Annexes to Advice to Government on the consumer and competition issues relating to liberalisation of 900MHz and 1800MHz spectrum for UMTS

Advice to the Secretary of State for Business, Innovation and Skills

Ofcom advice to Government

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Contents

Annex 1

Overview and results of technical analysis

Introduction

A1.1 This annex describes results of technical analysis we have conducted on the potential for a quality advantage associated with UMTS networks for holders of 900 MHz spectrum compared with those with access only to 2100 MHz spectrum.

A1.2 The technical analysis we have undertaken seeks to assess if 900 MHz spectrum is likely to provide the holders an unmatchable quality advantage compared to those relying on 2100 MHz, in the context of the use of UMTS to provide mobile broadband services, and how big this advantage might be. It does this by comparing the quality of mobile broadband services that could be provided by the incumbent holders of 900 MHz spectrum, through deployment of UMTS900 network(s), with what operators without access to 900 MHz spectrum could provide using their UMTS2100 networks.

A1.3 The analysis accounts for both the physical characteristics of the spectrum and the difference in the site numbers accessible to the operators. It has been updated to take account of the T-Mobile/Orange merger (with the creation of the new combined operator Everything Everywhere) and the greater site numbers available to them as a result, as well as significant comments received on our February 2009 technical analysis.

A1.4 The following sections cover:

- Our assumptions for possible network deployments;
- Overview of our approach to the technical analysis;
- Key uncertainties in the analysis;
- Key results from the analysis for throughput, pilot channel quality and capacity; and
- More technical results are included in appendices 1 and 2.

A1.5 Further information on our modelling approach and responses to our February 2009 technical analysis is provided in Annex 5. Annex 6 contains information on additional analysis we have undertaken on the impact of non-homogeneous network deployment (i.e. non-uniform site placement and clutter distribution) for a sample area in London.

Potential network deployments

A1.6 A key prior question to assessing the potential for an unmatchable quality advantage is to consider what networks could be deployed by O2 / Vodafone, using their liberalised 900 MHz spectrum, and by their competitors (Everything Everywhere (EE) / H3G[1]) in order to minimise any competitive advantage. Our

[1] A simplifying assumption is that H3G gains access to all of the sites of the merged EE network

assumptions are for around 2013, by which time O2 / Vodafone could have deployed fairly extensive UMTS900 networks and EE could have completed its integration. We believe it more likely that operators will initially focus their deployments on improving their network in more densely populated areas, as these will offer benefits to more consumers, and hence be more profitable than extending coverage to less densely populated areas. Therefore our technical analysis considers network deployments in the most densely populated areas of the country, covering 80% of the population. In addition, the competitive impact of deployments in this area is likely to be more significant than extending rural coverage given the greater number of people affected.

A1.7 The table below sets out six comparisons and our assumptions for the number of sites that different networks could deploy in the 80% population area. Supporting analysis of site numbers is contained in Annex 3. Note that although we consider that the site numbers assumed for comparisons 3 and 4 are plausible the rate of site acquisition is relatively aggressive. Comparison 1 is based on operators primarily relying on existing sites. Comparison 2 assumes O2 and/or Vodafone only roll out a subset of their existing site base (perhaps limited to major town and city centres). Comparison 3 represents more aggressive roll-outs whereby operators acquire (or share) additional sites. We consider it reasonable to assume such strategies will be correlated due to the competitive pressure they would exert on one another. Comparison 4 represents a possibly less likely situation where O2 and/or Vodafone more aggressively roll out but EE / H3G are for some reason unable to respond, which in some senses represents a worst case in terms of the potential competitive distortion that might arise. Comparison 5 illustrates the impact of frequency differences, independent of site number differences, when both the 900 MHz and 2100 MHz only operators have 7,000 sites. Comparison 6 is similar to Comparison 5 but this time when both the 900 MHz and 2100 MHz only operators have 4,000 sites.

Comparison	900 MHz incumbent (O2/Vodafone) deployment		Deployment by operators without 900 MHz spectrum (EE and H3G)	
	Description	**Site numbers in 80% area**	**Description**	**Site numbers in 80% area**
1	Upgrade existing sites to UMTS900	7,000 UMTS900 (+ existing UMTS2100)	Integration of sites from T-Mobile and Orange	13,000 UMTS2100
2	Upgrade subset of existing sites to UMTS900	4,000 UMTS900 (+ existing UMTS2100)	Integration of sites from T-Mobile and Orange	13,000 UMTS2100
3	Upgrade existing sites to UMTS900 plus site acquisition or sharing	10,000 UMTS900 (+ existing UMTS2100)	Integration of sites from T-Mobile and Orange plus new site acquisition	16,000 UMTS2100
4	Upgrade existing sites to UMTS900 plus site acquisition or sharing	10,000 UMTS900 (+ existing UMTS2100)	Integration of sites from T-Mobile and Orange	13,000 UMTS2100
5	Like for like comparison of frequency difference	7,000 UMTS900	Like for like comparison of frequency difference	7,000 UMTS2100
6	Like for like comparison of frequency difference	4,000 UMTS900	Like for like comparison of frequency difference	4,000 UMTS2100

Table A1.1: Table of comparisons

A1.8 In practice the relative positions of operators may shift over time, with EE / H3G having more of an advantage early on (due to their initially larger UMTS2100 network) and Vodafone / O2 potentially completing their UMTS900 network towards the end of 2012 before EE has finished its network integration (end 2013).

A1.9 It is also important to note that Comparisons 1, 3 and 4 represent our working assumptions for plausible but relatively aggressive deployments. O2 / Vodafone could deploy less aggressively than this as illustrated by Comparison 2, in which case the risk of competitive distortion would be less. Nonetheless, we do think they will have an incentive for a relatively extensive UMTS900 deployment in the near future (rather than, for example, delaying re-farming of their 900 MHz spectrum until LTE900 is available) because of the competitive threat from an improved EE network.

A1.10 In addition to the comparisons above, we have also conducted a limited analysis of the performance of a 7,300 site UMTS900 network, a 9,000 site UMTS900 network, a 9,000 site UMTS2100 network and a 15,000 site UMTS2100 network to provide points of comparison with the results from the February 2009 consultation.

Approach to the analysis

A1.11 There are several aspects to the quality of mobile broadband services, including speed of data transfer, consistency of coverage (particularly within buildings), and the capacity of the network to carry traffic. We have considered measures of technical network performance to model this and chosen three measures which we believe most closely relate to the consumer experience.

- *Single user throughput*: defined as the downlink bit rate which can be successfully delivered to a single active user per cell at a particular depth and consistency of indoor coverage. This is the downlink bit rate or download speed which a user could experience *when not contending with other users for service in that cell*, so that the cell delivers the maximum possible data rate to a single user consistent with the signal quality experienced by that user. *The signal quality is determined by assuming that all cells are simultaneously active and devoting most of their resources to serving users with data.* If more than one user was active at any one time in the cell, e.g. if the network was more heavily loaded, each user would receive a share of the maximum throughput.

- *Pilot channel quality:* defied as the percentage area within the 80% population area where the quality of the pilot carrier at a given depth of indoor coverage is above a certain threshold (i.e. the unloaded Ec/Io parameter is above a typical threshold of say -10 dB to -14 dB).

- *Data capacity:* defined as the percentage of the total population in the 80% population area who, when simultaneously active, can receive a consistent average downlink bit rate at a given depth and consistency[2] of indoor coverage. This aggregates the available capacity from all frequency bands and carriers available to the operator, in so far as it can deliver the required service quality.

A1.12 In all of this modelling we have assumed operators have implemented HSPA with 15 codes allocated to HSDPA services.

A1.13 For our consultation in February 2009 we analysed the potential advantage of 900 MHz spectrum by examining the difference in the number of cell sites required to deliver a given level of service (quality and demand) using 900 MHz versus other frequency bands. The model used for this purpose made a number of simplifying assumptions in order to be tractable and transparent to stakeholders. We also conducted an analysis of the difference in network quality which would result from networks where the number of sites was such as to achieve only partial quality matching.

A1.14 Amongst responses from stakeholders, two particular issues were raised which suggested material changes were desirable to that modelling approach.

a) First, some stakeholders asserted that our approach to modelling the ‘partial quality matching’ scenarios was too simplistic and predicted user throughput levels which were too high, especially at the edges of the cells.

b) Second, the model assumed for simplicity that the area for analysis could be decomposed into smaller areas with uniform characteristics (“Urban”, “Suburban”, “Rural” etc.), each of which was analysed individually and then combined to give an aggregate performance assessment. This ‘*uniform’ clutter* modelling was

[2] e.g. over locations within a cell, and types of building

criticised by some stakeholders as being unrepresentative of the real environment, with the result that it would tend to overestimate the advantages of 900 MHz.

A1.15 In response to these issues (and others), we have conducted our further modelling as follows.

a) We have constructed a new model which explicitly accounts for the variation of signal conditions around the whole coverage area and which should capture the cell edge behaviour and other aspects more explicitly. This model is still based on a ‘uniform’ clutter approach.

b) We have conducted an investigation in a limited geographic region (an area within the Greater London region) of a more realistic ‘non-uniform’ clutter environment to determine whether this materially alters findings arrived at using the new uniform clutter model. These results are provided in Annex 6.

A1.16 A separate development since February 2009 has been Ofcom’s consultation on a request from 3G operators to vary their 2.1 GHz licences to increase the permitted power limits. We issued a statement on this in September 2010 granting the request to allow 2.1 GHz licensees to increase their power by 3 dB. We have conducted a limited analysis of the impact of this power increase on the relative advantage of 900 MHz over 2.1 GHz and concluded that it is likely to make no material difference for the scenarios considered in this analysis (see the appendices to this annex for these results).

Key uncertainties in the analysis

A1.17 There are inherent uncertainties in undertaking a theoretical and forwarding looking comparison of network performance. Two of the most important uncertainties are:

- **Uncertainties over how well signals at different frequencies penetrate into buildings (‘building penetration loss’ or BPL).** The advantage of lower frequencies over higher frequencies in penetrating walls and windows varies enormously between different building constructions, making it very difficult to determine an average effect accurately. For example, if buildings which are particularly hard to penetrate with high frequencies are prevalent, or are most important in determining the perception of quality amongst important consumer segments, then the advantages of the 900 MHz network will be greater. Different stakeholders expressed very different views as to the appropriate values of BPL to apply in the analysis. In order to deal with this uncertainty we have considered a range spanning the most plausible values (shown as ‘BPL: depth 2 - base case’ and ‘BPL: depth 2 - rising faster’ in the results). We believe the true answer, in terms of average effect, most likely lies somewhere within this range, but we do not have a view as to exactly where.

- **Uncertainties over feasible network size.** The potential for an unmatchable advantage depends on the number of sites it is feasible for different operators to deploy in the relevant timescale. When Everything Everywhere complete its integration of the old T-Mobile and Orange networks, the number of sites which actually turn out to be useful could be more or less than the number currently anticipated. Further, O2 and/or Vodafone might be able to deploy a larger UMTS900 network than we currently anticipate if they successfully implement a more extensive site sharing arrangement (and this receives any necessary regulatory approval).

A1.18 Consequently our analysis considers a number of different cases including different assumptions on these key uncertainties.

Summary of the throughput analysis

A1.19 The charts in Appendix 1 below compare the single user[3] throughput in the downlink direction (i.e. from the base station to the user) for an indoor user of a UMTS900 network (e.g. O2 or Vodafone UMTS900) with that of a UMTS2100 network (e.g. the merged 'Everything Everywhere' or H3G UMTS2100) under a wide range of scenarios. Comprehensive results for each of the comparisons highlighted in Table A1.1 above are provided.

A1.20 For this summary, we concentrate on two key comparisons only.

Comparison 1

A1.21 Comparison 1 represents a credible scenario where Vodafone and O2 deploy UMTS900 within the 0 – 80% most densely populated area of the country using their existing site base and EE and H3G complete the H3G/T-Mobile network integration with the inclusion of a number of Orange sites into a larger shared UMTS2100 network.

A1.22 Figure A1.1 below illustrates the single user throughput performance of a 7,000 site UMTS900 network in comparison to a 13,000 site UMTS2100 network for users who are, on average, relatively deep inside buildings and/or for buildings which have, on average, relatively high building penetration losses i.e. circumstances where the differences between frequencies are more likely to be pronounced (i.e. for BPL depth 2 – see Annex 5 for the definition of the different BPL depths).

[3]The data rate at which a consumer could download data if they were the only active user within the cell. If there were more users the capacity would be shared between them.

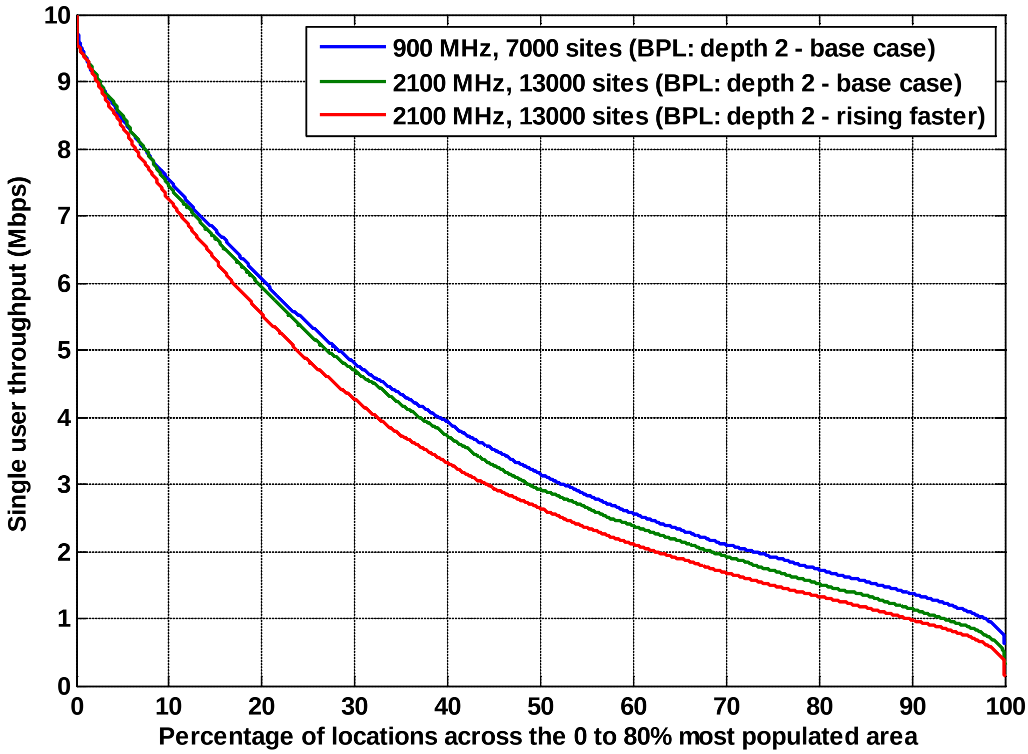


Figure A1.1: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

A1.23 Figure A1.1 should be interpreted as follows: the x-axis indicates the percentage of locations at ‘depth 2’ across the whole coverage area ordered such that those having the best signal conditions are to the left, and those with the worst to the right. So “20%” in Figure A1.1 represents the 20% of locations with the best signal conditions and hence highest throughput for each of the 900 MHz and 2100 MHz networks (these are not necessarily the same 20% of locations). The y-axis shows the throughput attained or exceeded at all of these locations when a single user consumes the full capacity of the serving cell (e.g. in a single sector of one base site). Thus we see that both the 900 MHz network and the 2100 MHz network with base case BPL, achieve a single-user downlink speed of at least 6 Mbps to the first 20% of depth 2 locations. By contrast the 2100 MHz network with ‘rising faster’ BPL can deliver 6 Mbps to only the first 17% of locations, but can still deliver at least 5.5 Mbps to the first 20% of locations.

A1.24 An alternative view of the same comparison is given in Figure A1.2. In this figure the y-axis shows the percentage difference in the single user throughput for the 2100 MHz network compared to the 900 MHz network. So for example, the minimum throughput offered at the 80th percentile of locations is approximately 22% lower for the 2100 MHz network when compared to the 900 MHz network (for locations at BPL: depth 2, rising faster with frequency – i.e. the red line). As noted above, we believe the true answer in terms of aggregate effect will lie somewhere between the red and green lines on this graph, but we cannot say exactly where.

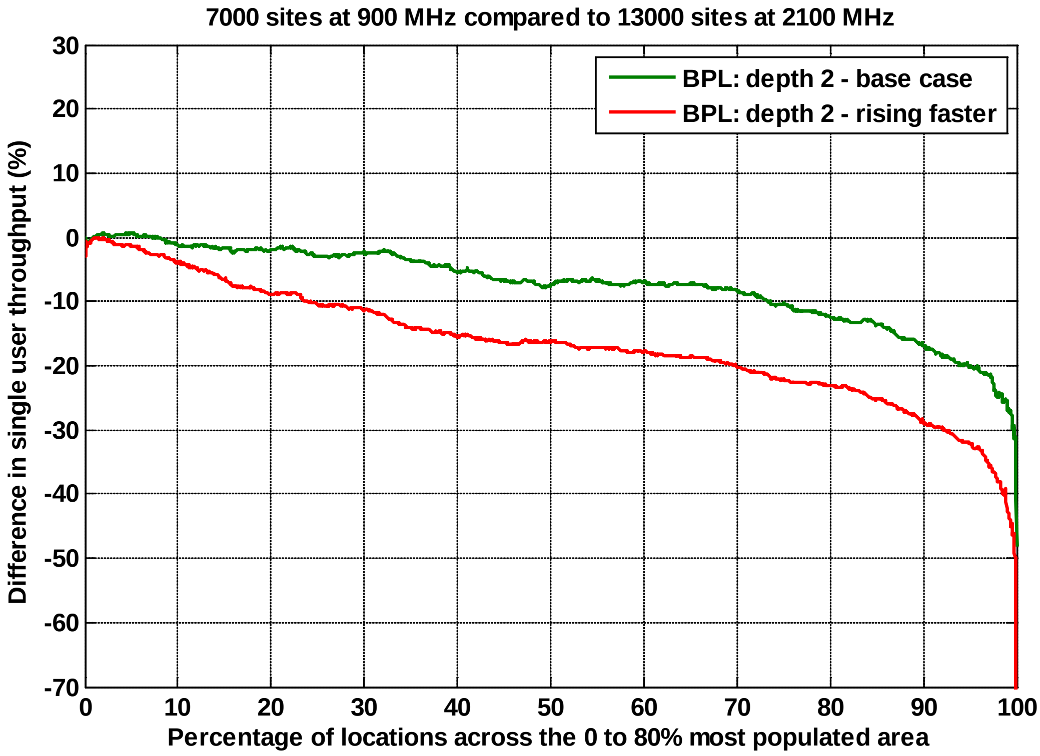


Figure A1.2: Percentage difference in throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL: depth 2, base case and rising faster with frequency.

A1.25 Thus our analysis indicates that a UMTS900 network, even with considerably fewer sites than a UMTS2100 network, can deliver a throughput advantage in a proportion of locations which have the most challenging signal conditions and hence the lowest data throughputs.

A1.26 However, the importance of this advantage depends strongly on the construction of the buildings, with relatively little or no advantage experienced for buildings of relatively light attenuation or where users are not particularly deep within the building (e.g. they may be close to windows). Under such circumstances the throughput performance at both frequencies is relatively similar and little advantage may be experienced for users on the 900 MHz network. This is illustrated in Figure A1.3 which compares the percentage difference in single user throughput for a 7,000 site UMTS900 network compared to a 13,000 site UMTS2100 network under BPL depth 0, depth 1 and depth 2 base case conditions.

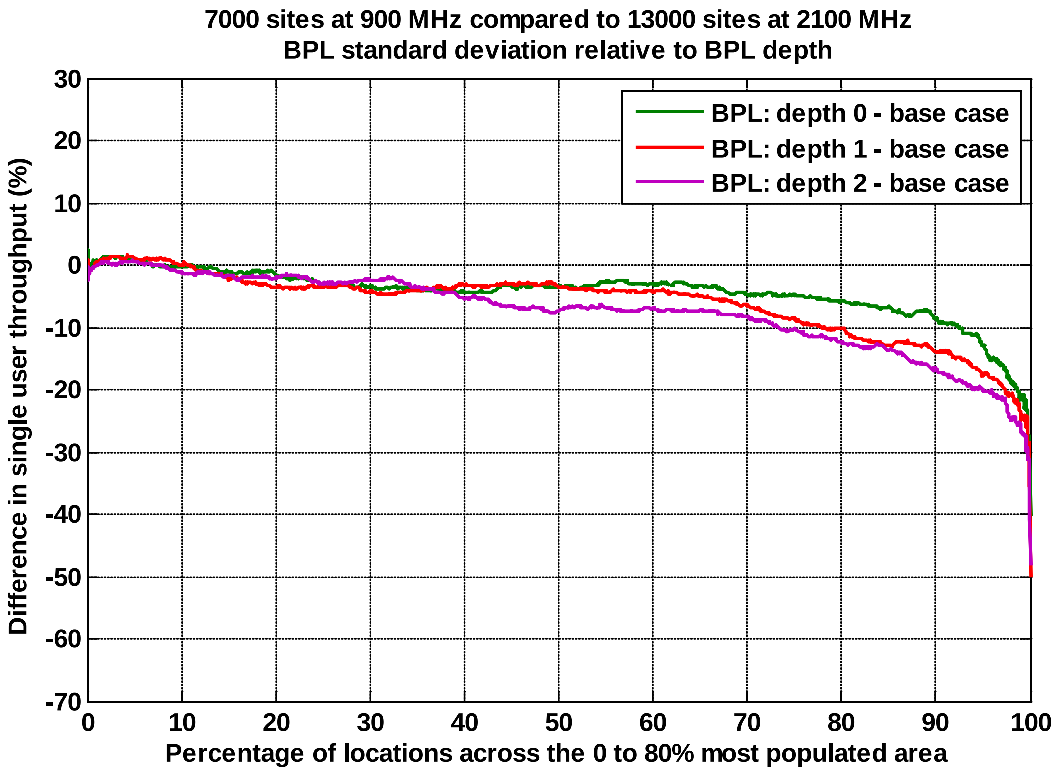


Figure A1.3: Percentage difference in throughput for UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL depths 0, 1 and 2 base case and BPL standard deviation relative to BPL depth.

A1.27 It should be stressed that the depth 0 results under the above assumptions (i.e. BPL base case and where the BPL standard deviation is relative to the depth) represent particularly easy to serve users. Under these assumptions, a 13,000 site 2100 MHz network can come close to matching the single user throughput performance of a 7,000 site 900 MHz network for the majority of locations (it only dips below 10% less throughput for the last 7 or 8% of locations – i.e. beyond 92 or 93% locations on the graph).

A1.28 Under slightly more challenging conditions (i.e. BPL rising faster with frequency and where the BPL standard deviation is the same for all depths – i.e. the depth 2 values are applied to depth 0 and depth 1) the depth 0 results still show an improvement in relative throughput performance when compared to the depth 1 and depth 2 results but this improvement is less pronounced, as can be seen in Figure A1.4 below.

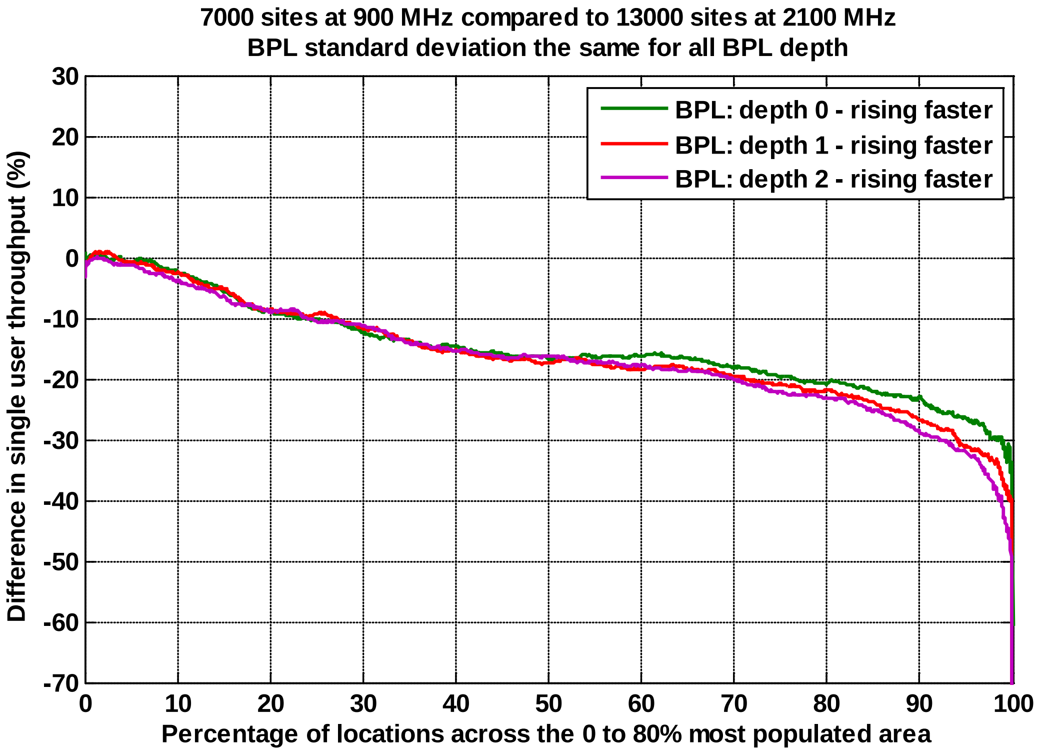


Figure A1.4: Percentage difference in throughput for UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL depths 0, 1 and 2 base case and BPL standard deviation the same for all BPL depths.

A1.29 In conclusion, our results for Comparison 1 show that a 7,000 site UMTS900 network may have better single user throughput performance than a 13,000 site UMTS2100 network in the 0 to 80% most densely populated areas of the country. However, the size of this throughput advantage depends on building construction types (and the impact on signal attenuation) and on the location of users within a building. For many building types and user locations the throughput advantage is predicted to be relatively modest, albeit for some the difference may be more material.

Comparison 5

A1.30 Comparison 5 provides a like for like comparison of the affect of frequency on single user throughput independent of site differences.

A1.31 Figure A1.5 illustrates the difference in single user throughput performance for 7,000 site UMTS900 network in comparison to a UMTS2100 network also with 7,000 sites for users who are, on average, relatively deep inside buildings and/or for buildings which have, on average, relatively high building penetration losses (i.e. BPL depth 2 base case and rising faster with frequency).

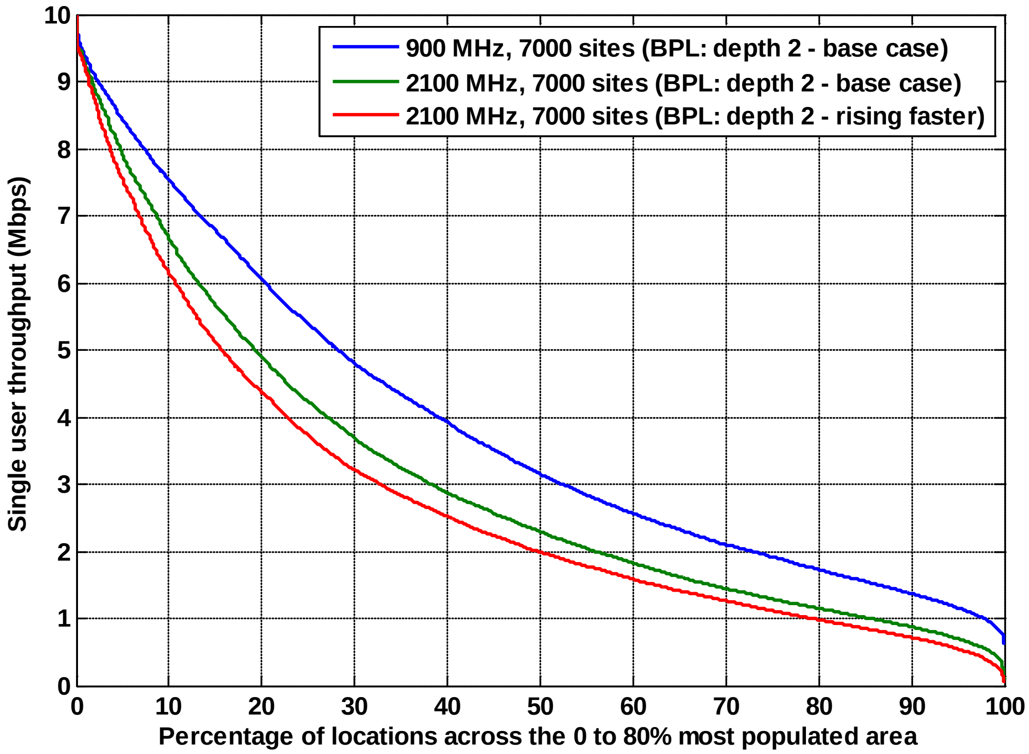


Figure A1.5: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

A1.32 Under these conditions the 900 MHz network has a significant advantage over a 2100 MHz network for all locations at depth 2.

A1.33 Even for particularly easy to serve users (i.e. BPL: depth 0 where the BPL standard deviation is relative to the depth), 900 MHz still provides a throughput advantage over a similar sized 2100 MHz network though the size of the advantage is reduced as illustrated in Figure A1.6 below.

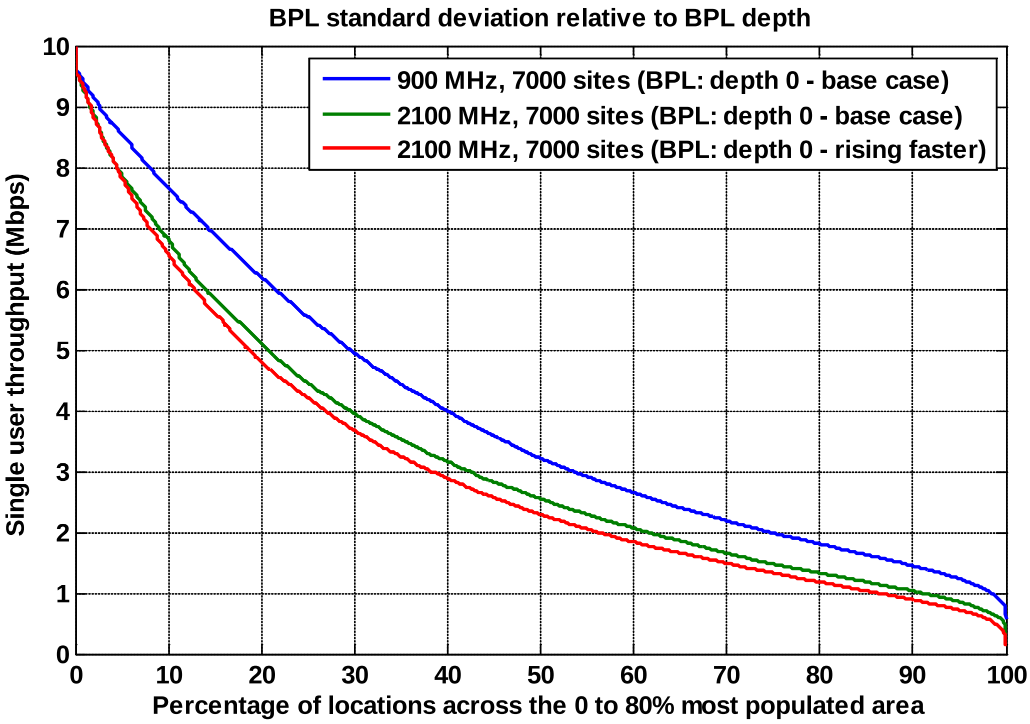


Figure A1.6: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 network over the same area. BPL: depth 0, base case and rising faster with frequency where the BPL standard deviation is relative to the depth.

A1.34 In conclusion, our results for Comparison 5 show that for networks of the same size (i.e. 7,000 sites in the 0 to 80% most densely populated areas of the country) a UMTS900 network is likely to have consistently better throughput performance than a UMTS2100 network for most building types and user locations within those buildings.

Results of the pilot channel quality analysis

A1.35 Pilot channel quality is a key parameter for UMTS networks. The pilot channel (CPICH) is important in cell selection and handover. Unless a terminal receives a signal with sufficient pilot channel quality and strength, it cannot access network services.

A1.36 The figures in Appendix 2 below compare the Ec/Io of the unloaded CPICH (i.e. a measure of pilot channel quality) in the downlink direction (i.e. from the base station to the user) for an indoor user of a UMTS900 network (e.g. O2 or Vodafone) with that of a UMTS2100 network (e.g. EE / H3G) under a wide range of scenarios. Comprehensive results for each of the comparisons highlighted in Table A1.1 above are provided.

A1.37 For this summary, we concentrate on the same 2 key comparisons that we considered for the throughput analysis above.

Comparison 1

A1.38 Figure A1.7 below illustrates the Ec/Io performance of a 7,000 site UMTS900 network in comparison to a 13,000 site UMTS2100 network for users who are, on average, relatively deep inside buildings and/or for buildings which have, on average, relatively high building penetration losses i.e. circumstances where the differences between frequencies are more likely to be pronounced (i.e. BPL depth 2 – see Annex 5 for the definition of the different BPL depths).

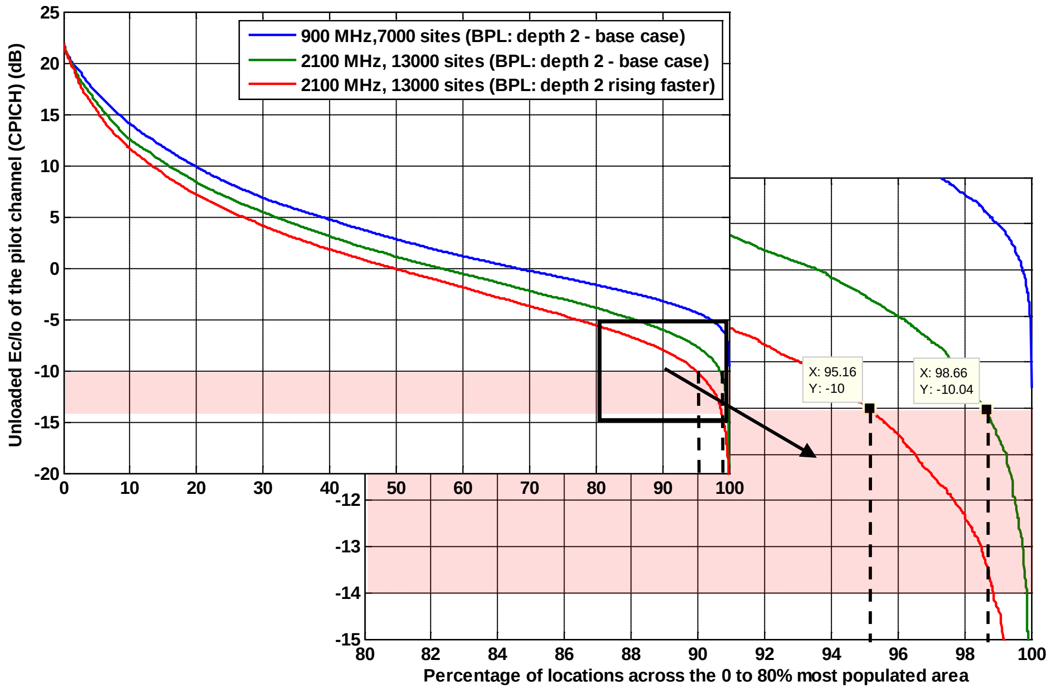


Figure A1.7: Ec/Io for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

A1.39 Figure A1.7 should be interpreted as follows: the x-axis indicates the percentage of locations at ‘depth 2’ across the whole coverage area ordered such that those with the best signal conditions are to the left, and those with the worst to the right. So “20%” in Figure A1.7 represents the 20% of locations with the best signal conditions and hence Ec/Io for each of the 900 MHz and 2100 MHz networks (these are not necessarily the same 20% of locations). The y-axis shows the unloaded Ec/Io of the CPICH attained or exceeded at all of these locations

A1.40 The highlighted portion of the figure shows the likely range of the Ec/Io threshold (i.e. -10 dB to -14 dB – the level of Ec/Io likely to be necessary for good service). For a UMTS2100 network under depth 2: rising faster with frequency conditions the performance drops below -10 dB for the last 4.8 % of locations and for depth 2: base case conditions the performance drops below -10 dB for the last 1.3 % of locations. By contrast, for a 900MHz network with 7,000 sites Ec/Io falls below -10 dB for an insignificant proportion of locations within the overall 80% population area.

A1.41 However, given that mobile networks are typically only designed to provide coverage for around 95% of locations, the Ec/Io performance of a 13,000 site UMTS2100 network may not put it at a material disadvantage when compared to a 7,000 site UMTS900 network even though the UMTS900 network has better overall Ec/Io performance.

Comparison 5

A1.42 Figure A1.8 below provides a like for like comparison of the affect of frequency on Ec/Io performance independent of site differences.

