Annex 13

Access to lower frequencies in more densely populated areas – site counts

Summary

Introduction

A13.1 This annex presents our refined estimates of the differences in cost of deploying UMTS (3G) networks after liberalisation, between operators that hold liberalised spectrum, and those who do not.

A13.2 To support our September 2007 consultation on mobile spectrum liberalisation we undertook two important pieces of empirical analysis in order to inform our policy development. These assessed:

a) The cost differences in deploying mobile services using different frequency bands (900/1800/2100 MHz).

b) The costs of clearing and releasing 900MHz spectrum.

A13.3 Both elements are technically complex to assess and important for policy development. This annex and Annex 15 deal specifically with the cost differences of access to lower frequencies in more densely populated areas.

A13.4 We received extensive comments from mobile network operators (MNOs) and others, expressing a range of different views. These comments were published on our website and the public portions of these are summarised in this annex.

A13.5 Additionally, there have been significant developments in the market for mobile broadband since our last consultation, which are summarised in Annex 6.

A13.6 We have undertaken considerable work to consider specific comments and developments in order to refine our analysis. This annex reports purely on the technical and empirical aspects of this analysis. The findings resulting from the technical study feed into the analysis of differences between bands which is reported in Annex 10. The potential policy implications are reported elsewhere in this consultation.

Objectives

A13.7 The overall aims of this analysis are:

i) to calculate the difference in the number of sites and the resultant cost differences arising from building and operating radio networks that provide the same service with different spectrum holdings and

ii) to determine differences in the level of service (the *quality* as defined in Annex 6) which would be experienced by customers from networks with a given number of sites using different spectrum holdings.

A13.8 The analysis is based on the use of UMTS (3G) technology and on macrocell radio networks, although the impacts of using other methods to provide service are also considered. This annex considers the more densely populated regions of the UK where 80% of the population live, while less densely populated areas are considered in Annex 14.

A13.9 A large number of scenarios are examined to represent differing possible views regarding market demand, technical parameters and approaches to network design and roll-out.

A13.10 The cost difference is calculated by comparing networks that provide the same service with different spectrum holdings. The analysis is separated into two parts:

- In this annex, we present our refined approach to calculating the number of sites needed to deploy a UMTS network in a given band (Part I).
- In Annex 15 we translate those site numbers into costs in pounds (Part II).

A13.11 Questions of whether operators would actually build such a network and the policy implications of each scenario are not considered in this annex, but in Annexes 10 - 12 and in the main body of this document.

Methodology

A13.12 The method used in the technical analysis to determine the number of sites for a given scenario is summarised as follows:

- For a given market demand, and technological method of meeting this demand, the quantity of traffic that will need to be served by macrocells in a given frequency band is forecast, and translated into the required technical performance metrics.

- A set of technical parameters is fixed relating to the scenario under consideration. These may include the service quality level required, the propagation characteristics at a given frequency band and the morphology and population distribution of the relevant area of the UK.

- A calculation is performed to estimate the density of base station sites which would be necessary to provide acceptable service in each of a number of representative environments (clutter types).

- These results are then extrapolated, based on clutter types to determine the number of sites required to serve the entire densely populated area.

A13.13 We remain confident that this is the correct high level approach. While responses to the consultation questioned various parameters and elements of the approach, there was no indication that the general methodology was inappropriate.

A13.14 However, we have made significant changes to the technical model used in the calculation process and to many of the individual parameters, in response to the issues raised and further evidence gathered.

A13.15 The simulation technique employed previously required the selection of particular geographical areas for simulation purposes, which cannot be especially large due to the computational complexity involved (for example, an area of 100 square kilometres was used previously). This creates technical difficulties in reliably extrapolating to the whole of the area of interest (for comparison, the 80% population area is approximately 30,000 square kilometres).

A13.16 Our refined approach uses analytical techniques for predicting the performance of UMTS systems that are widely used in the industry for dimensioning and analysing networks. It takes the technical and service parameters for a given scenario as input and produces and estimate of the required density of sites to support this service at a given frequency as output. The site density is calculated for each of a number of generic clutter types, which are used to specify both the propagation and traffic characteristics. In this way, reliance on the selection of a particular representative simulation area is avoided, and extrapolation can be performed via knowledge of the characteristics of the clutter over the whole of the 80% population area. Additionally, the refined technical model permits more generic analysis of the variation of site density with the distribution of traffic than the simulation approach.

A13.17 We use the same model to determine the quality level which a network with a given number of sites can deliver, for specified technical and service parameters. In this context, quality refers to the throughput which is attainable for a given proportion of the users.

A13.18 Our refined model indicates differences in site count that would be encountered in a real network deployment. However, there are known limitations associated with the technical model:

- No direct account is taken of real-world propagation, cost or site planning constraints.
- The approach analyses a single service and user class at a time
- No direct account is taken of power control and call admission control processes which are a feature of realistic networks.
- Interference control using features such as antenna downtilts is not modelled directly.

A13.19 Nevertheless, we believe that this approach to modelling is a better basis for comparison since it allows a wider range of parameters to be explored and provides a more consistent framework for determining the consequences over the whole area of interest than did the previous area-specific approach.

Scope

Issues

A13.20 Responses to our consultation in September 2007 highlighted differences in forecasts of overall site numbers between operators and Ofcom. In addressing this we have refined our analysis and carefully analysed operators' responses and other sources in the public domain, and found that our results are not inconsistent with these sources as far as the broad behaviour is concerned.

A13.21 Several relevant technical issues were also raised in the responses to our consultation. In this annex only those issues relating to the site numbers which are the output of the technical model, or relating to the technical parameters that are assumed within the analysis, are considered.

A13.22 Some of these issues lend themselves to qualitative analysis and have been taken onboard in our revision of the modelling approach. Others have quantitative implications and where necessary, have led to a refinement of the parameter set as used in the modelling of UMTS networks for 2G liberalisation.

A13.23 The specific issues that have been addressed are:

i) Forecasts of mobile broadband demand.

For which we have explored a range of values, and found that if the volume of data demand per user is high enough then the network could become capacity constrained and this could significantly affect the impact of any site differences.

ii) Planning issues for networks comprising mixed frequency bands.

For which we have developed a method of analysis using the results of the single frequency band modelling to provide an estimate of the effect of having a portfolio of mixed bands. We have analysed some mixed frequency cases and found that where the networks are coverage constrained adding spectrum has little impact. However, when the network becomes capacity constrained, adding a high frequency 'layer' reduces traffic in the lower frequency layer and allows the expansion of cell size resulting in fewer sites required across the network.

iii) Alternative coverage techniques.

For which we have examined a range of alternative technologies and modelled their use by considering that smaller cells are used to provide in-building coverage or to offload traffic from the macrocells. If such cells were very widely deployed, they could provide an alternative means of delivering deep indoor coverage which could reduce the number of macrocells deployed with a reduced difference between frequency bands. Using alternative cell types to reduce the traffic carried in the macrocell network may actually increase the cost difference by reducing the cell loading and hence make the network more coverage constrained rather than capacity constrained. However, the major part of the traffic and coverage is still likely to be delivered via macrocells and it is expected that this will continue to act as the primary means – and largest cost driver – for delivering mobile broadband service using 3G technologies. We therefore consider that it is still appropriate to base our policy considerations primarily on macrocell deployments.

iv) Propagation differences between frequency bands.

