electronics, Great Circle Design and one confidential response did not agree with the proposal to exempt terminals complying with the relevant technical parameters from the requirement for individual licensing. We observed that the stakeholders that were opposed to licence-exemption for terminals cited concerns about the potential for interference from terminals into short range devices in the spectrum above 862 MHz.

A11.110 In the January consultation we noted that terminals that would be exempted from licensing would be mobile devices that were placed on the European market and operated under the control of the mobile network. We suggested that a requirement for individual licensing for mobile terminals was unlikely to influence the usage patterns of these devices but would simply introduce an administrative burden. As such, we took the view that requiring subscribers to obtain licences for individual mobile terminals that are operated under the control of the network would not have a material impact on the likelihood of interference into adjacent services.

A11.111 We did not receive any further comment on exemption of terminals following the January 2012 consultation. Nevertheless, we have further considered the position in respect of terminals in the 2.6 GHz band. Our analysis of the potential impact of terminal emissions on radars had been based on the terminal power limit in the harmonised standard EN 301 908, i.e. 23dBm for the 2.6 GHz band. However, the Commission Decision requires us to authorise terminals up to 31dBm/(5 MHz) TRP for mobile or nomadic terminals and 35dBm/(5 MHz) EIRP for fixed or installed terminals. We therefore considered that there was a risk of terminals with these higher output power powers being installed in locations where they could have an impact on radars, and we particularly want to avoid the scenario of fixed directional antennas pointing towards nearby radar sites. We have therefore decided that these higher power terminals should not be exempted from licensing but should be authorised under the network operator's licence.

A11.112 We intend to develop the exemption regulations for 2.6 GHz terminals on the basis of the power limits in the European Harmonised standards for terminals for the paired and unpaired bands, which are EN 301 908 (which contains 23dBm terminals for FDD and TDD and is therefore applicable across the whole 2500 to 2690 MHz range) and EN 302 544 (which contains 26dBm TDD terminals and is therefore applicable in the 2570 to 2620 MHz unpaired spectrum.

A11.113 We intend to develop the exemption regulations for 2.6 GHz terminals on the basis of the power limits in the European Harmonised standards for terminals for the paired and unpaired bands, which are EN 301 908 (which contains 23dBm terminals for FDD and TDD and is therefore applicable across the spectrum that we are making available for FDD uplink in 2500 to 2570 MHz, and unpaired use in 2570 to 2620 MHz) and EN 302 544 (which contains 26dBm TDD terminals and is therefore applicable in the spectrum that we are making available for unpaired use in 2570 to 2620 MHz).

Annex 12

Detail for a responses annex on Annual Licence Fees for 900 MHz and 1800 MHz spectrum

A12.1 This Annex sets out a summary of the responses relating to Annual Licence Fees (ALF) in our January 2012 consultation. In Section 12 we set out our provisional thinking to date on how we will set ALF, but note that we have taken no decisions at this stage. We will consult specifically on the revision of ALF for 900 MHz and 1800 MHz spectrum after the Auction.

Summary of our position in January 2012 consultation

A12.2 In Section 8 and Annex 13 of our January 2012 consultation, we set out further discussion of how to implement the requirement on us under the Direction to revise Annual Licence Fees (ALF) for 900 MHz and 1800 MHz spectrum after completion of the Auction. This built on what we said in the March 2011 Consultation and responses to that.

A12.3 The Direction requires Ofcom after completion of the Auction to revise the 900 MHz and 1800 MHz licence fees so that they reflect the full market value of the frequencies in those bands, and in revising them we must have particular regard to the sums bid for licences in the Auction.

A12.4 We stressed that what was set out in the January 2012 consultation was our provisional thinking, and that we would consult specifically on the revision of ALF for 900 MHz and 1800 MHz spectrum after the Auction.

A12.5 In the January 2012 consultation we updated our proposed approach in response to a concern from some respondents to the March 2011 consultation that a direct link between prices in the Auction and ALF could result in incentives that reduce Auction efficiency. In particular, some respondents to the March 2011 consultation were concerned that a mechanistic link between Auction prices and ALF would create inappropriate incentives. They were concerned this would lead bidders in the Auction that would have to pay ALF to shade their bids to manage the impact of their own bids on the ALF they would have to pay.