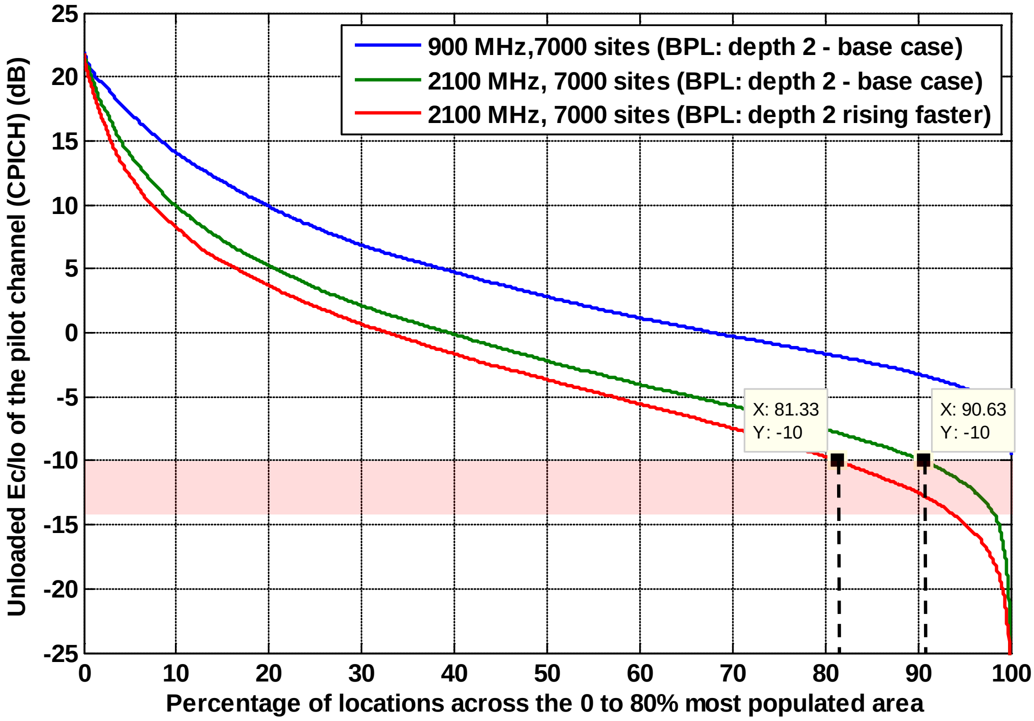


Figure A1.8: Ec/Io for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with 7,000 sites UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

A1.43 As can be seen, the Ec/Io performance of a 7,000 site UMTS2100 network covering the 0 to 80% most densely populated areas of the country is significantly worse than for a UMTS900 network of the same size and covering the same area. For BPL depth 2 base case conditions the UMTS2100 network's Ec/Io performance drops below -10 dB for the last 9% of locations and for BPL depth 2 rising faster with frequency conditions it drops below -10 dB for the last 19% of locations. As we have already seen, for a 900MHz network with 7,000 sites Ec/Io falls below -10 dB for an insignificant proportion of locations within the overall 80% population area.

Results of the high speed data capacity analysis

A1.44 The high speed data capacity cases presented here are as follows.

- Comparison 1: Vodafone and O2 upgrade their existing 7,000 sites within the 0 to 80% most populated areas of the country to add a single UMTS900 carrier, Vodafone dedicates its UMTS900 carrier and two of its UMTS2100 carriers to high speed data traffic, O2 dedicates its UMTS900 carrier and one of its UMTS2100 carriers to high speed data traffic. EE and H3G complete the integration of their networks to give them access to 13,000 sites within the 0 to 80% most populated areas of the country. EE dedicates three of its UMTS2100 carriers to high speed data traffic; H3G dedicates two of its UMTS2100 carriers to high speed data traffic.

- Comparison 2: Vodafone and O2 upgrade only a subset of their existing sites within the 0 to 80% most populated areas of the country to add a single UMTS900 carrier giving them a total of 4,000 UMTS900 sites and 7,000 UMTS2100 sites, Vodafone dedicates its UMTS900 carrier and two of its UMTS2100 carriers to high speed data traffic, O2 dedicates its UMTS900 carrier and one of its UMTS2100 carriers to high speed data traffic. EE and H3G complete the integration of their networks to give them access to 13,000 sites within the 0 to 80% most populated areas of the country. EE dedicates three of its UMTS2100 carriers to high speed data traffic; H3G dedicates two of its UMTS2011 carriers to high speed data traffic.

- Comparison 3: Vodafone and O2 upgrade their existing sites plus acquire additional sites (perhaps including more extensive site sharing) within the 0 to 80% most populated areas of the country to add a single UMTS900 carrier giving them a total of 10,000 UMTS900 and UMTS2100 sites, Vodafone dedicates its UMTS900 carrier and two of its UMTS2100 carriers to high speed data traffic, O2 dedicates its UMTS900 carrier and one of its UMTS2100 carriers to high speed data traffic. EE and H3G complete the integration of their networks plus acquire additional sites to give them access to 16,000 sites within the 0 to 80% most populated areas of the country. EE dedicates three of its UMTS2100 carriers to high speed data traffic; H3G dedicates two of its UMTS2011 carriers to high speed data traffic.

- Comparison 4: Vodafone and O2 upgrade their existing sites plus acquire additional sites (perhaps including more extensive site sharing) within the 0 to 80% most populated areas of the country to add a single UMTS900 carrier giving them a total of 10,000 UMTS900 and UMTS2100 sites, Vodafone dedicates its UMTS900 carrier and two of its UMTS2100 carriers to high speed data traffic, O2 dedicates its UMTS900 carrier and one of its UMTS2100 carriers to high speed data traffic. EE and H3G complete the integration of their networks but do not acquire additional sites leaving them access to 13,000 sites within the 0 to 80% most populated areas of the country. EE dedicates three of its UMTS2100 carriers to high speed data traffic; H3G dedicates two of its UMTS2011 carriers to high speed data traffic.

A1.45 In these figures, Vodafone's capacity is higher than O2's due to the additional 2100 MHz carrier held by Vodafone. We have assumed that each operator reserves 1 UMTS2100 carrier for voice/low speed data (i.e. non-HSDPA traffic) and its remaining carriers for high speed data (i.e. HSDPA traffic). We also assume that Vodafone and O2 only deploy 1 UMTS900 carrier. Only high speed data carriers are included in the calculation.

A1.46 These figures should be interpreted as follows. The x axis represents the percentage of the population within the 80% most densely populated area of the country that can simultaneously be served with the indicated downlink throughputs if they were relatively deep inside buildings with the corresponding propagation conditions[4]. For example, in Figure A1.9 around 1.0% of the population could be served with an average of 0.512 Mbps with the O2 network of 7,000 sites.

A1.47 This analysis suggests that the main factors in determining the capacity of the network to serve users at a given data throughput are the number of sites and the quantity of spectrum available, with the specific spectrum bands playing a smaller

[4] Note that the indicated downlink throughputs represent the average downlink throughput that would be experienced by all users in the relevant propagation conditions.

role. They show that EE / H3G are likely to have greater capacity than Vodafone or O2 in all comparisons apart from Comparison 4 where Vodafone could have slightly higher capacity than H3G.

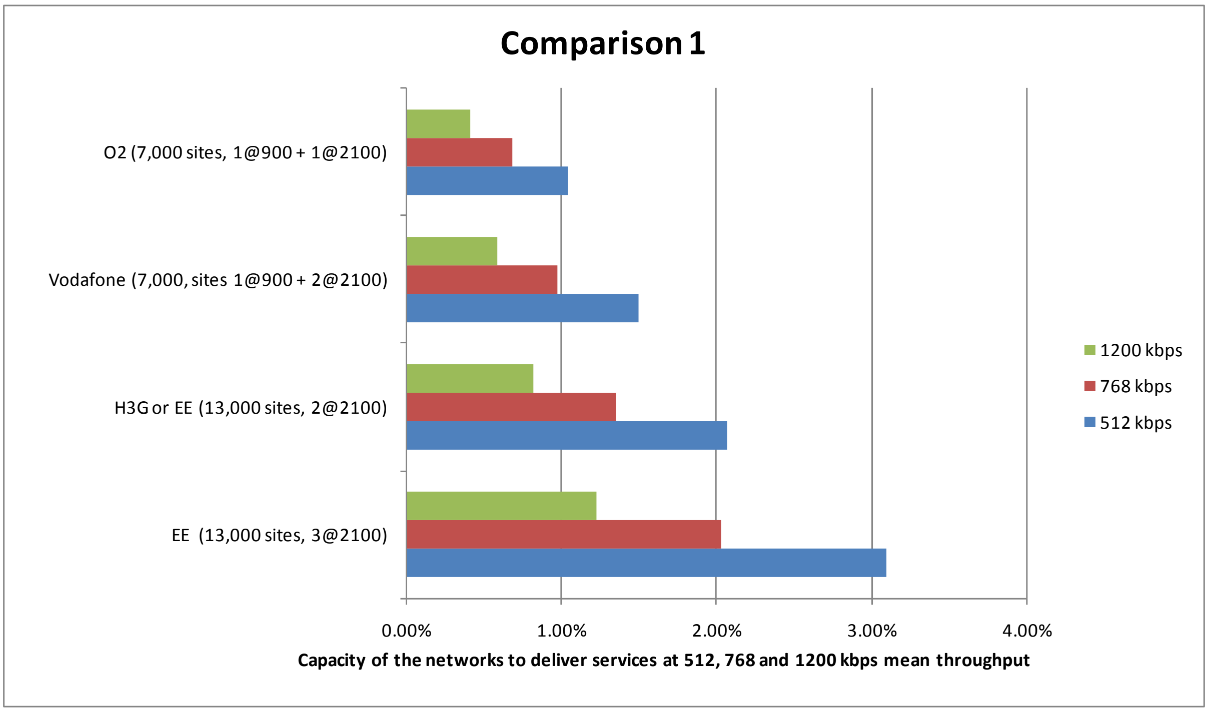


Figure A1.9: Data capacity: users supported concurrently at throughput of 0.512, 0.768 and 1.2 Mbps for Vodafone and O2 with 7,000 sites at 900 MHz and 2100 MHz and for EE and H3G with 13,000 sites at 2100 MHz distributed over the 80% population area (BPL: depth 2, base case).

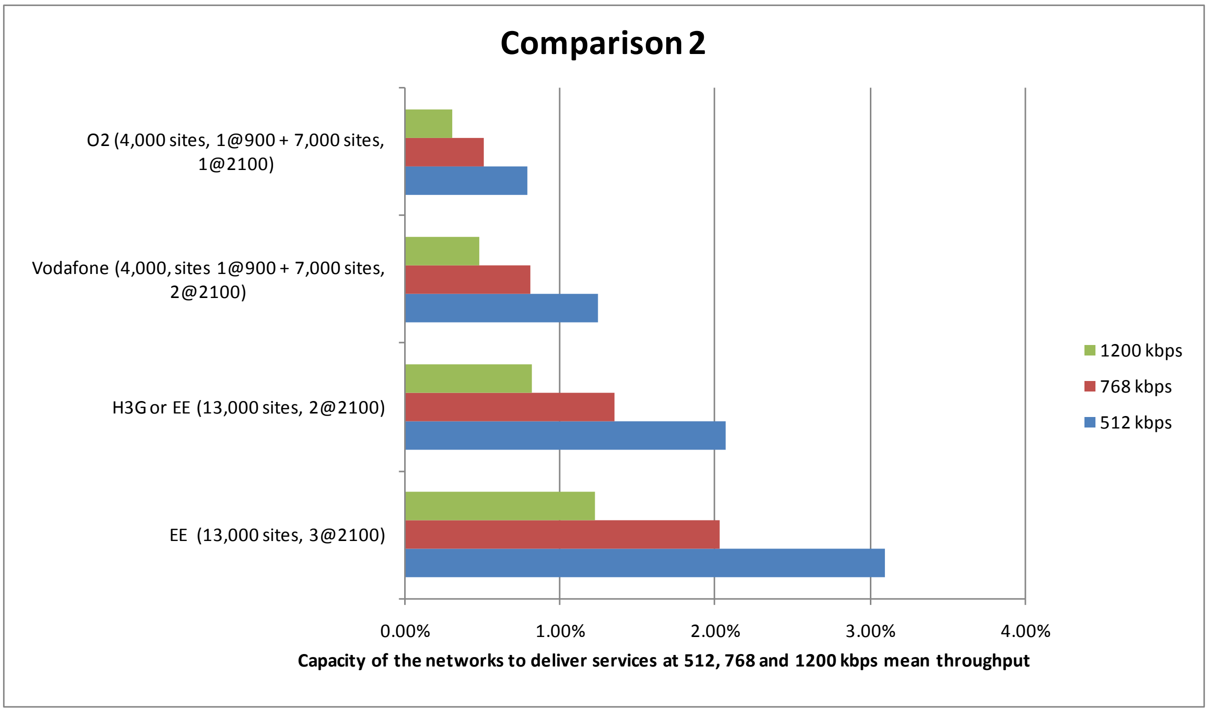


Figure A1.10: Data capacity: users supported concurrently at throughput of 0.512, 0.768 and 1.2 Mbps for Vodafone and O2 with 4,000 sites at 900 MHz and 7,000 sites at 2100 MHz and for EE and H3G with 13,000 sites at 2100 MHz distributed over the 80% population area (BPL: depth 2, base case).

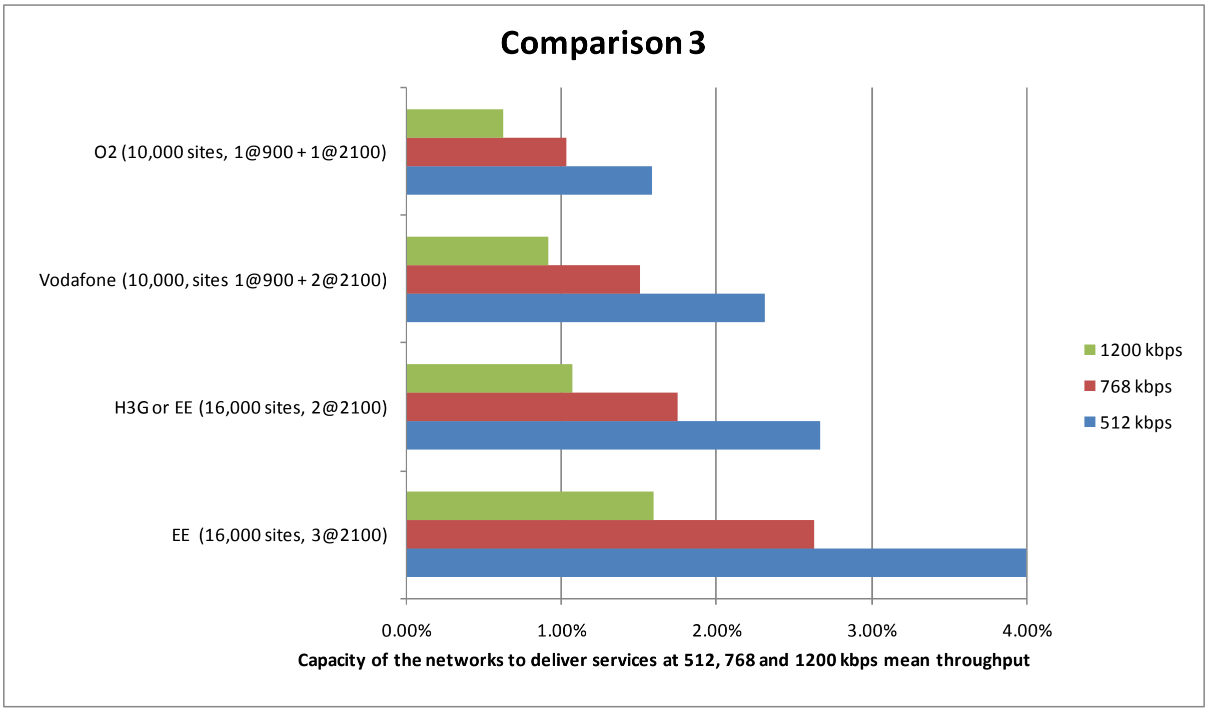


Figure A1.11: Data capacity: users supported concurrently at throughput of 0.512, 0.768 and 1.2 Mbps for Vodafone and O2 with 10,000 sites at 900 MHz and 2100 MHz and for EE and H3G with 16,000 sites at 2100 MHz distributed over the 80% population area (BPL: depth 2, base case).

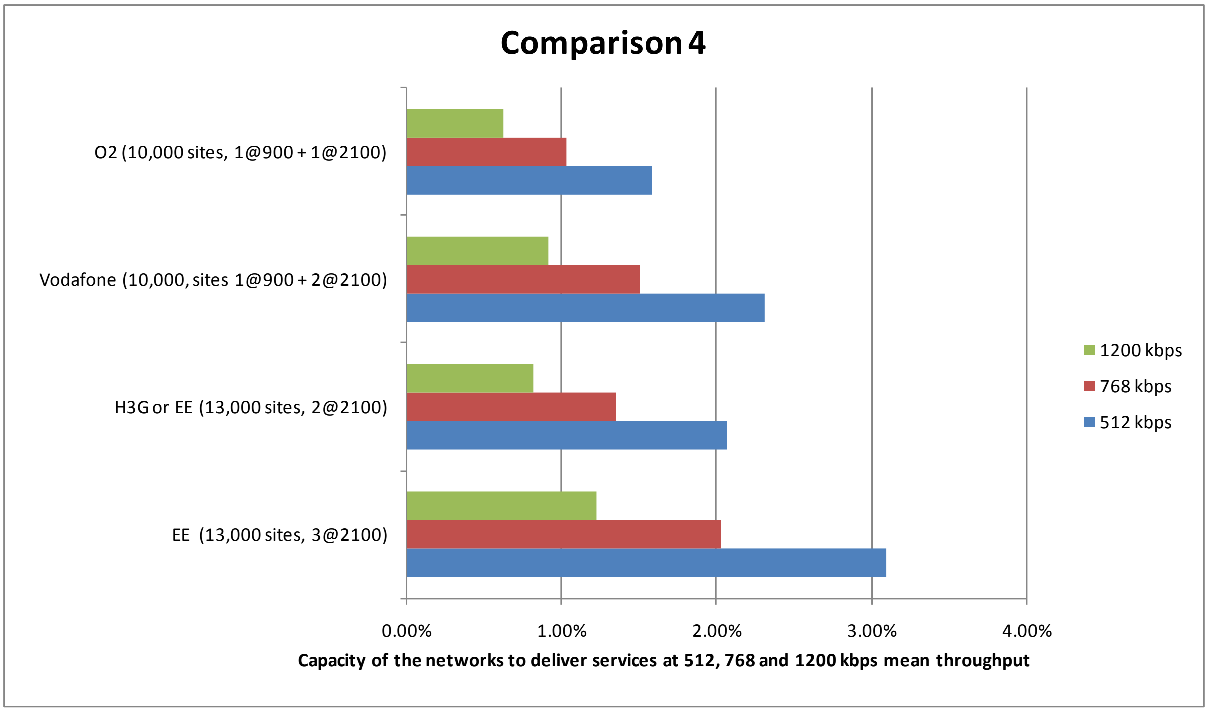


Figure A1.12: Data capacity: users supported concurrently at throughput of 0.512, 0.768 and 1.2 Mbps for Vodafone and O2 with 10,000 sites at 900 MHz and 2100 MHz and for EE and H3G with 13,000 sites at 2100 MHz distributed over the 80% population area (BPL: depth 2, base case).

A1.48 It could be argued that EE's need to integrate both legacy T-Mobile and Orange customers would mean that they may need to dedicate the equivalent of two UMTS2100 carriers to voice/low speed data traffic, in which case the EE high speed data capacity would equal that of H3G's in the above figures.

A1.49 It should be stressed that the capacity calculations above are based on an idealised situation; they should not be taken as representing the real/actual capacity of the networks. However, they do provide a reasonable representation of the comparative capacity on these networks.

A1.50 It should also be noted that in practice it is unlikely that an operator would completely dedicate carriers to HSDPA and non-HSDPA traffic in the way we have suggested. Rather, for a least some carriers, a mix of traffic would be carried. However, we don't believe that it is necessary to go to the detail of modelling mixed carriers to understand the general capacity behaviour of the networks.

Comparison with the February 2009 consultation

A1.51 In the February 2009 consultation we conducted an analysis comparing the esimates of indoor throughput for 900 MHz and 2100 MHz networks. This analysis was conducted under BPL conditions equivalent to the 'depth 2 - base case'. Figure A1.13 below is taken from the consultation and compares the throughput performance of a UMTS900 network with 9,000 sites in the 0 – 80% most populated areas of the country with a UMTS2100 network also with 9,000 sites covering the same area.

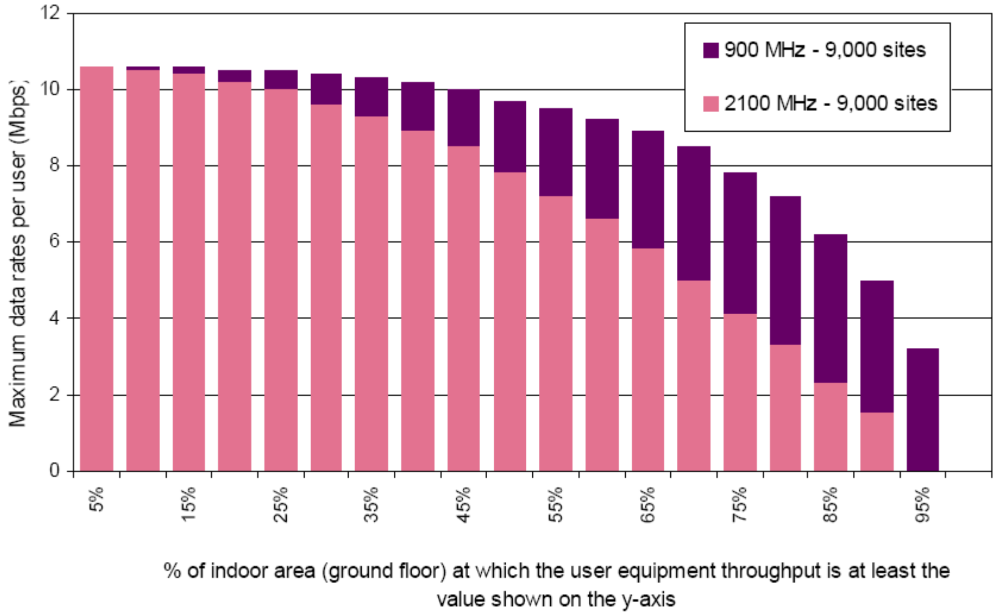


Figure A1.13: Throughput achieved by networks with the same number of sites (9,000) and different spectrum bands (900 MHz and 2100 MHz) – source Figure 4, February 2009 consultation.

A1.52 As can be seen, this comparison shows a gradual degradation in throughput as users move from locations with the best signal conditions to those with the worst. It also shows that a UMTS900 network can provide greater throughput than a UMTS2100 network in most indoor locations and that this throughput advantage generally increases as you move from left to right (i.e. from the best signal locations to the worst).

A1.53 We have conducted a similar comparison with our revised model, the results of which are given in Figure A1.14 below.

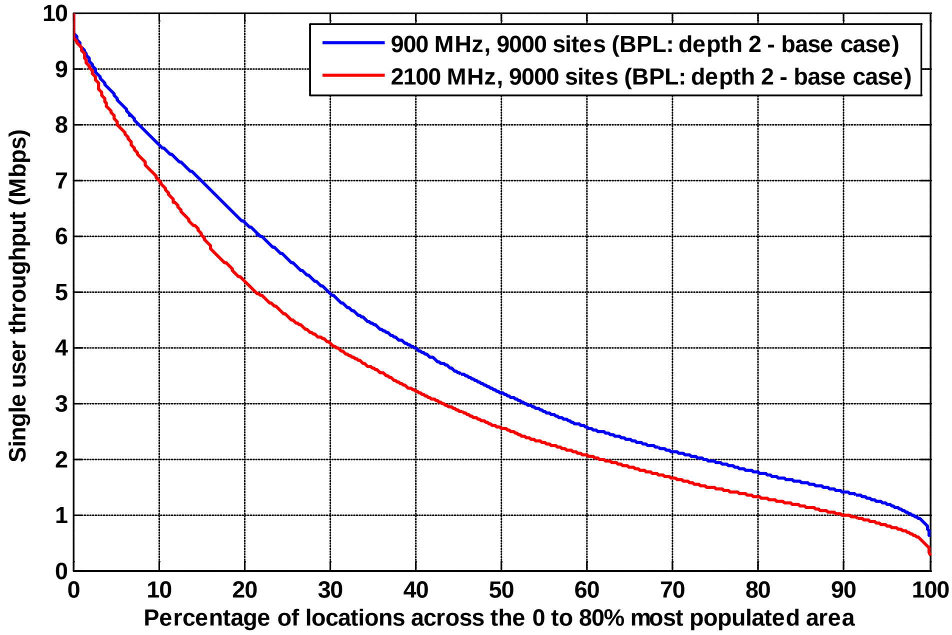


Figure A1.14: Throughput for a UMTS900 network with 9,000 sites distributed over the 80% population area compared with a 9,000 site UMTS2100 network over the same area. BPL: depth 2, base case.

A1.54 Comparing Figures A1.13 and A1.14 we can see that there are some similarities in behaviour and some differences. For instance, Figure A1.14 shows a degradation in throughput as you move from locations with the best signal conditions to the worst. It also shows that a UMTS900 network can provide greater throughput than a UMTS2100 network. However, it also shows that throughput falls off much more rapidly as you move from locations with the best signal locations to the worst (which is a result of the more sophisticated modelling of interference across the cell that we are now using). Also the overall size of the difference in throughput between 900 MHz and 2100 MHz is significantly reduced in most locations.

A1.55 Figure A1.15 below is also taken from the February 2009 consultation and compares the throughput performance of a UMTS900 network with 7,300 sites in the 0 – 80% most populated areas of the country with a UMTS2100 network with 9,000 sites and a UMTS2100 network with 15,000 sites covering the same area.

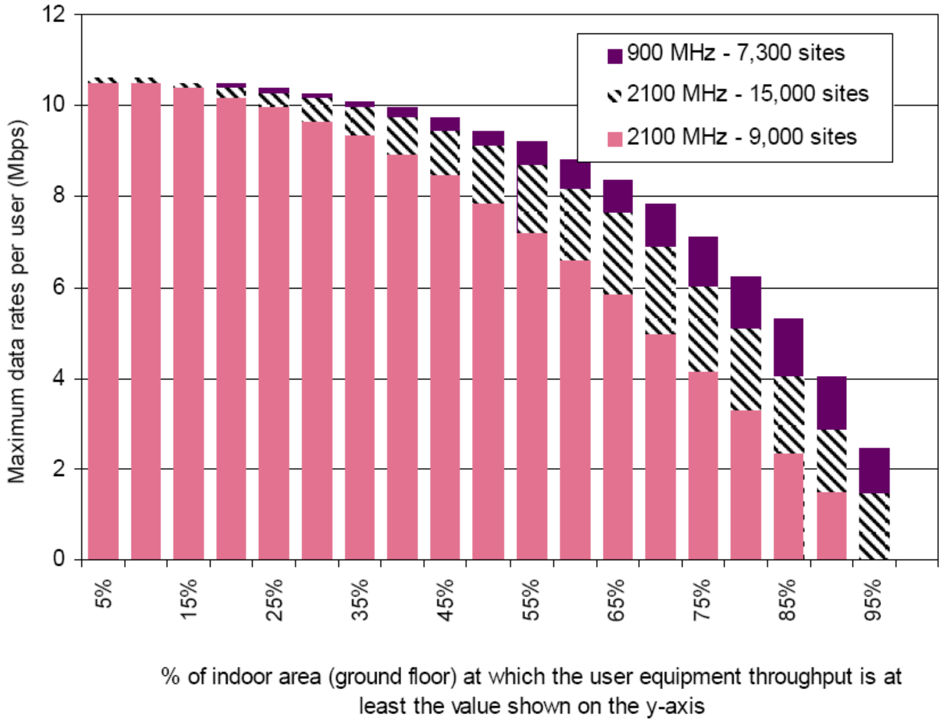


Figure A1.15: Throughput achieved by a 7,300 site UMTS900 network, a 9,000 site UMTS2100 network and a 15,000 site UMTS2100 networks – source Figure 5, February 2009 consultation.

A1.56 This figure demonstrates that on the basis of our February 2009 modelling a UMTS900 network with only 7,300 sites can provide greater throughput in the majority of indoor locations than a UMTS2100 network with either 9,000 or 15,000 sites can.

A1.57 Again we have conducted a similar comparison with our revised model, the results of which are given in Figure A1.16 below.

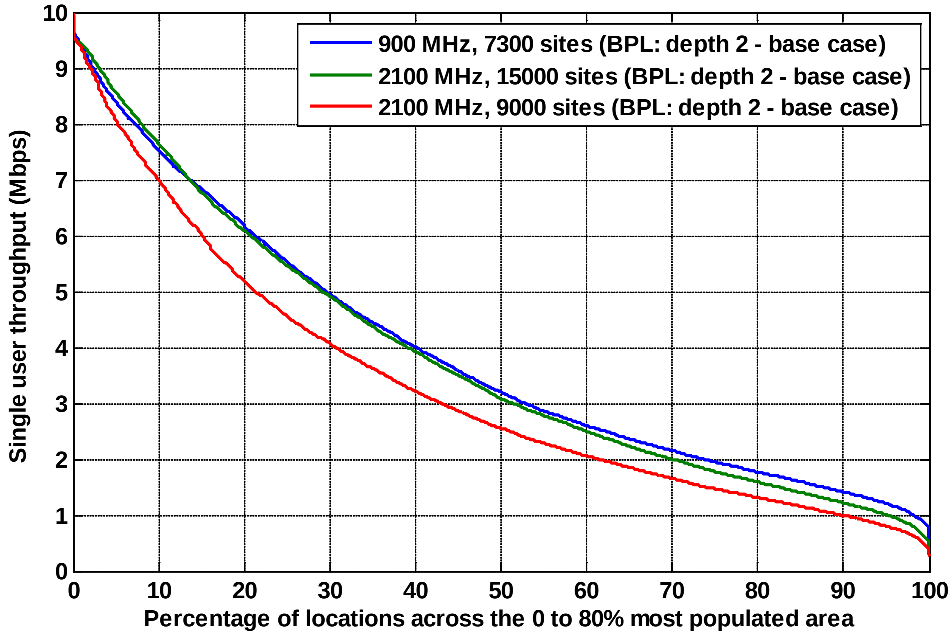


Figure A1.16: Throughput for a UMTS900 network with 7,300 sites distributed over the 80% population area compared with a 9,000 site UMTS2100 network and a 15,000 site UMTS2100 network over the same area. BPL: depth 2, base case.

A1.58 As can be seen, our revised modelling indicates that a 15,000 site UMTS2100 network can come close to matching the throughput performance of a 7,300 site UMTS900 network for a significant proportion of indoor locations (at depth 2) but the 7,300 network still maintains a throughput advantage in the hardest to serve locations (60% and above on the graph).

A1.59 Comparing Figures A1.15 and A1.16 we again can see that the overall size of the difference in throughput between 900 MHz and 2100 MHz is reduced in most locations.

A1.60 In conclusion, comparing the results of our revised modelling approach to those of the February 2009 consultation we see similar behaviour in that there is a throughput advantage for 900 MHz over 2100 MHz in the majority of locations for the range of site counts modelled. However, the size of the throughput advantage of 900 MHz is generally reduced for our revised modelling compared to that conducted for the earlier consultation.

Appendix 1 to Annex 1 – Results of the throughput analysis

The figures below compare the single user[5] throughput in the downlink direction (i.e. from the base station to the user) for an indoor user of UMTS900 network (e.g. O2 or Vodafone UMTS900) with UMTS2100 network (e.g. the merged 'Everything Everywhere' or H3G UMTS2100) under a wide range of scenarios. Comprehensive results for each of the comparisons highlighted in Table A1.1 above are provided.

Figures A1.17, A1.19, A1.25, A1.27, A1.29, A1.31 and A1.33 below should be interpreted as follows.

- The x-axis indicates the percentage of locations across the whole coverage area which corresponds to 'depth 2' and with the propagation conditions as described in Annex 5, ordered according to those with the best signal conditions. So "20%" in Figure A1.17 represents the 20% of locations with the best signal conditions and hence highest throughput for each of the 900 MHz and 2100 MHz networks (these are not necessarily the same 20% of locations). The y-axis shows the throughput attained or exceeded at all of these locations when a single user consumes the full capacity of the serving cell.

Figures A1.18, A1.20, A1.21, A1.22, A1.23, A1.24, A1.26, A1.28, A1.30, A1.32, A1.34 and A1.36 below should be interpreted as follows.

- The y-axis shows the percentage difference in the minimum downlink single user throughput for the 2100 MHz network compared to the 900 MHz network. So in Figure A1.18 for example, the minimum throughput offered at the 80th percentile of locations is approximately 22% lower on the 2100 MHz network than on the 900 MHz network (for locations in the depth 2 signal conditions and with building penetration losses rising faster with frequency).

[5]The data rate at which a consumer could download data if they were the only active user within the cell. If there were more users the capacity would be shared out between them

Comparison 1 – Depth 2

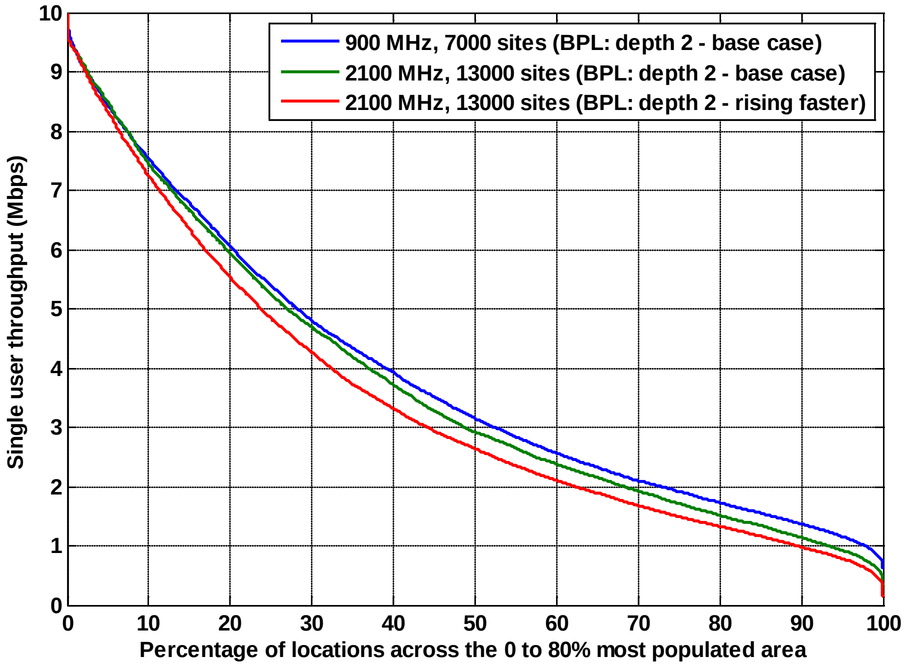


Figure A1.17: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

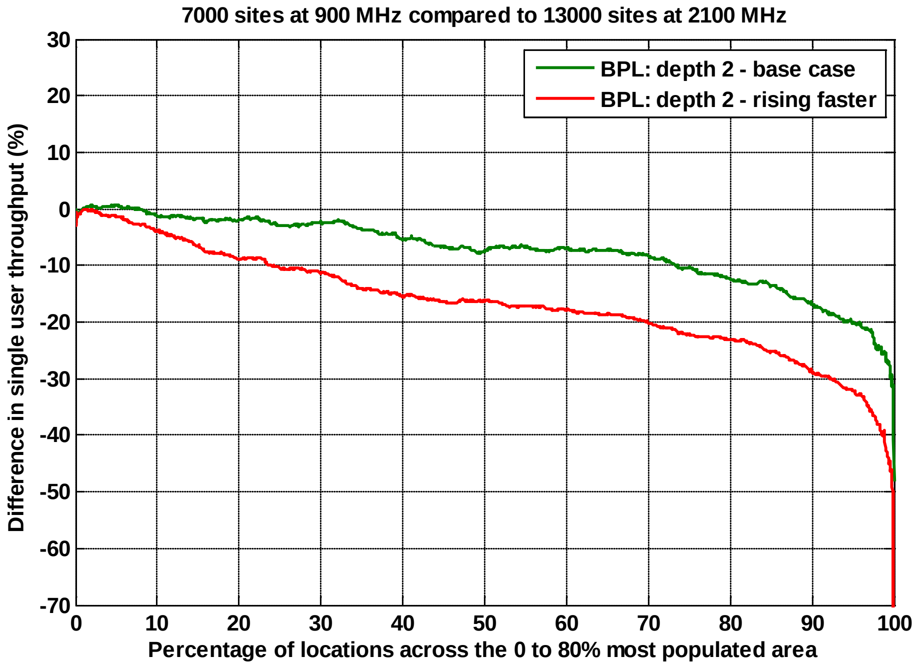


Figure A1.18: Percentage difference in throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 1 – Depth 2 + 2100 MHz power increase

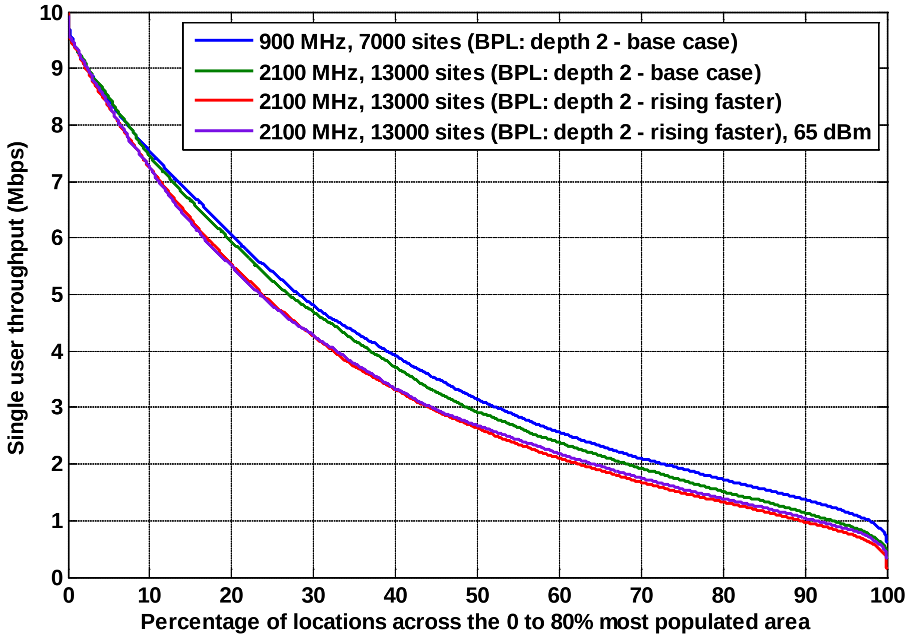


Figure A1.19: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency, plus 2100 MHz power increase (to 65 dBm).