For which we have carried out an extensive study of the physics of propagation, the published literature and MNO responses, particularly relating to the behaviour of building penetration loss (BPL) with frequency and environment. As a result we have extended the range of values explored in our investigation, including cases where BPL does not vary with frequency and where it increases more rapidly with frequency than previously considered. In all cases we now consider that BPL should vary according to the clutter type.

v) User terminal performance.

- For which we have further researched our assumptions and have accounted for:
    - A 3dB difference in the receiver sensitivity between the 900MHz and 1800MHz bands and the 2100MHz band.
    - 24dBm transmit power for Release 99 and HSDPA data services as opposed to 21dBm as assumed in the previous consultation.
    - 5 variations on user terminal performance relating to body loss. Body loss varies over a significant range according to the type of terminal and usage (e.g. between voice services, data services on a mobile phone and data services on portable computers).

vi) Simulation area and extrapolation.

For which we have adopted a different approach to the September 2007 consultation, one that allows the direct calculation of the density of sites required in a given clutter environment. This has allowed us to explore the effects of non uniform population density and the extent of coverage where only the most populous areas are targeted.

vii) Quantity of spectrum.

For which we have calculated site numbers for 1 and 2 carriers at 900MHz, 2 and 4 carriers at 1800MHz and 2 carriers at 2100MHz. The case of 1 carrier at 900 MHz decreases the data volume at which networks become capacity constrained compared to 2 carriers, reducing the effect of frequency differences if data volumes are sufficiently high.

viii) Use of HSDPA

For which we have enhanced the model to account for HSDPA traffic and shown that HSDPA delivers high bitrate data more efficiently, decreasing the extent of capacity constraints so that the network remains coverage constrained to a higher level of data demand. This increases the likelihood that the network will be coverage constrained and is therefore more likely to produce site differences between frequency bands. Since HSDPA delivers more capacity for a given number of sites than conventional (Release 99) UMTS traffic and is already being widely deployed by operators, we consider that this is the most relevant comparison for our policy analysis, though Release 99 traffic is also investigated.

ix) Site engineering issues.

For which we looked at the effects of additional combiner losses due to antenna sharing and the use of masthead amplifiers. We have found that combiner loss is negligible but that the use of masthead amplifiers has the potential to provide cost savings in some circumstances.

A13.24 Other variations to the parameters that have been explored include:

i) Pilot signal quality, which we find to be an important determinant of the number of sites required at low traffic volumes and where there is some uncertainty about the correct values to use. We have therefore explored a wide range of values.

ii) Use of uplink receiver diversity compared with none in the base case.

iii) Different degrees of sectorisation at the node B for which we compare the use of 6-sector sites with that of 3-sector sites used in the base case.

iv) Proportion of users in soft handover for which we compare a value of 40% of users with 20% as in the base case.

v) A maximum load factor of 50% rather than the 75% used in the base case.

Scenarios

A13.25 In examining the various parameters, we have examined the sensitivity of the outcomes relative to a base case set of parameters for each parameter in turn. This base case is intended to represent a reasonably plausible set of technical assumptions. The values appropriate to a particular operator and service offering will vary, but the base case provides a reasonable basis for determining the differences in the properties of different frequency bands. Additionally the sensitivities ensure that our forecasts encompass the potential range of those differences. We have then examined a range of results which correspond to a range of important market parameters specified in Annex 11, particularly :

a) The depth of indoor coverage.

b) The per-user throughput.

c) The data volumes demanded per user per day.

A13.26 To account for potential variations in the technical parameters, as well as investigating sensitivities with respect to the individual parameters, we have also investigated two additional full parameter sets; "low-end technical parameters" which is characterised by having some parameters that are less challenging than the base case and therefore result in lower site counts and "high-end technical parameters" which includes some more demanding parameters and consequently higher site counts.

A13.27 The base case parameter set and the variations have been shared with key stakeholders in order to take advantage of their extensive practical experience and ensure that the range of our investigation spans the range of plausible values.

A13.28 In summary, the main parameters are as follows.

a) Clutter breakdown for 80% population coverage of the UK (most densely populated areas) is given in Table 1 below.

Table 1: Clutter breakdown in the 80% area

Suburban	8,985 km^2
Open In Urban	1,387 km^2
Urban	573 km^2
Dense Urban	27 km^2
Total	10,971km^2

b) The average user densities assumed within each clutter type are given in Table 2.

Table 2: Average user densities per clutter type.

Suburban	1,261 users/km^2
Open In Urban	1,261 users/km^2
Urban	5,183 users/km^2
Dense Urban	6,369 users/km^2

c) The number of carriers is varied from 1 to 4 depending on frequency band (see above)

d) Average BPL values range from 3dB (shallow penetration depth at 900MHz) to 19.5dB (high penetration depth at 2100MHz, rising with the frequency).

e) Other base case parameters are given in Table 3 below.

Table 3: Other Base Case Parameters.

Sectors per site	3
Cell area coverage confidence	95%
Body loss	3dB (voice) 5dB (data)
Pilot signal quality target (Ec/Io)	-8dB
Users in soft handover	20%
Maximum load factor before cell splitting	75%

Results

A13.29 The results presented in this summary are for the base case as described above, unless indicated otherwise. Several deployment scenarios are considered for the base case parameter set. These are defined by the data volume per user per day, the frequency band, the number of carriers available, the maximum data rate per user at the cell edge and the depth of indoor coverage.

A13.30 We consider a variable data volume per user, averaged across all users, of between 0.1 and 30MB/user/day for each band. Different numbers of carriers are considered in each band as follows:

- 1 or 2 carriers at 900 MHz
- 2 or 4 carriers at 1800 MHz
- 2 carriers at 2100 MHz

A13.31 The maximum data rate per user is either 384 kbps, 1.2 Mbps or 2.4 Mbps and the depth of indoor coverage is either depth 1 or depth 2 as defined in Table 13 and Table 14, where depth 2 is a more consistent service level across the area of a building and depth 1 is a shallower service level but still provides a measure of in-building service.

General behaviour

A13.32 The general behaviour of the technical model described above can be illustrated with reference to the following Figure 1. This shows the number of sites required to deliver a given service on the vertical axis versus the average volume of data accessed by users on the horizontal axis. Note that this figure is illustrative only.