A12.6 We noted at the outset that we did not intend our proposals in the March 2011 consultation to be read as implying that we would adopt a mechanisatic link between Auction prices and ALF. Nevertheless, we considered in detail the question of incentives for bidders to shade bids. We considered that a mechanistic link between Auction prices and ALF can create incentives for ALF payers either to shade bids or not to bid at all. In some circumstances however, the incentives may not distort the allocation of spectrum. ALF payers would be likely to engage in strategic demand reduction through bid shading only if they believe that they can affect the level of ALF and that they can improve their surplus. However, their scope to achieve both can be limited by other considerations. This is for two reasons:

12.6.1 First, if bidders had an expectation of a minimum level of ALF (e.g. one inferred from reserve prices in the UK Auction or from prices in comparable

Auctions in other countries), then any pay-off from not bidding or shading bids would be more limited.

12.6.2 Second, if there are several bidders and their valuations are relatively close to each other, then the price set by the losing bidder would be unlikely to change materially whether or not an ALF payer shaded its bids or did not participate. Indeed, in such circumstances an ALF payer shading its bids in the hope of reducing ALF would have the potential consequence of losing without a material offsetting benefit to it of a reduction in ALF. If so, there would be little incentive for the ALF payer to shade its bids.

A12.7 We explained that these mitigating factors and our intention to use several sources of information to determine full market value for the purposes of setting ALF mean that we still thought that the methodology using linear reference prices set out in March 2011 consultation was a relevant and helpful input to ALF.

A12.8 However, we considered what other information on the full market value of spectrum we might extract from bids in the Auction (if it is sufficiently competitive), without creating the potential risk of bid-shading incentives. We developed another methodology, which we referred to as the Additional Spectrum Methodology. We set out that our intention was to use this approach alongside other approaches to take a rounded view in exercising our judgement as to the full market value of spectrum relevant to the setting of ALF.

A12.9 The three methodologies we proposed to use to estimate full market value were:

a) the linear reference price methodology described in the March 2011 consultation, using all bids made in the UK Auction;

b) the Additional Spectrum Methodology described in the January 2012 consultation; and

c) values from Auctions for comparable spectrum in other countries that we consider to be sufficiently competitive, adapted to reflect UK circumstances.

A12.10 We recognised that we need to consider the calculations under each methodology and their outputs with care. They have limitations individually and in combination. However, by using a broad set of relevant data and by using market transaction information in particular, we believe that our approach is likely to be appropriate to the circumstances.

A12.11 We also clarified that if the 2x15 MHz of 1800 MHz spectrum to be divested by Everything Everywhere were sold in the Auction, we would expect to include bids for this lot as part of any Auction information we might consider for the purpose of assessing ALF.

Issues raised in responses

A12.12 Below we consider issues raised in responses under the following headings:

12.12.1 Additional Spectrum Methodology;

12.12.2 Methodologies and information used to inform ALF;

12.12.3 Value of 900 MHz spectrum compared to 800 MHz spectrum;

12.12.4 Legal basis for setting ALF;

12.12.5 Uncertainty over ALF on 1800 MHz spectrum; and

12.12.6 Other ALF issues.

A12.13 For each of these topics we first summarise the non-confidential responses, and then set out our view of them.

Additional Spectrum Methodology

Summary of responses

A12.14 Everything Everywhere did not see a great need for the Additional Spectrum Methodology. It considered that Ofcom had shown that the concerns about bid shading as a result of ALF being linked to Auction prices were very unlikely to be valid.[127]

A12.15 Telefónica considered that the Additional Spectrum Methodology had a number of significant limitations. These included that an extrapolation of the 800 MHz spectrum bids in themselves appeared to be of little value because the 900 MHz spectrum is not a direct substitute. Telefónica considered that even if 800 MHz and 900 MHz spectrum were direct substitutes, for the Additional Spectrum Methodology to be able to calculate an opportunity cost there would need to be sufficient demand, at least in the first round. Given the sub 1 GHz caps and where Ofcom sets the reserve price, this may not happen.[128]

A12.16 Vodafone also had concerns about the Additional Spectrum Methodology. It identified what it considered to be three problems, two of which were non-confidential:[129]

12.16.1 Bidders would be making bids assuming 2x30 MHz of 800 MHz spectrum. It is unreasonable to assume they would have made the same bids if, hypothetically, there were additional 800 MHz spectrum.

12.16.2 If the outcome of the Additional Spectrum Methodology is that the implied prices for Vodafone and Telefónica are very different, Ofcom would feel obliged to consider the average of the prices (in conjunction with the other methodologies). This distorting impact on the Auction therefore remains.