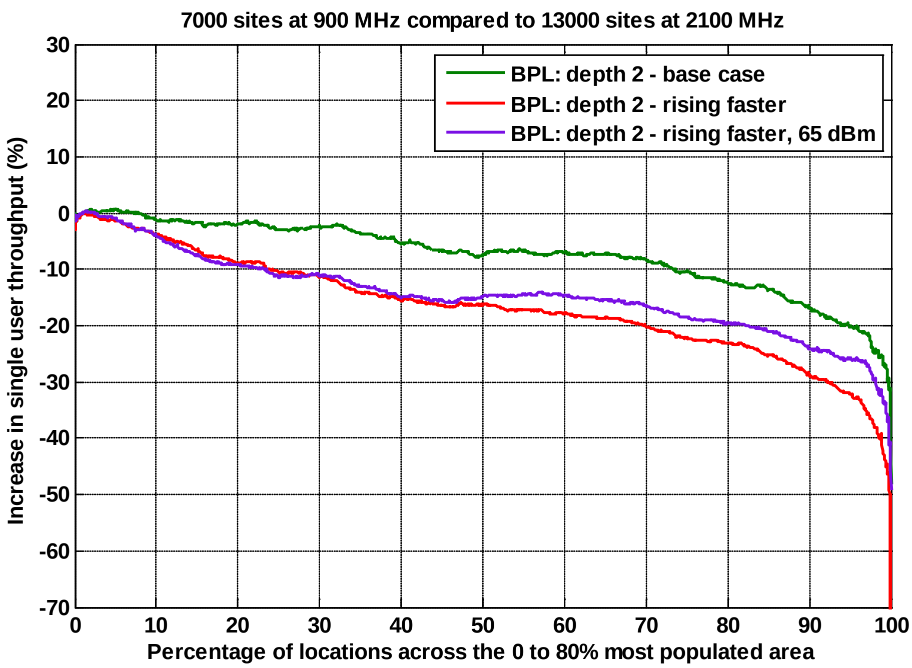


Figure A1.20: Percentage difference in throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL: depth 2, base case and rising faster with frequency, plus 2100 MHz power increase (to 65 dBm).

Comparison 1 – Depths 1, 2 & 3 – BPL standard deviation relative to BPL depth

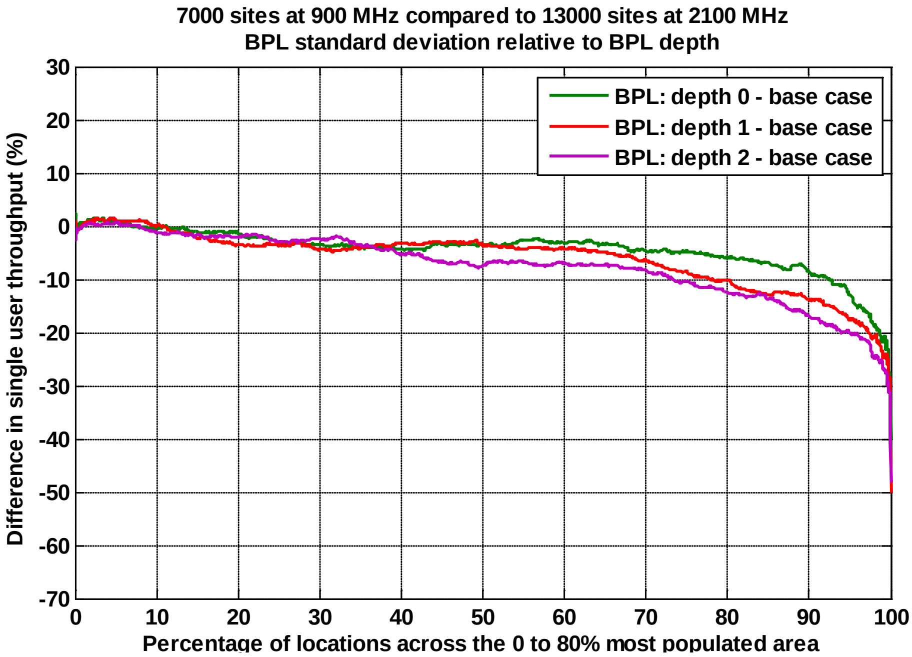


Figure A1.21: Percentage difference in throughput for UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL depths 0, 1 and 2 base case and BPL standard deviation relative to BPL depth.

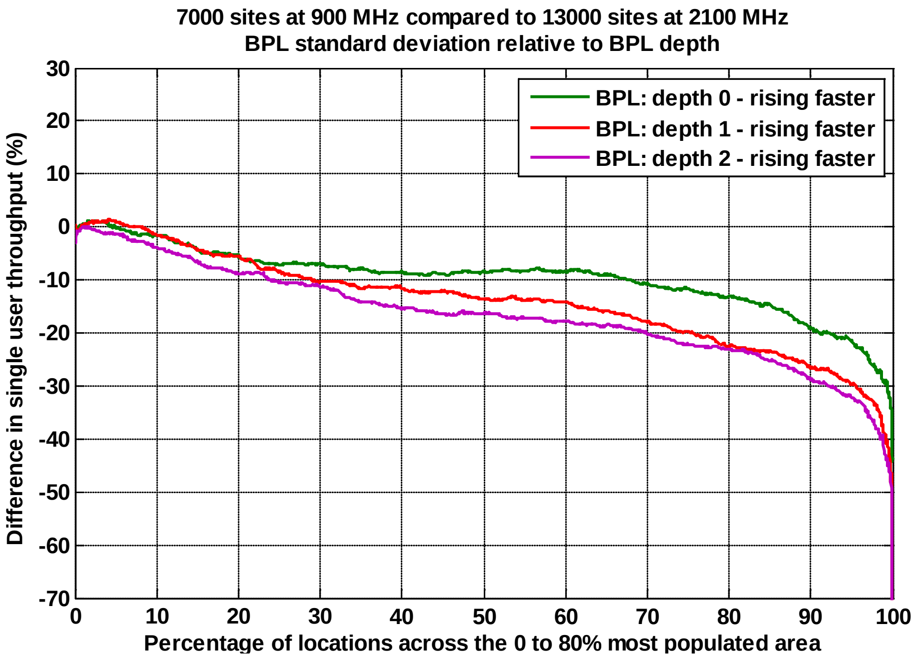


Figure A1.22: Percentage difference in throughput for UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL depths 0, 1 and 2 rising faster with frequency and BPL standard deviation relative to BPL depth.

Comparison 1 – Depths 1, 2 & 3 – BPL standard deviation the same for all BPL depths

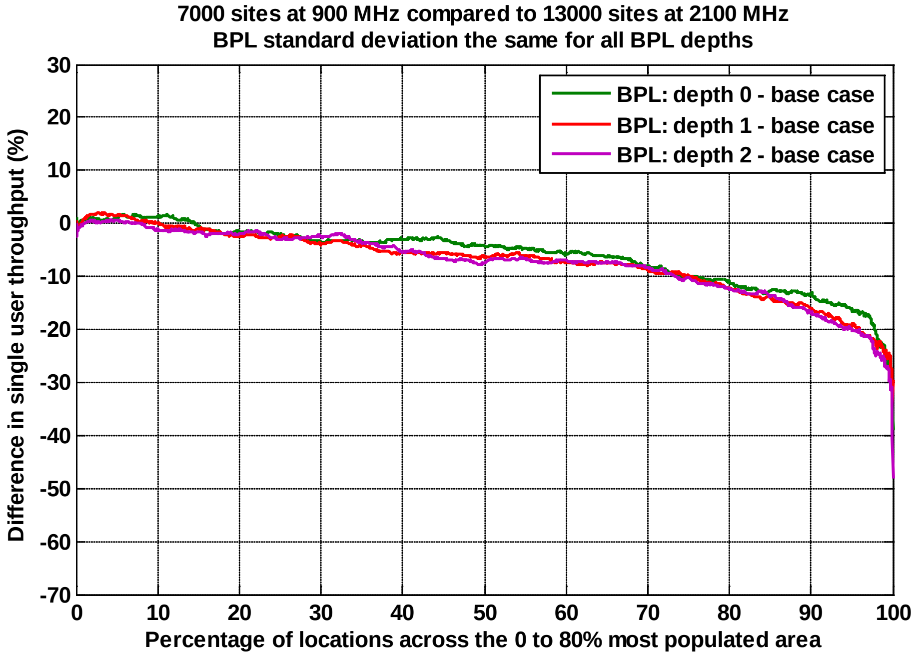


Figure A1.23: Percentage difference in throughput for UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL depths 0, 1 and 2 base case and BPL standard deviation the same for all BPL depths

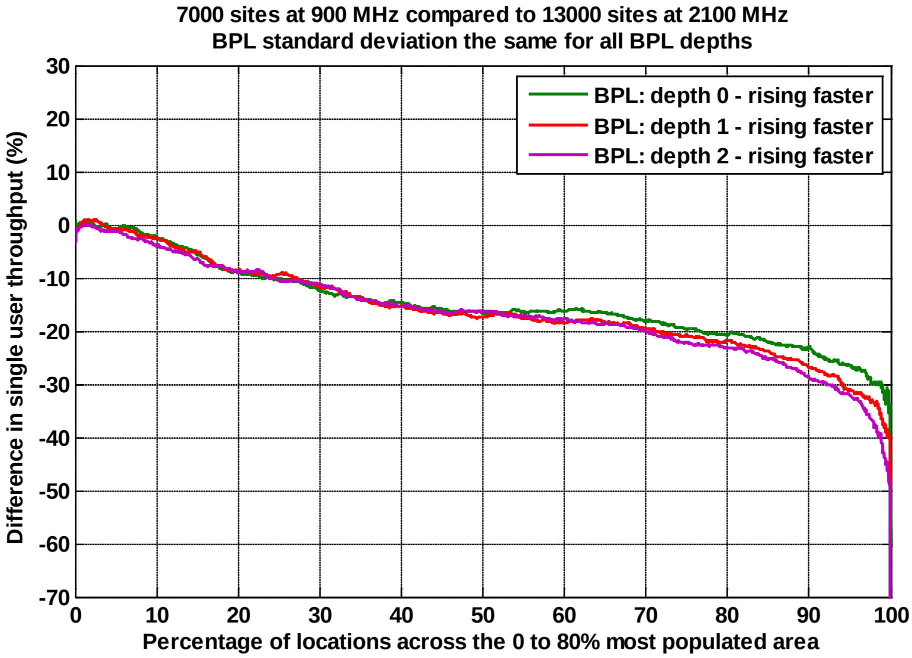


Figure A1.24: Percentage difference in throughput for UMTS900 network with 7,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL depths 0, 1 and 2 rising faster with frequency and BPL standard deviation the same for all BPL depths.

Comparison 2 – Depth 2

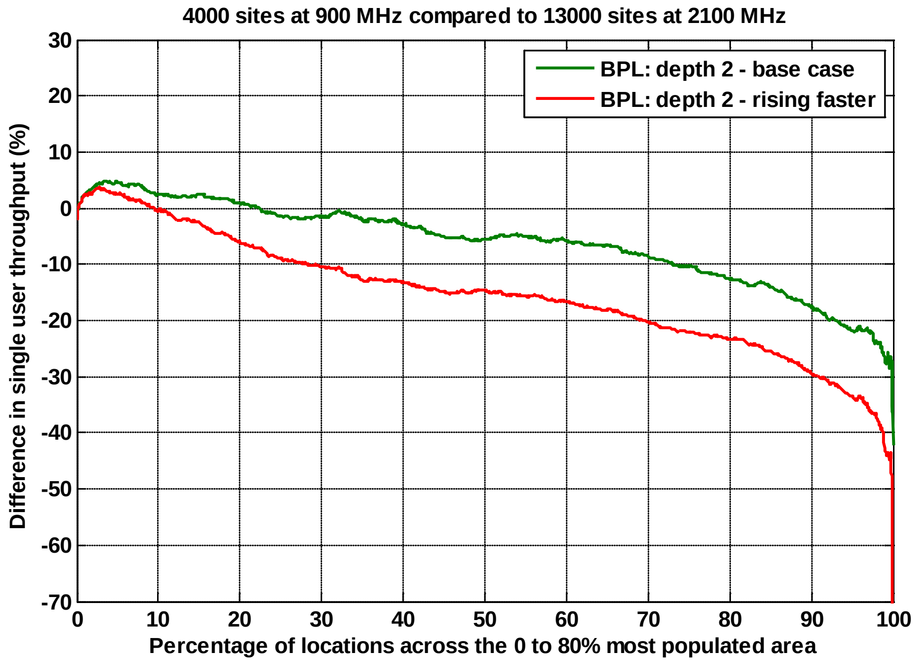


Figure A1.25: Throughput for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

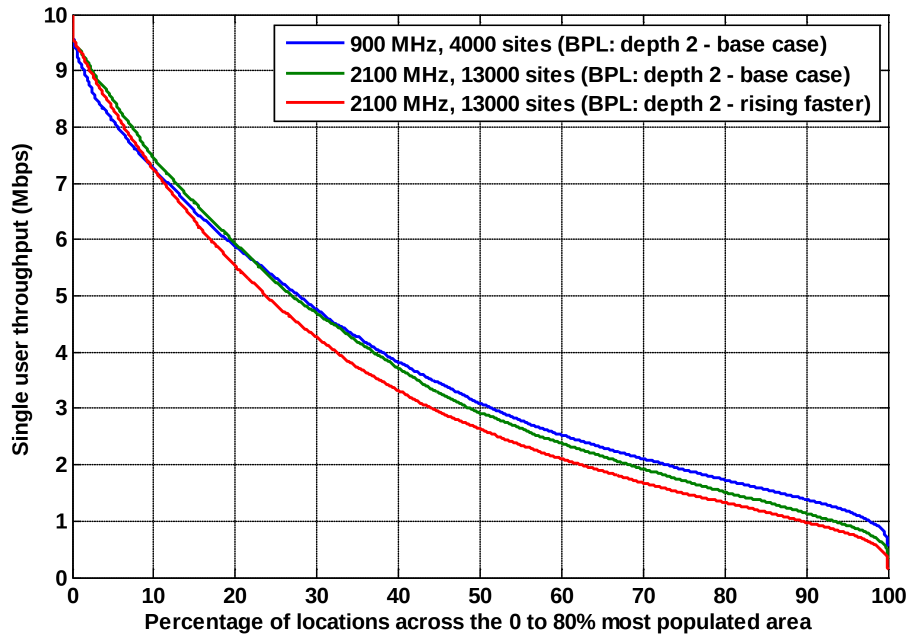


Figure A1.26: Percentage difference in throughput for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 3 – Depth 2

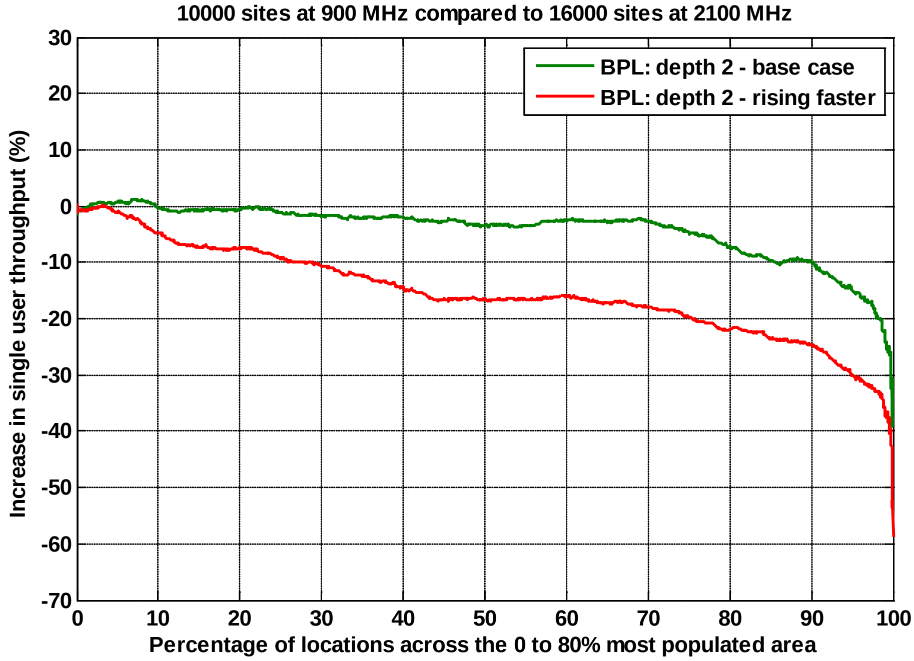


Figure A1.27: Throughput for a UMTS900 network with 10,000 sites distributed over the 80% population area compared with a 16,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

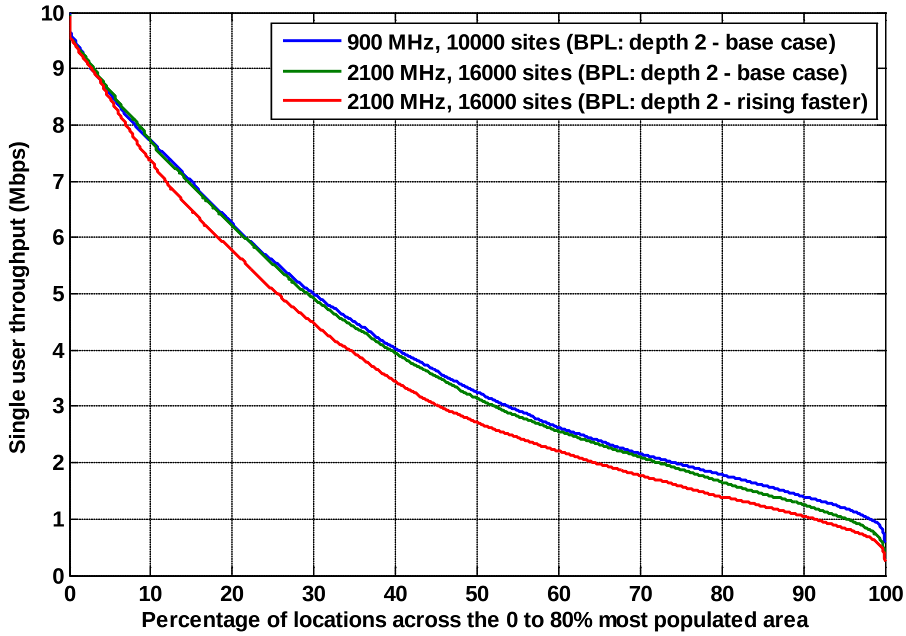


Figure A1.28: Percentage difference in throughput for a UMTS900 network with 10,000 sites distributed over the 80% population area compared with 16,000 sites at UMTS2100 over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 4 – Depth 2

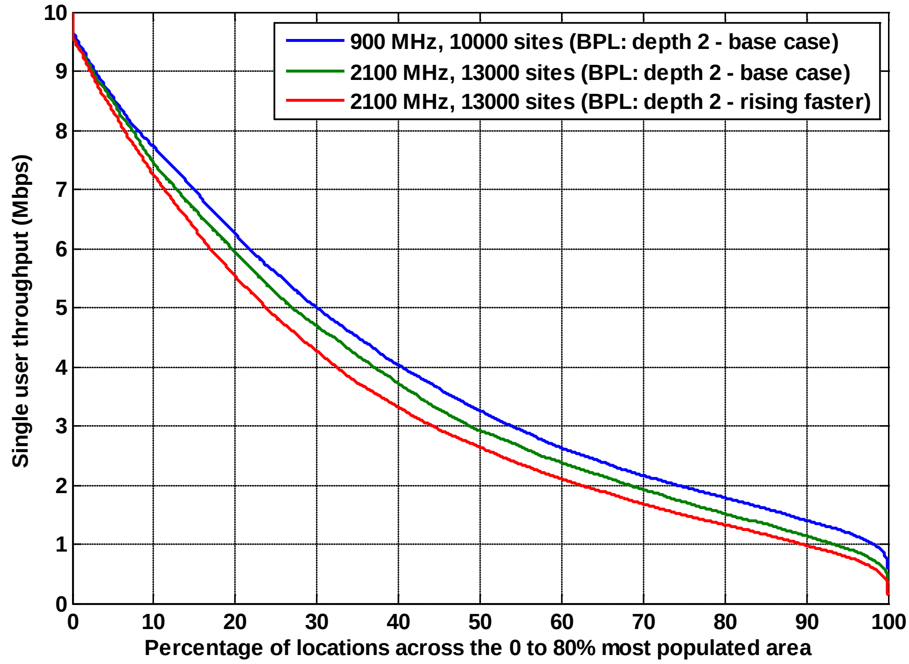


Figure A1.29: Throughput for a UMTS900 network with 10,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

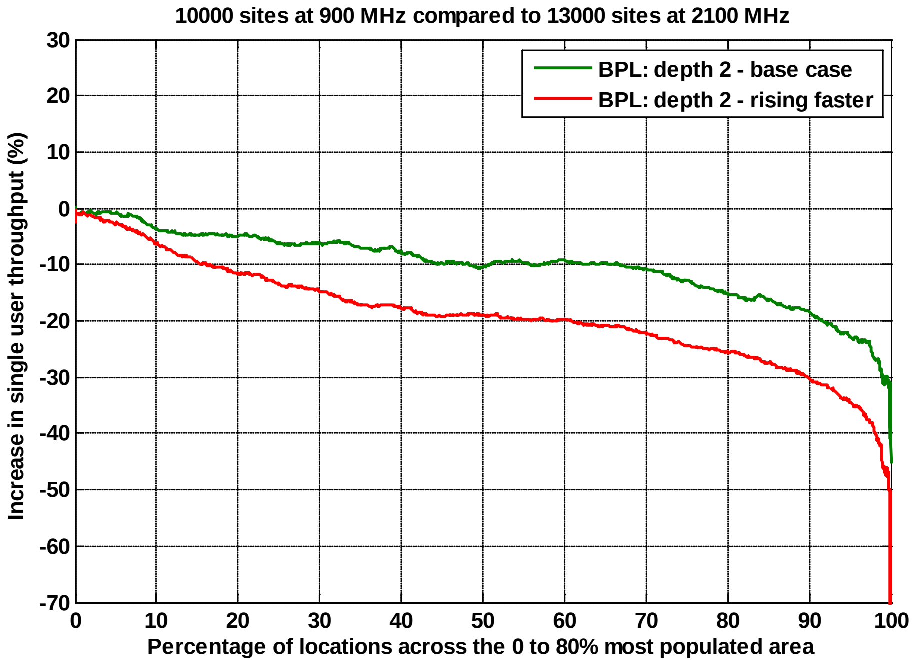


Figure A1.30: Percentage difference in throughput for a UMTS900 network with 10,000 sites distributed over the 80% population area compared with 13,000 sites at UMTS2100 over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 5 – Depth 2

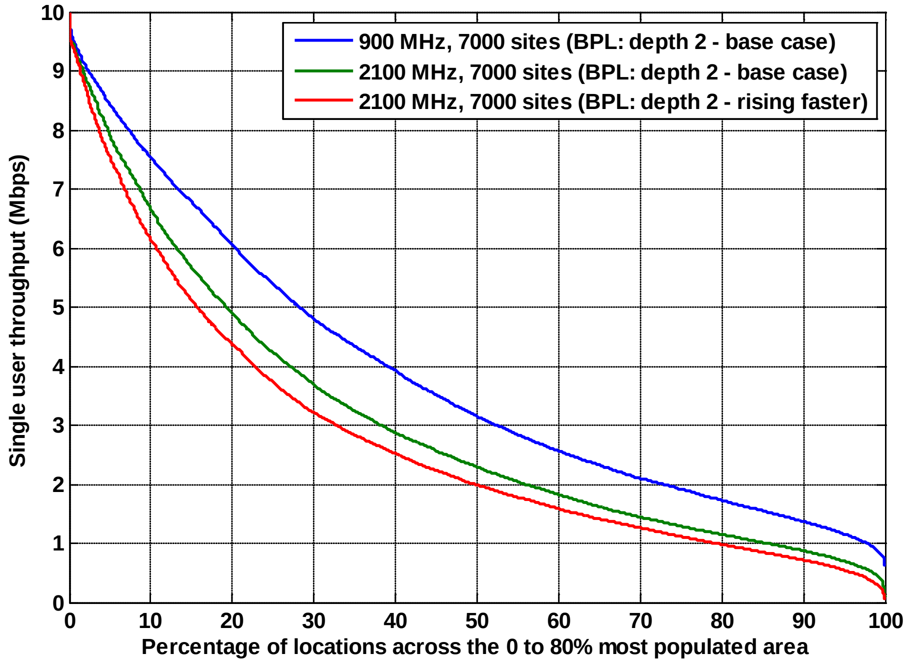


Figure A1.31: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

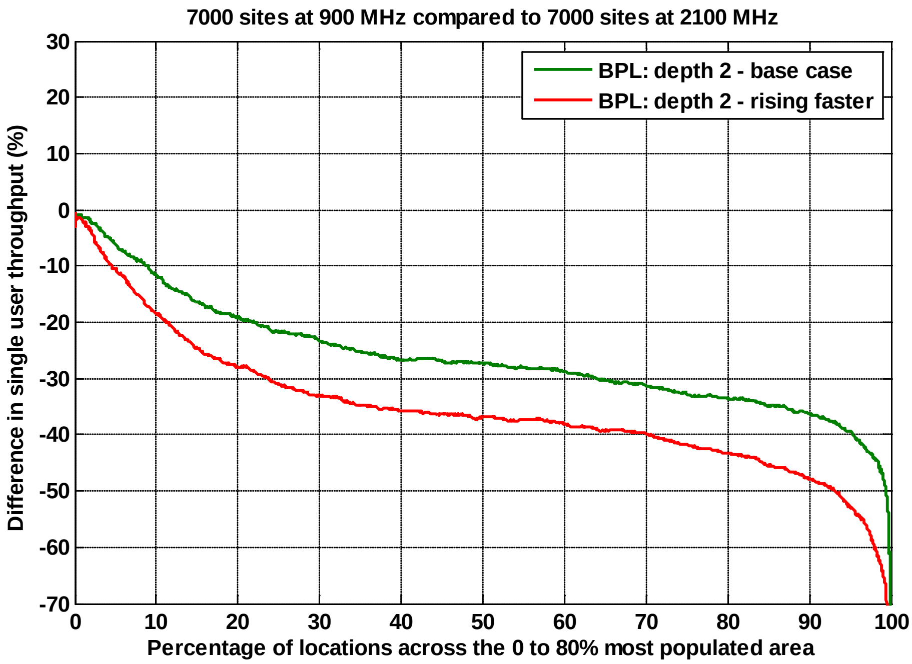


Figure A1.32: Percentage difference in throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with 7,000 sites at UMTS2100 over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 5 – Depth 0 – BPL standard deviation the same for all BPL depths

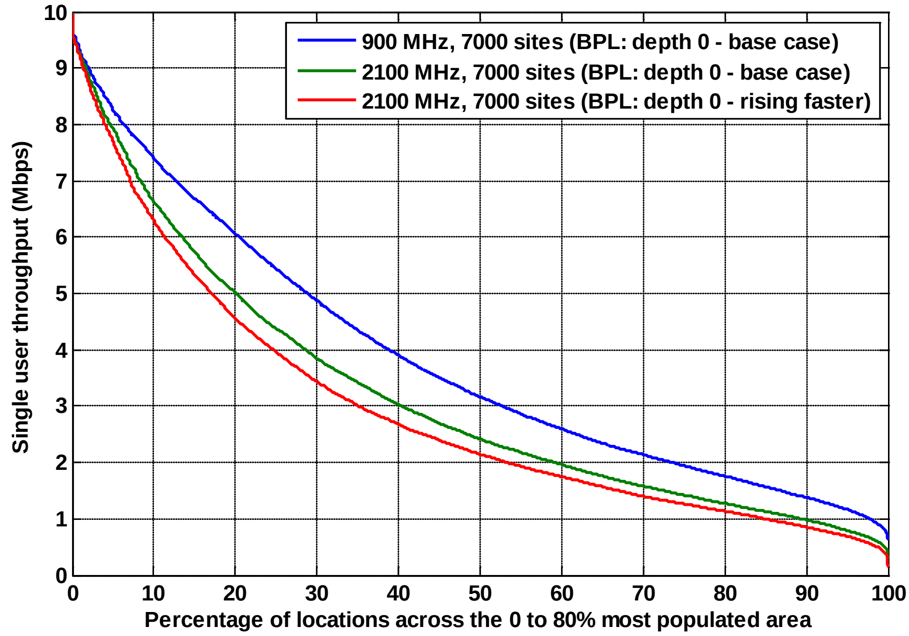


Figure A1.33: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 MHz network over the same area. BPL: depth 0, base case and rising faster with frequency.

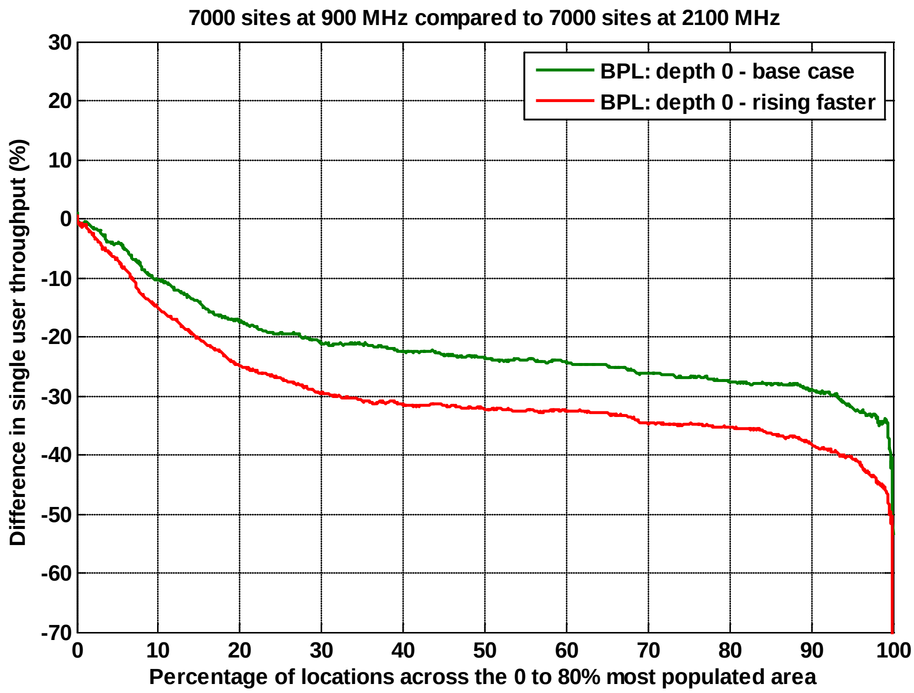


Figure A1.34: Percentage difference in throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with 7,000 sites at UMTS2100 over the same area. BPL: depth 0, base case and rising faster with frequency.

Comparison 6 – Depth 2

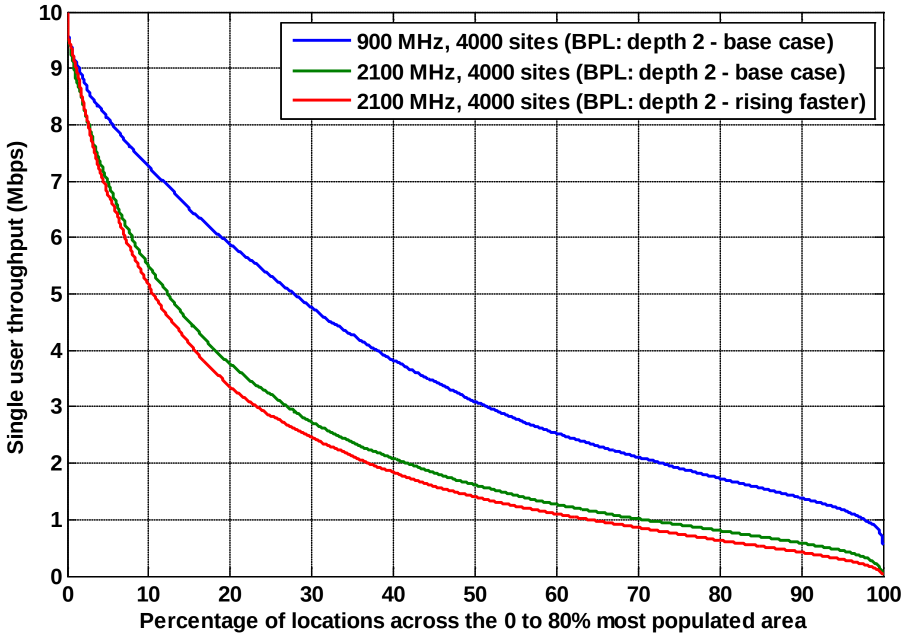


Figure A1.35: Throughput for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

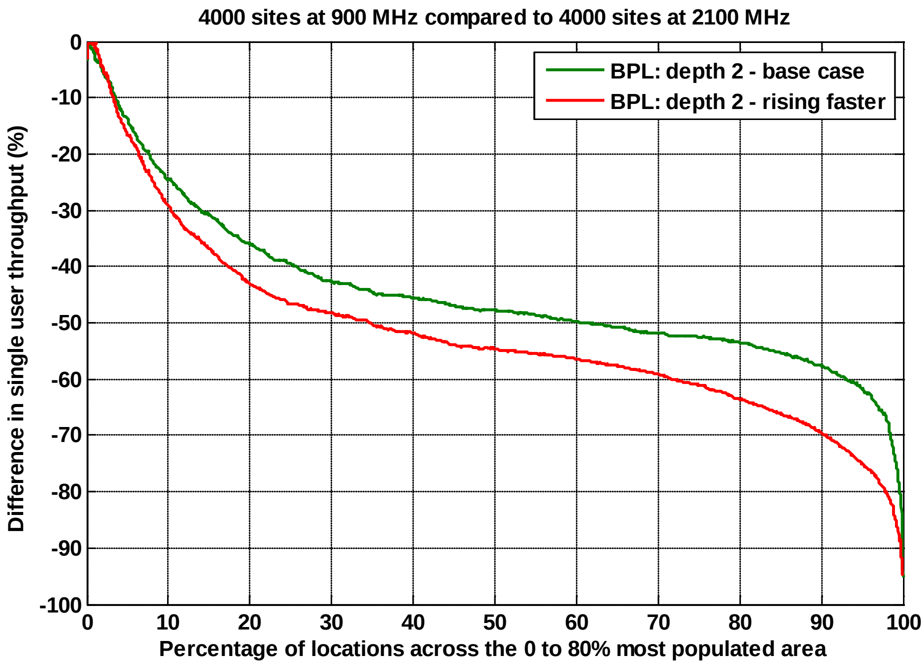


Figure A1.36: Percentage difference in throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with 7,000 sites at UMTS2100 over the same area. BPL: depth 0, base case and rising faster with frequency.

Appendix 2 to Annex 1 – Results of the pilot channel quality analysis

The figures in below compare the Ec/Io of the unloaded CPICH (i.e. a measure of pilot channel quality) in the downlink direction (i.e. from the base station to the user) for an indoor user of UMTS900 network (e.g. O2 or Vodafone UMTS900) with UMTS2100 network (e.g. the merged 'Everything Everywhere' or H3G UMTS2100) under a wide range of scenarios. Comprehensive results for each of the comparisons highlighted in Table A1.1 above are provided.

Figures A1.37 to A1.43 should be interpreted as follows.

- The x-axis indicates the percentage of locations across the whole coverage area which corresponds to 'depth 2' and with the propagation conditions as described in Annex 5, ordered according to those with the best signal conditions. So "20%" in Figure A1.37 represents the 20% of locations with the best signal conditions and hence Ec/Io for each of the 900 MHz and 2100 MHz networks (these are not necessarily the same 20% of locations). The y-axis shows the unloaded Ec/Io of the CPICH attained or exceeded at all of these locations.

Comparison 1 – Depth 2

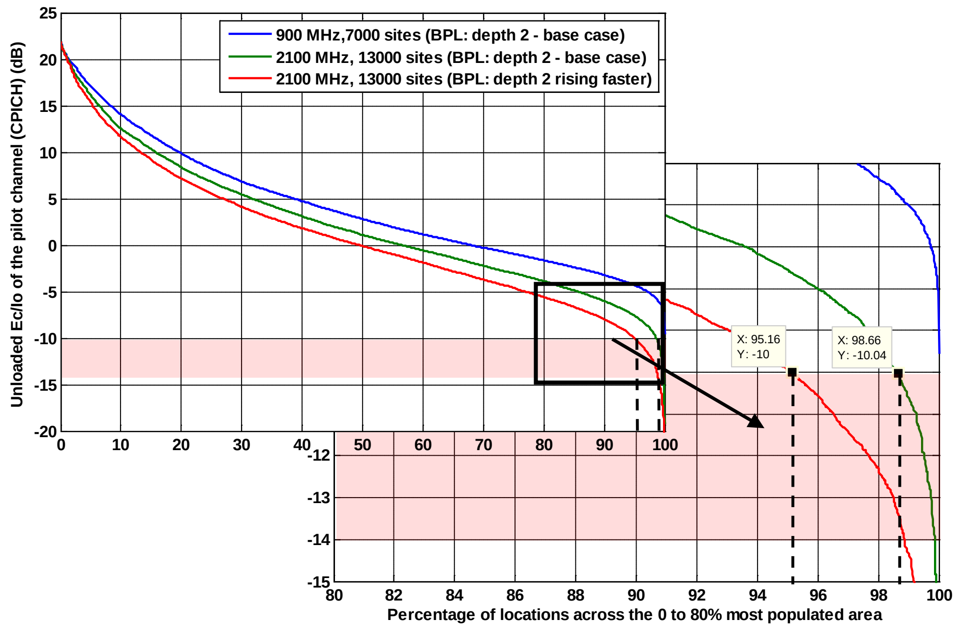


Figure A1.37: Ec/Io for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 1 – Depth 2 + 2100 MHz power increase

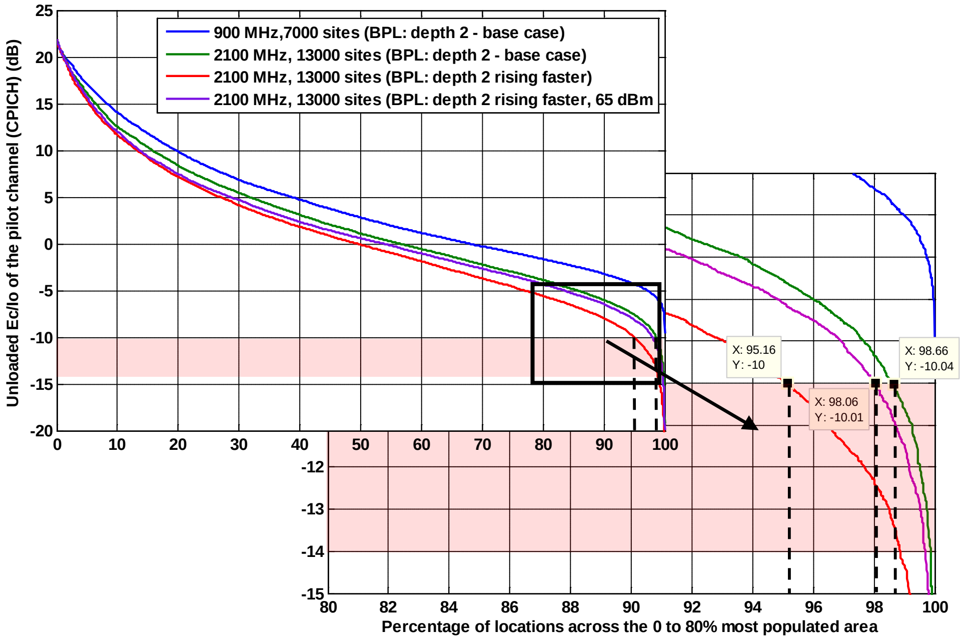


Figure A1.38: Ec/Io for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency, plus 2100 MHz power increase (65 dBm).