A13.33 The curves of this figure (Figure 1) may be interpreted by observing that in most cases, up to a certain point the increase in the number of sites required versus demand is relatively flat. This is indicative of the fact that for these demand levels the network is coverage limited, whereby the site numbers are driven primarily by

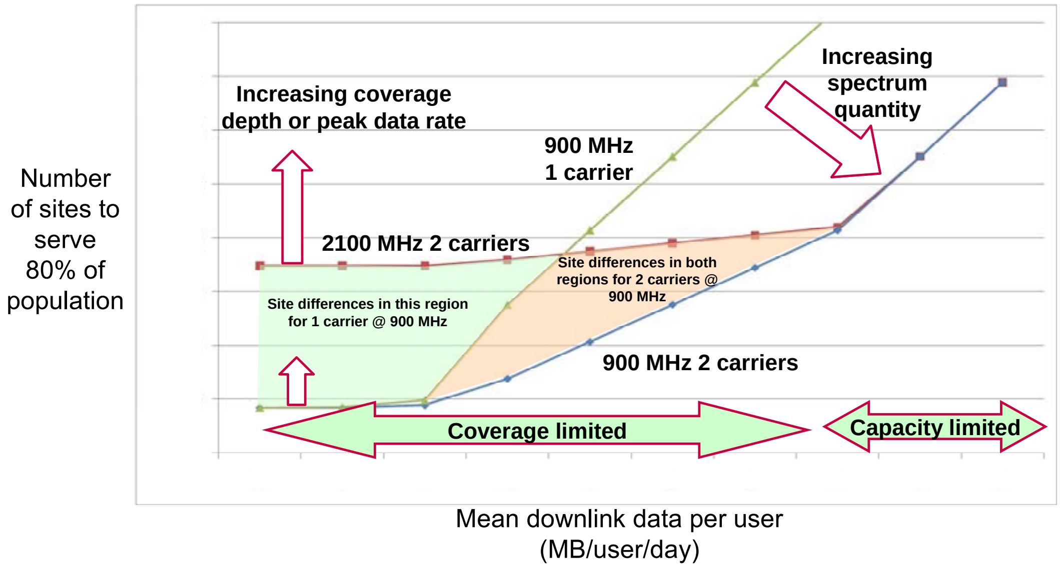


Figure 1: Illustration of behaviour of 3G network coverage and capacity limitations.

the need to provide adequate coverage for the data rate concerned across the 80% area.

A13.34 When the traffic demand increases beyond a certain point, which varies from case to case, a significant increase in the number of sites versus demand is observed. This corresponds to the network becoming capacity constrained where the number of sites required to provide coverage is not sufficient to support the capacity demand and so more sites are required.

A13.35 In Figure 1 the point at which a 2 carrier network at 900MHz starts to become capacity constrained is at a lower traffic level than a 2 carrier network at 2100MHz.

A13.36 This is explained by the fact that at lower levels of demand the 2100MHz network needs many more sites than does the 900MHz network in order to provide coverage at the same quality over the same area due to less favourable propagation at the higher frequency. Given a similar capacity per site and coverage level it is clear, therefore, that the 2100MHz network with many more sites can support higher levels of demand before becoming capacity constrained.

Base case results

A13.37 Our final results for the base case are shown in Figure 2 below, based on serving all downlink traffic using HSDPA.

A13.38 These results are for 900MHz and 2100MHz networks only since the number of sites needed to provide service using 1800MHz spectrum is not materially different from that required to provide service using 2100MHz spectrum. The difference in path loss due to frequency between 1800MHz and 2100MHz is balanced by the difference in the base station antenna gain and the assumed UE noise figure in each band. Using Release99 and the base case parameters, the differences at some example demand levels are given in Table 4 below.

Table 4: Difference in site count between 1800MHz and 2100MHz

Demand	No. sites for 2x1800MHz	No. sites for 2x2100MHz	Difference
1 MB / user / day	12,818	12,776	0.3%
10 MB / user / day	13,490	13,448	0.3%
30 MB / user / day	18,911	18,914	0.02%

Table 5 provides results for selected scenarios, which are used in the cost difference analysis described in Annex 15.