A12.17 Vodafone therefore considered that the Additional Spectrum Methodology did not alleviate the problem of distortion in the Auction caused by the linkage of ALF to Auction fees.[130]

A12.18 H3G also considered that the Additional Spectrum Methodology was flawed. It considered there were at least five fundamental objections to it:[131]

12.18.1 The prices it produces are systematically lower than full market value, since the latter should be based on 'Walrasian prices' rather than opportunity cost[132];

[127] Everything Everywhere's non-confidential response, answer to question 8.1, page 44.
[128] Telefonica's non-confidential response, paragraphs 321-322.
[129] Vodafone's non-confidential response, paragraph 87.
[130] Vodafone's non-confidential response, paragraph 88.
[131] H3G's non-confidential response, section 8.

12.18.2 It can result in extremely low and unstable prices. H3G provided numerical examples of how this could occur;

12.18.3 It suffers from a “missing bids” problem, that is, the Auction will not generate sufficient bids to calculate a full opportunity cost owing to factors such as spectrum caps;

12.18.4 It is ad hoc methodology and without an objective basis; and

12.18.5 It is contrary to the goals of Ofcom’s wider competition policy objectives.

A12.19 H3G considered that ALF should be based on the “linear reference” prices proposed in the first consultation or on “Walrasian” prices, which it considered to be the average of the lowest accepted bid and the highest rejected bid for a spectrum block.

A12.20 BT had doubts about the Additional Spectrum Methodology because, unless there were different fees for different operators with the same spectrum, the amounts bid by the operator will still affect its charges for retained spectrum. BT questioned whether spectrum caps could constrain the bids and this could distort the analysis of the hypothetical scenario of extra spectrum being available. Also, BT considered the Additional Spectrum Methodology was centred around marginal spectrum values which might be different to the full value.[133]

Ofcom’s response

A12.21 Everything Everywhere argued there is little need for the Additional Spectrum Methodology, since we have demonstrated that the risks of bid shading by bidders with the intention of reducing their ALF levels are low. However, while we consider the risk of bid shading has been overstated by Vodafone, we remain of the view that it is sensible to consider the Additional Spectrum Methodology, alongside other information, to further mitigate this risk.

A12.22 We agree with many of the points made in responses about the limitations of the Additional Spectrum Methodology.[134] For example, we agree with Telefónica that there would need to be sufficient demand at least in the first round to be able to calculate values with the Additional Spectrum Methodology. However, while recognising that the Additional Spectrum Methodology has some limitations, we remain of the view that it could have some value, and consider that it is worth considering taking account of its results alongside other sources of information. This is because we consider that all methodologies we propose to use to estimate full market value have both advantages and limitations. We will therefore need to treat the output from each of the methodologies, including the Additional Spectrum Methodology, with care.

[132] H3G defines Walrasian prices as a combination of the lowest accepted bid and the highest rejected bid for a unit. In contrast, the concept of opportunity cost considers the highest rejected bid for one unit, then the second highest rejected bid for the second unit and so on.
[133] BT’s non-confidential response, page 18.
[134] We recognised many of these limitations in the January 2012 consultation. In paragraphs A13.73 to A13.75 of the January 2012 consultation, we said that estimates generated by the Additional Spectrum Methodology could well be non-linear in the quantity of spectrum retained, and even for the same quantity of spectrum, the estimates might differ between similar bidders (e.g. between Telefónica and Vodafone who currently hold the same amount of 900 MHz spectrum).

A12.23 We consider that some of the limitations of the Additional Spectrum Methodology are overstated in responses:

12.23.1 Vodafone argued that bidders make bids according to a specific amount of spectrum being available in the Auction and that it is unrealistic to assume they would make the same bids if more spectrum were available. However, we think bids still contain useful information. To the extent that firms' private value is driven to a significant degree by their existing holdings of spectrum, the amount available for sale in the Auction ought to make little difference.

12.23.2 H3G's criticisms of the additional spectrum methodology centre around the use of what it argues are 'Vickrey prices' to set the ALF levels, rather than 'Walrasian prices'. H3G argued that the methodology can produce extremely low prices and suffers from a 'missing bids' problem. We note that in a situation where there are complementarities between lots, as is frequently the case in spectrum Auctions, Walrasian pricing could result in a bidder paying more than their valuation for a desired package of lots. Since marginal values would exceed average value in this case, prices set with respect to the former could exceed the latter. Such prices clearly could not be considered a 'market value' for a given quantity of spectrum as no voluntary transactions would actually occur at these prices. The approach employed by the additional spectrum methodology does not suffer from this problem since it is based on what rivals are prepared to pay in total for the relevant quantity of spectrum.