Comparison 2 – Depth 2

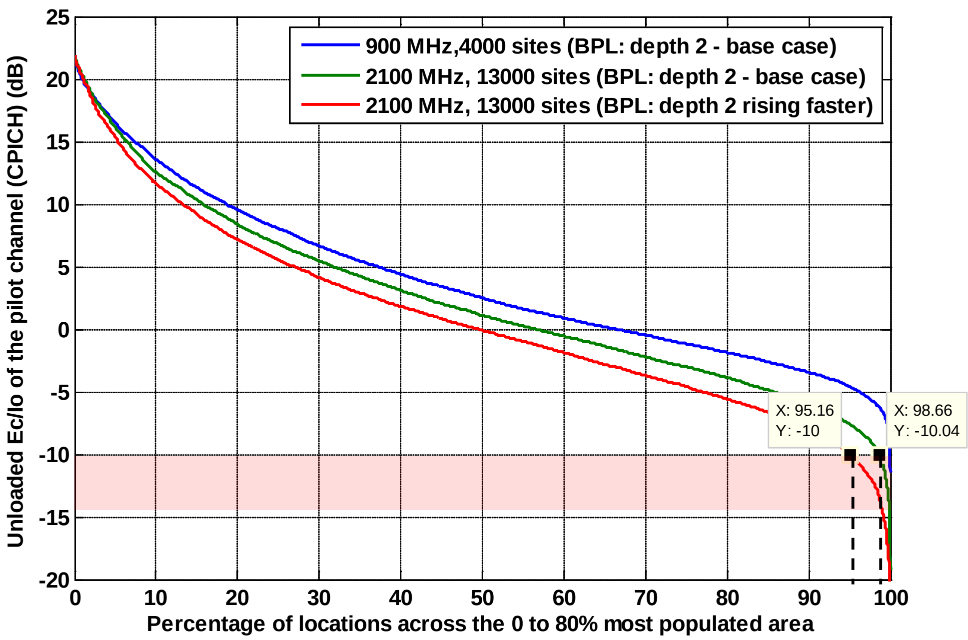


Figure A1.39: Ec/Io for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 13,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 3 – Depth 2

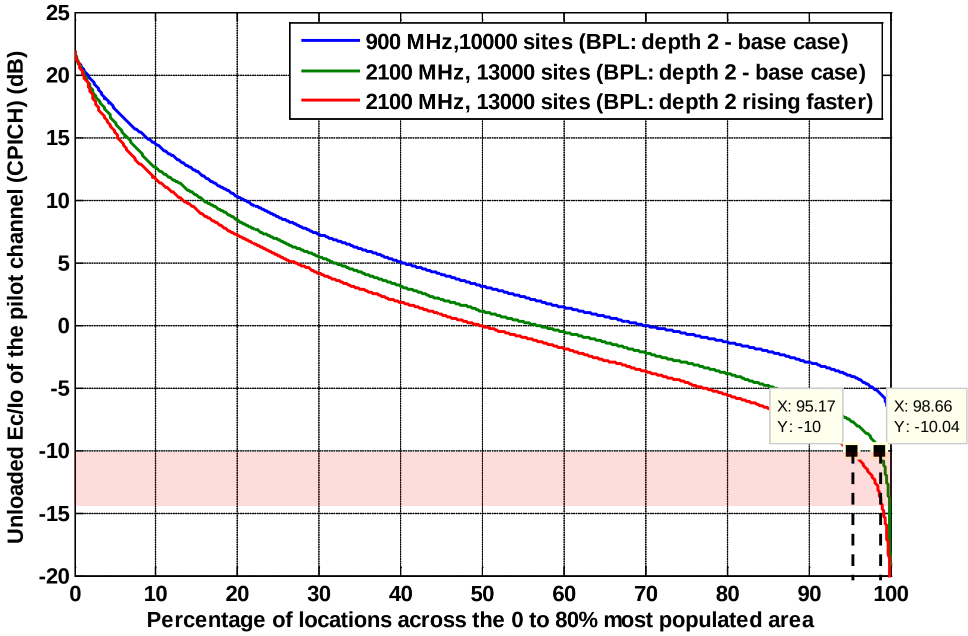


Figure A1.40: Ec/Io for a UMTS900 network with 10,000 sites distributed over the 80% population area compared with a 16,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

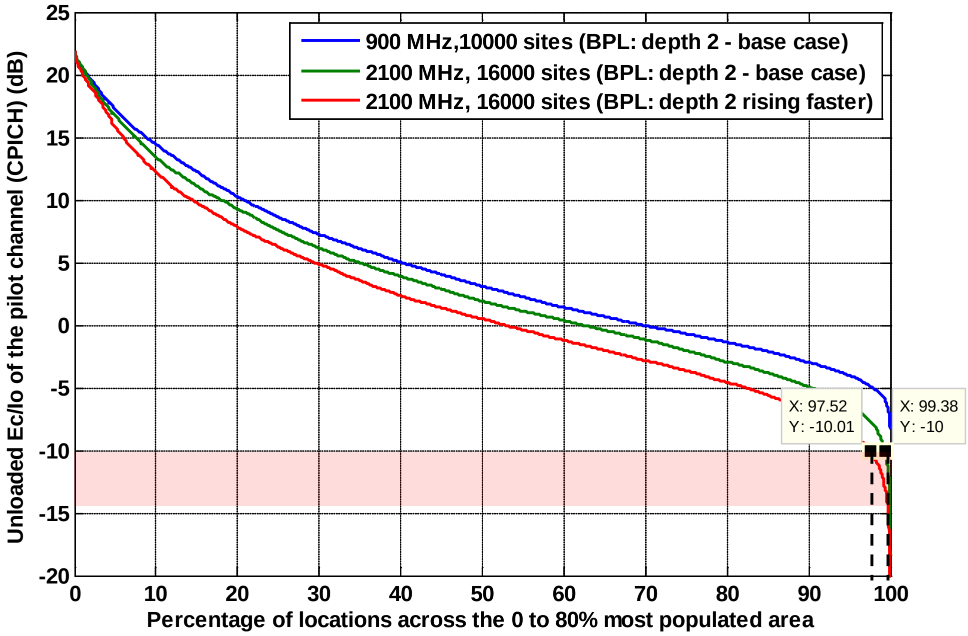


Figure A1.41: Ec/Io for a UMTS900 network with 10,000 sites distributed over the 80% population area compared with a 16,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 5 – Depth 2

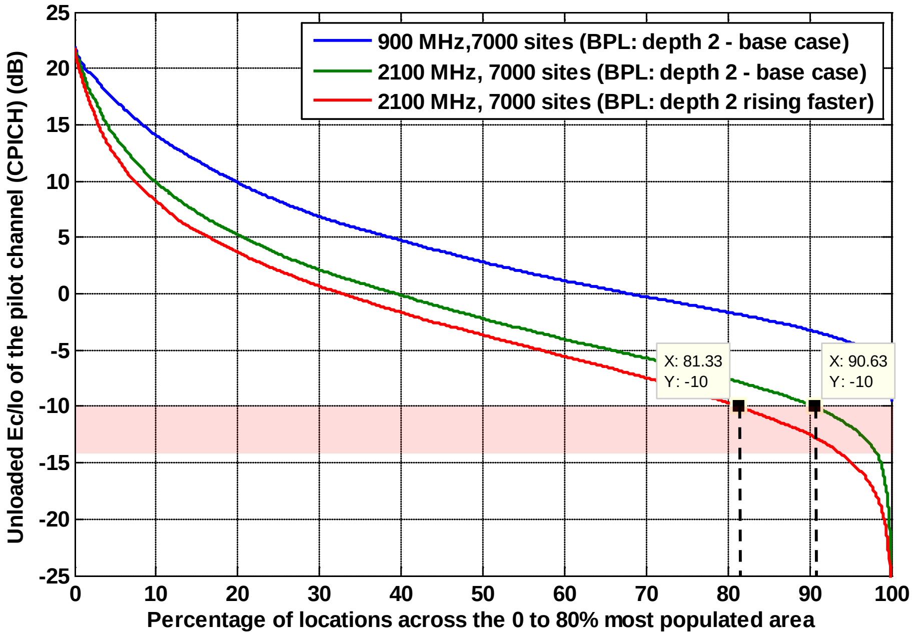


Figure A1.42: Ec/Io for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

Comparison 5 – Depth 2 – BPL standard deviation the same for all BPL depths

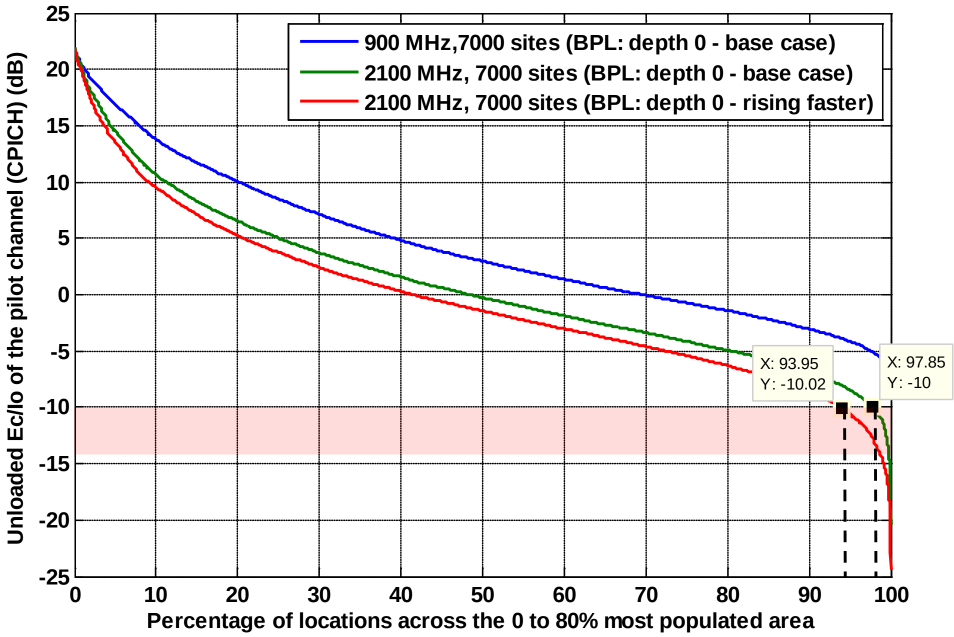


Figure A1.43: Ec/Io for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 network over the same area. BPL: depth 0, base case and rising faster with frequency.

Comparison 6 – Depth 2

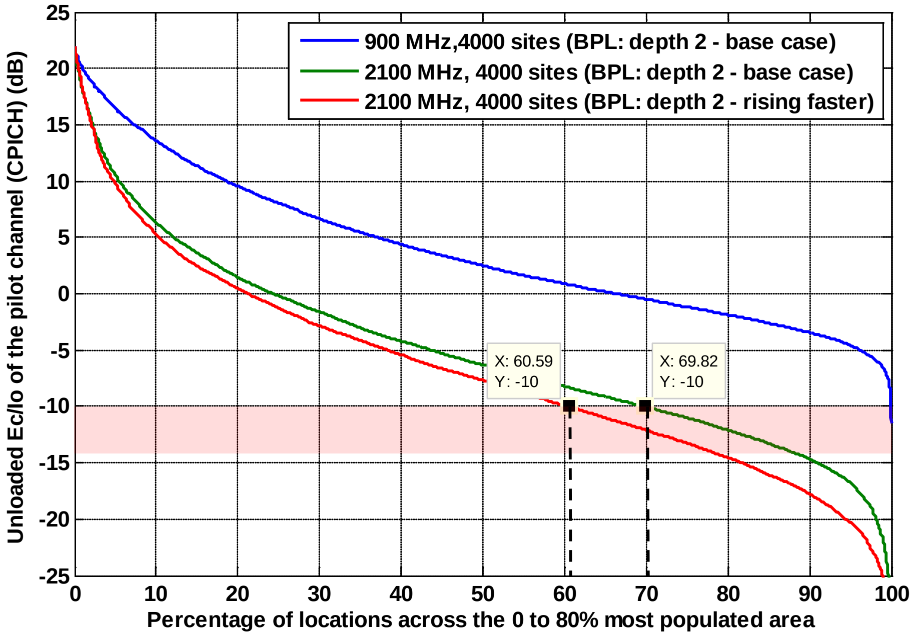


Figure A1.44: Ec/Io for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 network over the same area. BPL: depth 0, base case and rising faster with frequency.

Annex 2

Benefits to consumers of liberalising 900MHz and 1800MHz spectrum for UMTS

A2.1 This annex sets out the benefits that consumers could receive if 900MHz and 1800MHz spectrum were liberalised so that UMTS technology could be deployed to provide 3G services. We describe the benefits qualitatively, then illustrate them with some results from our technical research on the quality differences between UMTS 900 and UMTS 2100 networks. Finally, we look at the impact that delaying liberalisation might have on these consumer benefits.

Potential benefits to consumers of liberalising 900MHz and 1800MHz spectrum

A2.2 In this section, we discuss two potential sources of benefit to consumers from liberalisation of 900MHz and 1800MHz spectrum:

- **Increased capacity** – UMTS 900 and UMTS 1800 are both likely to give operators better options to increase capacity (and thereby serve more customers and accommodate higher usage per customer)

- **Higher quality services** – UMTS 900 could have technical quality advantages over UMTS 2100 networks due to better propagation, though that this is unlikely to be the case for UMTS 1800 according to the technical analysis detailed in our 2009 February Consultation[6].

Increased capacity from use of UMTS 900 and UMTS 1800

A2.3 Operators may be able to increase capacity more quickly using liberalised 900MHz and 1800MHz spectrum than other sources of mobile broadband spectrum – for example 800MHz spectrum will only be available for use in 2013 or 2014. Further, using more spectrum may be a cheaper way of increasing capacity than other means such as deploying more sites.

A2.4 In addition to allowing operators to meet growing demand more effectively, liberalisation may also benefit consumers if an operator's UMTS 2100 network is currently congested (and we have had some stakeholder feedback to suggest this may be the case). Relieving current congestion will particularly benefit an operator's existing 3G customers as well as any new customers.

A2.5 We provide an indicative illustration of the impact of liberalisation on capacity in Figure A2.1 below. Differences in frequency do not significantly alter the capacity that can be provided, the number of 3G carriers provides a reasonable proxy for the capacity of the operators (although the number of sites will also affect capacity).

[6] Application of spectrum liberalisation and trading to the mobile sector, February 2009 http://stakeholders.ofcom.org.uk/consultations/spectrumlib/

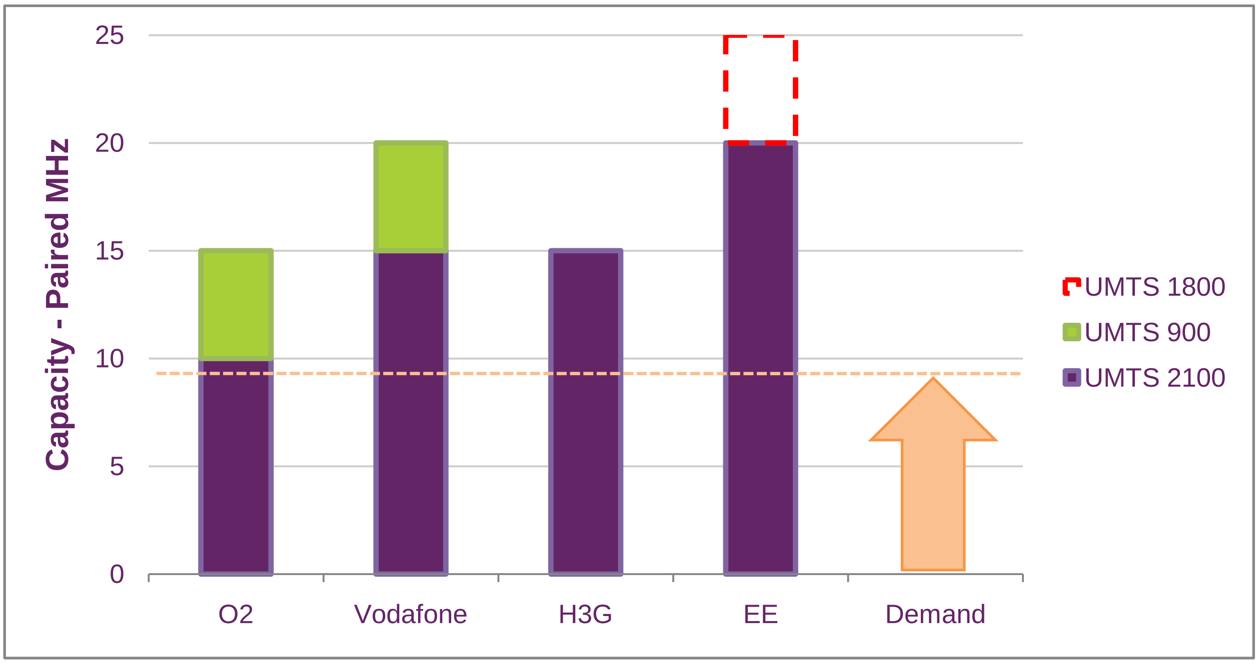
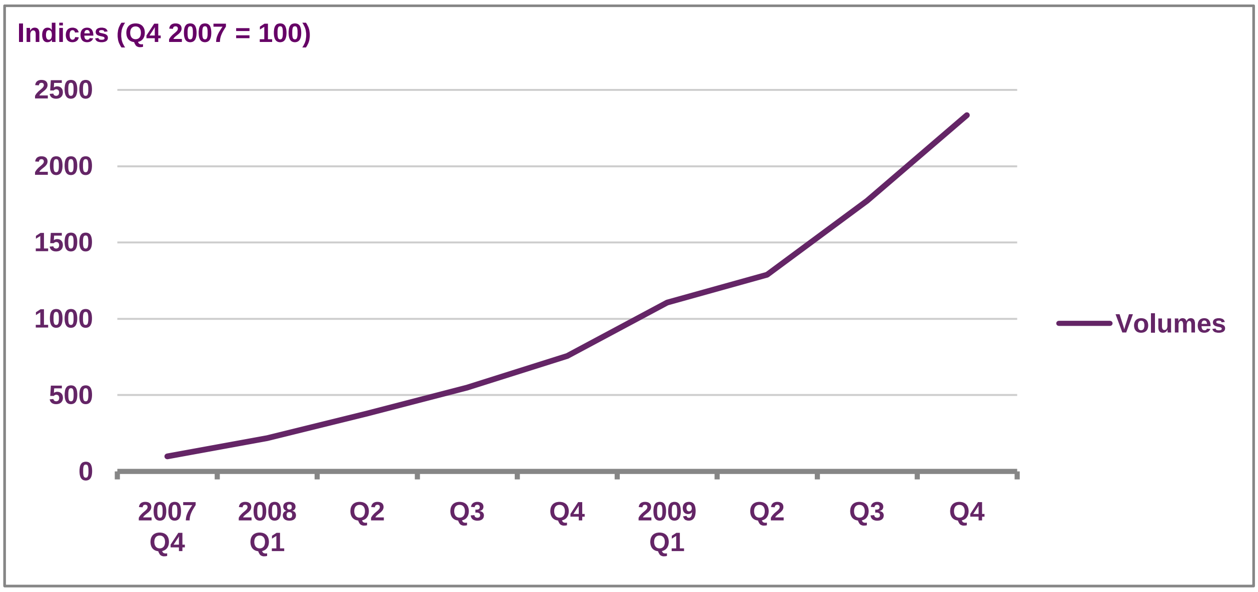


Figure A2.1: Impact of liberalisation on capacity

A2.6 Figure A2.1 provides an indication of the effect of liberalisation of 900MHz and 1800MHz spectrum for UMTS on capacity. Hence, we show the impact for a scenario where O2, Vodafone and Everything Everywhere clearing 2x5MHz of (900MHz or 1800MHz[7]) spectrum for UMTS rather than trying to predict how much spectrum they could clear in the short term. Over a longer period, e.g. by 2013 or 2014, auctioned 800MHz and 2.6GHz spectrum would be available for use and would be an alternative source of additional capacity.

A2.7 Figure A2.1 also gives an indicative representation of the current level of demand (in terms of the peak load) across the operators, based on views that stakeholders have expressed to us.

[7] Although developments in the use of 1800MHz for UMTS are not as far developed as for 900MHz spectrum, it is plausible that operators could deployed it, if they needed to do so.



Source: Ofcom / operators. Note: Includes estimates where Ofcom does not receive data from operators; data revenue is likely to be understated as it excludes any data element included within standard pay-monthly tariffs.

Figure A2.2: Recent growth in mobile data volumes (Communications Market Outlook 2010, Ofcom)

A2.8 Figures A2.1 and A2.2 taken together indicate that liberalising 900MHz and 1800MHz could have a considerable impact on O2 in the short term. Vodafone could also be affected if demand continues to grows as rapidly as it has been up to when new spectrum is available and could be used to provide additional capacity.

Higher quality services from use of UMTS 900

A2.9 Hence the benefits of improved quality of service apply mainly to the liberalisation of 900MHz spectrum for UMTS. Consumers may enjoy the following benefits, in terms of better quality service from liberalisation of 900MHz spectrum for UMTS:

- Consistency of coverage – mobile broadband service should be more consistently available (i.e. there should be fewer failed and dropped calls) both indoors and outdoors because of the increased signal strength that 900MHz allows and consumers should be able to use mobile broadband services in more widely, and.

- Better service quality inside buildings (i.e. at home and in the office) – consumers should, in general, enjoy an increase in the speed of mobile broadband services inside buildings because of the improved signal coverage that 900MHz spectrum provides.

- In rural (i.e. less densely populated) areas, UMTS 900 consumers might also benefit from wider geographic coverage, i.e. more areas might be served than with a UMTS 2100 only network, both indoors and outdoors

A2.10 In order to illustrate the impact of liberalising 900MHz spectrum on quality, as set out above, we investigated how far a 900MHz operator's could offer an improved quality of service if, instead of relying on its current UMTS 2100 network, it were able to deploy a UMTS 900 network using the same number of sites. For the avoidance of doubt, this would not be the right comparison to take to assess the risk of a distortion of competition from liberalising 900MHz spectrum. This is because the non-900MHz operators are likely to have considerably more sites than this in the relevant period for the assessment of the impact on competition.

A2.11 We analyse two technical measures of network quality:

- The *single user throughput* – i.e. the maximum download speed or *throughput* that a user would enjoy if it were the sole user on a network
- The *pilot channel quality* – broadly speaking, this needs to be above a certain threshold for a user to be able to get service, otherwise there may be no service or calls may be dropped.

A2.12 We compare these measures for a UMTS 900 network and a UMTS 2100 network each with 7,000 sites – we consider that 7,000 sites would be sufficient to provide reasonable national coverage (excluding rural areas)[8] using UMTS 900. We also consider that it would be plausible for the 900MHz operators to roll out this number of sites by the beginning of 2013 (assuming liberalisation at the end of 2010). This is consistent with our analysis in our annex on the duration of any competitive distortion.

A2.13 The results of our analysis for single user throughput are shown in Figures A2.3 & A2.4 below. Figure A2.3 shows how the download speed a single user could experience varies from the easiest to serve (best quality) to hardest to serve (worst quality) locations inside buildings for a UMTS 900 network and a UMTS 2100 networks of 7,000 sites.

A2.14 Figure A2.4 charts the percentage difference in download speed between UMTS 900 & 2100 over the same range of locations as in Figure A2.3. We find that the advantage of UMTS 900 depends on how difficult a customer location is serve, so our results need careful interpretation:

- In the easiest to serve locations, maximum download speeds are greatest, but the advantage of UMTS 900 over a UMTS 2100 network (with the same number of sites) is smallest – the benefit to consumers is relatively high in both cases.
- In the most difficult to serve locations, maximum download speeds are lowest, and a small (e.g. 0.5Mbps) difference in download speed between UMTS 900 and a UMTS 2100 network (with the same number of sites) may make the difference between whether the service is usable or not.
- For users in the majority of potential locations between these points, the advantage of a UMTS 900 network over a UMTS 2100 network (with the same number of sites) lies roughly between 0.5Mbps and 1Mbps. So, consumers would experience materially better quality with UMTS 900, though the difference would not be as fundamental as in the hardest to serve locations.

A2.15 To provide some additional context, Figures A2.3 & A2.4 also show results for a UMTS 2100 network with 13,000 sites. In broad summary, our results show that a 900MHz operator could benefit from deploying UMTS 900 instead of UMTS 2100 on a 7,000 site network. The 7,000 site UMTS 900 network would have a much

[8] Effectively coverage to 80% of the population in more densely populated areas in the UK.

smaller advantage over a 13,000 site UMTS 2100 network, which is the likely scale of network that Everything Everywhere could deploy in the same time period. However the advantage does not appear to be material.

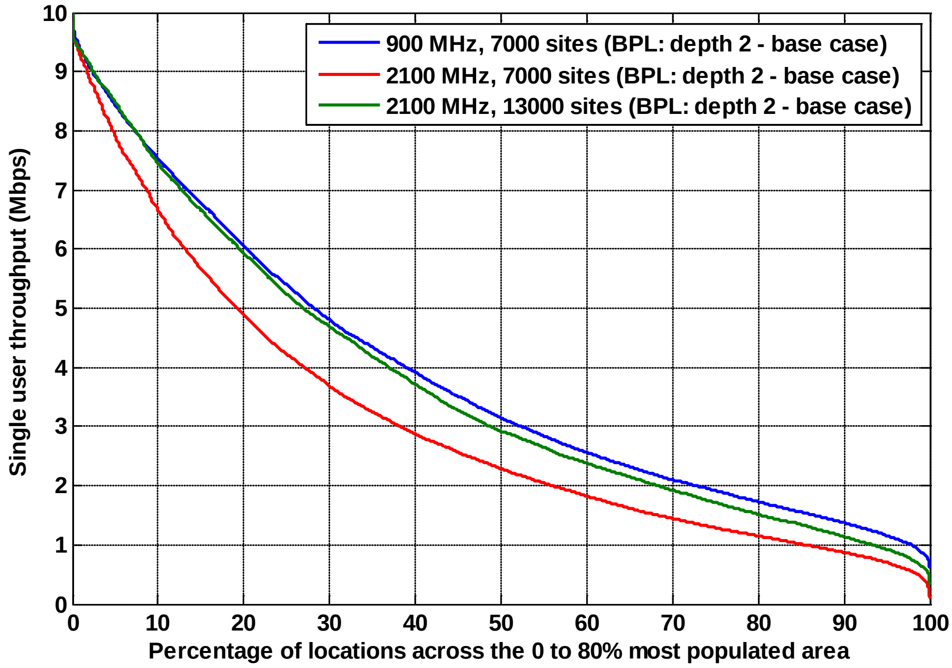


Figure A2.3: Throughput for a single user

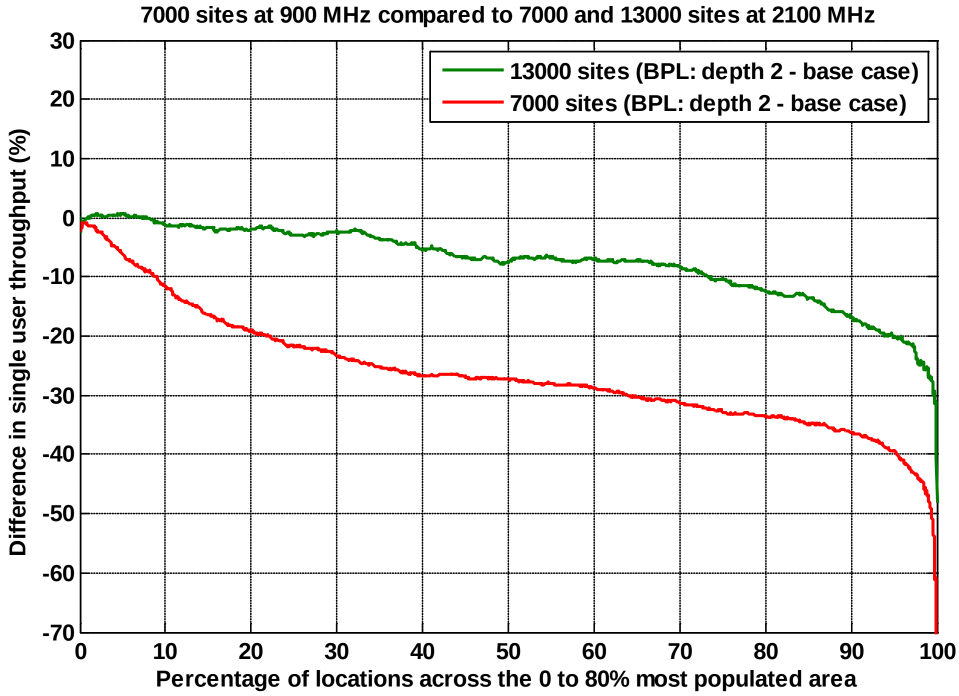


Figure A2.4: Increase in the throughput for a 900MHz compared to 2100MHz network (equal number of sites)

A2.16 The results of our analysis for pilot channel strength are shown in Figure A2.5 below. It compares a UMTS 900 network with a UMTS 2100 network of the same size. It shows that UMTS 900 can make the difference between getting a usable service and not for a material number of customers – those in the 10% or 20%[9] hardest to serve locations, assuming that the threshold is at the highest end of its likely range (as shown by the shaded band in the diagram)[10]. I.e. for these locations, the pilot channel strength is below the threshold needed to use services on a UMTS 2100 network, but above the threshold on a UMTS 900 network.

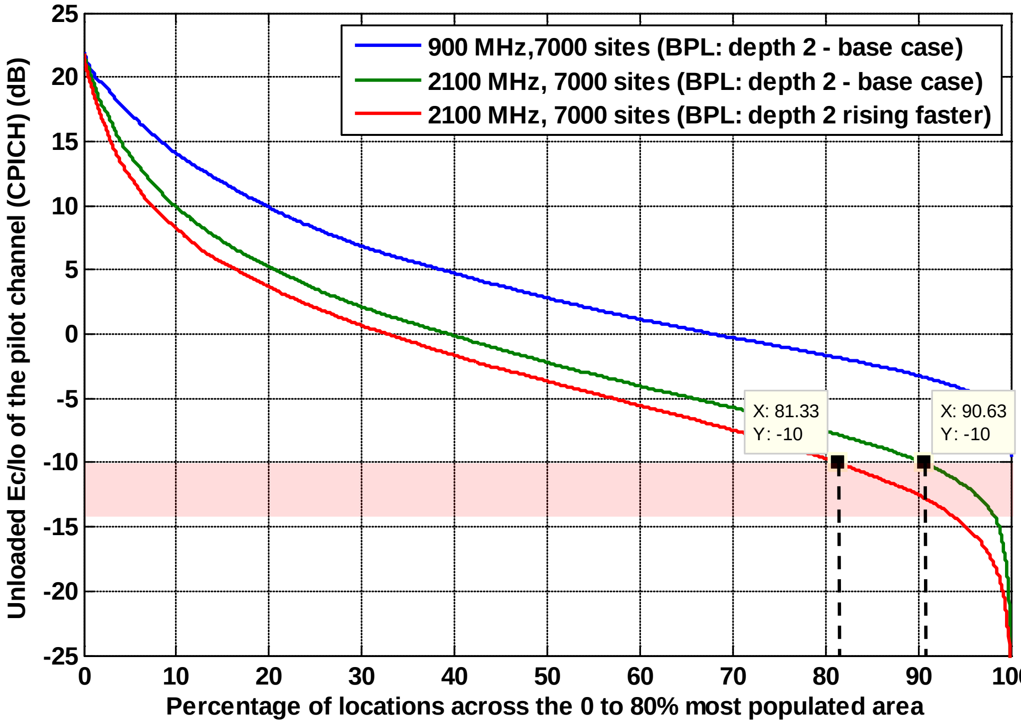


Figure A2.5: Pilot channel strength for a 900MHz network compared to a 2100MHz network (equal number of sites)

The impact on consumers of delays to liberalising 900MHz and 1800MHz spectrum for UMTS

A2.17 Liberalisation of the 900MHz spectrum is now on the critical path for 3G services being delivered with 900MHz spectrum. I.e. if operators were able to use 900MHz spectrum for 3G, there would be no other barriers to its use. UMTS 900 equipment is available (and there have been deployments in other countries). There is also a reasonable stock of UMTS 900 handsets in circulation in the UK, and this is continuing to grow.

A2.18 Developments in the use of UMTS for 1800MHz spectrum are less well advanced. Nevertheless, based on our research we consider that manufacturers could

[9] The 10% relates to our base case assumptions on the propagation differences between frequencies and the 20% relates to our alternative scenario with more pronounced propagation differences.
[10] It is our current understanding that the threshold for pilot channel strength lies in the range -10 dB to -14 dB.

produce some types of user equipment – particularly dongles for using mobile broadband on laptops – relatively quickly if they received orders from operators.

A2.19 Hence, we consider that delaying liberalisation of 900MHz and 1800MHz spectrum for UMTS is likely to make at least some consumers worse off because they would have to wait longer to enjoy the benefits of increased capacity and higher quality, as described above.

A2.20 Moreover, if liberalisation were delayed, it could lead to a fall in competitive intensity, at least in the short term, because the 900MHz operators could be at a disadvantage to other operators as liberalisation of 900MHz for UMTS could enable them to counter the following factors:

- By virtue of having more 2100MHz spectrum, Everything Everywhere would have more capacity to meet future growth in demand for mobile broadband (and so offer a better service to more customers), at least until 800MHz and 2.6GHz spectrum was available. Liberalisation for UMTS would allow the 900MHz operators to increase UMTS capacity.

- Everything Everywhere (and H3G through its agreement with Everything Everywhere) has a substantially higher installed base of 2100MHz sites than Vodafone or O2. Further, it might take some time before Vodafone and O2 could each build enough new 2100MHz sites to match Everything Everywhere's network. This could allow Everything Everywhere to provide a materially higher quality of service than Vodafone or O2 if liberalisation for UMTS were delayed. If liberalisation is not delayed, we consider that Vodafone and O2 would be able to deploy UMTS 900 networks quickly enough[11] to match the quality of Everything Everywhere's network.

[11] We consider that Vodafone and O2 would be likely to be able to upgrade many of their existing GSM900 sites and this is likely to be faster (and less expensive) than acquiring new sites.

Annex 3

Cost of Clearance and Release – updated analysis

Introduction

A3.1 In paragraphs (A3.5 – A3.42) we detail the changes we have made to derive our updated estimates of the cost of clearance and release of 900 MHz spectrum.

A3.2 In this analysis we express the costs as a range going from very low to very high. The very low and very high figures are the extremes that account for all plausible assumptions that take the calculated values one way or another. The low and high values represent the range that the costs are most likely to fall within.

A3.3 In paragraph A3.43 onwards we provide our overall updated estimates.

Cost of clearance and release

A3.4 In the February 2009 consultation[12] we considered three approaches to estimate the cost of clearance and release of GSM spectrum in the 900 MHz and 1800 MHz bands. The approaches previously taken are as follows:

i) **Approach 1** – Synthesised Frequency Hopping (SFH) upgrades plus UMTS2100 Widening

ii) **Approach 2** – SFH upgrades plus cell splitting

iii) **Approach 3** – GSM1800 upgrades plus cell splitting

A3.5 All three are applicable to 900 MHz however only the first two are applicable to 1800 MHz.

SFH as an approach to capacity relief

A3.6 In their responses to the February 2009 consultation both Vodafone and O2 raised concerns about Ofcom's estimate based on the use of synthesised frequency hopping (SFH). O2 had fundamental concerns which would rule it out entirely whereas Vodafone believed it is essential for higher release quantities (≥ 2 blocks) but believed we had made errors in our analysis (underestimating the SFH clustering factor for lower release quantities and underestimating the upgrade costs).

A3.7 In our previous analysis SFH upgrades formed an integral part of our approaches described in 1 and 2 above. However for 900 MHz, approach 3, resulted in lower costs and was therefore used as the basis for the policy analysis.

A3.8 Given that approaches 1 and 2 were not used in the 900 MHz policy analysis and the concerns of both Vodafone and O2 of our estimates base on SFH, we have decided not to continue with these approaches in our further analysis.

[12] http://stakeholders.ofcom.org.uk/binaries/consultations/spectrumlib/summary/spectrumlib.pdf

Vodafone comments on cost of release

A3.9 Vodafone raised five issues where they believed there were ‘flaws’ in Ofcom’s methodology which would lead to an overall underestimate. These are:

i) The assumption that only 9 GSM carriers are dedicated to micro and pico cell layers. Vodafone dedicate significantly more than 9 carriers in many urban areas and that they split spectrum between macro and micro/pico layers in a number of areas not just within M25;

ii) We have underestimated the true costs of performing GSM1800 upgrades to existing 2G sites;

iii) The BCCH carrier re-use factors we assume outside of urban areas are ‘overoptimistic’;

iv) The approach of modelling ‘average sites’ under-estimates the number of cell splits in a ‘real world’ network;

v) Our assumptions about SFH are ‘flawed’; meaning that we miscalculate both the number of sites needing to be upgraded and the cost of implementing SFH.