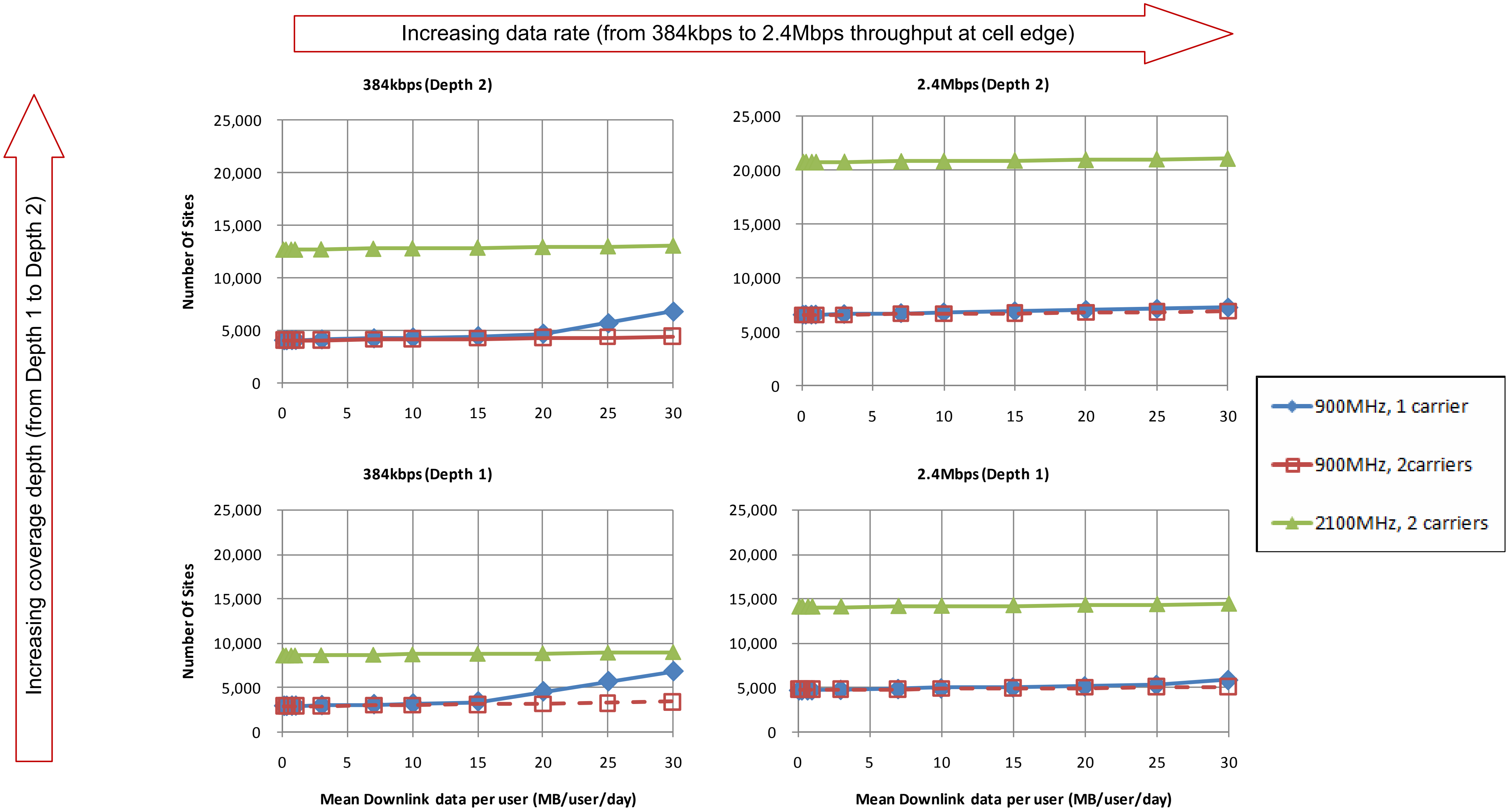


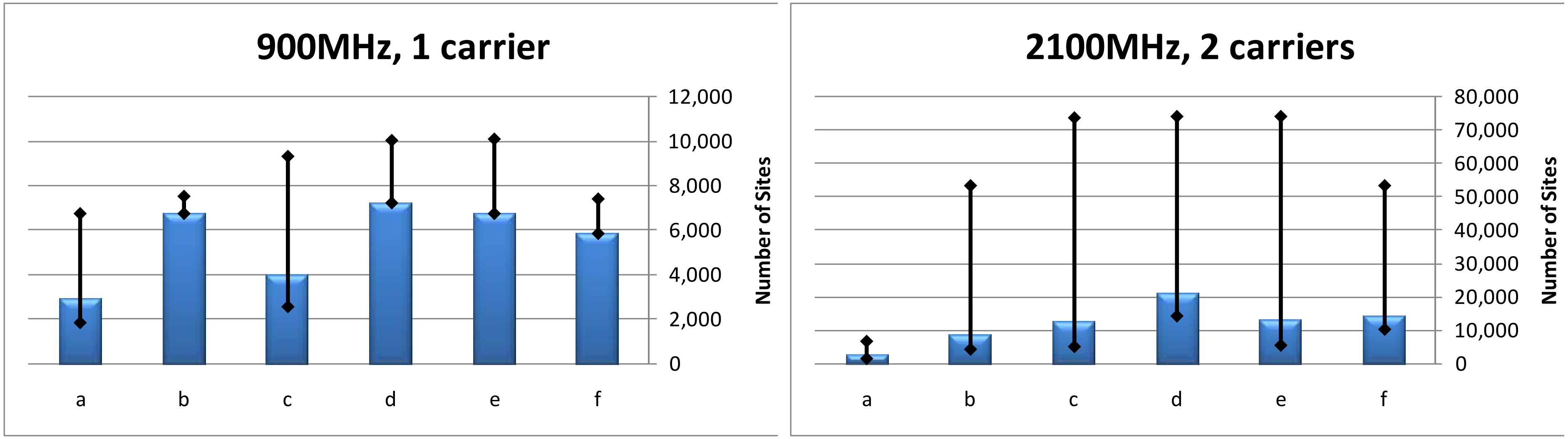
Figure 2: Results for base-case technical-parameters

Table 5: Site count results for selected scenarios. Results are rounded to the nearest 100 sites.

Scenario		Parameters			900MHz, 1 carrier	2100MHz, 2 carriers
		Data rates	Indoor Depth	Volume		
a	Lower demand	384 kbps	Depth 1	1 MB / user / day	2,900	8,600
b	As "lower demand" but high volume	384 kbps	Depth 1	30 MB / user / day	6,800	9,000
c	As "lower demand" but deep indoor coverage	384 kbps	Depth 2	1 MB / user / day	4,000	12,700
d	Higher demand	2.4 Mbps	Depth 2	30 MB / user / day	7,300	21,100
e	As 'higher demand' but low data rates	384 kbps	Depth 2	30 MB / user / day	6,800	13,100
f	As 'higher demand' but low indoor depth	2.4 Mbps	Depth 1	30 MB / user / day	5,900	14,400
g	As 'higher demand' but higher volume (40MB)	2.4 Mbps	Depth 2	40 MB / user / day	7,900	21,200
h	As 'higher demand' but higher volume (60MB)	2.4 Mbps	Depth 2	60 MB / user / day	11,800	21,400
i	As 'higher demand' but poorer suburban coverage (90%)	2.4 Mbps	Depth 2	30 MB / user / day	5,900	13,400

Sensitivity to technical parameters

For each of the scenarios used in the cost difference analysis we have also assessed the sensitivity of the site counts to the technical parameters used. The results of this sensitivity analysis are presented in Figure 3. The sensitivity of the results to variations in individual technical parameters has also been investigated and complete tables are included in the main body of the annex.



Scenario from Table 5

Scenario from Table 5

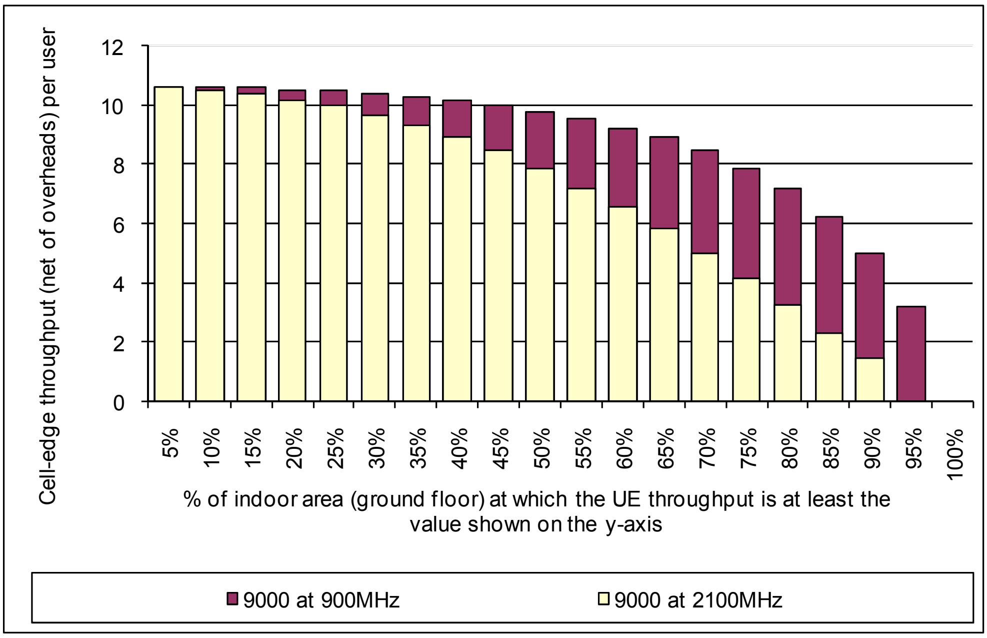
Figure 3: Sensitivity of results for selected scenarios to technical parameters used (base case results, and sensitivity ranges)

Quality Comparisons

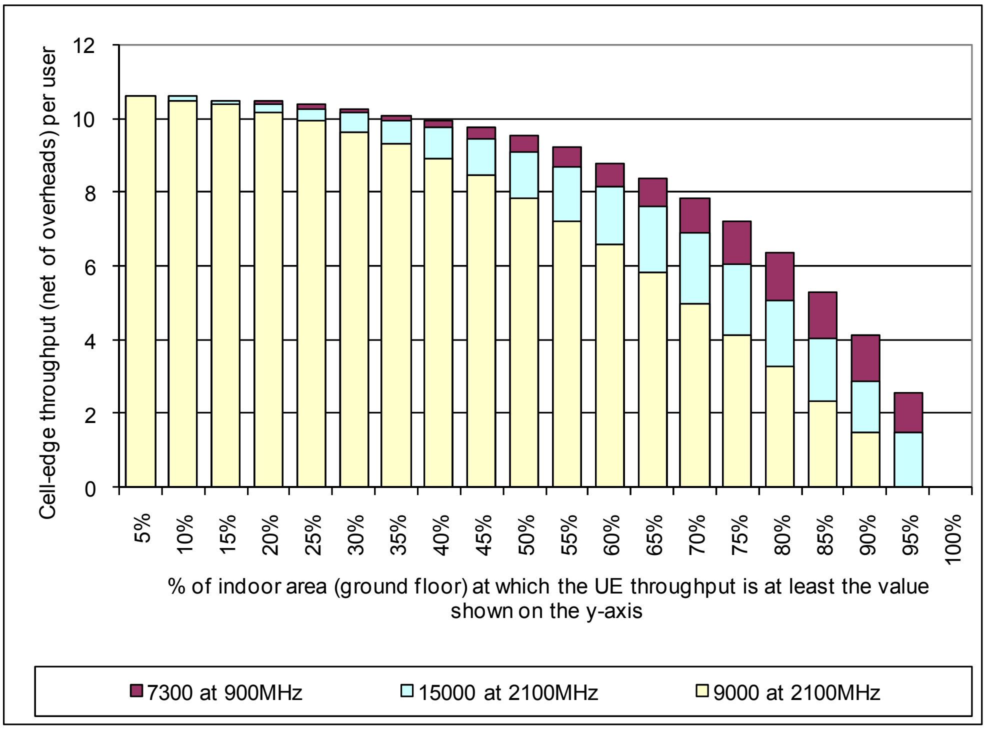
A13.39 In order to establish how the quality delivered by given networks may vary, we have used the technical model to fix the number of sites and determine the proportion of users who can achieve at least a specified level of throughput.