12.23.3 We do not agree with H3G that the Additional Spectrum Methodology is contrary to Ofcom's wider competition policy objectives. H3G argues that a strong link between Auction prices and ALF reduces the strategic investment incentives on national wholesalers who would be paying ALF. Because the Additional Spectrum Methodology weakens the link between Auction prices and ALF, H3G considers it strengthens strategic investment incentives. We have separately put in place measures to promote a fourth national wholesaler that we consider are likely to undermine incentives for strategic investment to exclude a fourth national wholesaler. We therefore regard the fact that the Additional Spectrum Methodology may help to reduce the risk that those paying ALF will shade their bids as an advantage and not as a disadvantage.

A12.24 We consider Telefónica's arguments about the relative value of 800 MHz and 900 MHz spectrum from paragraphs A12.49 below.

Methodologies and information used to inform ALF

Summary of responses

A12.25 Telefónica welcomed Ofcom's clarification in the January 2012 consultation that there would not be a mechanical link between the Auction bids and the calculation of ALF. It considered it was more prudent for Ofcom to take a range of factors into account. Telefónica also considered that to the extent Auction values were relevant they are only relevant if they expressed intrinsic valuations, rather than strategic valuations. It said it was unclear how Ofcom would determine this.[135]

[135] Telefonica's non-confidential response, paragraphs 310 and 319.

A12.26 Vodafone said our proposals for ALF lacked sufficient clarity for operators to be able to make well informed bids in the forthcoming Auction or in any private sale of the 1800 MHz spectrum. Vodafone was extremely concerned with the proposed methodologies, even though it accepted that the precise calculations would be subject to further consultation. Its three main concerns were:[136]

12.26.1 It considered Ofcom was wrong to assume that the amounts paid for 800 MHz spectrum would provide a reliable indicator of the full market value of 900 MHz spectrum;

12.26.2 Even if 800 MHz and 900 MHz spectrum were worth the same, there would still be a risk of distortion in the Auction through bid shading if Ofcom uses the amounts paid for spectrum and/or its Additional Spectrum Methodology; and

12.26.3 A fourth operator has the opportunity to artificially drive up the price of spectrum – and therefore ALF – to penalise its competitors.

A12.27 Vodafone disagreed with our analysis in the January 2012 consultation that suggested that the risk of bid shading is low for a number of reasons:[137]

12.27.1 Vodafone did not consider that it would make any sense to reduce the potential distortion caused by linking ALF to Auction prices by placing weight on the reserve price, as there was no sense in which a reserve price set by a regulator could represent full market value;

12.27.2 Vodafone questioned whether there would be several bidders with valuations relatively close to one another. It considered it was not obvious that there would be a 'losing' bidder in the 800 MHz band. There may only be four bidders and four winners. The price for 800 MHz would then be set by the marginal values that winners express for packages *larger* than their actual winning package. Vodafone considered that this could be influenced by bidders in the supplementary round, where it considered there is little incentive to report values truthfully and every incentive to try to manipulate prices (and ALF).

12.27.3 Vodafone also considered there was considerable scope for distortion because it was very likely that the losing bidder could have a value *far* below the value of the next-placed bidder. It noted that in Germany and Italy there were only four bidders.

12.27.4 Vodafone also considered that the distorting impact of ALF was much higher in Ofcom's illustrative example, because Ofcom assumed a ratio of 1:1 for the amount of 800 MHz : 900 MHz spectrum. Vodafone noted that for a 2x5 MHz block of 800 MHz, the ratio for Vodafone and Telefónica was 1:3.5.

A12.28 Vodafone suggested that Ofcom remove this potential distortion by:[138]

12.28.1 Using technical and cost modelling to estimate the opportunity cost of spectrum;

[136] Vodafone's non-confidential response, paragraphs 69 to 70.
[137] Vodafone's non-confidential response, paragraph 85.
[138] Vodafone's non-confidential response, paragraphs 71 to 72 and the answer to question 8.2.

12.28.2 Supplementing this approach by using examples from other Auctions where 900 MHz spectrum is sold alongside 800 MHz spectrum; and

12.28.3 Changing the Auction rules to use 100 per cent deposits and bidder credits rather than reserving spectrum, so as to mitigate the risk that others seek to inflate artificially the price of spectrum and ALF.

A12.29 Vodafone considered there were a number of advantages to using technical and cost modelling to estimate the value of 900 MHz spectrum:

12.29.1 It can be used to calculate the 'full market value of spectrum';

12.29.2 There is no risk of distortion to the Auction;

12.29.3 This method can reflect the fact that 900 MHz is not a substitute for 800 MHz; and

12.29.4 The necessary modelling and analysis can be done by Ofcom before the Auction and then form part of the post-Auction consultation.