Areas where GSM carriers dedicated to micro/pico layers

A3.10 Vodafone point out that they split spectrum for a micro/pico cell layer in many major UK cities not just inside the M25. Therefore Ofcom is significantly underestimating the cost of 900 MHz spectrum clearance and release.

A3.11 In our analysis we used the area within the M25 as a proxy for areas where the layers were split. It is clear from Vodafone’s comments that they do not split the entire area within the M25 and therefore our own split (i.e. approx 1000 sites) is an over estimate for this area. In the absence of more detailed information on the number of macro sites affected we still believe that using cells within the M25 as a proxy is reasonable.

A3.12 It is worth noting that prior to our consultation, Vodafone were fully aware of our approach to this a chose to not raise an issue with it at the time.

Number of GSM carriers dedicated to micro/pico layers

A3.13 Vodafone also commented that our analysis was based on reserving 9 GSM carriers for micro/pico layers but that Vodafone reserve more carriers than this in the busiest traffic areas (e.g. in London). However they do not state whether they reserve more than 9 GSM carriers in areas outside London.

A3.14 The figure of 9 was used on the basis that this was the number quoted by O2 and seemed a reasonable minimum – however, Vodafone are correct that we did not explicitly calculate the impact of traffic displaced from the micro/pico layer if it is squeezed into 9 carriers.

A3.15 We have accepted that our calculations should assume Vodafone reserves more carriers for micro/pico layers and revised our calculation accordingly (i.e. we now model 15 carriers reserved on all Vodafone sites inside the M25).

GSM 1800 upgrade costs

A3.16 Vodafone believe that we have underestimated the true cost of upgrading a GSM site to add GSM1800 carriers.

- o Our estimate £21,400 (based on approx two carriers per sector)
- o Their estimate £35,000 (also based on two carriers per sector)

A3.17 The main cause of the difference is that they do not think they can simply add GSM1800 carriers to the same cabinet as used for their GSM900 carriers but they would need to add a second cabinet dedicated to GSM1800.

A3.18 We have accepted Vodafone's assertion that they would need to add a second cabinet to add GSM1800 carriers to a site which does not already use 1800 MHz spectrum. Therefore we have revised our calculations to account for this.

Revised baseline for the cost of clearance and release of 900 MHz spectrum

A3.19 Accounting for 15 carriers reserved for micro/pico layer in the Vodafone network and higher GSM1800 upgrade unit costs are revised baseline for the cost of clearance and release of 900 MHz spectrum is provided below in Tables A3.1 and A3.2 (based on approach 3).

Costs	Low	High
1 Block	£50m	£80m
2 Blocks	£90m	£140m
3 Blocks	£150m	£250m
4 Blocks	£290m	£480m
5 Blocks	£580m	£970m

Table A3.1: Cost of clearance

Costs	Low	High
1 Block	£60m	£110m
2 Blocks	£200m	£340m
3 Blocks	£490m	£830m

Table A3.2: Cost of release

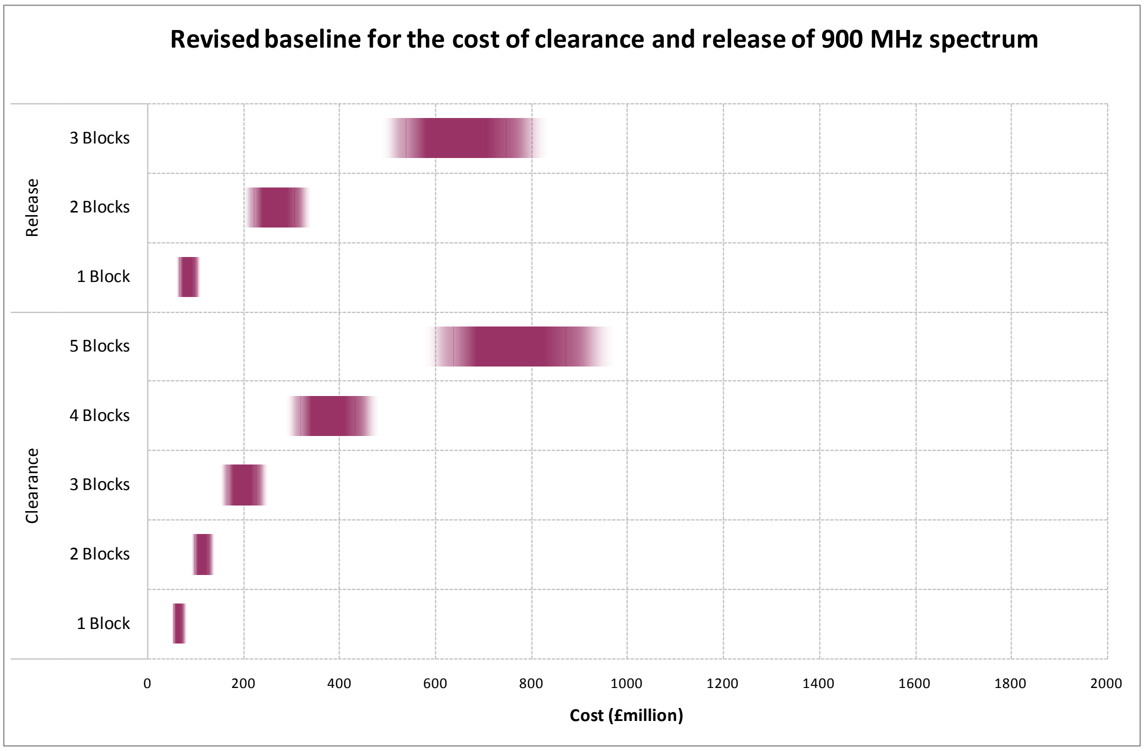


Figure A3.1: Revised baseline for the cost of clearance and release of 900 MHz spectrum

GSM carriers re-use

A3.20 Vodafone was concerned that the GSM carrier re-use factors we assumed in the consultation were overoptimistic in a practical network outside of urban areas.

A3.21 For a baseband hopping network, we assumed reuse factors of:

- o 15 for BCCH carriers; and
- o 13 for TCH carriers

A3.22 Vodafone believe that a factor of 15 for BCCH carriers is only achievable in urban areas and only for lower spectrum clearances e.g. ≤ 3 blocks. Vodafone claim that this is due to terrain and that they can only achieve high re-use factors where they can interleave with TCH carriers.

Our further analysis of the achievable GSM carriers re-use

A3.23 The following equation can be used to estimate achievable frequency re-use cluster size *N*:

$$N = \frac{1}{3}\left(C/I \cdot \frac{6}{\beta}\right)^{\frac{2}{\gamma}}$$

Where γ is the propagation path-loss exponent;
C/I is the required carrier to interference ratio; and

β is the number of sectors per site

A3.24 Higher path-loss exponents result in smaller re-use cluster sizes.

A3.25 The GSM standard specifies a $C/I_{(s)}$ ratio of 9 dB for co-channel operation. However, when designing a network, operators will generally require this to be achieved with a cell edge location probability of 95%. We would therefore need to add 1.645 (from the normal distribution for 95% probability) times the standard deviation of the wanted signal power (σ) to $C/I_{(s)}$ to obtain the required C/I ratio.

A3.26 The propagation path-loss exponent (γ) used in the Cost-231 Hata and Extended Hata propagation models typically used for mobile network planning activities does not vary intrinsically with the macro cell clutter type/environment. However, it does depend on antenna height as follows:

$$\gamma = (44.9 - 6.55\log(h))/10$$

Where h is the base station antenna height;

- As h increases the path-loss exponent γ decreases.

A3.27 Therefore if, as might be expected, average antenna heights in rural environments are higher than in suburban which in turn are higher than in urban environments then suburban and rural environments will need higher re-use cluster sizes (supporting Vodafone's views).

A3.28 However, analysis of the average base station antenna heights in actual GSM networks indicates that these vary surprisingly little with clutter type. Average heights are around 21 m for urban and suburban environments and 23.5 m for rural environments.

A3.29 Another important factor in estimating achievable re-use cluster sizes standard deviation (σ) of the wanted signal power.

- An expression derived by Okumura for this is as follows:

$$\sigma = 0.65\log(f)^2 - 1.3\log(f) + A$$

Where f is the frequency in MHz; and
A has a value of 5.2 in urban and 6.6 in suburban/rural environments

A3.30 In an urban environment, this gives us an assumed standard deviation of the wanted signal power of:

$\sigma_{(urban)}$ = 7.1 dB (for 900 MHz) & 8.8 dB (for 1800 MHz)

- And for the suburban/rural environment, of

$\sigma_{(suburban)}$ = 7.9 dB (for 900 MHz) & 9.3 dB (for 1800 MHz)

A3.31 Combining the information about average base station antenna heights and standard deviation for the wanted signal power leads to the following re-use cluster sizes whilst relaxing the location probability for the suburban and rural environments by a small amount (2%) we get the following:

	BCCH	TCH
Location probability	**(97%)**	**(95%)**
Urban 900 MHz	**15.0**	**12.5**
Urban 1800 MHz	**18.0**	**14.5**
Location probability	**(95%)**	**(93%)**
Suburban 900 MHz	**16.5**	**14.0**
Suburban 1800 MHz	**19.5***	**16.0**
Rural 900 MHz	**17.0**	**14.5**
Rural 1800 MHz	**20.5***	**16.5**

A3.32 We believe these values are suitable for deriving the high and very high estimates below.

Cell splitting

A3.33 Both Vodafone and O2 believe that we have not calculated the number of cell splits correctly and that we have misinterpreted the Red-M study results on this.

A3.34 O2 think that we should use the Red-M results directly and should not use our own estimation method.

A3.35 Both O2 and Vodafone do not think it appropriate to adjust the Red-M results by 1 block – but fail to indicate how we should account for increased use of GSM1800.

A3.36 To account for the impact of a more pessimistic estimate of the number of cell requiring splitting, the very high estimates below are based on a 50% increase in the number of cells needing to be split.

Site sharing

A3.37 It is possible that a requirement to clear and release spectrum would drive the 900 MHz operators to share sites much more aggressively than they currently do.

A3.38 To account for this we have adjusted the very low estimates assuming that 50% of cell split sites needed are existing sites available through site sharing deal, the rest being new builds.

Revised/updated costs of clearance and release – 900 MHz

A3.39 The following results take into account the three main issues discussed above:

- Frequency re-use;
- Cell splitting;
- Site sharing.

A3.40 They represent our best estimate for the range of likely costs associated with the clearance and release of 900 MHz spectrum.

A3.41 The estimates below in Tables A3.3 and A3.4 are based on 20 year NPV with a discount rate of 3.5%. These are the combined costs of both O2 and Vodafone.

Costs	Very Low	Low	High	Very High
1 Block	£45m	£50m	£110m	£150m
2 Blocks	£80m	£90m	£190m	£250m
3 Blocks	£140m	£150m	£340m	£460m
4 Blocks	£260m	£290m	£640m	£880m
5 Blocks	£520m	£580m	£1300m	£1800m

Table A3.3: Cost of clearance

Costs	Very low	Low	High	Very High
1 Block	£60m	£60m	£150m	£210m
2 Blocks	£180m	£200m	£450m	£630m
3 Blocks	£440m	£490m	£1100m	£1550m

Table A3.4: Cost of release

A3.42 The basis for these estimates are:

i) Very low

- o As low plus
- o 50% of cell split sites needed are available through site sharing deal

ii) Low

- o Traffic - 110% of 2009 levels
- o Unit costs low (0.75 of mean)
- o Frequency re-use the same as 2009 consultation

iii) High

- o Traffic – 110% of 2009 levels
- o Unit costs high (1.25 of mean)
- o Frequency re-use less efficient than 2009 consultation

iv) Very high

- o As high plus
- o Cell splits increased to 150% of estimated number

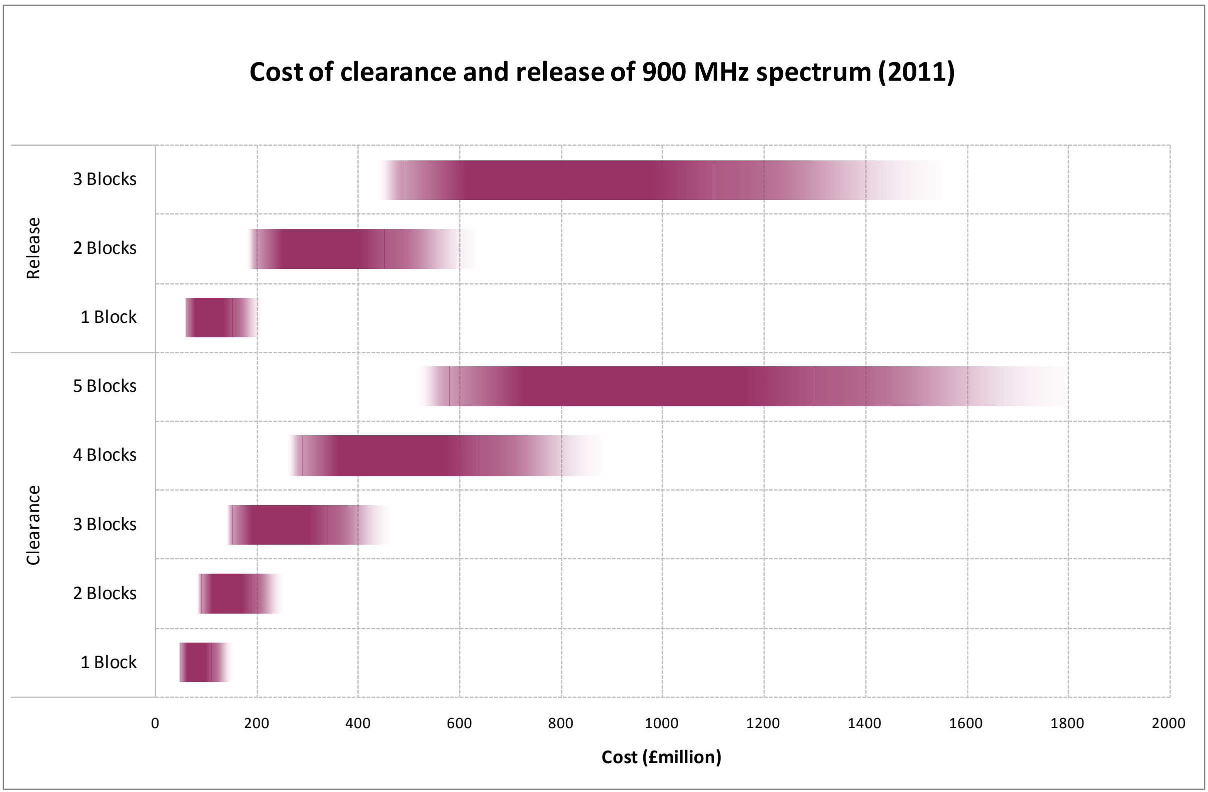


Figure A3.2: Cost of clearance and release of 900 MHz spectrum (2011)

Other issues

A3.43 There were various comments about predicted traffic growth – Vodafone makes the point that due to the long lead times we need to err on the side of caution and propose a 10% increase (which is what we actually modelled). O2's comments on traffic growth were harder to interpret as they mixed 2G and 3G traffic together and did not provide a disaggregated view on 2G traffic growth.

A3.44 Vodafone also pointed out that some GSM carriers are effectively reserved as guard channels between different operators' blocks thus effectively reducing the pool of available carriers. Though this may be the practical situation today, given the pressure on spectrum that clearance and release may bring, it seems likely that they would find ways of using these carriers more effectively in future.

Concluding remarks

A3.45 We believe that that the costs of release as set out above are realistic. However there are a number of uncertainties.

- GSM frequency re-use estimates are base on our best engineering judgement but a detailed site by site re-planning exercise would be needed by operators in practice and it is possible that this could lead to different values.

- Cell splitting factor, again this is based on our best engineering judgement but in practice an operator would need to carry out a detailed site by site planning exercise.

- The analysis assumes a nationwide clearance. However if a 900 MHz operator only planned to roll out UMTS900 in a limited geographic area then the cost of release would be reduced.

- GSM1800 upgrade costs assume a separate GSM1800 electronics rack is added to upgraded base stations however it is possible (or even likely) that a multi-standard base station electronics rack would be deployed that could also be used for other technologies (e.g. UMTS900 and future LTE at 800 or 2600 MHz deployments) thus sharing some of the costs with these upgrades.

- There are other costs that may be shared when upgrading sites for UMTS900, e.g. antenna work, other necessary civil engineering, etc.

- The site data and unit costs used are largely base on data gathered in preparation for our February 2009 Consultation which may have changed.

Annex 4

Overview of technical challenges in implementing regulated roaming

A4.1 This annex provides an overview of the technical challenges involved in implementing regulated roaming for the purpose of mitigating coverage advantages that UMTS networks using the 900MHz band may have over UMTS networks using higher frequency spectrum only.

A4.2 We first consider what the objective of providing access to a network using 900MHz would be. We then explore the option of roaming to provide a temporary access solution to 900MHz networks. This consists of a review of:

a) existing industry experience in the design and implementation of roaming solutions;

b) the specific challenges that the objective for UMTS 900MHz pose because of the resulting multiple pockets of coverage;

c) the main effects of roaming for users and for the operators involved; and

d) additional information on how roaming works in practice.

Objective of an access provision in the context of 900MHz liberalisation for UMTS – temporary access to mitigate coverage differences

A4.3 Seeking to implement a regulated access solution would only be relevant in circumstances where a distortion of competition from liberalisation of 2G spectrum for UMTS use was likely to occur with material impacts resulting for consumers.

A4.4 If such a distortion was likely to occur, then regulated access would be designed to provide operators who do not have sub-1GHz spectrum with temporary access to a 900MHz network. The objective would be to address any advantage that UMTS900 might provide to 900MHz operators until operators without 900MHz can use other resources to achieve similar or better services. Figure A4.1 illustrates when temporary access to a 900MHz network might be relevant for operators that do not hold sub-1GHz spectrum.

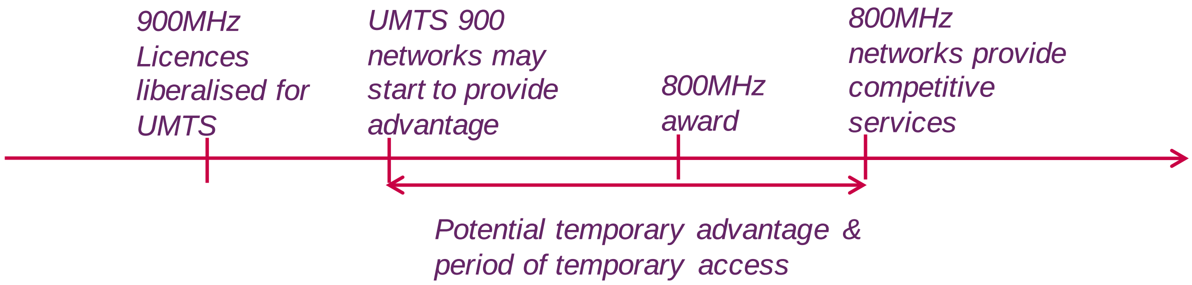


Figure A4.1: When temporary access to a 900MHz network might be relevant

A4.5 This objective has the following implication if regulated access were to operate as an effective mitigation tool. It would involve achieving a similar user experience for users of:

- UMTS900 operators (who also have a UMTS2100 layer); and

- any access seeker, i.e. an operator without 900MHz relying primarily on 2100 MHz for its own UMTS services.

A4.6 This is likely to involve arranging for access to be available and effective in those places where coverage differences may materialise, and to achieve comparable depth of coverage into buildings and breadth of coverage across the country between the two categories of operators. In particular, this includes similar coverage:

a) when users are inside buildings (and there may be areas where an operator that does not hold any 900MHz spectrum provides outdoor coverage but does not achieve sufficient coverage indoors); and

b) when users are in rural areas where an operator that does not hold any 900MHz spectrum has insufficient coverage.

A4.7 As we will explain in more detail later, this means that the access solution requires access to the whole of a 900MHz operator's network.

A4.8 It is also likely to require that service performance – e.g. latency, speed of access to service, download and upload speeds – is good enough to be of value to customers (ideally comparable to that on their home network) and ideally also that the full set of applications to which users have access on their home network is available during access.

A4.9 In this annex, we focus on technical and practical challenges of providing temporary access to a UMTS900 network as well as the implications of doing so, for users as well as operators. The access solution that we focus on is roaming as it is the access solution for which there exists the largest body of industry experience worldwide. Throughout we refer to the 'access seeker' as the operator that does not hold any 900MHz spectrum (but holds 2100MHz spectrum) that might benefit from regulated access to the network of an 'access provider', i.e. an operator with liberalised 900MHz (as well as 2100MHz) as part of its spectrum portfolio.

There are many existing examples of roaming agreements for access over large areas

A4.10 A number of mobile operators across the world have negotiated and implemented roaming agreements. One of many examples is the commercial deal that H3G and Orange struck in 2006 so that H3G can get access to 2G services in rural areas of the UK where its 2100MHz network footprint does not extend.

A4.11 The requirement to provide access in these well-known examples relates to pre-identified wide areas in two cases.

a) The first case is national roaming where, in a given country, operator A's customers can access operator B's services in large areas where A's network coverage is insufficient but B's coverage is fine. A typical implementation is in respect of rural areas, such as in the agreement between H3G and Orange in the UK that we refer to above.

b) The second case is international roaming where operator C's customers from say continental Europe get access to operator D's services in the whole of the UK.

A4.12 However, even in these well known cases, there is a degree of complexity involved to deliver a national roaming solution. For example, we understand that the design and implementation of the H3G/Orange roaming deal in the UK took approximately 12-18 months.

A4.13 We also note that, here, we are considering a regulated roaming solution. This may be more difficult than a situation in which two operators negotiate roaming on commercial terms, for example where the access seeker can choose from a number of wholesale suppliers of roaming services in a competitive market. There would only be at most two operators able to provide temporary access to a UMTS 900 network. The incentives for the parties involved in the implementation of a roaming solution may be different from those that generally applied in the examples we mentioned.

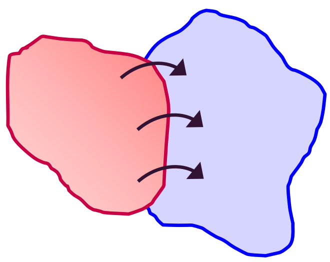
A specific implication of the objective for UMTS 900 access – multiplicity of small pockets of access

Access across the whole of the provider's network involving small pockets

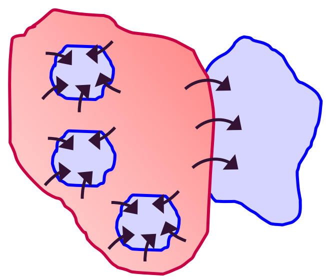
A4.14 The common roaming solutions we described deal with pre-identified large areas, typically rural areas in the case of national roaming. Figure A4.2 illustrates how roaming occurs when users move from an area of good home network coverage (red) to area of poor/no home network coverage but where the access provider's coverage is sufficient (blue). The transition boundaries at which user switch from the access seeker's network to the access provider's network may stretch over large distances but operators are able to identify them in advance and they arise in areas of lower population density.

A4.15 In the case of UMTS 900 roaming, the requirement is to provide services where the access seeker's network does not provide sufficient coverage but where the access provider's (900MHz holder) network does. This means providing access in buildings and other small areas dotted across the country in all types of areas, from dense urban to rural. This might be in addition to providing national roaming for large outdoor rural areas.

A4.16 Buildings might create numerous pockets of UMTS900 access within network cells where the access seeker's outdoor coverage is sufficient and therefore access is only relevant inside buildings. It might be difficult or impossible to anticipate in advance precisely where access would occur at any given time. This would likely depend on where users are and what they services they are using and would likely change in a dynamic way. Figure A4.2 also illustrates these pockets in the UMTS900 roaming case, bringing them into contrast with the more common wide-area roaming case.



Typical national roaming where users transfer from one large coverage area to another



UMTS900 roaming in this case where users transfer from one large coverage area to potentially small pockets (e.g. in buildings)

Figure A4.2: National roaming over large areas with relatively few transition boundaries vs. UMTS 900 roaming with multiple small pockets

Challenges of small pockets of coverage and transitions

A4.17 Each time an access seeker crosses a boundary, it roams onto the access provider's network i.e. it goes through a transition from one network to the other. That can be from the access seeker's to the access provider's network or back from the access provider's to the access seeker's network.

A4.18 As Figure A4.2 illustrates, there are many more locations where roaming would need to occur for a UMTS900 access solution to meet its objective, compared to the more common national or international roaming implementations. This has the potential to result in more transitions between the two networks involving more users and happening more frequently.[13]

a) Each transition, to and from the access provider's network, is likely to have negative effects for users that roam.

b) If a user is in the holding a voice call or using data services (e.g. an internet session) at the time the transition, then it will be at an increased risk of:

- delays or other disruptions to the quality of its service; or
- possibly a dropped call or an interruption data service.

c) A user may be "out of service" i.e. unable to use services or receive calls during transition.

d) User equipment (e.g. handsets, laptops with 3G dongles) may require more frequent battery charges, as each transition requires extra battery resources. This may be particularly true when it comes to returning to the access seeker's network, i.e. where the access seeker's signal quality returns to a sufficient level, but the access provider's signal quality remains good.

A4.19 Operators party to a roaming agreement may reduce the occurrence of transitions through optimisation. Such optimisation involves a choice between two options, with different implications for the operators and users.

[13] We note, however, that regulated access for UMTS relates primarily to data services and that the indications are that most mobile data use takes place indoors and that a particular user may be unlikely to get in and out of roaming pockets while using data services.

- They can trigger roaming “earlier” (when the access seeker’s signal quality is higher). This will increase the sizes of the areas where the access provider’s network is in use, reducing the probability that users would cross boundaries. However, the resulting increased roaming traffic may create potential downsides for the access seeker because of a reduced use of its own network and increased roaming fees, and for the access provider because of the need to deal with increased roaming traffic.

- They can also trigger roaming “later” (when the access seeker’s signal quality is lower). This will reduce the sizes of the areas where the access provider’s network is in use and might eliminate some areas where roaming would otherwise occur. This would result in greater use of its own resources for the access seeker and reduced roaming traffic for the access provider. However, this would create a risk of degraded experience for some of some of the access seeker’s users.

A4.20 Resolving the optimisation issues for the purpose of UMTS900 roaming is likely to be more complex in this case than in the more common national roaming case. This is because of the multiplicity of small pockets of access, some of which are likely to be in areas of dense usage and coverage large numbers of users, and the potential for these to change dynamically in certain places, depending on local network conditions at the time. We provide some additional information on associated technical issues.

A4.21 We mentioned the capacity of access provider’s 900 MHz network as part of the optimisation issue. There will need to be sufficient capacity to meet both the needs of the access seeker and the access provider. Operators might also be concerned about the potential implications of a temporary failure of the access seeker’s 2100MHz network in a given area, and whether this would result in failure of the access provider’s 900MHz network as well, because of the associated transfer of traffic.

A4.22 We referred to potential commercial or technical objectives of operators to maximise use of their own resources and manage the amount of roaming traffic. By way of further illustration, a set of technical considerations to take into account might be that the access seeker could be more likely than the access provider to wish to keep traffic on the 900 MHz layer, avoiding excess transitions (which degrade quality) and reducing loading on their own network (which is higher for a given user – especially indoors – at 2100 MHz than at 900 MHz). The access provider might conversely be concerned about loading on its 900MHz network if roaming users were mostly indoors.

A4.23 This may result in roaming customers imposing a greater unit load than home customers and the extra load may degrade performance for all customers (home and roaming). However, the commercial conditions may mitigate this and incentivise the access seeker to keep traffic to their own network unless 900 MHz is vital.

A4.24 We also note that handset behaviour in roaming conditions is variable and is part of the complexity of the optimisation that operators face. Although roaming activity is set in standards, the specific behaviour of a given handset is dependent on the individual manufacturer, so roaming is likely to be more effective as a technical solution for some handsets than others. Addressing these differences effectively may be difficult given the complexity of the issue and the potential lack of alignment of incentives between the two parties.

Two main versions of roaming – with or without in-call hand-over

A4.25 We now provide more detail on the two main versions of roaming available to operators and a high level of the steps involved in transitions, first from the access seeker to the access provider's network and then back from the access provider to the access seeker's network. This highlights the kind of interaction between networks that is necessary for roaming to work, the different quality of service that users might experience depending on the extent of investments operators are prepared to commit, and how or when the potential issues we identified above could materialise.

A4.26 The two main roaming implementations are a simple version with no in-call hand-over and a "fuller" version which supports in-call hand-over.

A4.27 The main advantage of the simple version is to allow an operator sending users onto another network to make reduced investments in network changes and process management to enable this roaming solution. However, the associated downsides are that users lose coverage at each transition (e.g. a user would experience a dropped call if it was holding one at the time of a transition).

A4.28 The main advantage of the fuller version is to offer the scope for much reduced service interruptions at the time of transitions, including maintaining calls or data sessions that are in progress at the time of a transition in a seamless process. To achieve this, an operator sending users onto another network needs to make more material investments in network features and process management.

A4.29 The choice between the simple and the "fuller" version of roaming is relevant to each type of transition:

- from the access seeker to the access provider's network – the access seeker needs to decide whether to invest to manage information about the access provider's network (e.g. relationships with neighbouring cells etc); and
- from the access provider back to access seeker's network – the access provider needs to decide whether to invest to manage information about the access seeker's network.

A4.30 We understand that access seekers generally implement the fuller version of roaming in order to improve customer experience. It seems less common for access providers to implement a fuller version as it requires investments and optimisation in their network to enhance the experience of the access seeker's roaming users.

Main steps in a roaming transition – from the access seeker to the access provider's network

A4.31 The nature of the main steps that a handset needs to go through to complete a transition from its home network (access seeker) to a host network (access provider) depends on the version of roaming that the operators implement. For simplicity, we refer to a customer of the access seeker as "AS user", to the access seeker's network as "AS network" and to the access provider's network as "AP network".

A4.32 When an AS user reaches a predefined threshold of signal quality on its home network (i.e. when the AS network coverage becomes insufficient), then the following steps take place.

i) The AS user handset scans local cells and selects the best one in the AP network to connect to.

ii) If the best cell belongs to the AP network, the AS user's handset tries to register with the cell. The AP network checks that the handset is eligible to connect and verifies facts such as user's rights to access services and handset capabilities.

iii) If the "simple" version of roaming version is implemented, during the transition from AS to AP network, the handset will be out-of-coverage for a period i.e. it will be unable to start or continue a call or data session for as long as it takes for the transition to complete.

iv) If the "fuller" roaming version is implemented, in addition to the handset scanning for the best cell(s) to connect to, the AS network sends a list of surrounding cells the handset can access (called "neighbours"). This enables a seamless transition and avoids a temporary loss of service (including dropped calls). There may however be risks to a seamless transition if the process is not defined sufficiently well, locally or more generally. One such risk stems from the need for the operators involved to exchange technical information about their networks. This is likely to be a sensitive part of the implementation (e.g. to provide and act on the information across all relevant parts of the networks on a regular basis and in time to reflect changes); it may become even more challenging if one access provider offers roaming services to more than one access seeker.

A4.33 Typically, once an AS user is on the AP network, it receives the same service quality as AP users.

Main steps in a roaming transition – from the access seeker to the access provider's network

A4.34 The two options to return an AS user onto its home network are identical to the previous options to transfer that user to the AP network: one involves a temporary loss of service and the other enables a seamless transition with call hand-over.

A4.35 In the case that involves a loss of service, once on the AP network, an AS user handset will periodically scan to check the level of AS network coverage (which causes additional battery drain). If the AS signal quality reaches a pre-defined threshold (i.e. the AS network coverage is back to a sufficient quality level), then the AS user handset selects best cell in AS network to connect to. While the handset leaves the AP network and the connection to the AS network takes place, the user will be out-of-coverage for a period.

A4.36 The alternative option maintains coverage for users during the transition by defining neighbour relationships between the AS and AP networks in the AP network. This requires more effort/investment from the access provider, and is effectively equivalent to what the access seeker needs to do to achieve seamless transitions from the AS network to the AP network as described above. Again, the benefits for AS users come from avoiding a temporary loss of service and the associated risk of dropped or missed calls for example. And again the operators have to engage closely on a technical level to ensure that seamless transitions can effectively take place.

A4.37 In both transitions (from AS to AP network and back) the selection of the pre-defined threshold for signal quality matters to:

- the number of transitions for users and associated effects e.g. battery drain;

- the time that users spend on the AP network and the overall volume of use that AS users make of the roaming facility; and

- the risk of “ping pong” where a user may switch back and forth between the two networks without being able to settle on one for a sufficiently long period of time to get a meaningful service because signal qualities on both networks are close or changing in a way that can trigger repetitive transitions.

Annex 5

Description of technical modelling approach and responses to technical analysis contained February 2009 consultation

Introduction

A5.1 This Annex describes the approach which we have used for technical modelling of the potential advantages of UMTS operating at 900 MHz versus 2100 MHz. The Annex comprises the following sections:

- *Modelling Approach*, which describes the model we have used for generating the results in the main paper.
- *Parameters and Assumptions*, which tabulates the parameters used within the model.
- *Summary of issues raised in response to the February 2009 consultation*, which summarises the main issues that were raised in response to the technical modelling work in our February 2009 consultation, particularly those which have led to changes in our modelling approach.

Modelling Approach

A5.2 This section describes the modelling approach we have adopted for our current analysis. This approach has evolved from the one we adopted for our 2009 consultation, partly in response to comments received and partly as a consequence of our own considerations.

A5.3 The main results presented in Annex 1 for the 0 to 80% most populated areas of the country have been derived using what we have termed a ‘uniform’ model, a description of this which is given below.

A5.4 Annex 6 provides the results of additional modelling carried out to look at the impact of non-uniform site and clutter distributions. This analysis considered a more realistic distribution of sites overlaid on the clutter distribution for a sample area centred on West London. The aim was to establish whether the results obtained from the uniform clutter model carried out for the 0 to 80% most populated areas of the country could be relied upon, or whether a more detailed, ‘non-uniform clutter’ model would be needed for the wider picture.

Uniform Model

A5.5 The ‘uniform’ modelling approach adopted is similar to that set out in section 7.2.2 of HSDPA/HSUPA for UMTS [1]. The high level steps in the modelling are illustrated in Figure A5.1 below and described as follows.

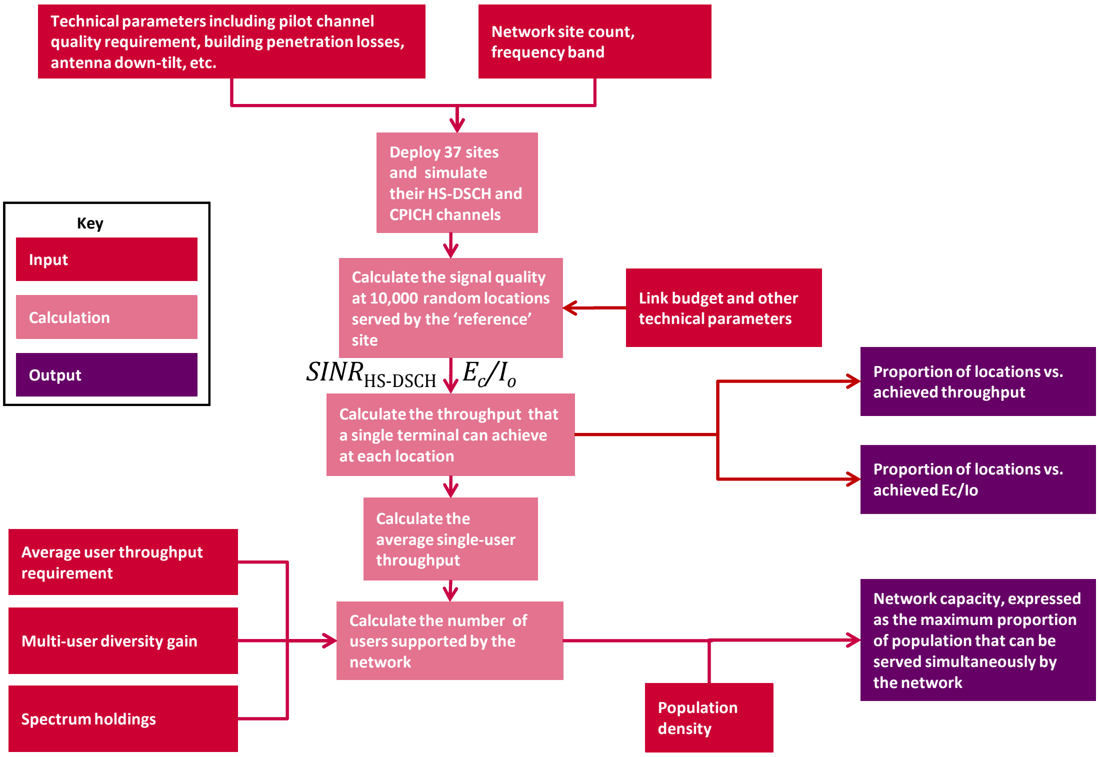


Figure A5.1: 'Uniform' model flowchart

A5.6 In the text below the following definitions apply:

base station array:	the geometric array of 37 base stations used in the modelling
'reference' site:	the centre base station in the base station array
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 'reference' site that is assumed to be providing a data service to the UE during a Monte Carlo snapshot
non-serving sector:	a sector of any site in the base station array that is not the serving sector

A5.7 A Monte Carlo approach was used to model the downlink performance of a number of hypothetical HSPA networks. The results presented in Annex 1 are for example networks of 4,000, 7,000 and 10,000 sites for 900 MHz and 4,000, 7,000, 13,000 and 16,000 sites for 2100 MHz. Each network comprises sites covering four clutter categories (Dense Urban, Urban, Suburban and Rural) covering the 0 to 80% most densely populated locations of the country.

A5.8 For each example network the different clutter categories are modelled independently with a uniform array of base stations with a characteristic inter-site distance (in km) drawn from the table below.

Example network	900 MHz			2100 MHz	
	4,000 sites	7,000 sites	10,000 sites	13,000 sites	16,000 sites
Dense Urban	1.604	1.213	1.014	0.890	0.802
Urban	1.959	1.481	1.239	1.086	0.979
Suburban	1.944	1.469	1.229	1.078	0.972
Rural	5.850	4.422	3.700	3.245	2.925

Table A5.1: Inter-site distances

A5.9 These inter-site distances have been derived on the following basis: sites are assumed to have equal capacity and the proportion of cells in each clutter category is assumed to be equal to the population in each category according to the table below.