A13.40 Figure 4 shows the downlink throughput achieved by networks with various site numbers. The y-axis in this figure is the downlink throughput per user using HSDPA, while the x-axis is the proportion of indoor users who achieve at least this throughput. Base-case technical parameters are used and users are assumed to be indoors and uniformly distributed across the coverage area.

A13.41 Figure 4 (a) shows the situation when each network has 9,000 sites. Figure 4 (b) shows the case when the 900 MHz operator uses 7,300 sites, while the 2100 MHz operator deploys extra sites to reduce the difference in throughput, first to 9,000 and then to 15,000 sites. Throughput differences are apparent even at 15,000 sites.



(a) Downlink throughput achieved by networks with 9,000 sites at 900 MHz and 9,000 sites at 2100 MHz.



(b) Downlink throughput achieved by networks with 7,300 sites at 900 MHz, 9,000 sites at 2100 MHz and 15,000 sites at 2100 MHz.

Figure 4: User throughput (Mbit / second) achieved by different networks versus proportion of coverage area

Conclusions

A13.42 In conclusion, we have refined our methodology for calculating the site differences between frequency bands. The new methodology is more flexible, allowing us to explore a wider range of different deployment scenarios and also gives a better view of likely site numbers across the UK.

A13.43 We have also conducted a thorough review of the parameters used in the model taking input from responses to our previous consultation, from discussions with key stakeholders and through a rigorous analysis of industrial and academic research and the parameters set in the 3GPP standards body.

A13.44 The new parameter sets have been shared with key stakeholders to ensure they encompass the range of views expressed to us.

A13.45 We have used the revised model and parameter sets to investigate several deployment scenarios and detailed forecasts of site numbers have been produced for HSDPA networks based on different

- frequency bands,
- numbers of carriers,
- levels of user demand,
- data rates; and
- coverage depths.

A13.46 Our analysis of site numbers indicates that, in order to provide the specified levels of coverage and data rates, a network using 900 MHz spectrum would need less than half the number of sites to cover the 80% population area compared to one using only 2100 or 1800 MHz spectrum, if the level of user demand is less than the available capacity of the 900MHz network.

A13.47 When the user demand increases beyond this point, a significant increase in the number of sites versus demand is observed. This corresponds to the network becoming capacity constrained where the number of sites required to provide coverage is not sufficient to support the traffic demand and so more sites are required.

A13.48 The number of additional sites required to expand capacity beyond this point is not dependent on frequency, given equal quantities of spectrum, so capacity constraints could lead to the differences between bands reducing and potentially eventually disappearing if traffic levels were sufficiently high over a sufficiently wide portion of the network.

A13.49 Our analysis shows that if operators with 900 MHz spectrum deployed sufficient sites to provide at least 2.4 Mbps to users at cell edge then capacity constraints do not appear to have any material impact on an HSDPA-based network at 900 MHz if average usage was 30 MB / user / day, even if an operator used only one 900 MHz carrier and did not operate a 2100 MHz network.

A13.50 However, operators deploying UMTS at 900 MHz may already have a 2100 MHz network with at least two carriers available. The effect of having these two carriers in addition to one carrier at 900 MHz, is that they have greater capacity than the analysis of one carrier at 900 MHz suggests, and therefore with one 900 MHz carrier and two 2100 MHz carriers they are likely to be able to handle volumes well in excess of 30 MB/user/day without capacity constraints having a material impact.

A13.51 In conclusion, if operators with 900 MHz deploy a single UMTS900 carrier with sufficient sites in order to realise a coverage advantage, then they will have sufficient capacity to deal with foreseeable traffic growth at least up to 30 MB / user / day.

A13.52 We have also examined the differences in quality associated with deployments at 900 MHz versus those at 1800 or 2100 MHz. Quality is examined here in terms of the proportion of the coverage area over which a given throughput can be maintained for given demand levels for a given number of sites. We have determined that significant increases in quality, may arise for quantities of sites which we consider to be realistic for operators to deploy, even when the number of sites is larger at 2100 MHz (e.g. 15,000 or 9,000 sites) than at 900 MHz (e.g. 7,300 sites).

A13.53

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Introduction

Structure

A13.54 This annex is structured as follows:

a) We explain the **objectives** of the analysis presented in this annex and in Annex 15.

b) We provide a description of the **methodology** which was applied in our previous consultation and which has been refined for this consultation.

c) We present a **list of the issues** we identified after consultation and present a **summary of the consultation responses** and outcomes of subsequent discussions with mobile operators which have led to the need to refine our analysis. This yielded a set of grouped issues that were investigated.

d) We provide an **issue-by-issue analysis**. For each major issue, we then explain the issue raised in more depth, describe what we have done to investigate the issue and explain our findings.

e) We then **summarise the changes to our analysis** technique which result from our investigation of the issues, resulting in the refined analysis approach.

f) Finally, we present the **results** of the refined analysis.

Objectives

A13.55 The overall aims of this analysis are:

iii) to calculate the difference in the number of sites and the resultant cost differences arising from building and operating radio networks that provide the same service with different spectrum holdings and

iv) to determine differences in the level of service (the *quality* as defined in Annex 6) which would be experienced by customers from networks with a given number of sites using different spectrum holdings.

A13.56 Radio networks are assumed to be based on the use of UMTS (3G) technology from macrocells, although the impact of alternative supply techniques is considered. This annex considers the more densely populated regions of the UK, while less densely populated areas are considered in Annex 14.

A13.57 A large number of scenarios are examined to represent differing possible views regarding market demand, technical parameters and approaches to network design and roll-out.

A13.58 The cost difference is calculated by comparing networks that provide the same service with different spectrum holdings. The analysis is separated into two parts:

- In this annex, we present our refined approach to calculating the number of sites needed to deploy a UMTS network in a given band (Part I).

- In Annex 15, we translate those site numbers into costs in pounds (Part II).

A13.59 Questions of whether operators would actually build such a network to yield a commercial return, and the policy implications of each scenario are not considered in this annex, but in Annexes 7, 8 and 9 and in the main body of this document.