A12.30 Vodafone considered the reasons Ofcom gave for suggesting it may not use technical and cost modelling, and rejected those reasons:

12.30.1 Ofcom said that technical and cost methodologies are subject to a considerable margin of error, especially in relation to technologies that are in the early stages of commercial deployment such as LTE. Vodafone said these alleged errors had not prevented Ofcom from estimating AIP in the past. Furthermore, Vodafone considered that using the price paid for 800 MHz spectrum to estimate the value of 900 MHz spectrum would also be subject to potentially larger errors because it considered that 900 MHz spectrum was not a good substitute for 800MHz spectrum, and the price of the latter could reflect 'distorted' bidding intended to drive up the cost of the former. It therefore considers technical and cost modelling would use more robust and widely available data on 3G costs.

12.30.2 Ofcom considers that technical and cost modelling could potentially lead to ALF rates that appeared out of line with full market value as inferred from the Auction. Vodafone agreed with this, but considered that this was potentially very useful information. It could, for example, indicate that the full market value inferred from the Auction was overestimating the market value of 900MHz spectrum.

12.30.3 Because it considered that other methodologies may provide more useful information, Ofcom considered that this put in question the value of undertaking the complex technical and cost modelling task in the first place. Vodafone considered that, on the contrary, because the price paid for 800 MHz spectrum in the Auction may not be a good proxy for the market value of 900 MHz, the technical and cost modelling would be an additional source of information which lacks the distortive properties of Auction prices, and was therefore invaluable.

A12.31 Vodafone also considered that Ofcom would have sufficient time to carry out the necessary technical and cost modelling so as to consult on the results before the Auction. Vodafone also said that Ofcom's doubts about the accuracy of technical and cost modelling had not emerged in the past.

A12.32 H3G considered that Ofcom should reinstate the direct linkage between ALF and the Auction prices. It considered a direct linkage to be consistent with the Direction, and that any incentives on those holding 900 MHz and 1800 MHz spectrum to reduce demand were similar to those in SMRA Auctions.

A12.33 H3G also considered that international benchmarks should only provide a floor for ALF if the UK Auction is not fully competitive. It considered that the German and Italian Auction were most relevant.[139]

Ofcom's response

A12.34 While we do not consider there is no risk of a distortion to the Auction as a result of ALF, we consider that Vodafone has overstated this risk:

12.34.1 We expect to draw on a range of evidence in setting ALF, including considering international benchmarks and the Additional Spectrum Methodology. We will not consider only the linear reference price of 800 MHz spectrum resulting from the Auction. It would therefore be risky for bidders to alter their bids to try to influence ALF, because we may place little weight on their bids if we consider there is better information available, or if we consider that they may have changed their bids for strategic reasons.

12.34.2 We consider that the reserve prices are likely to act as a minimum expected level of ALF which will tend to reduce the pay-offs from not bidding or shading bids. We consider this is a reasonable expectation given the way we are proposing to set reserve prices, which includes using evidence from comparisons with international Auctions for 800 MHz spectrum. Given this, we would therefore not expect the market value of 800 MHz spectrum to be below the reserve prices.

12.34.3 We consider that it is likely that there will be at least four bidders for 800 MHz spectrum, as we think it likely that all four of the existing national wholesalers will bid for 800 MHz spectrum. It is possible that they will all bid on 2x10 MHz of 800 MHz spectrum, or more in the case of H3G and Everything Everywhere. This is also likely to reduce the pay-offs from some potential bidders not bidding or shading their bids, because the losing bidder may not have a value far below the value of the next-placed bidder.

A12.35 We agree with Vodafone that the 1:1 ratio we used in our numerical illustrations in the January 2012 consultation understates the potential distortion. This is because Vodafone and Telefónica have more 900 MHz spectrum than they are allowed to bid for under the sub 1 GHz spectrum cap. We used a simple 1:1 ratio in the numerical illustrations to aid exposition. If only bidding for 2x5 MHz of 800 MHz, we accept that the ratio would be 1:3.5.

A12.36 In response to Vodafone's argument for considering the relative prices of 800 MHz and 900 MHz spectrum when they have been Auctioned together, we confirm that we expect to consider such Auction results. As well as informing the relative values of the two bands, we also expect to consider directly information from international Auctions on the value of 900 MHz spectrum. Such information will be less useful for countries where the Auction was less competitive. We also agree with Telefónica that it is only the intrinsic value that we want to capture from international Auctions,

[139] H3G's non-confidential response, page 16 and Section 8.

and that we may need to consider the particular circumstances of different Auctions to try to understand whether or not there was likely to be strategic investment behaviour. We also agree with Telefónica that this may not be easy to determine.