Clutter	Area (km^2)	Population
Dense urban	29	148,861
Urban	666	2,292,982
Suburban	10,147	35,474,823
Rural	20,297	7,834,317

Table A5.2: Population statistics

A5.10 The network performance statistics for each clutter category are then combined in proportion to the population represented by each clutter category within the overall 0 to 80% area to give the total performance of that particular example network.

A5.11 The following bullets describe in detail the steps involved in each Monte Carlo run.

- A base station array with a characteristic inter-site distance for the example network and clutter type under consideration is generated consisting of a central ‘reference’ site with three tiers of interfering sites (37 sites in total). For each Monte Carlo run, sites are of uniform size and each site has an identical configuration i.e. antenna height and sector orientation etc. The base station array is illustrated below.

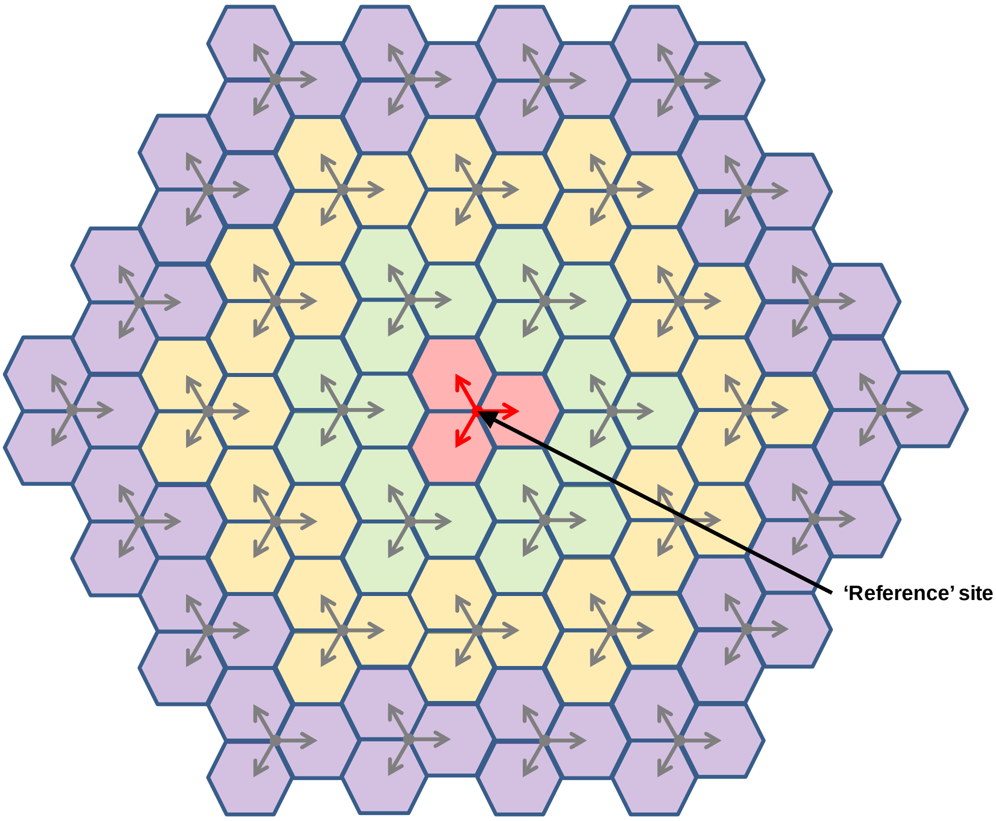


Figure A5.2: Layout of the base station array

- For the area around the 'reference' site a uniformly spaced rectangular 50 x 50 metre grid is established. For each grid node, two arrays of random variables are generated. The values for the first array are drawn from a distribution with mean 0 and standard deviation σ_s and represent the shadow fading values in decibels from each site to that location. The values for the second array are drawn from the normal distribution with mean m_{bpl} and standard deviation σ_{bpl} and represent the building penetration loss values for each site to that location. Every 250th Monte Carlo iteration these shadow fading and building penetration values are re-generated from a new set of random variables.

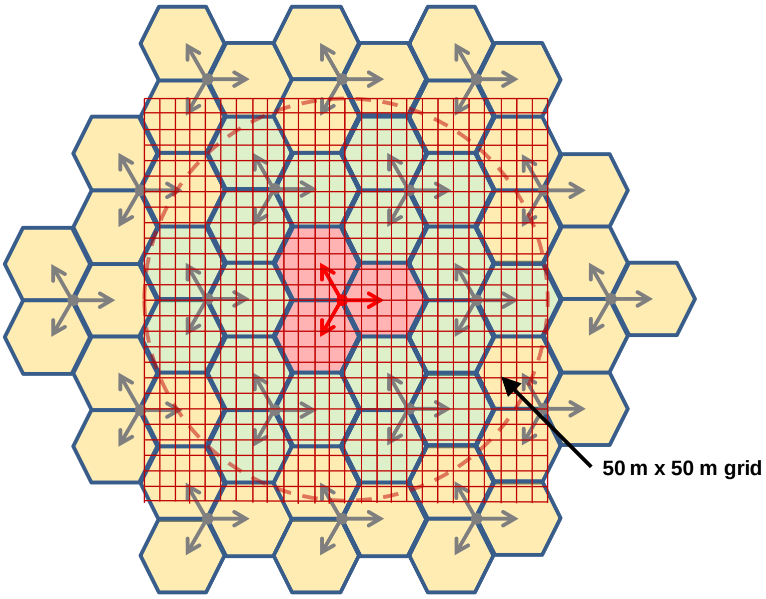


Figure A5.3: 50m x 50m grid

- The standard deviation σ_S (in decibels) of the shadowing is derived from the empirical relationship given by formula (1) below taken from [2]:

$$\sigma_S = 0.65\ \log(f_c)^2 - 1.3\log(f_c) + 5.2 \tag{1}$$

- The mean building penetration loss (BPL) m_{bpl} used depends on the clutter at the UE location and the specific scenario under investigation. Stakeholders have expressed very different views on the appropriate values of BPL to apply to our analysis. As we did in the 2009 consultation [3], we have defined three building penetration depths reflecting a wide range of building types and user locations within buildings:
    - Depth 0 represents the conditions for users who are on average, not very deep inside buildings and/or in buildings which have, on average, relatively low penetration losses (e.g. users who are closer to windows);
    - Depth 1 represents the conditions for users who are deeper within buildings and/or buildings with higher penetration losses;
    - Depth 2 represents the conditions for users who are on average, considered to be deep inside buildings and/or in buildings which have, on average, relatively high penetration losses (e.g. users who are near the core of a building well away from external walls and windows).
- The values used (in decibels) are taken as appropriate from our 2009 consultation [3] and reproduced in the table below.

Building penetration depth scenario	**Depth 0**							
	Mean increasing with frequency – **Base Case**				Mean **rising faster** with frequency			
Clutter*	DU	U	S	R	DU	U	S	R
900 MHz	7.0	5.0	3.0	3.0	7.0	5.0	3.0	3.0
2100 MHz	9.0	7.0	5.0	5.0	16.0	14.0	12.0	12.0
Building penetration depth scenario	**Depth 1**							
	Mean increasing with frequency – **Base Case**				Mean increasing with frequency – **Base Case**			
Clutter*	DU	U	S	R	DU	U	S	R
900 MHz	11.5	9.5	7.5	7.5	11.5	9.5	7.5	7.5
2100 MHz	14.0	12.0	10.0	10.0	21.5	19.5	17.5	17.5
Building penetration depth scenario	**Depth 2**							
	Mean increasing with frequency – **Base Case**				Mean **rising faster** with frequency			
Clutter*	DU	U	S	R	DU	U	S	R
900 MHz	14.0	12.0	10.0	10.0	14.0	12.0	10.0	10.0
2100 MHz	17.0	15.0	13.0	13.0	24.0	22.0	20.0	20.0

Table A5.3: Mean BPL values

* The clutter categories in the table above are as follows: DU = Dense Urban; U = Urban; S = Suburban; and R = Rural

- It is plausible that the standard deviation of the BPL σ_{bpl} could be loosely related to the mean value of BPL (i.e. for higher BPL values, σ_{bpl} will be, on average, higher). To illustrate the impact of this we have modelled a few cases where values of σ_{bpl} used follow such a relationship, and are taken from the table below:

Building penetration depth scenario	**Depth 0**	
	Mean increasing with frequency – **Base Case**	Mean **rising faster** with frequency
900 MHz	3.0	4.0
2100 MHz	3.0	6.0
Building penetration depth scenario	**Depth 1**	
	Mean increasing with frequency – **Base Case**	Mean **rising faster** with frequency
900 MHz	4.5	6.0
2100 MHz	4.5	9.0
Building penetration depth scenario	**Depth 2**	
	Mean increasing with frequency – **Base Case**	Mean **rising faster** with frequency
900 MHz	6.0	8.0
2100 MHz	6.0	12.0

Table A5.4: BPL standard deviation values (related to mean BPL)

- It is equally plausible that the standard deviation of the BPL σ_{bpl} could be largely independent of the mean value of BPL. We have therefore modelled some other cases where σ_{bpl} does not vary with depth, and are taken from the table below:

Building penetration depth scenario	**All depths (0, 1 and 2)**	
	Mean increasing with frequency – **Base Case**	Mean **rising faster** with frequency
900 MHz	6.0	8.0
2100 MHz	6.0	12.0

Table A5.5: BPL standard deviation (independent of mean BPL)

- For each Monte Carlo snapshot a UE is dropped at a random location drawn from a uniform distribution within a radius equal to 1.5 times the inter-site distance of the base station array from the ‘reference’ site. See illustration below.

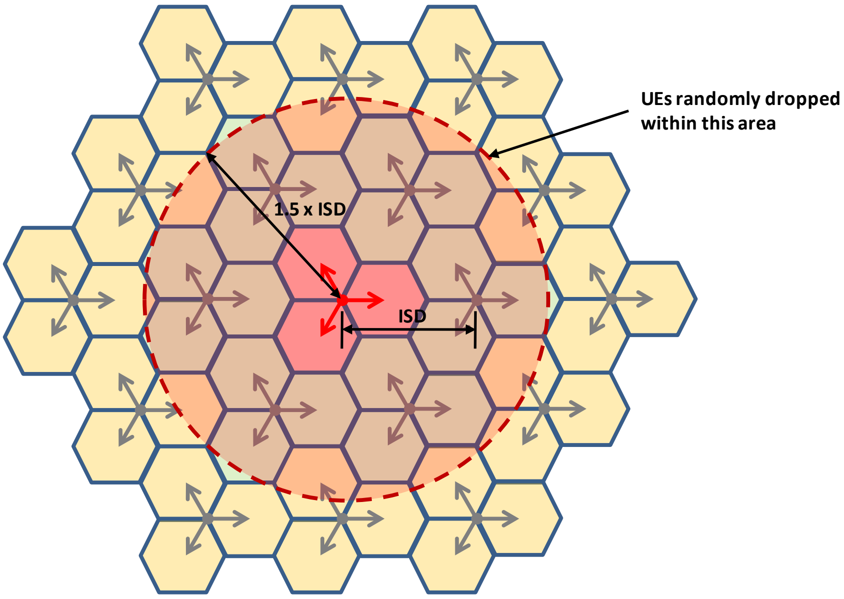


Figure A5.4: Area UEs are dropped

- Simple geometry is used to calculate the distance and angle between each transmitter in the base station array (i.e. for each sector of all 37 sites) and the UE location.
- Using the angle information the gain of every antenna in the direction of the UE location is calculated by combining the azimuth and elevation radiation patterns of each antenna and the bore-sight gain.
- Shadow fading and building penetration loss values for each base station in the array at the UE location are calculated by linear interpolation from the four closest 50 x 50 metre grid nodes according to the method in section 3.2.4 of [4].
- The coupling loss to the UE location from each sector of each base station in the array is calculated accounting for path-loss using the Extended Hata model from [5] (the Dense Urban path-loss being set to the Urban path-loss + 3 dB), antenna gain in the direction of the UE, shadow fading and building penetration loss.
- The theoretical radiation patterns (in decibels) are obtained from equations (2) and (3) below which are taken from [6]:

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

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

- The values of φ_{3dB}, θ_{3dB}, and bore-sight gain are taken from a typical multi-band antenna from the Kathrein catalogue (742-265); $\mathrm{A_m} = 25$ dB; $\mathrm{SLA_v} = 20$ dB and the antenna down-tilt θ_{tilt} are set to 6 degrees for all scenarios.
- If the minimum coupling loss value from all the sites in the base station array is not from a sector of the 'reference' site, the UE location is discarded (as that location will be better served by a site that is not the 'reference' site) and another

UE is dropped as above. This is repeated until the minimum coupling loss value for the current UE location is from a sector of the ‘reference’ site.

- The other-cell interference power (P_{other}) at the UE location is calculated from the sum of the interference power received (transmit power multiplied by coupling loss) from each sector of each base station in the array (including from non-serving sectors of the ‘reference’ site) assuming 20% of the total power available to each sector is dedicated to common (i.e. non-data) channels such as the CPICH and that the data channel HS-DSCH is loaded to 80% of its maximum. In calculating other-cell interference, shadow fading and building penetration losses from sites other than the ‘reference’ site are assumed to be cross-correlated with a factor of 0.5 (i.e. by multiplying the shadow fading and building penetration loss values for each site in the array at the UE location by √0.5). Shadow fading and building penetration losses for different sectors of the ‘reference’ site are assumed to be fully correlated. This follows the method described in section 3.2.4 of [4]

- Own-cell interference power (P_{own}) at the UE location is calculated from the power of the common channels received from the serving sector (i.e. 20% of total transmit power multiplied by coupling loss).

- The wanted power available for high speed data ($P_{\text{HS-DSCH}}$) at the UE location is calculated from the full HS-DSCH power available to the serving sector (i.e. 80% of total transmit power multiplied by coupling loss).

- The geometry factor G for the UE location is calculated using equation (4):

$$G = P_{\text{own}}/(P_{\text{other}} + P_{\text{noise}}) \tag{4}$$

where: P_{own} and, P_{other} are as defined above and P_{noise} is the receiver noise power

- From this the $SINR_{\text{HS-DSCH}}$ is calculated using equation (5) below (taken from equation 7.3 of [1]):

$$SINR_{\text{HS-DSCH}} = \text{SF}_{16}\frac{P_{\text{HS-DSCH}}}{P_{\text{own}}}\frac{1}{1-\alpha+G^{-1}} \tag{5}$$

where: SF_{16} is the HS-DSCH spreading factor of 16, $P_{\text{HS-DSCH}}$ is the received power of the HS-DSCH and α is the downlink orthogonality factor.

- Orthogonality is related to the delay-spread of received signals which in turn is related to the multi-path environment. It is expected that, on average, delay-spread will be greater the further the UE is from the base station and greater in urban environments than suburban environments. We have therefore chosen to model the downlink orthogonality factor α as varying across the ‘reference’ site according to a model suggested in [7]:

$$\alpha = 1/\left(1 + \frac{d}{x}\right) \tag{6}$$

- where: d = the distance (km) from the UE location to the base station of the ‘reference’ site and x has a value specific to the clutter category (for Dense Urban x = 0.7, Urban x = 0.9, Suburban x = 2.8 and Rural x = 11).

- The unloaded Ec/Io of the pilot channel (CPICH) at the UE location is also calculated from equation (7):

$$E_c/I_0 = \frac{P_{\text{CPICH:own}}}{P_{\text{CPICH:other}} + P_{\text{noise}}} \tag{7}$$

- where: $P_{\text{CPICH:own}}$ is the own-cell CPICH power (i.e. 10% of total base station power) and, $P_{\text{CPICH:other}}$ is the other-cell interference power calculated from the sum of the CPICH power received (i.e. 10% of the total transmit power multiplied by coupling loss) from each sector of each base station in the array (including from non-serving sectors of the 'reference' site) and P_{noise} is the receiver noise power.

- This process is repeated for 10,000 Monte Carlo snapshots to generate the distributions of G factor, $SINR_{\text{HS-DSCH}}$ and Ec/Io across the 'reference' site. The figure below illustrates the UE locations served by the 'reference' site where these downlink performance statistics have been generated for a single Monte Carlo run.

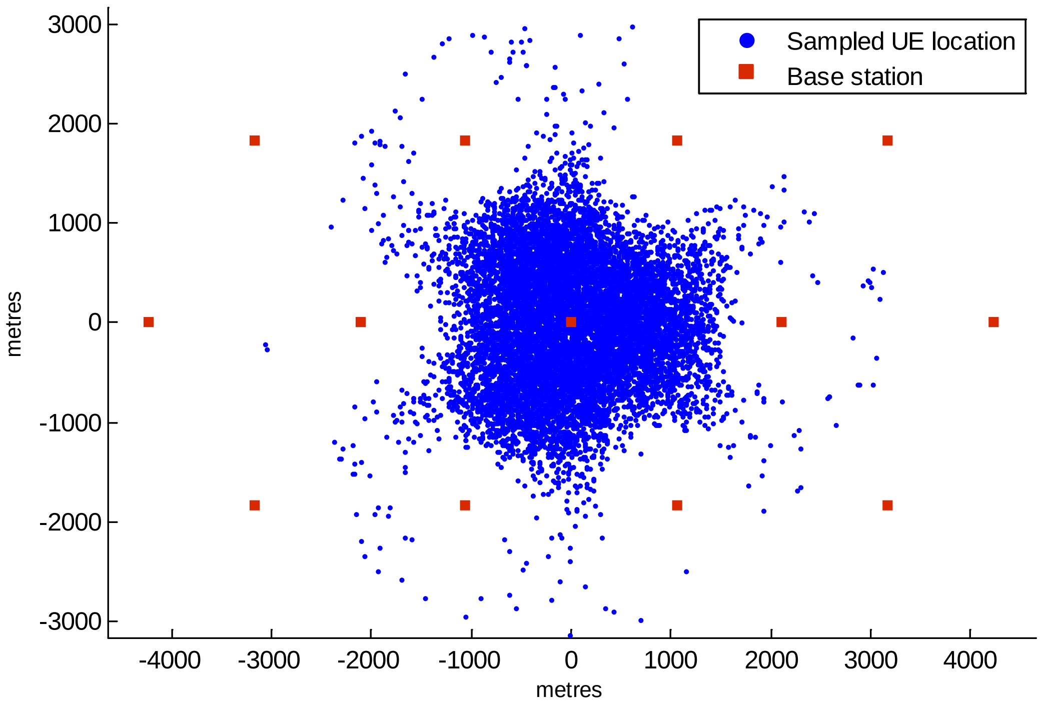


Figure A5.5: UEs served by the 'reference' site

- From the $SINR_{\text{HS-DSCH}}$, the average single-user throughput (in Mbps) achievable in each UE location is calculated using equation (8):

$$TP = \text{TP}_{\text{max}} \times \frac{e^{\left(\text{SINR}_{\text{shape}} \times SINR_{\text{HS-DSCH}}\right)}}{e^{\left(\text{SINR}_{\text{shape}} \times SINR_{\text{HS-DSCH}}\right)} + e^{\left(\text{SINR}_{\text{shape}} \times \text{SINR}_{\text{offset}}\right)}} \tag{8}$$

where: TP_{max} = 10.7; $\text{SINR}_{\text{shape}}$ = 0.18; and $\text{SINR}_{\text{offset}}$ = 19.6

- This function is a curve-fit to the 15-code values taken from Figure 7.5 of [1] illustrated in the figure below:

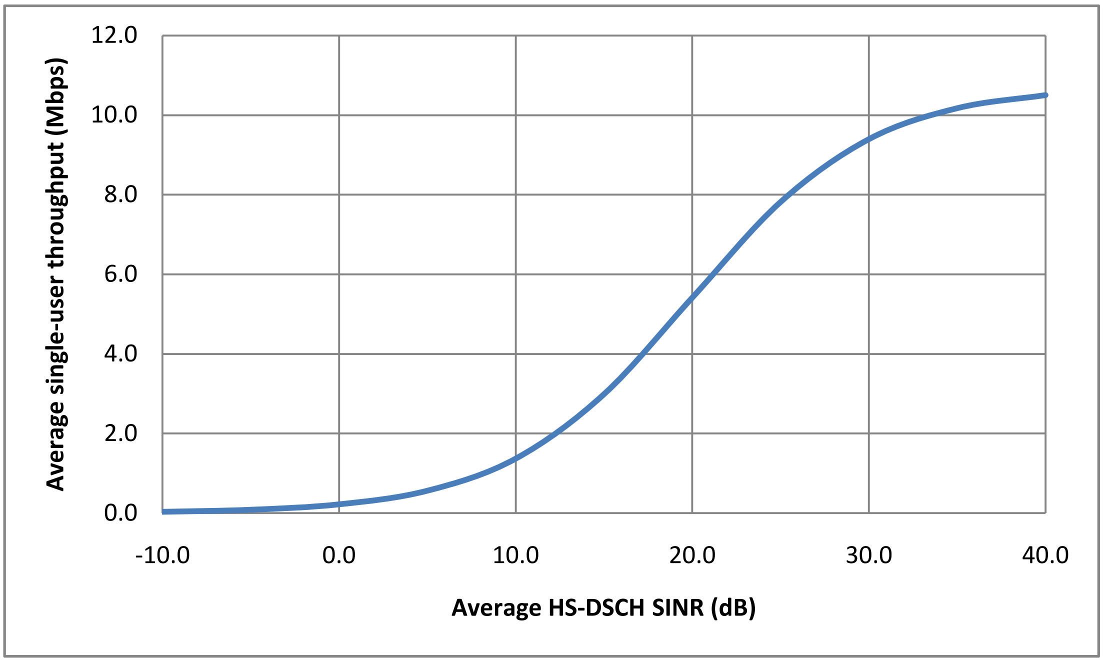


Figure A.5.6: Single user throughput mapping (15 codes)

A5.12 Once the single user throughput distribution of the ‘reference’ site is found the mean single user throughput for the site can be obtained from the average single user throughputs of the best 90% of the locations multiplied by 3 (the factor of 3 is to account for the sectorisation of the sites in the simulation). The number of users that can be supported in the ‘reference’ site for a particular target average throughput per user (e.g. 768 kbps, 1.5 kbps, etc) is related to the multi-user diversity gain G_{MUD}. The value of G_{MUD} varies according to the number of users being served, and for the purposes of this analysis we have assumed it follows the relationship in equation (9) below (taken from a curve fit to Figure 7.13 in [1]):

$$G_{\mathrm{MUD}} = 0.56 \times (1 - e^{-0.66351(N-1)}) \qquad (9)$$

A5.13 where: N is the number of users the cell could support at the target average throughput per user in the absence of multi-user diversity gain (i.e. the mean single-user throughput for the site divided by the target average throughput per user).

A5.14 The number of users that can be supported by a site in the presence of this gain is given by:

$$N_{\mathrm{MUD}} = N \times (1 + G_{\mathrm{MUD}}) \qquad (10)$$

A5.15 The number of users supported by any given operator for a site is then calculated by adding the number of users per carrier across all carriers for a given operator.

A5.16 The total number of active users in each clutter category is then divided by the total number of users in the whole area of interest. Finally, the percentage of total number of simultaneously active users in each clutter type was aggregated to find the percentage of total number of simultaneously active users for each network in the area of interest.

Non-uniform Model

A5.17 The ‘non-uniform’ modelling approach adopted is similar to that adopted for the ‘uniform’ modelling approach set out above but with a number of important differences which are highlighted in the bullets below (unless highlighted below all other assumptions and calculations are common to the both approaches – e.g. 3 sectored base site configuration, antenna characteristics, equations, etc.):

- Rather than establishing a regular array of base stations, sites locations are drawn from a synthetic database with reasonably realistic characteristics. This database was created to address both the coverage and capacity requirements of a given demand distribution as follows:
  - The input to the process is a database of the locations of Output Areas from GB census data. Each location has a number of households associated with it. A demand level is translated into the number of users simultaneously accessing service at each location.
  - Locations are prioritised according to the clutter type, in descending order of priority: Dense Urban, then Urban, then Suburban, etc.
  - Sites are placed initially adjacent to the highest priority locations, and the points covered by those sites are determined based on the unloaded coverage area of each site in the corresponding clutter type.
  - Sites are then added adjacent to the remaining uncovered locations until all relevant locations are covered
  - The number of active users served by each site is then determined, and the coverage area of the site is reduced to account for the effect of cell breathing on that site
  - Sites are then added to serve the newly un-served points following the same priority order
  - This process is repeated until all relevant locations are served within the capacity of the corresponding site
- This yields one site database with a given number of sites to serve the input demand level. The whole process can be repeated for a number of demand levels, allowing choice of a site database with (in principle) any desired number of sites.
- Two network sizes were modelled, one representing sites drawn from a equivalent 4,000 site network covering the 0 to 80% most densely populated locations of the country and a second 7,000 site network also covering the 0 to 80% most densely populated locations of the country.
- These sites are overlaid on an actual 50 m x 50 m clutter database covering the area of interest.
- The area chosen to model consisted of a 15 km by 15 km focus box centred on West London. The focus box is surrounded by a larger buffer box dimensioned so that the pilot channel Ec/Io seen by a UE at the edge of the focus box, from base

stations half way between the edge of the focus and buffer box is at least -14 dB. The overall size of the buffer box was 36.2 km by 36.2 km.

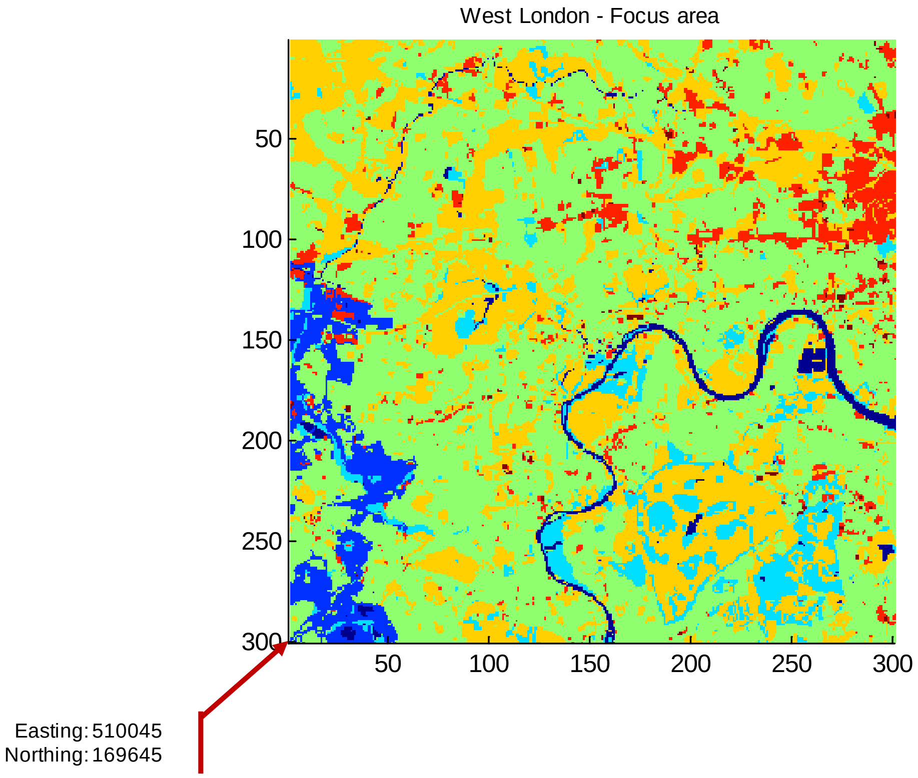


Figure A5.7: West London - Focus box

- The site, equivalent ISD, area and population breakdown of clutter categories within the focus box are given in the table below.

Clutter	Sites in focus box		Equivalent 'uniform' ISD (km)		Area (km^2)	Population
	4000 sites in 0 – 80% area	7000 sites in 0 – 80% area	4000 sites in 0 – 80% area	7000 sites in 0 – 80% area		
Dense Urban	1	1	1.782	1.304	0.868	5773
Urban	7	13	1.786	1.307	18.558	122868
Suburban	51	95	2.009	1.470	177.430	928647
Rural	7	13	3.838	2.809	28.145	40354

Table A5.6: Statistics for the focus area

- The total site counts for the combined focus & buffer boxes are 366 for the 4,000 site network and 633 sites for the 7,000 site network.

- For each sampled clutter point within the focus area, statistics for $SINR_{\text{HS-DSCH}}$, unloaded Ec/Io and single user throughput are calculated in a similar manner to the 'uniform' approach above. Results are obtained from the calculation of the received power at each sampled clutter point from every sector of the 37 closest base stations in the focus and buffer boxes. Propagation losses are again calculated using the Extended Hata model but with the clutter category based on the category of each sampled clutter point.

- The figure below provides an illustration of the results of the single user throughput calculation for each pixel for an example 4000 site network.

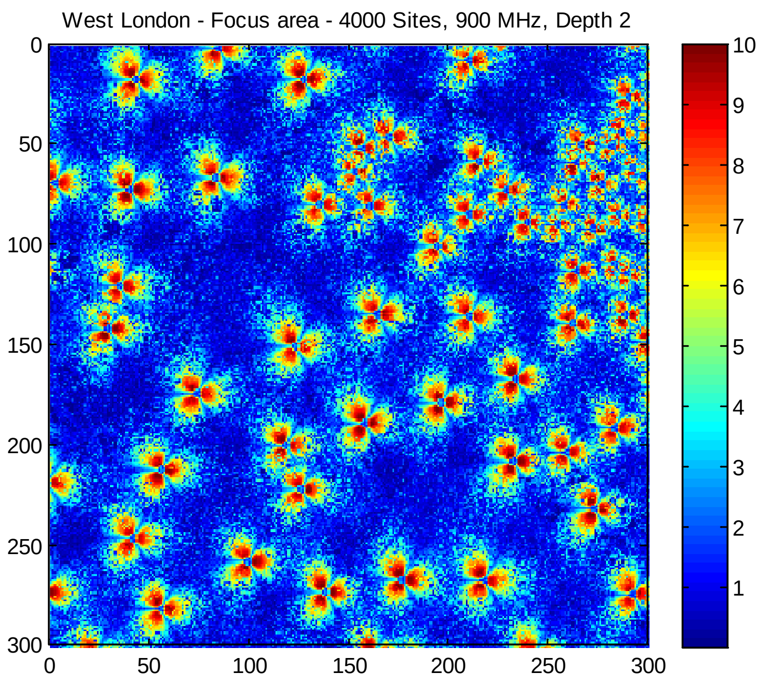


Figure A5.8: West London - Focus box – Single User Throughput (Mbps)

References

[1] "HSDPA/HSUPA for UMTS", Holma and Toskala , John Wiley and Sons

[2] "Antennas and Propagation for Wireless Communication Systems", S. Saunders & A. Aragon-Zavala, John Wiley and Sons

[3] "Application of spectrum liberalisation and trading to the mobile sector – A further consultation", Annex 13, Ofcom, 13 February 2009

[4] IEEE 802.16m-08/004r5, "Evaluation Methodology Document (EMD)"

[5] "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

[6] 3GPP TR 36.814, "Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects", http://www.3gpp.org/ftp/specs/html-INFO/36814.htm

[7] "The Downlink Orthogonality Factors Influence on WCDMA System Performance", Pedersen, K. I. Mogensen, P. E., IEEE VEHICULAR TECHNOLOGY CONFERENCE, 2002, CONF 56; VOL 4, pages 2061-2065

Parameters and Assumptions

Ref.	**Parameter**	**Value or range modelled**	**Units**	**Comment**
Base station				
1	Sectors per site	3		Industry practice
2	Total transmit power per carrier	43	dBm	Standard value
3	Proportion of total base station power allocated to the pilot channel	10%		Assumption – consistent with 3G roll out assessment
4	Proportion of total base station power allocated to other common (non HS data) channels	10%		Assumption
5	Antenna gain (bore-sight)	16.0 @ 900 MHz 18.3 @ 2100 MHz	dBi	Kathrein 742 265 multi-band antenna. Downtilt = 6 degrees.
6	Antenna horizontal 3 dB beam-width	64 @ 900 MHz 67 @ 2100 MHz	degrees	Kathrein 742 265 multi-band antenna.
7	Antenna vertical 3 dB beam-width	10.04 @ 900 MHz 4.44 @ 2100 MHz	degrees	Kathrein 742 265 multi-band antenna.
8	Antenna down-tilt	6	degrees	Assumption
9	Antenna height	25.0 (dense urban) 15.0 (suburban) 20.0 (all other areas)	m	Assumption
10	Cable, combiner and connector losses	0.0	dB	Assumes use of masthead amplifiers

UE				
11	Antenna gain (mean effective gain)	0.0	dBi	See Table 7.6 of [1]
12	Antenna height	1.5	m	Standard assumption
13	Body loss (relative to free space)	5.0	dB	Assumption
14	Receiver noise figure	10.0 (900 MHz) 7.0 (2100 MHz)	dB	3GPP TS 25.101
System				
15	Coverage Confidence	90% over cell area.	%	Industry data
16	Location variability (outdoor)	7.1 @ 900 MHz 8.1 @ 2100 MHz	dB	See equation (1) above
17	Location variability (outdoor) cross-correlation coefficient	1.0 (inter-sector) 0.5 (inter-site)		See [4]
18	Building penetration loss variability	See separate tables A5.4 and A5.5	dB	Assumption, values refined in light of stakeholder comments on [3] and further Ofcom consideration
19	Building penetration loss cross-correlation coefficient	1.0 (inter-sector) 0.5 (inter-site)		Assumption – common with 17
20	Mean building penetration loss	Varies according to frequency, clutter characteristics and BPL scenario. See table A5.3	dB	From [3]
21	Orthogonality factor	Distribution across cell - see	ratio	See [7]
22	Loading of HS-DSCH	80%		i.e. the HS-DSCH is loaded to 80% of its maximum
23	Ec/Io requirement	Range between -10 and -14 dB (unloaded)	dB	Base on industry feedback

24	Data rates	Average single user throughput versus SINR mapping based on HSDPA 15 codes		See Figure 7.5 of [1]

Summary of issues raised in response to 2009 consultation

A5.18 In this section we summarise the main issues raised in response to the technical modelling work in our February 2009 consultation. In each case we give our initial assessment of these.

A5.19 The non-confidential responses which provided comments specific to the technical analysis were British Telecom (BT), Telefónica O2 UK (O2), Vodafone (VF), Orange, and T-Mobile (TMO). Other responses were also received and have been considered in our analysis.

A5.20 In general, both VF and O2 provided very detailed commentary and technical analysis of the issues, with several similar themes. BT raised some distinct technical and related policy issues.

A5.21 Orange made no specific technical points, but stated that it “agrees with Ofcom’s view on the significant benefits that 900 MHz affords for UMTS…in terms of rural and in-building coverage”.

A5.22 T-Mobile provided little technical analysis but did make some technical arguments relating to the inadequacy of a single 900 MHz carrier to support multiple operators and made a statement that “liberalisation carries the potential for substantial consumer benefits as operators are able to offer significantly better levels of 3G coverage with the potential for higher quality mobile broadband offerings”.

A5.23 In the table below we have listed the main issues which were raised in the responses. We have also provided an initial assessment of whether the issue related to our modelling approach or the parameters/scenarios used and the potential impact on the outcomes.

Issue #	Issue	Methodology / Parameters & scenarios	Potential impact (H/M/L)
1	HSDPA cell edge throughput	M	H
2	UL link budget	M	L
3	Assumption of dedicated carrier at 900 MHz	P	M
4	Pilot channel quality	P	H
5	Proportion of power dedicated to pilot channel	P	M
6	Mapping of SINR to throughput	P	L
7	Uniform clutter	M	M
8	Cell area formula	M	M
9	Propagation model	M	L
10	Femto cells and other substitutes for macro cells	M/P	M
11	Mixed frequencies	P	M
12	Mobile equipment types	P	M
13	Traffic mix	P	M
14	Uncertain target capacity	P	M
15	Mobile transmit power for voice	P	L
16	Body loss for handheld browsing	P	L
17	Mobile antenna gain	P	L
19	Building penetration loss	P	M
20	Pareto implementation	M	L
21	Simulation Area	P	L
22	Duplex spacing for 900 MHz compared with 800 MHz	P	L

A5.24 We now examine issues relevant to technical analysis in this document, briefly stating the nature of the issue, the main points made in the responses and providing our assessment of the issue.

Issue #1: HSPDA Cell Edge Throughput

Issue:

A5.25 The target throughput for HSDPA analysis varies up to 2.4 Mbps. It is contended that such rates are too high to achieve in practice.

Responses:

A5.26 BT suggested that our analysis did not adequately reflect the full behaviour of the network in response to interference from neighbouring cells, and in practice the improvement in indoor coverage for 900 MHz would be less than that shown by Ofcom.

A5.27 O2 contended that in a heavily loaded network the interference levels at cell edge are too high to sustain the cell-edge throughput targets used as a basis for comparison in HSDPA (384 kbps – 2.4 Mbps) and that more realistic rates are in the range (0.1 – 0.5 Mbps). They conclude that a single 900 MHz carrier will not provide a UMTS 2100 operator with a significant data rate performance advantage above UMTS2100. They quote a cell-average throughput of 1- 2.5 Mbps for indoor use.

A5.28 VF state that cell edge HSDPA throughput will be limited to around 500 kbps when neighbouring cells are fully loaded. Also, they state that, in actual HSPA networks, the capacity will be lower than the theoretical maximum since advanced terminal architectures that can maintain orthogonality and avoid intra-cell interference are needed and that these are not supported by many of today's terminals. According to Vodafone, the mean throughput should be around 2.2 to 4.5 mbps.

Assessment:

A5.29 Our analysis was intended to provide a transparent modelling approach which was sufficiently simple to explain in full and to provide a publishable model implementation. Our main focus at that time was on estimating the number of sites required for coverage rather than a detailed assessment of comparative performance. In that context we adopted an approach which was based on CDMA load equations and link budgets but which did not model the details of the cell geometry. The relationship between the cell edge and cell average SINR was fixed to 6 dB as specified by common reference sources such as[14].

A5.30 Given, however, the significance of modelling 'partial matching' scenarios in which the number of sites for comparison between networks may be quite different and the aim is to determine the difference in the service quality (e.g. throughput and coverage depth) which may be delivered with different spectrum holdings, it may be more appropriate to examine the impact of a more explicit calculation of the distribution of SINR experienced across the cell. This is the purpose of the more detailed model which we have used in our updated analysis.