Methodology

Overview of Methodology

A13.60 The high level structure of our approach to this analysis is the same as used in the 2007 consultation and is illustrated in Figure 5, divided for clarity into two Parts.

A13.61 The method used in Part I of the analysis to determine the number of sites for a given scenario is summarised as follows:

- For a given market demand, and technological method of meeting this demand, traffic forecasts for macrocells in a given frequency band are produced, along with an assessment of the required performance characteristics.
- A set of technical parameters is fixed relating to the scenario under consideration. These may include the service quality level required, the propagation characteristics at a given frequency band and the morphology and population distribution of the relevant area of the UK.
- A calculation process is used to estimate the density of base station sites which are necessary to provide acceptable service in each of a number of representative environments (clutter types).
- An extrapolation process is used to extend the results based on clutter types to determine the number of sites required to serve the entire densely populated area.

A13.62 The general approach used in part II to determine the network cost given the number of sites is described in Annex 15.

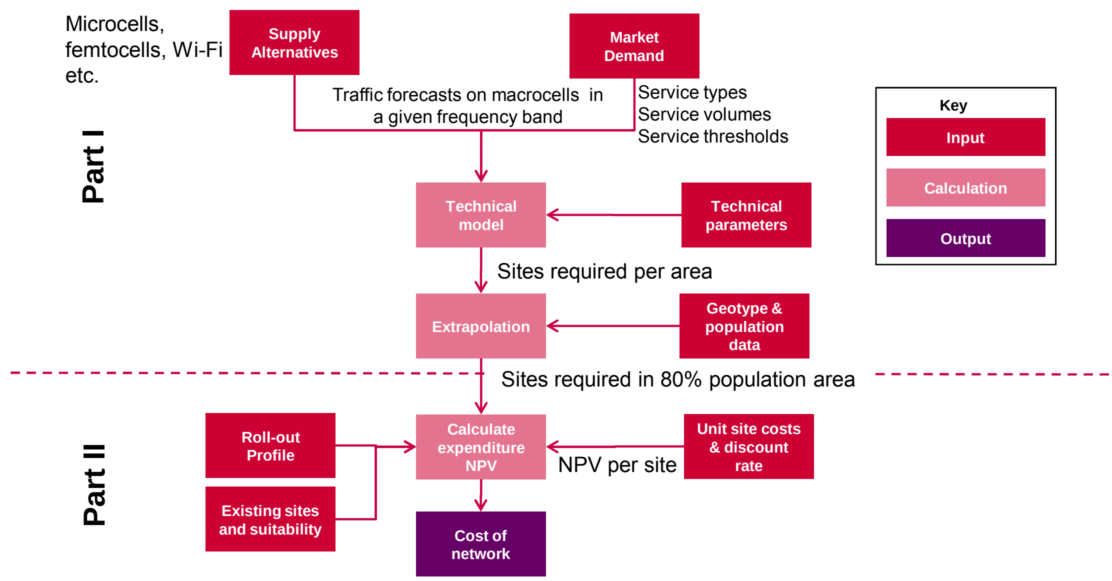


Figure 5: Methodology for Determining the Cost of Delivering Mobile Broadband Services.

A13.63 We remain confident that this is the correct high level approach. While responses to the consultation questioned various parameters and elements of the approach, there was no indication that the general methodology was inappropriate.

A13.64 However, we have made significant changes to the technical model used in the calculation process and to many of the individual parameters, in response to the issues raised and further evidence gathered.

A13.65 In examining the various parameters, we have examined the sensitivity of the outcomes relative to a base case set of parameters for each parameter in turn. This base case, specified in Table 19, Section A13.371, is intended to represent a reasonably plausible set of technical assumptions, but should not be taken to represent our view of the most likely parameters.

A13.66 We have then examined a range of results which correspond to a range of important market parameters as specified in Annex 6. In order to gauge the impact on this range of the various technical parameters sensitivities, we have determined the range for the base case parameters and for upper and lower values of key technical parameters.

Details of Refined Methodology

Supply Alternatives

A13.67 Our analysis focuses on the use of macrocells – those with antennas typically at or above building heights – to deliver mobile broadband services using UMTS standards. These cells constitute the major radio-network related cost in mobile systems currently. Alternative means of supply are discussed and considered in A13.180 *ff*.

A13.68 We are concerned with determining the number of sites required for networks which deliver service via spectrum holdings of a given operator which may include a combination of the frequency bands in consideration, namely 900, 1800 and 2100 MHz.

A13.69 The analysis proceeds by considering the number of sites required to deliver a given service level in each frequency band individually. The number of sites required with multiple frequency bands is determined by combining predictions from each band according to a method as described in A13.147 *ff*.

Market Demand

A13.70 Demand for data services is specified for the purposes of our analysis as follows:

- The density of users in a given clutter type (urban, suburban etc.) is specified based on population data and an assumed market penetration level.
- Users are considered to be separated into three types, with low, medium and high demand for mobile data services, according to specified proportions.
- Each user type accesses various data services, defined by the bit rates of the bearer services required to deliver them.
- Users may access services indoors or outdoors, according to specified proportions for each user type.
- Users of each type access differing quantities of data in total and with a specified mixture of downlink (from network to user) and uplink (from user to network) traffic.
- Services may be accessed on two main types of devices: handsets (including standard mobile phones and smart phones) and data-only devices (including mobile broadband 'dongles' and cellular modems embedded in computing devices such as laptops).

A13.71 The overall demand in a given scenario is specified by the average daily volume of all downlink traffic consumed on average across all users, including those users which do not consume any data. Scenarios are considered which vary between 3 and 30 MB on average per user per day. Additionally, users access voice services at a given traffic level.

A13.72 Full details of the demand assumptions used in the analysis are given in Table 19. The sources used to derive the market projections used in creating these assumptions are specified in Annex 11.

Technical Model

A13.73 In the September 2007 consultation, the main means of calculating the required macrocell site numbers was a simulation and optimisation process. In this consultation we have instead mainly used an analytical process embodied in a technical model.

A13.74 The simulation technique employed previously required the selection of particular geographical areas for simulation purposes, which cannot be especially large due to the computational complexity involved (for example, an area of 100 square kilometres was used previously). This creates technical difficulties in reliably extrapolating to the whole of the area of interest (for comparison, the 80% population area is approximately 30,000 square kilometres).

A13.75 The technical model is based on widely used analytical techniques for predicting the performance of UMTS systems. It takes the technical and service parameters for a given scenario as input and produces the density of sites to support this service at a given frequency as output. The site density is calculated for each of a number of generic clutter types, which are used to specify both the propagation and traffic characteristics. In this way, reliance on the selection of a particular representative simulation area is avoided, and extrapolation can be performed via knowledge of the characteristics of the clutter over the whole of the 80% population area. Additionally, the technical model permits more generic analysis of the variation of site density with the distribution of traffic than the simulation approach.

A13.76 There are however known limitations associated with the technical model:

10.76.1 No account is taken of real-world propagation, cost or site planning constraints.

10.76.2 The approach analyses a single service and user class at a time.

10.76.3 No direct account is taken of power control and call admission control processes which are a feature of realistic networks.

10.76.4 Interference control using features such as antenna downtilts is not modelled directly.

A13.77 Nevertheless, we believe that this approach to modelling is a better basis for comparison since it allows a wider range of parameters to be explored and a more consistent framework for determining the consequences over the whole area of interest.