A12.37 On technical and cost modelling, we accept that to the extent 800 MHz and 900 MHz spectrum are not close substitutes or if the likely relativities are very uncertain, then the Auction results for 800 MHz spectrum may be less informative for determining the value of the 900 MHz spectrum. In this case, there is likely to be more benefit in undertaking technical and cost modelling.

A12.38 We are therefore not ruling out using technical and cost modelling to inform ALF. But we consider that if international benchmarking and the bids in the UK Auction involving 800 MHz spectrum can inform the price of 900 MHz spectrum, we consider they are likely to give a better indication of full market value than such modelling, due to the considerable margin of error involved. In this case, undertaking the technical and cost modelling may be of limited benefit. We therefore do not currently envisage relying on technical and cost modelling, but will review this after the Auction if there are reasons for considering it is likely to be more reliable than other sources of information.

A12.39 The current situation is different to when technical and cost modelling has been used in the past to set ALF. We potentially have access to market based information to set ALF for the 900 MHz and 1800 MHz spectrum, and also we have been directed to have particular regard to the sums bid for licences in the Auction.

A12.40 In response to H3G's argument that the incentives to reduce demand with a mechanistic link to the 800 MHz Auction are similar to an SMRA Auction, we consider that this illustrates the advantages of the CCA Auction format that we are using. We consider that relying solely on a mechanistic link would give greater incentives for bid shading for those paying ALF.

A12.41 We also do not agree with H3G's argument that international benchmarks should only be used as a "floor" for ALF if the UK Auction is not fully competitive. Rather we regard international benchmarks as providing potential useful information which is independent of the UK Auction.

A12.42 In response to Vodafone's concerns about the risk that others will artificially inflate the price of spectrum and ALF, we have discussed above why we consider that Vodafone has overstated the risk of this. In Section 7, we also describe how we have removed the Final Price Cap which we consider further mitigates this risk. We therefore do not consider that it is necessary or proportionate to impose 100 per cent deposits. We have set out from paragraph [A3.441] why we prefer using the competition constraint rather than bidder credits for promoting a credible fourth national wholesaler. We set out below our views on why we are not taking a view on the relative values of 800 MHz and 900 MHz spectrum now.

Value of 900 MHz spectrum compared to 800 MHz spectrum

<u>Summary of responses</u>

A12.43 Vodafone considered Ofcom was wrong to assume that the amounts paid for 800 MHz spectrum would provide a reliable indicator of the full market value of 900 MHz spectrum. Vodafone considered that 800 MHz spectrum was clearly worth more than 900 MHz spectrum, due to:[140]

12.43.1 the relative performance of HSPA versus LTE (in terms of capacity, spectral efficiency, wider bandwidths and peak data rates);

12.43.2 the timing and uncertainty of LTE900; and

12.43.3 the standards for LTE900 does not allow 2x15 MHz contiguous blocks.

A12.44 Vodafone also suggested that Ofcom consider the amounts paid for 900 MHz spectrum in Auctions where it had been sold alongside 800 MHz spectrum, as this could give an indication of the relative values of the two frequencies. It said that the Auctions in Austria, Ireland and the Netherlands would fit this description. It considered that the price of 900 MHz spectrum in the Portugal and Spanish Auctions represented a clear overestimate of market value, since in both cases 900 MHz spectrum sold for the reserve price and in both cases the Auction ended with unsold 900 MHz spectrum. Vodafone said that in these Auctions the price of 900 MHz spectrum was 30% lower than 800 MHz spectrum.[141]

A12.45 Vodafone said it was critically important to it that Ofcom explicitly says that 900 MHz spectrum must have a lower market value than 800 MHz spectrum before the Auction.[142]

A12.46 Telefónica also considered that 900 MHz spectrum was significantly inferior to 800 MHz spectrum, because:[143]

12.46.1 The 900 MHz band is currently highly fragmented;

12.46.2 Lack of standardisation for wider bandwidths;

12.46.3 Lack of an LTE900 ecosystem; and

12.46.4 Uncertainty over any requirement to protect neighbouring users.

A12.47 It considered that the Auction would tell Ofcom nothing about the value of 900 MHz spectrum for GSM/UMTS in the period between now and when or if any LTE900 ecosystem emerges. To assess market value, Telefónica considered Ofcom would need to model the transition of value within the market (as oppose to subscribers) from 2G to 3G to 4G, which it considered may be intractable or be highly complex.[144]

A12.48 In contrast, H3G considered that 900 MHz spectrum was worth more than 800 MHz spectrum, and that Ofcom should therefore add an appropriate amount to the value of 800 MHz spectrum when valuing 900 MHz spectrum. H3G excluded its reasons for considering the 900 MHz spectrum was worth more from the non-confidential version of its response.