A5.31 Together with the introduction of the detailed model, however, it is also necessary to examine whether the performance targets set are still appropriate. In view of the comments made, it may be more appropriate to compare the networks on the basis of the cell average (rather than cell-edge) throughput whilst also examining the variation in throughput performance in general across the cell area.

A5.32 We note also that there is an increasing advent of the use of HSPA+ technology in 3G networks and also of advanced receivers which have an increased tolerance to interference. Such technology is capable of delivering a higher throughput for a given SINR and would be less susceptible to the cell-edge limitations mentioned.

A5.33 Finally, most of the site count results published previously for throughputs below about 1.4 Mbps lead to the system anyway being limited by the pilot channel quality (Ec/Io) and the site counts themselves are then unaffected.

Issue #3: Shared versus dedicated carriers

Issue:

A5.34 The assumption that a 900MHz carrier would be dedicated for HSDPA data is invalid, as the channel would need to be shared with voice traffic in reality.

[14] WCDMA for UMTS Third Edition, Holma & Toskala, Wiley, 2004.

Responses:

A5.35 O2 stated that assuming a dedicated data carrier at 900MHz is incorrect for the following reasons:

- Since UMTS will likely replace GSM900 post 2015, it is in O2's interests to seed its base with UMTS900 devices capable of both voice and data. The building of a UMTS900 underlay just for data makes no sense.
- If there were a dedicated data carrier, smartphones would be relying on 2100MHz for voice. There will not be complete co-incidence in coverage with 900MHz for various reasons. This will causes excessive handover and impact on customer experience.
- It would be highly inefficient (and detrimental to battery life and user experience) for these devices to continually switch carrier for voice.

A5.36 VF stated that a requirement to carry significant amounts of voice traffic will reduce capacity for HSDPA. In practice this will reduce the differences between UMTS2100 and UMTS900 site numbers more rapidly than predicted.

Assessment:

A5.37 This issue relates to selection of appropriate scenarios for analysis rather than any direct issues with the technical modelling approach. The correct scenario depends largely on the operator and the timescale involved. In the near term non-900MHz operators gaining access to 900 MHz spectrum might only put data in a new 900MHz carrier, and in the long term existing 900 MHz operators could potentially clear enough spectrum to separate shared and dedicated carriers.

A5.38 We therefore believe it is appropriate to continue to conduct technical modelling on the basis of dedicated carrier where appropriate to the policy scenarios considered.

Issue #4 and issue #5: Pilot channel issues

Issue

A5.39 Various responses questioned the impact of varying assumptions in the pilot channel quality (Ec/Io) parameters and in the proportion of the available transmit power which is allocated to the pilot channel versus the dedicated (traffic-carrying) channels.

Responses

A5.40 One respondent suggested that the pilot channel can use up to 70% of total control channel power based, while Ofcom has assumed 50% in the model.

A5.41 O2 (Annex A 337-349): The pilot channel quality requirement, Ec/Io = -10 dB is a more realistic assumption for an unloaded network than Ofcom's value of -8 dB. This is confirmed by simulation work, and information from infrastructure vendors.

A5.42 A revised assumption of -10 dB would lead to each cell within the model covering a greater area, and therefore a reduction in the number of sites and of the site difference.

<u>Assessment</u>

A5.43 Within Annex 13 of the February 2009 consultation we varied Ec/Io threshold value over a wide range (-6 to -15 dB, Figure 53) and noted that the results were highly sensitive (A13.361). The base value of -8 dB was drawn from O2's suggestions prior to publishing the consultation. Further, we included -10 dB in our consideration of the technical sensitivities in Table 26.

A5.44 Our modelling already covers the range of pilot channel quality values asserted by responses, in our updated analysis we have further considered how the range of potential technical outcomes represented by this modelling impacts on the policy outcomes. For the purposes of this analysis we have assumed a range of values for Ec/Io of -10 to -14 dB may be appropriate.

Issue #6: Mapping of SINR to throughput

<u>Issue:</u>

A5.45 The mapping of signal quality (SINR) to throughput appears incorrect.

<u>Responses:</u>

A5.46 O2: It would appear that in Table 23 of Annex 13 of the consultation, Ofcom has misread the values from the throughput versus SINR curve from figure 7.5 on p130 of Holma. This has a consequent impact on the site numbers. O2 provide a table of corrected values as read from the curves, and resulting site counts. The corrections lead to a lower capacity per site and therefore a slightly earlier point when the 900MHz carrier is capacity limited.

<u>Assessment:</u>

A5.47 We read values from the published results and then fitted a smooth function through these values, so while any particular values may not match, the overall behaviour should be a reasonable approximation. A sensitivity calculation suggests that the differences are small, perhaps 2-3% of throughput. The mapping has been adjusted in the revised model to provide a better fit.

Issue #7: Clutter issues

<u>Issue:</u>

A5.48 Inaccuracies in results due to edge effects of uniform clutter assumptions, and assumption of perfectly tessellated hexagonal cells.

<u>Responses:</u>

A5.49 O2: Ofcom's claim that simplified clutter analysis is a standard approach in the industry is not true, O2 use a more detailed radio planning tool.

A5.50 In practice clutter is highly fragmented with lots of boundaries which dominate the number of sites required – this will lead to higher site numbers than Ofcom's model. Fragmentation affects different cell sizes in different ways. Therefore there is no substitute for a proper radio model. A comparison between O2's own site placement tool and Ofcom's model results in a decrease in the difference of sites required between 900MHz and 2100MHz.

A5.51 O2 claim a ratio between 1800 MHz and 900 MHz sites of 1.2 – 1.5:1 is more accurate than Ofcom's figure of 3:1. In addition, use of a radio planning tool shows the economic limit of coverage driven build is 11,000 sites per UMTS2100 operator (as stated in 2007 response).

A5.52 VF: When other technical errors are accounted for, the model significantly under-predicts site counts, due to the assumption of perfectly tessellated hexagons – e.g. 7,300 UMTS2100 sites. VF believes this is inconsistent with its own upper limit of 11,100 sites. The 'edge effect' gives the model an inherent planning efficiency not found in practice and tends to exaggerate frequency differences.

Assessment:

A5.53 The simplified approach was acknowledged in the consultation and outputs were compared with similar scenarios (including data from O2). In our updated analysis we have specifically modelled an area using a 'non-uniform' approach to clutter and site distribution and used this to verify the wider 'uniform' modelling approach.

Issue #11: Mixed Frequencies

Issue:

A5.54 Our technical modelling work focused on the traffic carried in one frequency band at a time, while in practice traffic would be carried on a mixture of bands (notably including the existing 2.1 GHz networks).

Responses:

A5.55 The modelling did not evaluate the case of 1 carrier at 900 *and* 2 at 2100, which will lead to a rather different number of sites at 900 MHz, so the number used has no justification.

A5.56 One respondent mentioned that inter-frequency UMTS handover is more challenging than in GSM, requiring the use of 'compressed mode', which either reduces performance or causes some increase in dropped calls.

Assessment:

A5.57 We acknowledged the importance of mixed frequency of operation in our technical modelling, and used logical arguments rather than detailed numerical modelling to show that cost differences were likely to be material when mixed frequency scenarios were considered. In our updated analysis we include the contribution of both 900 and 2100 MHz carriers to the capacity of the network to deliver services of relevant quality levels.

Issue #13: Traffic mix

Issue:

A5.58 The technical model calculates for a single service type at a time, while in practice the network simultaneously carries a wide mixture of traffic, which will affect the network cost.

Responses:

A5.59 VF: The network carries Release 99 and HSDPA voice and data traffic simultaneously on a single carrier. This will reduce the differences between UMTS 2100 and 900 more rapidly as data traffic increases, presumably because the 900 MHz capacity is reduced.

A5.60 H3G: Assert that release of a single 900 MHz carrier will not be adequate to reduce the cost differences from 2100 MHz.

Assessment:

A5.61 The relevance of this issue depends on the specific scenario relevant to a given policy issue. In our updated analysis we have not made explicit assumptions regarding the traffic mix rather we have modelled single user throughput. The issue is similar in impact to issue #3.

Issue #14: Uncertain target capacity

Issue:

A5.62 The assumption that operators would design networks to a known target capacity ('green-field' approach) does not hold true in practice.

Responses:

A5.63 O2: Real networks are built incrementally rather than as green field. Green field approach would require perfect information on future demand, large investment and long implementation delays. When this is taken into account the differences in site numbers between frequency bands are likely to be reduced

Assessment:

A5.64 Our updated analysis does not consider the numbers of sites required to deliver a given quality level, but rather the quality level delivered with given plausible site numbers, so the issue is not directly relevant here.

Issue #8: Cell area formula

Responses:

A5.65 One respondent suggested a different conversion factor from cell radius to site coverage area for a 3 sectored site.

Assessment:

A5.66 This was not an error in our modelling but a different approach to approximation of the real area of a sectored site which in practice is irregular and impacted by both antenna radiation patterns and propagation effects. A different geometrical construction is used in our updated analysis which adopts the same conversion as suggested by the respondent.

Issue #9: Propagation model

Responses:

A5.67 One respondent pointed out an error in the implementation of the Hata propagation model.

A5.68 Even if correctly implemented, the model is not recommended for comparing frequencies across the breakpoints of the model.

Assessment:

A5.69 The impact of the formula change at 2.1GHz is very small. The model has anyway been adjusted to reflect this.

A5.70 The Extended Hata model is widely used for regulatory purposes. It is not likely to be accurate for specific site planning purposed where operators may have developed and tuned their own bespoke models. However, for the purposes of modelling a network as a whole we believe that it is fit for purpose.

Issue #16: Body loss for handheld browsing

Responses:

A5.71 One respondent commented that our assumption on body-loss e.g. 5 dB is excessive. They suggest a lower value be used with the baseline assumption for speech. While losses could be higher for belt worn devices, users are unlikely to be browsing in this situation.

Assessment:

A5.72 The body loss is subject to significant practical variation and the correct value to select for calculations is open to debate. We have continued to use 5 dB in our updated analysis as a basis for comparison.

Issue #17: Mobile Antenna Gain

Responses:

A5.73 One respondent question our assumption that UE antenna gain is independent of frequency. In practice a single multi-band antenna is used, which will be inherently less efficient at lower frequencies (Chu-Harrington limit).

Assessment:

A5.74 The theory quoted here is correct, although manufacturers may use different antenna structures for different frequency bands so this is not a like-for-like comparison.

A5.75 The difference is anyway very small in the context of other issues, so unlikely to require further action.

Issue #19: Building penetration loss

Responses:

A5.76 One respondent mentioned that the scientific opinion on in-building penetration loss is mixed. Another respondent mentioned that the standard deviation used by Ofcom is too low.

Assessment:

A5.77 Our own findings also suggest that the scientific opinion on in-building penetration loss is mixed. Higher standard deviation would increase difference with frequency. We have considered an increasing mean BPL with frequency with a standard deviation of 12 dB as one of the cases in our updated analysis.

Annex 6

Results of technical analysis using a non-uniform modelling approach in a sample area

Introduction

A6.1 This annex describes the results of technical analysis we have conducted to analyse the impact of ‘non-uniform’ clutter and site distributions on our analysis of network performance.

A6.2 The technical analysis presented in Annex 1 relies on a ‘uniform’ approach to modelling. By this we mean that the model is based on the simulation of perfectly tessellated tri-sectored base stations arranged in a hexagonal array. The performance of this array is calculated for the four different clutter categories separately and these are then combined to give the overall network performance.

A6.3 However, in reality, networks are far from this ideal. Population and clutter types are non-uniformly distributed. Base stations placement needs to account for this non-uniformity as well as for local terrain and planning constraints. This results in a non-homogeneous network of sites overlaid on non-uniform clutter and population distributions.

A6.4 It is possible that the effects of this non-uniformity may affect network performance to the extent that a ‘uniform’ modelling approach is not a reliable method of assessment.

A6.5 To determine whether this is in fact the case we have modelled a sample area centred on West London (a 15 km x 15 km box) using a more realistic distribution of sites (drawn from a synthetic database with reasonably realistic characteristics) overlaid on an actual 50 m x 50 m clutter database.

A6.6 For comparison we also used the ‘uniform’ model to produce results based on inter-site distances derived from the clutter distributions of the same area.

A6.7 Results are presented for networks representing two overall site count numbers for the 0 – 80% most populated areas of the country (i.e. 4,000 sites and 7,000 sites) at 900 MHz and 2100 MHz. Results are also presented for different building penetration assumptions (i.e. ‘BPL: depth2 – base case’ and ‘BPL: depth 2 rising faster ‘ with frequency).

A6.8 The aspects of network quality we have chosen to model are

- *Single user throughput*: defined as the downlink bit rate which can be successfully delivered to a single active user per cell at a particular depth and consistency of indoor coverage. This is the downlink bit rate or download speed which a user could experience *when not contending with other users for service in that cell*, so that the cell delivers the maximum possible data rate to a single user consistent with the signal quality experienced by that user. *The signal quality is determined by assuming that all cells are simultaneously active and devoting* *most of their resources to serving users with data.* If more than one user was active at any one time in the cell, e.g. if the network was more heavily loaded, each user would receive a share of the maximum throughput.

- *Pilot channel quality:* defied as the percentage area within the 80% population area where the quality of the pilot carrier at a given depth of indoor coverage is above a certain threshold (i.e. the unloaded Ec/Io parameter is above a typical threshold of say -10 dB to -14 dB).

Results of the throughput analysis

A6.9 The single user throughput results presented are:

- Non-uniform model:
  - Figure A6.1: Throughput of a UMTS900 network with 4,000 sites and a UMTS2100 network with 4,000 sites.
  - Figure A6.2: Percentage difference in throughput for a 4000 site UMTS900 network when compared with a 4000 site UMTS2100 site network.
  - Figure A6.3: Throughput of a UMTS900 network with 4,000 sites and a UMTS2100 network with 4,000 sites.
  - Figure A6.4: Percentage difference in throughput for a 4000 site UMTS900 network when compared with a 4000 site UMTS2100 site network.
- Uniform model:
  - Figure A6.5: Throughput of a UMTS900 network with 4,000 sites and a UMTS2100 network with 4,000 sites.
  - Figure A6.6: Percentage difference in throughput for a 4000 site UMTS900 network when compared with a 4000 site UMTS2100 site network.
  - Figure A6.7: Throughput of a UMTS900 network with 4,000 sites and a UMTS2100 network with 4,000 sites.
  - Figure A6.8: Percentage difference in throughput for a 4000 site UMTS900 network when compared with a 4000 site UMTS2100 site network.

Non-uniform model

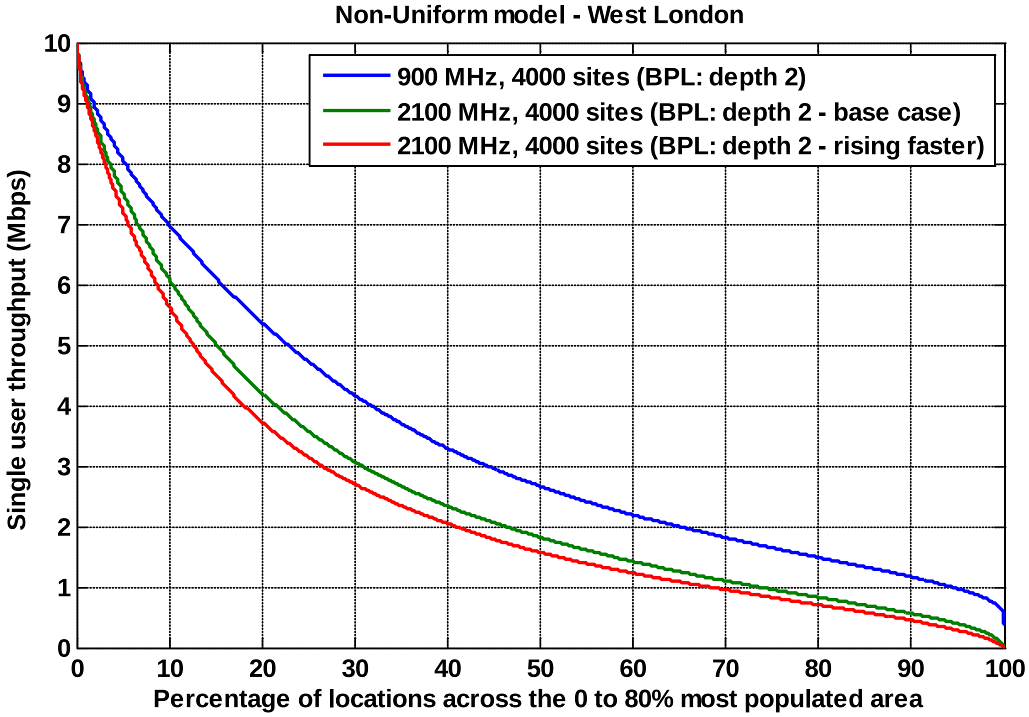


Figure A6.1: Throughput for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

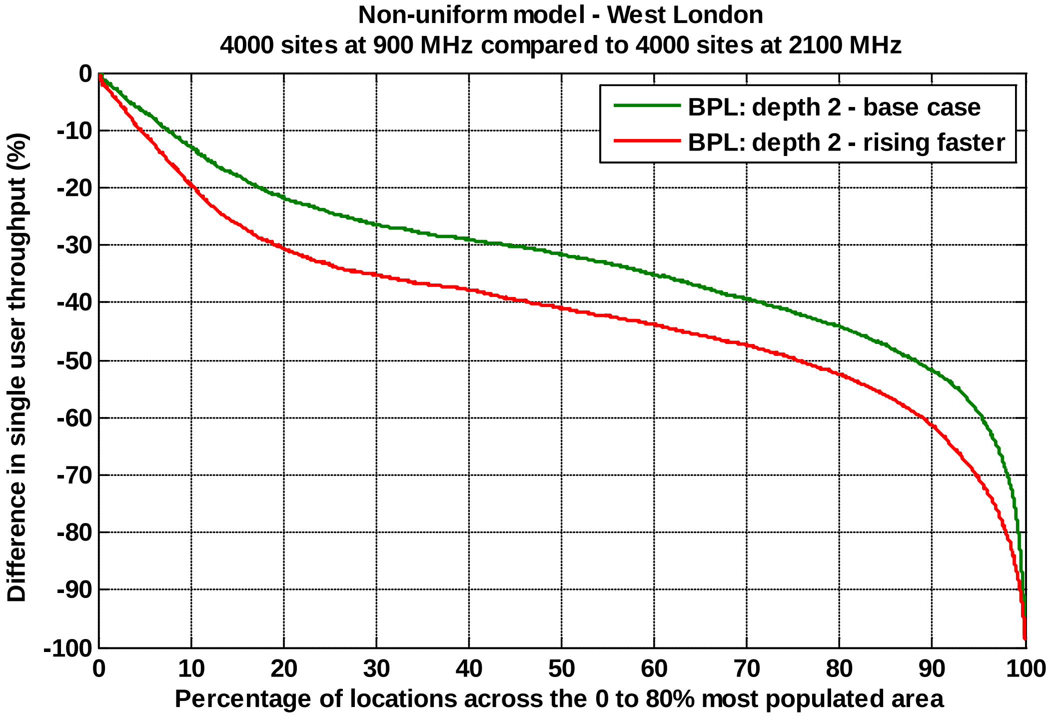


Figure A6.2: Percentage difference in throughput for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

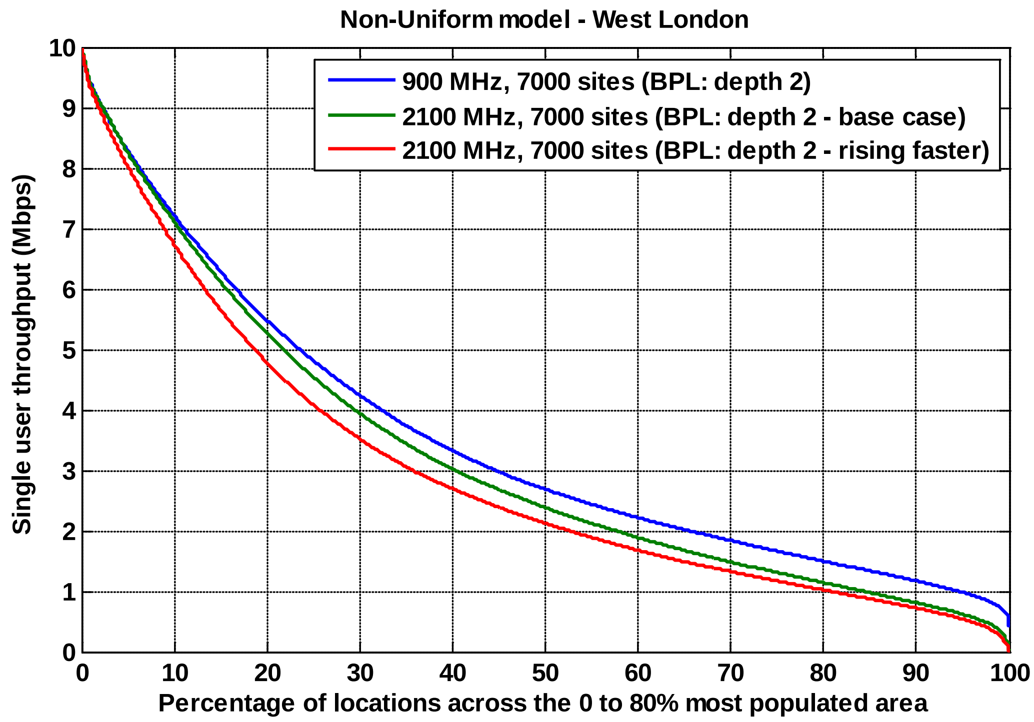


Figure A6.3: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

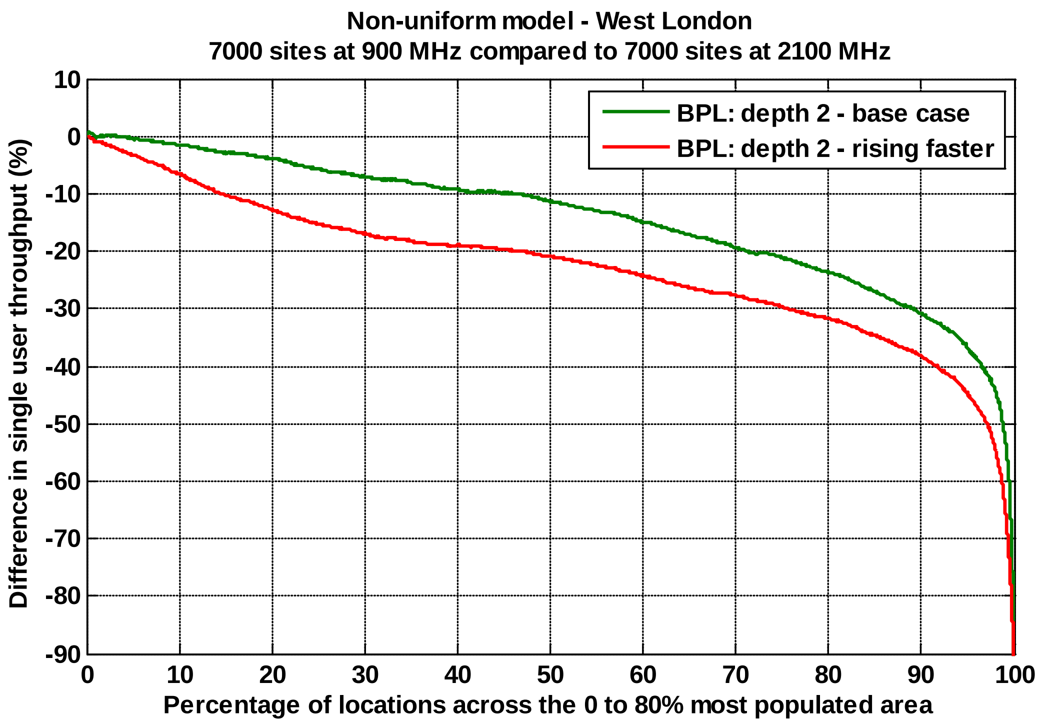


Figure A6.4: Percentage difference in throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

Uniform model

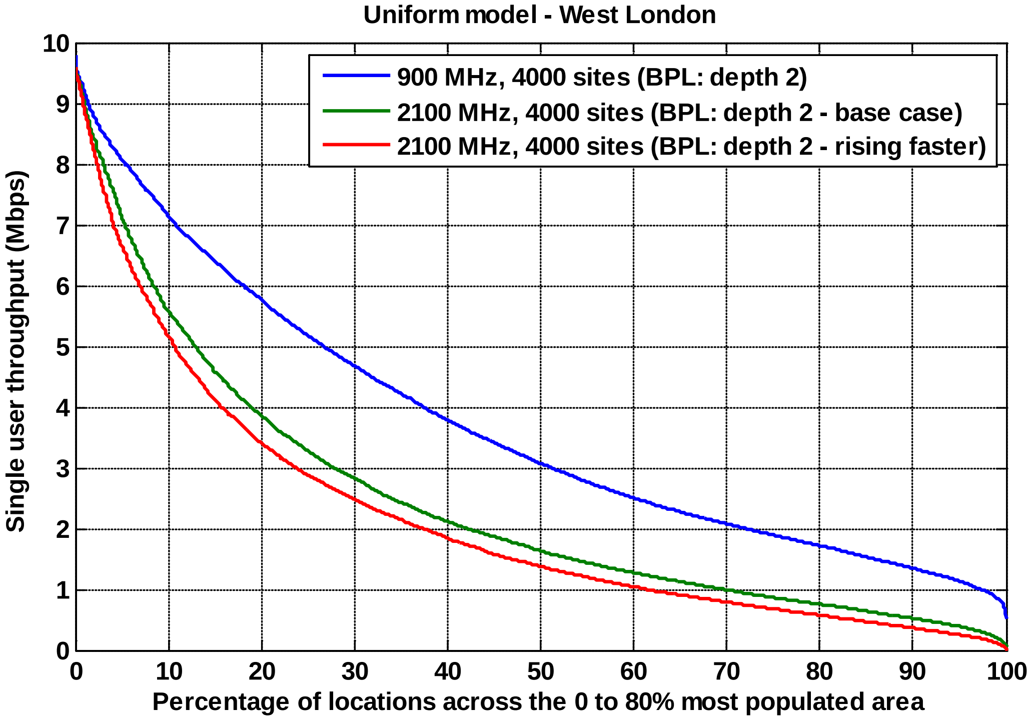


Figure A.6.5: Throughput for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

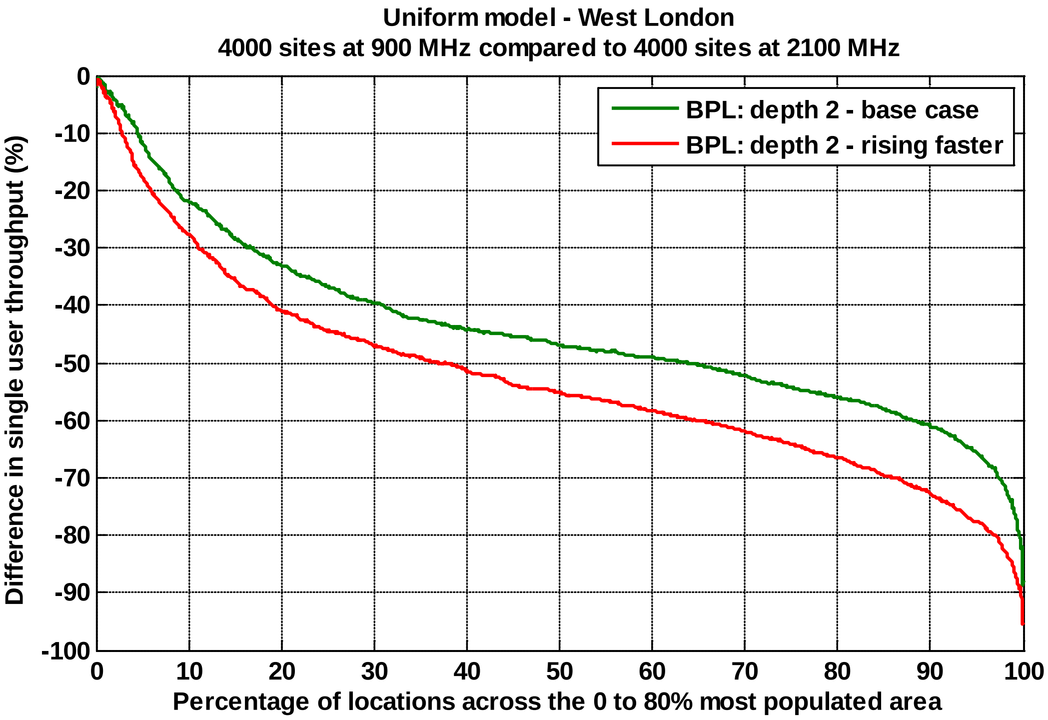


Figure A6.6: Percentage difference in throughput for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

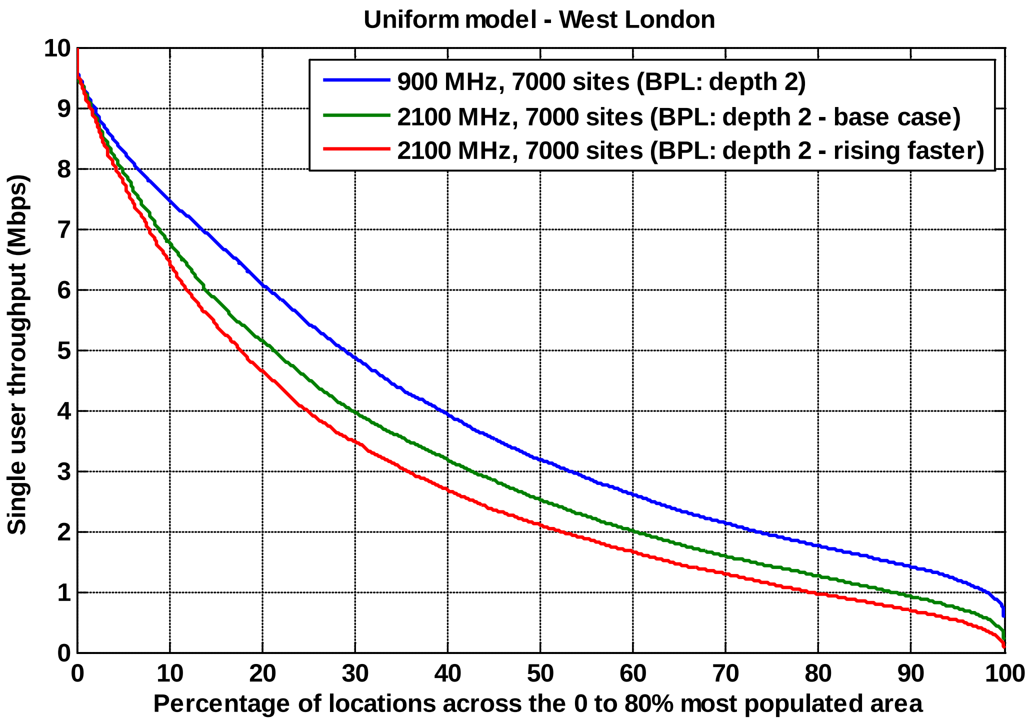


Figure A.6.7: Throughput for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 MHz network over the same area. BPL: depth 2, base case and rising faster with frequency.

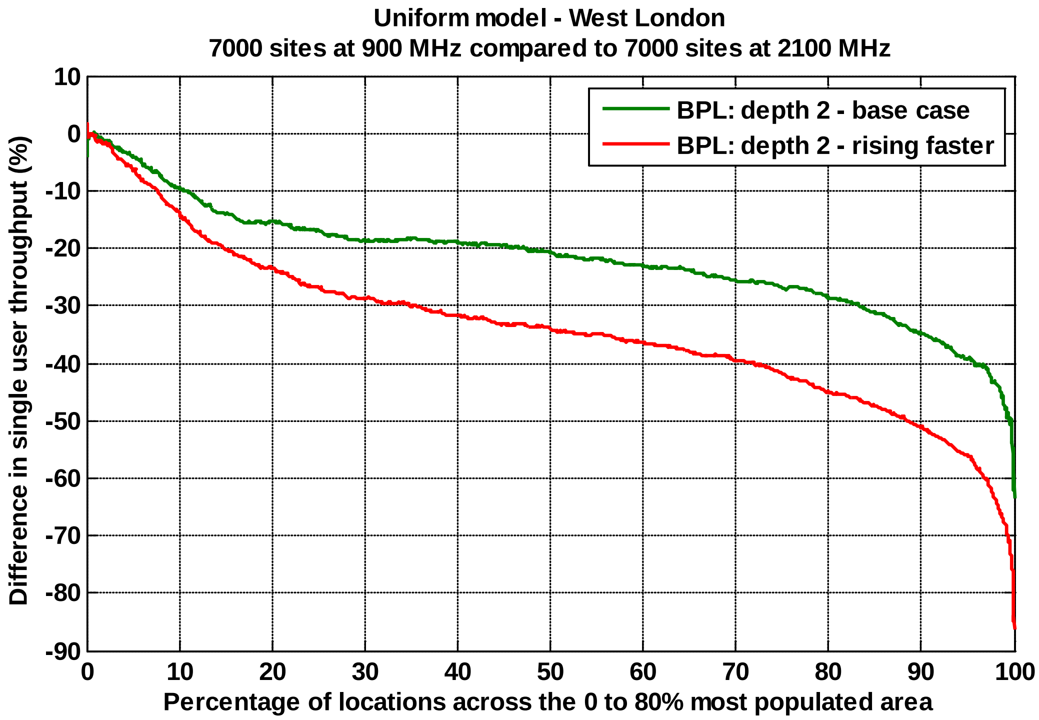


Figure A6.8: Percentage difference in throughput for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

Conclusions of throughput analysis

A6.10 For both the 4,000 site and 7,000 site cases it can be seen that the difference in performance between a UMTS900 network and a UMTS2100 network of the same size is smaller for the 'non-uniform' model in comparison the 'uniform' mode.

A6.11 In summary, these results indicate that the 'uniform' model may tend to overestimate the downlink single user throughput advantage of a UMTS900 network in comparison to a UMTS2100 network, at least for the sample area modelled.

Results of the pilot channel quality analysis

A6.12 The single user throughput results presented are:

- Non-uniform model
    - Figure A6.9: Ec/Io of a UMTS900 network with 4,000 sites and a UMTS2100 network with 4,000 sites.
    - Figure A6.10: Ec/Io of a UMTS900 network with 4,000 sites and a UMTS2100 network with 4,000 sites.
- Uniform model
    - Figure A6.11: EcIo of a UMTS900 network with 4,000 sites and a UMTS2100 network with 4,000 sites.
    - Figure A6.12: Throughput of a UMTS900 network with 4,000 sites and a UMTS2100 network with 4,000 sites.