A13.78 The process embodied in the technical model is illustrated in conceptual form in Figure 6 and broadly follows the approach given in [1]. The details of the model are provided in Appendix A13.1. The process commences by taking the specified traffic density and service parameters and computing the density of users which would concurrently access services in a given clutter type. This density is then used to calculate the number of users simultaneously accessing a given cell on the same frequency for an initial assumed site density and for the specified number of carriers.

A13.79 In the downlink, the transmit power used represents the proportion of the total power available for dedicated channels, which bear the traffic to particular users. The remaining transmit power is used for common channels, which create an additional source of loading.

[1] Holma and Toskala, “WCDMA for UMTS”, Third Edition, John Wiley, 2002.

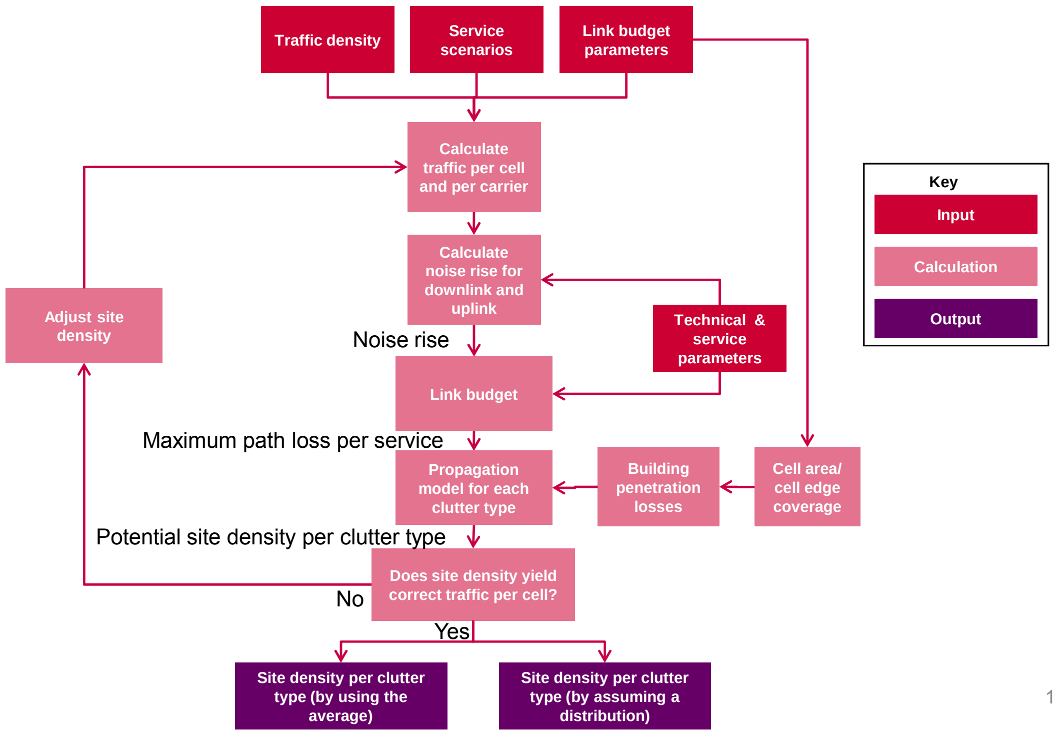


Figure 6: Process used for calculating site densities via technical model.

A13.80 The noise rise created by the concurrent users and the pilot power in each cell is calculated for the uplink and downlink separately.

A13.81 If the resultant noise rise exceeds a specified limit the site density is increased to maintain the noise rise at or below this level, to ensure that the network delivers acceptable performance.

A13.82 The noise rise is then used as one element of a link budget, which combines the various technical and service parameters applicable to the scenario of interest to determine the maximum acceptable path loss for the downlink and uplink. In the downlink, account is taken of the limited transmit power available from the base station to share amongst users.

A13.83 The maximum acceptable path loss is then used to calculate the maximum cell range via an appropriate propagation model and hence to determine the density of sites required to meet the service in each clutter type.

A13.84 This density is then used to confirm whether the cell would cover the same quantity of traffic as was initially calculated. If not, the site density is adjusted and the process is repeated to ensure that a consistent outcome is produced.

A13.85 The site density is initially calculated independently for the uplink and downlink. Finally the larger of these two values is retained, representing the need for the network to deliver both uplink and downlink service from the same sites.

A13.86 A similar link budget is separately calculated with respect to the common pilot channel in the downlink to ensure that the pilot power and pilot quality (usually denoted Ec and Ec/Io respectively) meet specified thresholds. If attainment of the Ec or Ec/Io targets leads to a lower maximum acceptable path loss than the calculation involving the dedicated power, then again the site density is adjusted to reflect this restriction.

Extrapolation to wider area

A13.87 This annex is concerned with the number of sites required to serve the most densely populated areas of the country. These are defined in most scenarios by the area within which 80% of the population live.

A13.88 In order to translate from the site densities produced by the technical model into an estimate for this wider area a process of extrapolation is used.

A13.89 In a simple case, the total number of sites required is determined by multiplying the site density calculated for each clutter type by the area of each clutter type within the target area and summing the results. This effectively assumes that the site density in the clutter area is represented by the number of sites required to serve the average density of users across the area.

A13.90 In practice, the user density may vary significantly within one clutter type. In order to represent this effect, the technical model can be run for a wide range of user densities. A distribution of user densities is calculated, representing the relative frequency of given user densities within each clutter type. These distributions are used to individually to weight the site densities from the technical model, before again multiplying by the total area of each clutter type and summing. This process accounts in a more complete fashion for the influence of 'hot spots' where traffic peaks occur.

A13.91 The impact of this is considered in Section A13.311 *ff*.

Definition of densely populated areas

A13.92 Traffic densities are derived from user densities, which in turn are derived from population densities.

A13.93 Population densities and the 80% population area are defined using 2001 UK census data for England, Wales and Scotland[2] mapped to postcode districts. The 80% area thus corresponds to the smallest area which contains 80% of the population according to the postcode district data.

A13.94 For propagation purposes, a clutter database was used with 50m resolution and seven clutter classes. A sample of this data is shown in Figure 7.

[2] Note that clutter data was not available for Northern Ireland, so only England, Wales and Scotland were considered.

Figure 7: Example of clutter data (dense urban = dark red, urban = red, open-in-urban = pale green, suburban = yellow, forest = dark green, open = bright green, water = blue).

A13.95 When the 80% population area, based on output areas from the 2001 UK census, is divided into postcode sectors and these are mapped to the clutter types, the total area associated with each clutter type is as shown in Table 6.

Table 6: Distribution of clutter types over the 80% population area.