Ofcom's response

[140] Vodafone's non-confidential response, paragraph 77.
[141] Vodafone's non-confidential response, paragraph 84.
[142] Vodafone's non-confidential response, paragraph 83.
[143] Telefonica's non-confidential response, paragraph 312.
[144] Telefonica's non-confidential response, paragraphs 313-4.

A12.49 We have not assessed the relative values of 900 MHz and 800 MHz spectrum in detail, and do not have a firm view on this. There are countervailing arguments, as set out in the different responses. We will assess the points raised fully when we consult on ALF after the Auction.

A12.50 We do not agree that it is critically important for Ofcom explicitly to address this issue now. This is because:

12.50.1 We would anyway be unable to give a definitive view at this time. This is because we would have to take account of the further information that is likely to become available before ALF is set for 900 MHz spectrum, and responses to our planned ALF consultation. To take a definitive position now would be likely unlawfully to fetter our discretion.

12.50.2 There is likely to be materially better information on which to make this assessment by the time we consider setting ALF for 900 MHz spectrum in 2013. In particular, there may be more information about the following which may be relevant to setting ALF for 900 MHz spectrum:

a) Additional European Auction results involving both 800 MHz and 900 MHz spectrum being Auctioned together;

b) The timescales for using 900 MHz spectrum for LTE, including the availability of LTE900 user devices and any development on standards; and

c) The value of initial deployments of LTE and how this compared to HSPA.

There may also be additional information on the relative value that stems from responses to our specific ALF consultation.

12.50.3 We consider the risk of a distortion to bidding in the combined 800 MHz and 2.6 GHz Auction has been overstated by Vodafone (for the reasons set out above, especially in paragraphs A12.34 to A12.38). This reduces the value that would be gained from a preliminary assessment now.

Legal basis for setting ALF

<u>Summary of responses</u>

A12.51 Vodafone considered that Ofcom's approach to ALF was inconsistent with its obligations under Community and domestic law.[145]

A12.52 In summary, Vodafone's argument was that Ofcom has failed to explain why it is considering a different fee setting methodology to that previously adopted, that the use of Auction values for 800 MHz is not a reliable basis for setting 900 MHz licence fees, creates a clear risk that Ofcom's proposals may distort a competitive bidding process and that Ofcom's current approach is damaging to legal certainty, because the regulatory regime governing licence fees will not be known until after the Auction process takes place.

[145] Vodafone's non-confidential response, paragraph 111 and Annex 3.

A12.53 Telefonica also noted that in its consultation on ALF after the Auction Ofcom must show how ALF is compatible with Community Law.[146]

Ofcom's response

A12.54 We do not agree that Ofcom has failed to explain why it is considering using a different methodology to set fees for 900 MHz and 1800 MHz spectrum. We have explained that the Direction requires us to revise those fees to reflect the full market value of the frequencies in those bands, and that in doing so, we must have particular regard to the sums bid for licences in the Auction. The Direction was made by the Secretary of State fully cognisant both of the duties set out in the Community law framework, and the nature of the spectrum that would be the subject of bids in the Auction.

A12.55 We remain of the view that our proposals (which we note will be subject to further consultation by us before we make any final decisions on revised licence fees) are consistent with our obligations both under the Direction as set out above, and the European framework which permits us to set fees which reflect the need to ensure optimal use of spectrum, provided that we do so in an objectively justified, transparent, non-discriminatory and proportionate manner. We agree with Vodafone that the Direction must be interpreted consistent with the European framework. We do not however consider that the requirements of the Direction, nor our intention to set ALF after the Auction, are inconsistent with those European law requirements.

A12.56 We have not yet made any decisions as to the methodology that we will adopt when we come to revise the relevant licence fees after the Auction. Before we do so, we will consult all affected parties, who will have an opportunity to respond to our concrete proposals at that stage before any decisions are taken. We have set out above that we have no firm view as to the relative values of 800 MHz and 900 MHz spectrum, and will not reach any views until after the Auction, when we will take into account all relevant factors in revising the 900 MHz and 1800 MHz licence fees.