Non-uniform model

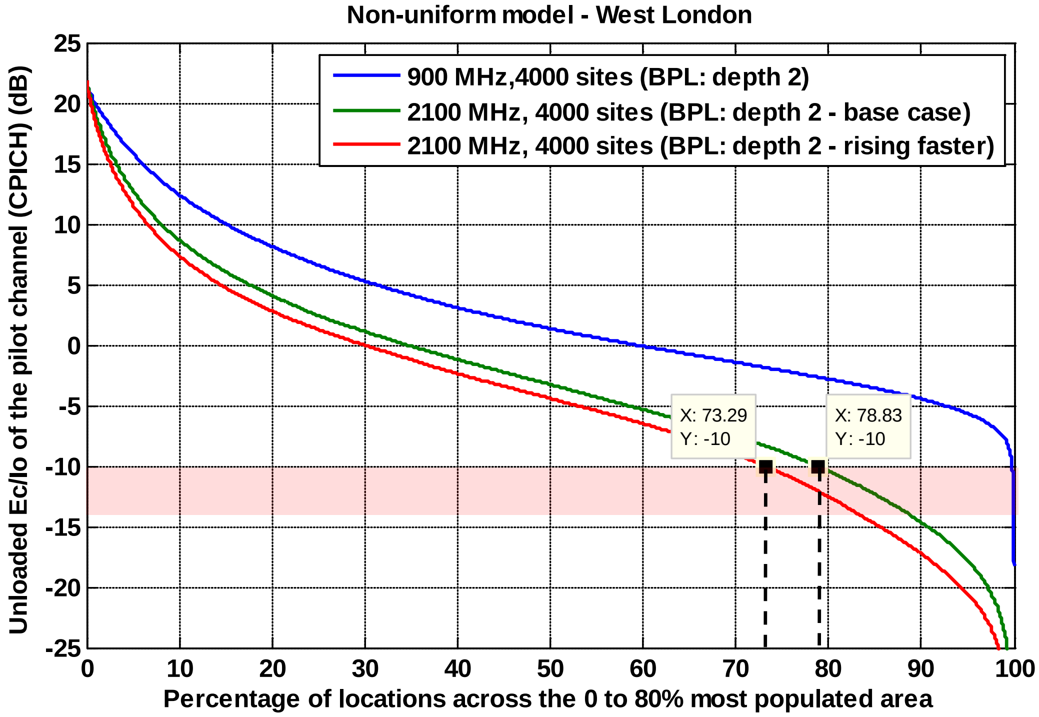


Figure A6.9: Ec/Io for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

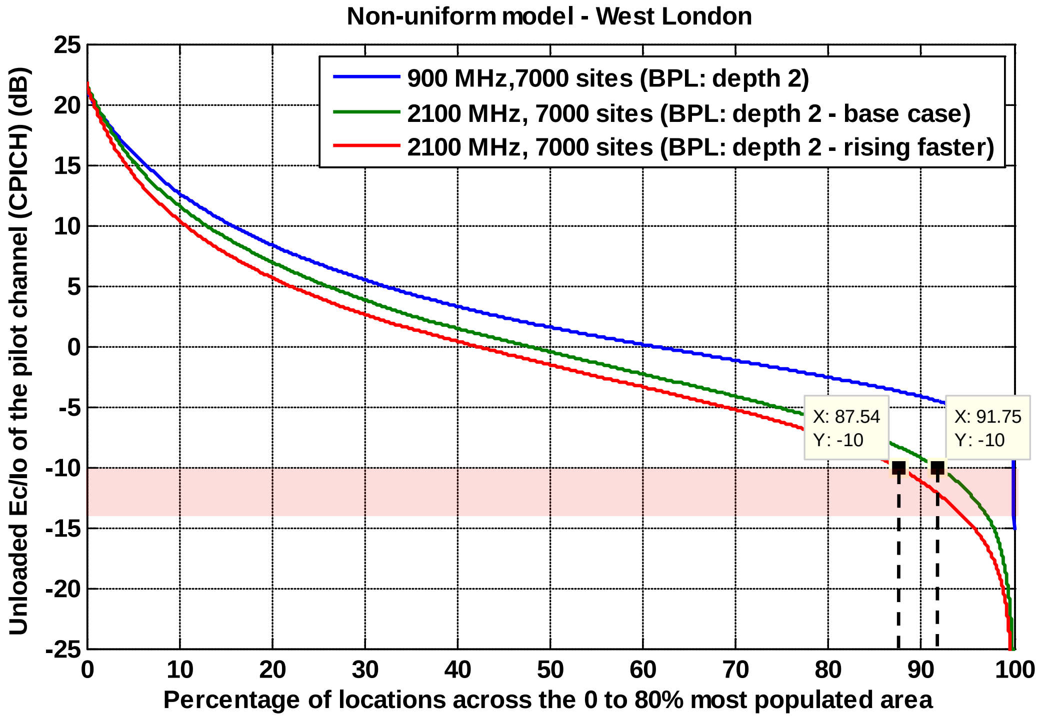


Figure A6.10: Ec/Io for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

Uniform model

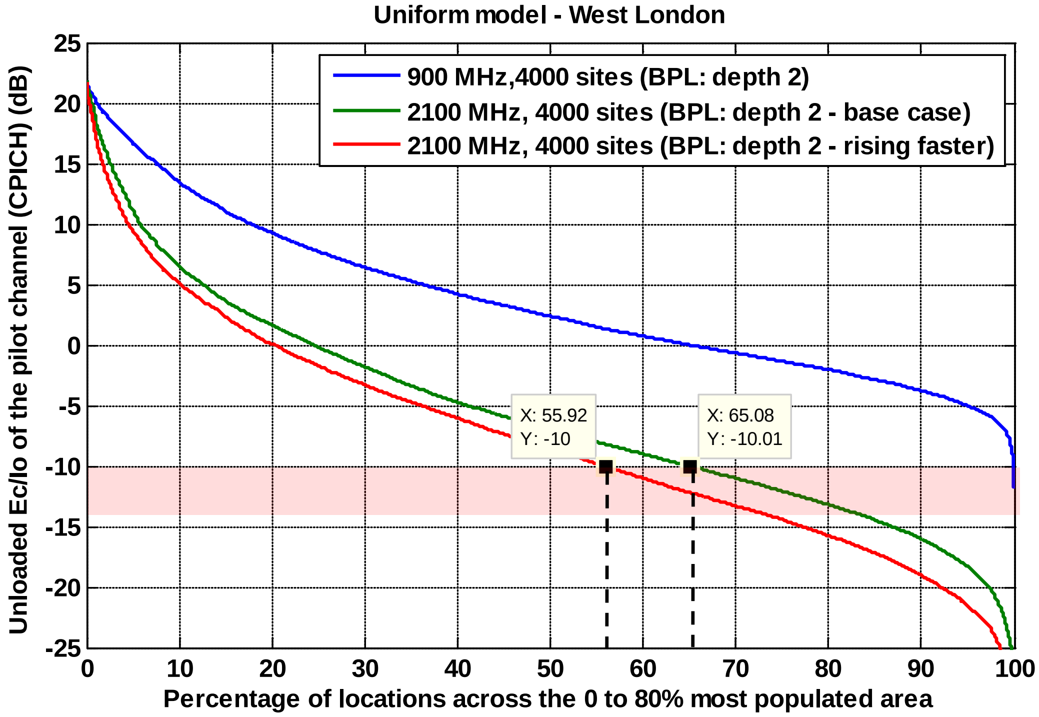


Figure A6.11: Ec/Io for a UMTS900 network with 4,000 sites distributed over the 80% population area compared with a 4,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

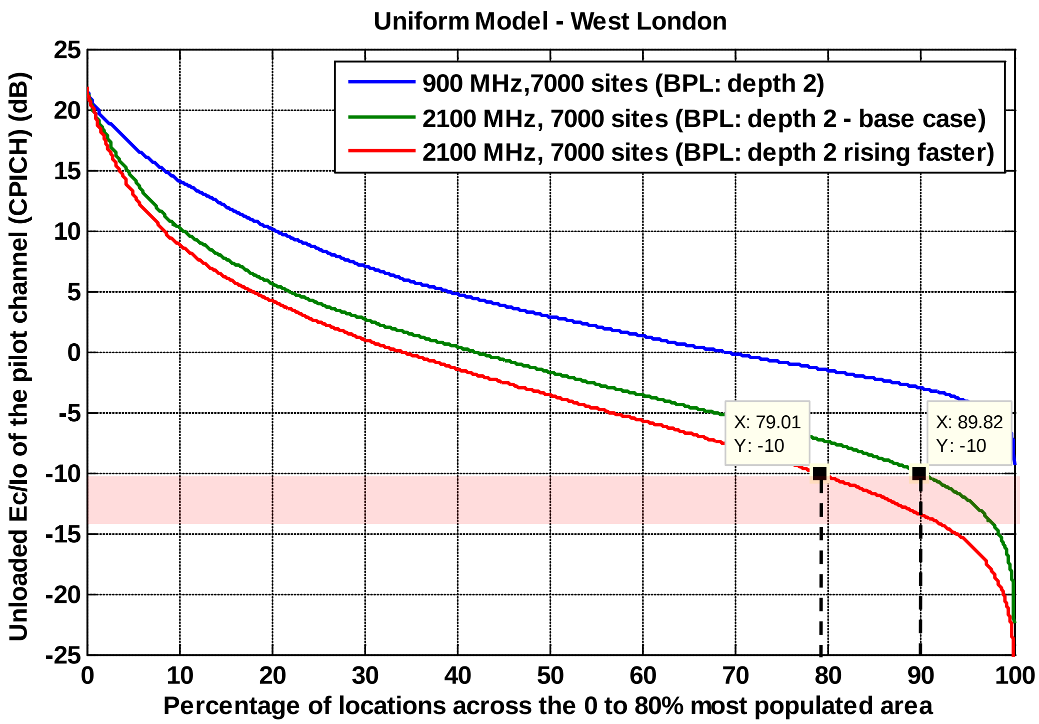


Figure A6.12: Ec/Io for a UMTS900 network with 7,000 sites distributed over the 80% population area compared with a 7,000 site UMTS2100 network over the same area. BPL: depth 2, base case and rising faster with frequency.

Conclusions of throughput analysis

A6.13 The results show that the difference between the Ec/Io performance of a UMTS900 and a UMTS2100 network of the same size (4,000 sites and 7,000 sites) is smaller for the ‘non-uniform’ model in comparison the ‘uniform’ mode.

A6.14 In summary, these results indicate that the ‘uniform’ model may tend to overestimate the Ec/Io advantage of a UMTS900 network when compared to a UMTS2100 network at least for the sample area modelled.

Annex 7

Network rollout assumptions for the 80% area

A7.1 This paper considers what are appropriate network rollout assumptions for deployment of 3G networks in the 80% population area by Everything Everywhere (EE), Hutchison 3G (H3G) and Vodafone / O2 by the end of 2013. EE currently expects to have completed its RAN integration by Q2 2013.[15]

A7.2 The site counts in this paper are largely based on externally available information. However, the rate at which operators could build brand new sites, rather than upgrade existing sites is relatively aggressive, but still plausible. This is because we are interested in scenarios where mobile broadband quality is important and where parties have an incentive to deploy new sites relatively aggressively.

Summary

A7.3 Below is a table summarising our assumptions for the number of base stations that different operators might deploy. The technical analysis looks at the quality of networks across the 80% population area. It is possible that operators could deploy more sites than the numbers listed below, but the unit cost of sites may start to increase.

	Date	Base stations
EE/H3G RAN share – 80% area[16]	End 2010	9,000
EE/H3G through upgrade of existing sites – nationally	Mid-End 2013	18,000
EE/H3G through upgrade of existing sites – 80% area	Mid-End 2013	13,000
EE/H3G with relatively aggressive deployment including site acquisitions – 80% area	End 2013	16,000
Vodafone or 02 (assuming no or relatively little site sharing) – 80% area	End 2013	7,000
Vodafone or 02 (with extensive site acquisitions or sharing)[17] – 80% area	End 2013	10,000

Table 7.1: Assumptions for base stations numbers per operator

[15] http://everythingeverywhere.com/2010/09/28/everything-everywhere-unveils-plans-for-growth-through-network-leadership-2/
See associated downloadable press pack for further details.
[16] MBNL is the current JV between T-Mobile and H3G for their 3G networks. We assume that MBNL continues to operate albeit with an expanded site base.
[17] Site acquisition is likely to be significantly more expensive than site upgrades or site sharing.

Key points to note

A7.4 The site counts and timing of network completion are assumptions based on the best available information. There are a number of key points to note:

- The key uncertainties relates to the extent that Orange sites are useful in enhancing the coverage of the EE/H3G network.
- The speed of expansion of the EE/H3G 3G network is driven largely by the expected rate of integration between Orange and MBNL.
- It is assumed that no more than 1,000 new sites can be built per annum, given the large number of existing sites in the UK.

EE/H3G site counts

A7.5 T-Mobile and H3G currently have a 3G RAN share agreement, which will continue into the future, so we assume that H3G will have access to all of EE's sites, should H3G wish to expand its network beyond its size at the end of 2010.

A7.6 MBNL is expected to complete the integration of the 3G RANs of T-Mobile and H3G by the end of 2010, in line with previous public announcements. They have publically announced they would have a total of around 13,000 base stations nationally, and we estimate that 9,000 of those would be in the 80% population area.

A7.7 As a result of the merger between Orange and T-Mobile to create EE, the two existing RANs of the former companies will be merged into one larger RAN. The effective size of the larger network will not be the sum of the two existing networks as some sites will be largely redundant for the purposes of enhancing coverage either due to existing passive sharing arrangements or because the sites are fairly close together.

A7.8 EE has publically announced that it intends to consolidate its national network to around 18,000 3G sites, but has not made a specific statement on the coverage in the 80% area. Even if EE were to decommission fewer sites than planned, there will be a point where increasing the number of sites will not enhance the coverage capabilities of the network for the reasons explained above. To further enhance the coverage capabilities of the network would require EE to acquire new sites in locations not near existing sites. We assume that the 18,000 national target is based on upgrading as many sites as possible without acquiring new sites.

A7.9 We assume that EE would have to start acquiring new sites when around 50% of Orange's upgradable site base has been used to enhance the MBNL network.[18]

A7.10 Evidence from operators suggests that networks can only acquire around 1,000 sites per annum. We assume that this is in addition to any integration of Orange sites. This combined rate of site acquisition and upgrade of existing sites is fairly fast relative to other network expansions in the UK, but we believe it to be feasible if there were competitive pressures to match the capabilities of the incumbent 900 MHz operators.

[18] Some 2G only sites may not be suitable for carrying 2G and 3G equipment, hence the desire to have 18,000 2G and 18,000 3G sites, but at more than 18,000 locations.

A7.11 Any expansion of the MBNL network will occur over the period 2011-2013 as Orange and T-Mobile integrate both their 2G and 3G RANs.

Vodafone/02 site counts

A7.12 Vodafone and O2 have fewer 2G locations than the 1800 MHz operators. Given their smaller number of existing 2G sites, we expect that they have fewer active 3G base stations than their competitors as they have fewer sites to upgrade.

A7.13 Vodafone or O2 could expand the size of their 3G networks either by acquiring new sites, or by entering into a site sharing agreement. Vodafone and O2 currently have a site sharing agreement that they entered into in May 2009.[19] However, this appears to be a relatively passive agreement in the UK and an announcement of an agreement does not mean that extensive network sharing will actually occur. Vodafone entered into a site sharing agreement with Orange in 2007 which did not leave to RAN integration. Site acquisition for either operator would be much more expensive than entering into a site sharing agreement. We assume that each operator would also be limited to acquiring only up to 1,000 sites per annum.

A7.14 Site sharing between the operators may be possible, although subject to regulatory approval, but it would take time for the operators to put into practice and to start to expand their 3G networks.

Do the site counts represent upper bounds?

A7.15 If more than 50% of Orange's sites are useful for coverage then MBNL can reach more than 13,000 sites in the 80% population area without embarking on a major acquisition process.

A7.16 If, for example, 75% of Orange's sites were suitable for upgrade, then MBNL could reach around 15,000 sites through upgrades, and 18,000 through an extensive site acquisition process. These numbers may be possible but could be challenging to achieve in practice.

[19] http://www.o2.com/media/press_releases/press_release_14381.asp?archive=yes

Annex 8

Timing and duration of any competitive distortion

A8.1 This annex sets out how long we consider any ‘interim period’ would be. By interim period, we mean the duration of any period of reduced competitive intensity as a result of UMTS liberalisation.

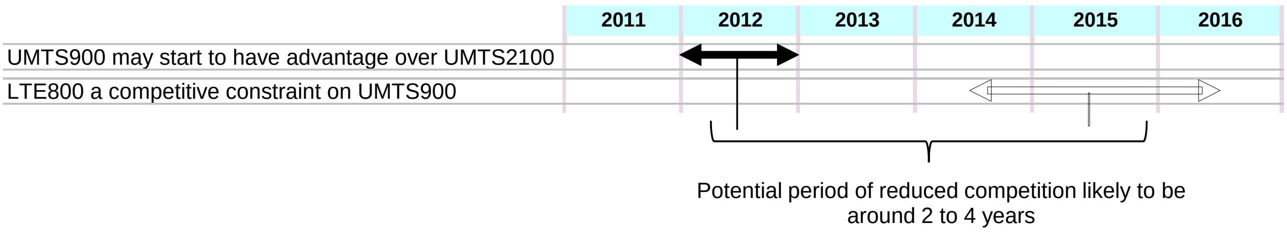
A8.2 In our February 2009 Consultation we said that:

> “There is also likely to be a material gap, of at least two to four years, between when consumers could start to benefit from high quality mobile broadband services using 900 MHz spectrum (around 2011 to 2012) and when the use and quality of services using 800 MHz spectrum, if deployed, could catch-up with 900 MHz services (around 2014-2015). … This is because 900 MHz user equipment and spectrum are likely to be available significantly earlier than 800 MHz equipment and spectrum.” (paragraph 4.6)

A8.3 We have considered responses to the February 2009 Consultation and subsequent developments. In the sections below we set out:

- when any advantage for UMTS900 might begin;
- the importance of LTE800 handsets;
- other assumptions for when LTE800 may act as a constraint on UMTS900; and
- our conclusion on when LTE800 may end any period of reduced competitive intensity.

A8.4 Our conclusions can be summarised by the diagram below.



A8.5 We believe that UMTS900 may start to have an advantage over UMTS2100 in 2012 and that LTE800 will act as a constraint on UMTS900 from mid 2014 to mid 2016. We therefore consider that if there were a period of reduced competitive intensity its duration would be likely to be around 2-4 years. This is broadly unchanged from our February 2009 Consultation, though this period would now start slightly later than we previously envisaged.

When any advantage for UMTS900 might begin

A8.6 In our February 2009 Consultation, we assumed that the 900 MHz operators would be able to refarm 900 MHz so as to provide UMTS900 services in urban and dense urban areas around 2 to 3 years after our decision to liberalise the spectrum. Some responses argued that the 900 MHz operators would be able to refarm the 900 MHz spectrum more quickly.

A8.7 We have updated our view of the time it would likely take for the 900MHz operators to gain a competitive advantage from rolling out UMTS900 following liberalisation. We consider this primarily from the network-side, i.e. the time that it would take to get a sufficient UMTS900 network to have a competitive advantage. In terms of handsets, we note that take-up of UMTS900-capable handsets is now likely to be considerably higher than it was in February 2009 and that anyway operators may be able to accelerate the take-up of UMTS900-capable handsets (e.g. through marketing or subsidies). We think that handsets are unlikely to be a constraint in terms of when the 900 MHz operators may be able to obtain an advantage with UMTS.

A8.8 In terms of rolling out UMTS900, we expect that this process would involve a sequence of equipment procurement covering roll-out beyond pilots, gradual implementation (including resolution of any practical issues with existing sites, such as lack of space and relevant permissions if new antenna are required) and careful tests for local optimisation of the new equipment, followed by on-going monitoring and refinement.

A8.9 In the February 2009 Consultation, we assumed that it would take 1½ to 2 years to clear one block of 900 MHz, with a further 6 months to a year for testing and optimising the initial sites once the spectrum was available. In parallel with this, we assumed it would take up to 2 years to roll out the network in urban and dense urban areas. We now believe that if the 900 MHz is liberalised, O2 and Vodafone may be able to take advantage of UMTS900 more rapidly. This is primarily because the operators may have already undertaken preparation for the move to UMTS900. Both O2 and Vodafone have applied to Ofcom requesting variation of their 900 MHz and 1800 MHz licences to allow them to deploy UMTS. We now assume that any competitive advantage to 900 MHz operators would start at some point in 2012. This is on the assumption that the spectrum was liberalised around the end of 2010. This implies 1 to 2 years after the licences are liberalised to be able to deploy sufficiently in urban and dense urban areas to achieve a competitive advantage. This is considerably quicker than the assumption in our February 2009 Consultation of 2 to 3 years.

A8.10 We note that following the merger of T-Mobile and Orange, the shared UMTS2100 network of Everything Everywhere and H3G will be significantly more extensive than the separate networks were previously. This may mean that there would need to be more extensive rollout of UMTS900 before the 900 MHz networks were superior. It is therefore possible that any advantage for Vodafone and O2 may start later than we have assumed.

The importance of LTE800 handsets

A8.11 In our February 2009 Consultation, we did not distinguish between the provision of mobile broadband through dongles and that provided to handsets. A number of responses to that consultation stressed that the distinction between handsets and dongles was important.[20] We agree with this and consider that the importance of services to handsets has become increasingly clear since February 2009.

A8.12 The distinction between services to handsets and to dongles is significant because it is likely to take considerably longer for there to be a range of attractive LTE handsets available to consumers than for LTE dongles. Dongles are relatively simple, standardised devices. In contrast, the design of handsets is more complicated. Handsets usually incorporate various additional features, such as cameras and radios. Battery life is a very important factor, as is size. And it is more important that they can operate with different technologies and frequencies, to enable the use of the handset in areas covered by different networks.

A8.13 With current handset design technology, it becomes increasingly difficult to incorporate additional frequencies into handsets[21]. In addition to multiple licensed bands that handsets need to support (existing 900MHz, 1800 MHz, 2.1 GHz, their equivalents in other world regions, or FM broadcast radio, as well as prospective new bands 800 MHz and 2.6 GHz), handsets (and in particular – high end smartphones) also need to support wireless technologies such as Bluetooth and WiFi which operate in licence-exempt bands. By adding more spectrum bands and technologies, space requirements, unit costs and possibly risks of interference between device components increase. This means that handsets manufacturers face choices as to which spectrum bands and technologies to include in handsets. Handset manufactures may therefore be reluctant to include LTE 800 MHz unless there is strong demand for it relative to other bands.

A8.14 Moreover, there are also significant economies of scale in handset manufacturing. This means that while handset designs may vary in different continents, handset manufactures may be reluctant to make handsets for a small market. This means that manufacturers will only want to include LTE at 800 MHz in handsets if there is sufficient demand for this frequency relative to other frequencies. This means that the timing of 800 MHz auctions and the timing of the early LTE800 network deployments can significantly affect when LTE800 handsets may be produced.

Growing momentum for LTE

A8.15 Since February 2009, momentum for LTE has continued. TeliaSonera launched the first commercial LTE network in December 2009 in Stockholm and Oslo using 2.6 GHz. At the time of the launch there were only single frequency LTE dongles available[22]. Dongles with LTE and that also supported 2G and 3G followed around 6 months later, and the first handsets capable of using LTE at 2.6 GHz are expected in 2011[23].

A8.16 There are now commercial LTE networks in a small number of other countries, including Finland, Poland and Uzbekistan. There are also substantial future deployments planned in Japan and the US later this year.

[20] Some responses to the 2009 Consultation used different terminology, distinguishing between a “mobile broadband” market segment being served by dongles and data cards, and a “mobile internet” market segment served with handsets (or just smartphones).
[21] It is possible that this may change in the future, with a shift to more flexible architectures, but this is far from certain. An example of potential developments in this area is http://www.rethink-wireless.com/article.asp?article_id=2422
[22] http://www.samsung.com/us/aboutsamsung/news/newsIrRead.do?news_ctgry=irnewsrelease&news_seq=15946
[23] http://www.lightreading.com/document.asp?doc_id=192794&

A8.17 In Japan, LTE developments include NTT Docomo's planned deployment of LTE at 2.1 GHz, which is expected to be launched in December 2010. At launch it only expects to have data-only devices, with handsets following in 2011/12[24]. Other Japanese operators, such as KDDI, are also planning to launch LTE.

A8.18 In the USA, MetroPCS launched an LTE network in September 2010 in Las Vegas. It plans to expand to other cities later in the year. From the time of the launch MetroPCS offered an LTE enabled handset (the Samsung Craft). This is the first commercially available handset that can use LTE.[25]

A8.19 There are several other planned LTE launches in North America in the near future. These include Verizon's plans to launch an LTE network at 700 MHz in the USA later in 2010. While it expects dongles and other data devices to be available before handsets, it has worked to encourage LTE700 handsets and expects them to follow relatively quickly, with a small selection of such handsets available in the first half of 2011.[26]

A8.20 While the first handsets able to use LTE are likely to be launched very soon, these handsets will be for the US and Japanese markets and not for the 800 MHz band.

LTE at 800 MHz

A8.21 The most important factor for determining when handsets that can use LTE at 800 MHz will be available is the extent of demand for such handsets from operators. This in turn depends on the availability of 800 MHz for mobile use amongst other things. There has been growing momentum for using LTE at 800 MHz within Europe.

A8.22 The European Commission has been encouraging clearing the 800 MHz and making it available for mobile use. In October 2009, it recommended[27] that Member States:

- take all necessary measures to ensure that broadcasting services cease using analogue transmission technology by 1 January 2012, and
- support regulatory efforts towards harmonised conditions of use other than, and in addition to, broadcasting services.

A8.23 Following this, in May 2010, the European Commission agreed a Decision[28] on harmonised technical conditions of use in the 790-862 MHz frequency band for terrestrial systems capable of providing electronic communications services in the European Union. Unusually, this Decision had no implementation deadline which gave Member States some leeway. In the Decision, Member States were not mandated to clear the 800MHz band but should they choose to do so, they must conform with the technical parameters in the annex of the Decision. These technical conditions are aligned with the characteristics of LTE equipment.

24 http://www.nttdocomo.com/binary/press/FY2010_1Q_Earnings.pdf
25 http://www.metropcs.com/presscenter/articles/mpcs-news-20100921.aspx
26 http://www.reuters.com/article/idUSTRE64D50R20100517
27 http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/legislation/dd_recommendation/en_rec.pdf
28 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010D0267:EN:HTML

A8.24 The European Telecommunications Standards Institute is currently updating the LTE harmonised standard to incorporating the above technical conditions for operation in the 800 MHz band. This standard is currently in the first phase of public comment (until November 2010) and is scheduled to be published in the OJEU in August 2011.

A8.25 In September 2010, the European Commission proposed its first radio spectrum policy programme. Among other things, this would mandate Member States to release the 800 MHz band for electronic communications services by 1 January 2013, unless there are exceptional circumstances that prevent this. To have force, this proposal would need to be approved by the European Parliament and Council.[29]

A8.26 The number of European countries that have decided to clear the 800 MHz band and release it for mobile use has increased. Most significantly, Germany auctioned its 800 MHz in May 2010 and allocated the frequencies in August 2010.[30] There are coverage obligations on the spectrum winners. The rules require network coverage first in priority areas that have no broadband supply at all. Densely populated urban regions may only be supplied once 90 per cent of those in less populated priority areas have access to broadband with at least 1 Mbps. Telefónica O2 Germany, Vodafone Germany and Deutsche Telekom won 800 MHz. Deutsche Telekom has begun deploying 800 MHz.[31] Vodafone Germany has said it will begin upgrading to LTE at the end of September 2010, and by next year will have 1,500 LTE base stations[32]. Telefónica O2 Germany also plans to start network deployment (using both 2.6 GHz and 800MHz) in September 2010.[33]

A8.27 Our understanding of developments in some other European countries is summarised below:

- In Austria, the Government has announced that the 800 MHz should be available for mobile services, with the auction expected at the end of 2011 or early 2012.[34]

- Denmark and Finland have decided to clear the 800 MHz band and make it available for mobile services. Both have both completed digital switch over. The timing of any award is unclear.

- In France, ARCEP consulted in July 2010 on the award of 800 MHz and 2.6 GHz bands.[35] It proposes to award the 800 MHz and 2.6 GHz licences between spring

29 http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/legislation/rspp/rspp_proposal_en.pdf

30 http://www.bundesnetzagentur.de/cae/servlet/contentblob/159588/publicationFile/8443/100830AllotmentFrequBlocks.pdf

31 http://lteworld.org/news/deutsche-telekoms-first-lte-base-station-operational

32 http://www.vodafone.com/start/media_relations/news/local_press_releases/germany/germany_press_release/vodafone_continues.html

33 http://www.nokiasiemensnetworks.com/news-events/press-room/press-releases/lte-pilot-network-to-provide-high-speed-broadband-in-halle-eas

34 http://www.oesterreich.gv.at/site/cob__39334/currentpage__0/6592/default.aspx

35 http://www.arcep.fr/index.php?id=8571&L=1&tx_gsactualite_pi1[uid]=1298&tx_gsactualite_pi1[annee]=&tx_gsactualite_pi1[theme]=&tx_gsactualite_pi1[motscle]=&tx_gsactualite_pi1[backID]=26&cHash=13e700e099

and early summer 2011. The spectrum will be available for mobile use from November 2011.

- In Ireland, ComReg is currently consulting on the approach to the release of 800 MHz, 900 MHz and 1800 MHz. The 800 MHz is expected to be available for mobile use in early 2013.[36]

- In Norway, press reports indicate the auction of 800 MHz is expected in 2011, with the spectrum available immediately after the auction.

- In Poland, the auction of 800 MHz is expected after the regulator's current consultation is complete and the tender documents are finalised. However, the timing for the availability of the 800 MHz is currently unclear.[37]

- In Spain, the auction of the 800 MHz may be in 2011, in a combined auction with other bands, but the spectrum may not be available for mobile services until January 2015, though this may be brought forward.[38]

- In Sweden, the regulator is planning to auction the 800 MHz in the first quarter of 2011, and the spectrum will be available as soon as it is assigned. The regulator is currently consulting on the auction rules, with a coverage obligation planned for one of the blocks.[39]

- In Switzerland, the regulator proposes to auction 800 MHz, together with a large quantity of spectrum in other frequencies, in 2011 or 2012.[40] The 800 MHz spectrum should be available for mobile services throughout Switzerland from 2015 at the latest, and in most parts of Switzerland it is already available for mobile services.[41]

A8.28 Further auctions for 800 MHz are therefore expected in 2011 with the spectrum available shortly after in some countries. In addition, other European countries are currently considering making 800 MHz available for mobile services. These countries include Greece, the Netherlands and Portugal. Other countries may follow.

A8.29 There is also increasing interest in using the 800 MHz band for mobile services outside Europe. Many countries in Africa have committed to using 800 MHz for mobile services.

A8.30 Since WRC-07 identified the 800 MHz band for International Mobile Telecommunications (IMT), which includes LTE, the ITU-R has worked on addressing the compatibility between new mobile systems and existing uses of the band under WRC-12 agenda item 1.17. The former Soviet Union uses this spectrum for defence systems, which will put constraints on its use for LTE in

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[36] http://www.comreg.ie/_fileupload/publications/ComReg1071.pdf

[37] http://www.en.uke.gov.pl/ukeen/index.jsp?place=Lead04&news_cat_id=61&news_id=876&layout=1&page=text

[38] http://www.cmt.es/cmt_ptl_ext/SelectOption.do?tipo=pdf&detalles=090027198009f447&nav=busqueda_resoluciones

[39] http://www.pts.se/en-gb/Documents/Consultations/200/Public-consultation-on-draft-auction-rules/

[40] http://www.bakom.admin.ch/dokumentation/medieninformationen/00471/index.html?lang=en&msg-id=30007

[41] http://rspg.groups.eu.int/_documents/documents/meeting/rspg20/rspg09_291.pdf

neighbouring countries. In Western Europe and Africa, there is existing TV use. The ITU-R studies in preparation for WRC-12 have set out options for dealing with both of these compatibility issues and CEPT will develop a European proposal to the WRC setting out its preferred method.

A8.31 In parallel, ITU-R has incorporated the European harmonised frequency plan for IMT into its draft revision of the relevant ITU-R Recommendation. For countries in ITU-R Region 1[42] that are making the 800 MHz band available, this should be the natural frequency arrangement. The alternative options in the ITU-R Recommendation are intended for use outside Region 1, i.e. in countries where the mobile allocation extends below 790 MHz.

A8.32 The total market size represented by the countries that have already committed to clear the whole of the 800 MHz band is considerable. Because of this, and the propagation advantages of 800 MHz, we consider that eventually it is likely to be a very important frequency for mobile services. However, we consider that there is considerable uncertainty about when handsets capable of using 800 MHz will start to be produced.

Conclusion on LTE800 handsets

A8.33 Even when the first LTE800 handsets become available, it may take longer for a reasonable selection of such handsets to be available. As there is considerable uncertainty over when there will be a reasonable range of LTE800 handsets, we assume a fairly wide range. We assume a reasonable selection of LTE800 handsets might be available from mid 2013 to end of 2015.

A8.34 This is significantly later than we assumed in the February 2009 Consultation, when we assumed LTE800 user equipment would be available mid 2011 to end 2013.

A8.35 We recognise that it could be argued that the late date for a reasonable selection of LTE800 handsets could be even later. However, we consider that this is only likely to be the case if there is relatively weak demand from MNOs for using LTE at 800 MHz. We are interested in the scenario where providing broadband services with sub 1 GHz is very important for competitiveness. We are therefore primarily interested in the situation where some MNOs have strong demand for LTE800 compatible handsets. We have therefore limited our range to the end of 2015.

UMTS1800 continues to be of little relevance

A8.36 As in our February 2009 Consultation, we consider that there continues to be a lack of momentum for the use of UMTS at 1800 MHz. Even if UMTS were deployed at 1800 MHz, the analysis we undertook for the February 2009 Consultation suggests that it would not in practice make a significant difference to the cost of network deployment compared to using UMTS at 2.1 GHz. Even if UMTS1800 were deployed we therefore do not think it would change the assessment materially.

Other assumptions for when LTE800 may act as a constraint on UMTS900

A8.37 In our February 2009 Consultation, we set out detailed assumptions on when 800 MHz may act as a constraint on UMTS900, including when the auction might happen, the availability of the spectrum, the speed of deployments and the duration

[42] Europe, Middle East, Africa, the former Soviet Union, including Siberia, and Mongolia

of testing. We have revised some of these assumptions, in the light of responses to the February 2009 Consultation and other information. We describe our key assumptions below.

A8.38 We now assume that the auction is completed between the first quarter of 2012 and mid 2012.

A8.39 In the February 2009 Consultation we assumed that the 800 MHz would be available from late 2012 to the end of 2013. After that consultation, we published our Statement on clearing the 800 MHz band in June 2009[43]. In that Statement, we said that the end of 2013 remains a challenging but credible target for clearing DTT from channels 61 and 62. We are progressing with the implementation of this, including on how it can be coordinated with DSO. Here we have assumed that the whole of the 800 MHz band is available from the end of 2013 to mid 2014.

A8.40 In the February 2009 Consultation, we assumed that it would take no longer than 2 years to deploy in urban and dense urban areas and 3 to 4 years to deploy across the 80% population area. Some responses argued that the cap Ofcom placed on the number of upgrades per year (3,000) was too low. One respondent argued that it had carried out a significantly higher number of upgrades per year. One response also questioned the assumption we made that a period of 6 months was needed for testing the spectrum after it was cleared, arguing that testing could be done before the spectrum is completely cleared.

A8.41 In the light of responses and indications of the speed of rollout from other countries, we consider that roll out could happen at a faster pace. We have therefore assumed that it might be possible for an initial deployment in urban / dense urban areas in 1½ to 2 years, rather than our original assumption of 2 years. For services to handsets, this may not be on the critical path, as that may be determined by when handsets are available. We assume a wider range of 2½ to 4 years for deployment to the 80% population area.

A8.42 On the period for testing, we recognise that network operators could potentially start installing equipment as soon as they have certainty about spectrum use. However, as we said in the February 2009 Consultation, we consider the equipment needs to be tested and optimised with cleared spectrum. We have therefore retained our assumption that it would take between six months and one year before the network could be in full use after the spectrum is cleared.

A8.43 In the February 2009 Consultation we assumed that competitive intensity would not increase until LTE800 handsets were in the hands of around 10% of subscribers, and that it would take 1½ years after a reasonable selection of handsets were available to achieve this.

A8.44 We noted in the February 2009 Consultation that this is a more rapid timetable than for UMTS900. This is because we assumed that the 800 MHz operator would be under pressure to catch up a 900 MHz operator who was using UMTS900. Hence the 800 MHz operators would be more likely to use strategies to encourage user equipment take up for those subscribers who care most about mobile data.

A8.45 However, it could be argued that competitive pressure for services to handsets would increase as soon as a reasonable selection of LTE800 handsets were

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[43] http://www.ofcom.org.uk/consult/condocs/800mhz/statement/clearing.pdf

available. Even though there would not be a base of customers who already have these handsets, operators could still try to attract customers by offering them contracts with LTE800 handsets. This may be especially the case because LTE800 would probably offer a superior service to consumers than UMTS900. We therefore now assume that there is an increase in competitive pressure as soon as a reasonable selection of LTE800 handsets is available.

Our conclusion on when LTE800 may end any period of reduced competitive intensity

A8.46 Based on the assumptions set out above, we have considered an early and a late scenario for when LTE800 may act as a competitive constraint on UMTS900. These are shown in figures A8.1 and A8.2 below.

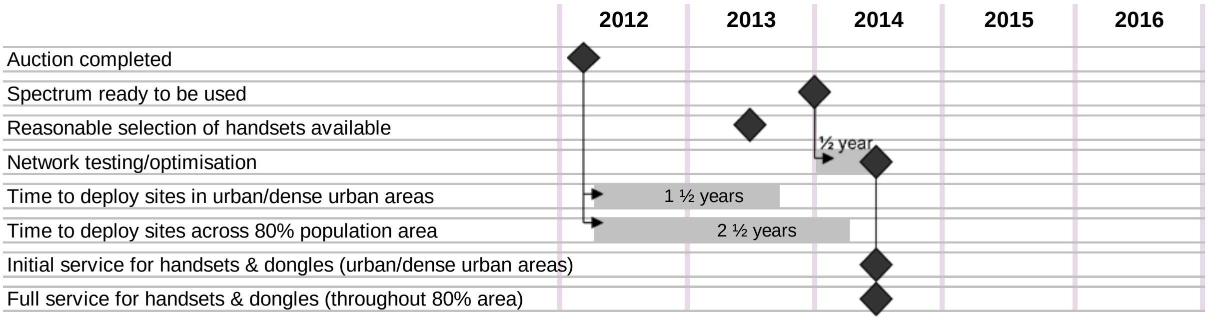

Figure A8.1: LTE deployment early scenario timeline

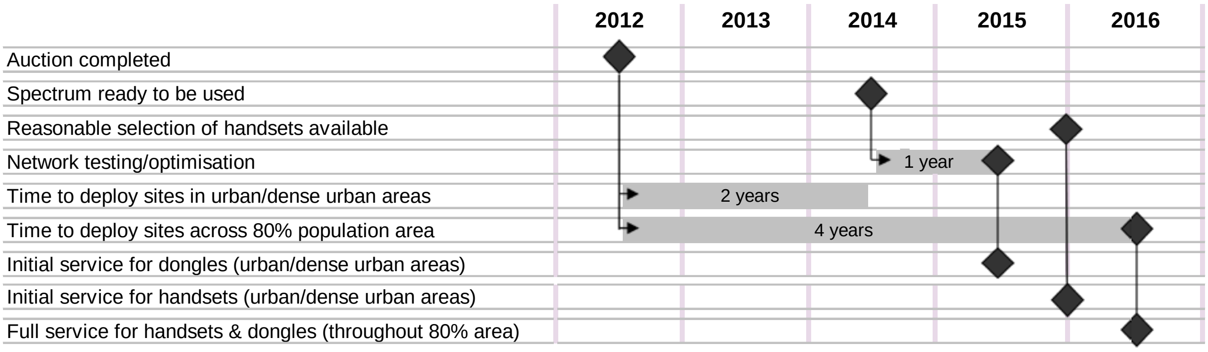

Figure A8.1: LTE deployment late scenario timeline

A8.47 In the early scenario, we assume that an LTE800 service can be offered and there is a reasonable selection of handsets that can use LTE800 by the middle of 2014.

A8.48 In the late scenario, we assume that an initial service can be offered in urban areas by mid 2015 for dongles and at the end of 2015 for handsets, and that a service can be offered throughout the 80% population area by mid 2016. In this scenario, we would therefore expect LTE800 to start to increase competitive pressure on UMTS900 in mid 2015, but that this would take longer for it to have full effect. While we have given considerable focus to handsets, we note that even if LTE800 were used initially for dongles, this could still help Everything Everywhere and H3G in terms of coverage for handsets. This is because using LTE800 rather than UMTS2100 for dongles may reduce the traffic load on the UMTS2100 network, which could tend to expand the coverage of that network for handsets.

A8.49 Given that we consider that UMTS900 may give the 900 MHz operators an advantage in 2012, we consider that if there were a period of reduced competitive intensity its duration is likely to be around 2-4 years. This is broadly unchanged from our February 2009 Consultation, though this period would now start slightly later than we previously envisaged.