A12.57 We have set out in Section 12 why we do not consider it appropriate to rule out taking account of bids in the Auction when setting ALF, despite recognising there may be some risk that this will affect bids in the Auction. We do not consider that uncertainty as to the way in which we will set revised fees after the Auction is such that bidders, including Vodafone, cannot make sufficiently informed investment and bidding decisions in the Auction.

Uncertainty over ALF on 1800MHz

Summary of responses

A12.58 Everything Everywhere was disappointed that Ofcom had not reduced the uncertainty for ALFs for 900 MHz and 1800 MHz spectrum. It considered this uncertainty was greater for 1800 MHz spectrum than for 900 MHz spectrum, because there may be no direct benchmark in the Auction for 1800 MHz spectrum, whereas it considered that 900 MHz spectrum has a direct reference in 800 MHz spectrum.[147]

[146] Telefonica's non-confidential response, paragraphs 307-309.
[147] Everything Everywhere's non-confidential response, answer to question 8.2.

A12.59 Vodafone also suggested it was unlikely that bidders would contemplate purchasing the divested spectrum with this uncertainty on ALF.[148]

Ofcom's response

A12.60 We are able to give some greater clarity on how we currently anticipate setting ALF for 1800 MHz spectrum if it is not in the Auction:

12.60.1 We would consider the linear reference price from the Auction per megahertz for 800 MHz and 2.6 GHz spectrum, the results of the Additional Spectrum Methodology, and we would consider the competitiveness of the Auction. We would also consider Auction results for 800 MHz and 2.6 GHz spectrum in other countries that we consider to be sufficiently competitive, adapted to reflect UK circumstances;

12.60.2 We would not necessarily take a simple mean of the prices of 800 MHz and 2.6 GHz spectrum. We will aim to take into account the relative value of the three frequencies, including by taking account of any international benchmarks on relative values;

12.60.3 We would consider any international benchmarks for the value of 1800 MHz spectrum;

12.60.4 We would use the real pre tax cost of capital to convert the lump sum valuations of 1800 MHz spectrum into annual fees (as discussed in paragraph A12.64 below); and

12.60.5 We would aim to set ALF at the full market value, which we interpret to mean that we will not discount our estimate of the price that would occur in a well functioning market, nor set it conservatively compared with the available market information.

A12.61 However, as we stressed previously, this is only our provisional thinking. We will consult specifically on the revision of ALF for 900 MHz and 1800 MHz spectrum after the Auction.

Other ALF Issues

Summary of responses

A12.62 Various other issues were raised in relation to ALF, including:

12.62.1 While supporting Ofcom's proposal to consider whether to update current fee levels for 900 MHz and 1800 MHz spectrum if new developments lead to a delay in the award of the 800 MHz, H3G considered that Ofcom should go further and implement interim ALF as soon as possible based on the German and Italian Auction prices;[149]

12.62.2 Everything Everywhere asked for clarity on the discount rate used in the calculation of ALF, and proposed that the Government's social preference rate as set out in the Green Book was most relevant;[150] and

[148] Vodafone's non-confidential response, paragraph 69.
[149] H3G's non-confidential response, section 8.
[150] Everything Everywhere's non-confidential response, answer to question 8.1.

12.62.3 Telefonica sought further clarity on the circumstances that would lead Ofcom to review ALF again, after it had been reset after the Auction.[151]

Ofcom's response

A12.63 As we said in the January 2012 consultation, if new developments led to a delay in the award of the 800 MHz and 2.6 GHz bands, we would expect to consider whether to update current fee levels for 900 MHz and 1800 MHz spectrum ahead of the Auction. We would therefore consider whether it might be suitable to introduce interim revised ALFs ahead of fully implementing the Direction after the Auction. But if the Auction is not delayed, we do not consider it would be a good use of resources to revise ALF, given that we are required by the Direction to revise ALF for 900 MHz and 1800 MHz spectrum after the Auction, when there is likely to be better information available.

A12.64 We anticipate that it would be appropriate to use an estimate of the bidders' cost of capital rather than the social discount rate to convert the lump sum valuations into annual fees. This is because we expect the bidder would use its cost of capital to inform its bid in the Auction. We discussed this further in Annex 11 paragraphs A11.37 to A11.38 of the March 2011 consultation.

A12.65 We plan to deal with the issue Telefonica raised on circumstances that would lead us to review ALF again (and other issues raised in response to the March 2011 consultation) when we consult on the revision of ALF after the Auction.

[151] Telefónica's non-confidential response, paragraph 323.