Clutter type	Area (km^2)
Water	514.6
Open	17565.2
Forest	2392.2
Suburban	8985.0
Open In Urban	1387.1
Urban	572.7
Dense Urban	26.7
total	31443.9

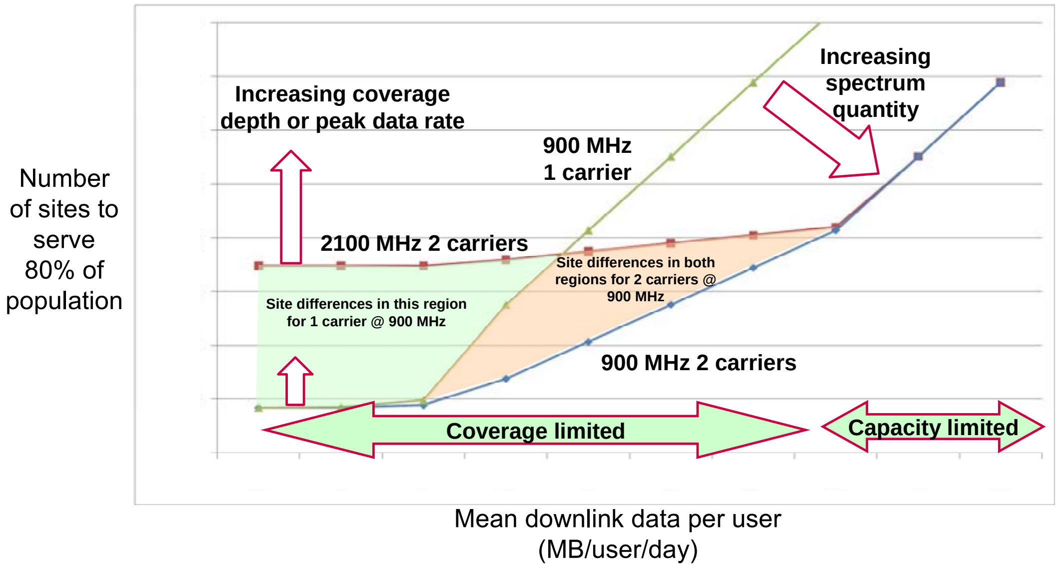


Figure 8: Illustration of behaviour of 3G network coverage and capacity limitations.

General behaviour of 3G networks

A13.96 The general behaviour of the technical model described above can be illustrated with reference to Figure 8. This shows the number of sites required to deliver a given service on the vertical axis versus the average volume of data accessed by users on the horizontal axis. Note that this figure is illustrative only and the particular numerical results should not be considered as representative.

A13.97 The green and blue lines show the behaviour of a 900 MHz network with 1 or 2 carriers respectively, while the red line shows the behaviour of a 2100 MHz network with 2 carriers.

A13.98 In each case, for low data volumes, the network is typically coverage limited. The limited transmit power of the mobile has to overcome propagation losses in order to produce a sufficiently strong signal at the base station receiver for successful communication, relative to the noise generated by the base station receiver. As the number of users increases, the number of sites rises due to interference amongst the co-channel users arriving at their own and surrounding base stations.

A13.99 Thus the site difference encountered for low capacity requirements is defined in part by the uplink system parameters, including propagation losses, antenna gains, the mobile device transmit power, the noise figure of the base station receiver and the peak service data rate.

A13.100 The site count for low data volumes is also impacted by the need to maintain adequate quality in the pilot channels which are transmitted continuously by all base stations. The extent to which the uplink or the pilot channel quality dominates depends on the particular service parameters selected.

A13.101 The site difference for very small numbers of users is not directly affected by the quantity of spectrum available. However, the rate of increase of sites due to interference amongst users is affected, as multiple carrier operation allows users to be spread between carriers reducing the interference amongst them.

A13.102 The downlink is affected by similar parameters, but is additionally constrained by the finite power available to serve users. Thus the site density defined by the downlink is initially smaller than the uplink, but as the user density rises, the site density is impacted by a combination of increased interference amongst users and by the constrained power available. The downlink site density therefore increases at a higher rate than the uplink and eventually becomes the determining constraint on the number of sites, resulting in a capacity limited system. When networks at both frequencies are downlink-limited, the number of sites required is essentially independent of frequency, assuming all system parameters are identical.

A13.103 Additionally, a limitation on the total interference level (the *noise rise*) has to be imposed, to ensure that the power control processes in the system remain stable and to maintain acceptable service quality. The number of sites required beyond this limit is then directly proportional to the user density and is unaffected by the propagation parameters.

A13.104 The shaded region in Figure 8 therefore defines the region in which site differences may be observed between networks using different frequency bands to deliver a similar service. This region will be quantified in detail in this annex. Results are mostly presented in a similar form to Figure 8.

Summary of responses

Introduction

A13.105 We examine next a list of issues raised by responses to our consultation and by other new evidence.

A13.106 For each issue we analyse the impact that the issue has on the results presented in the consultation.

A13.107 In many cases, we are investigating the issue quantitatively, while other issues lend themselves to a more qualitative approach.

A13.108 In determining the overall range of outcomes, we are combining multiple issues where appropriate.

A13.109 Each section summarises the issues, approach to analysis and findings so far.

A13.110 This section deals solely with comments relating to the site numbers which are the output of Part I of the analysis and relating to the technical parameters that are assumed within the analysis. Responses relating to the market scenarios are covered in Annex 11, while those relating to network costs are examined in Annex 15.

Summary of responses received

A13.111 We received a wide range of opinions on the site counts needed to achieve an appropriate level of mobile broadband service for 80% of the UK population, summarised as follows:

- O2 conducted their own assessment exercise and concluded that blanket indoor coverage, meeting the scenarios defined in Ofcom's 'High' and 'Medium' adoption scenarios, could be achieved with 11,500 sites at 2100 MHz, compared with 29,000 (high adoption) or 17,900 (medium adoption) in the consultation. This was based on their own demand forecasts and a network targeted to deliver -75 dBm indoor pilot signal coverage to users with an average traffic demand of 1MB/user/day.

- Vodafone produced an estimate of the number of sites required by adjusting Ofcom's estimates to include the impact of assuming in-building propagation loss to be the same at 900 and 2100 MHz (rather than 3dB higher at 2100 MHz in the consultation) and for the use of HSDPA (rather than 384 kbps release 99 traffic), yielding 15,100 sites at 2100 MHz for high adoption (versus 29,000 in the consultation).

- T-Mobile broadly supported Ofcom's findings, but noted that the savings of delivering services at 900 MHz are at least as high as Ofcom's estimates.

- Three suggested that the benefits of 900 MHz were underestimated by Ofcom due to the need to plan for higher maximum traffic loads, to account for the minimum cell radius arising from cell breathing effects and to account for planning for higher data rates in HSDPA.

- Orange broadly supported Ofcom's analysis of the effects, but stated that the analysis was overly simplistic and theoretical in places, for example in respect of the assumed coverage confidence levels.

A13.112 In summary the responses from operators indicated substantially different site numbers than our estimates, being substantially lower in the case of the 900 MHz operators and substantially higher in the case of the other operators.

A13.113 There is clearly a significant divergence of views relative to the consultation and amongst respondents and a need to examine and refine the analysis in detail.

Review

A13.114 Our main method of investigating this issue has been to re-examine and refine our own analysis, and the results of this analysis are reported later in this annex.

A13.115 In addition to conducting our own revised analysis to investigate this variation in site numbers, we have gathered data from other sources.

A13.116 One such source is a report by the Global mobile Suppliers Association (GSA), who provided a comparison of cell areas for various services at 900 and 2100 MHz[3]. The comparison of WCDMA coverage in Figure 9 yields site ratios of approximately 2.9 for voice and 3.1 for 1 Mbps data.

[3] "UMTS 900 Global Status", www.gsacom.com, Global mobile Suppliers Association.

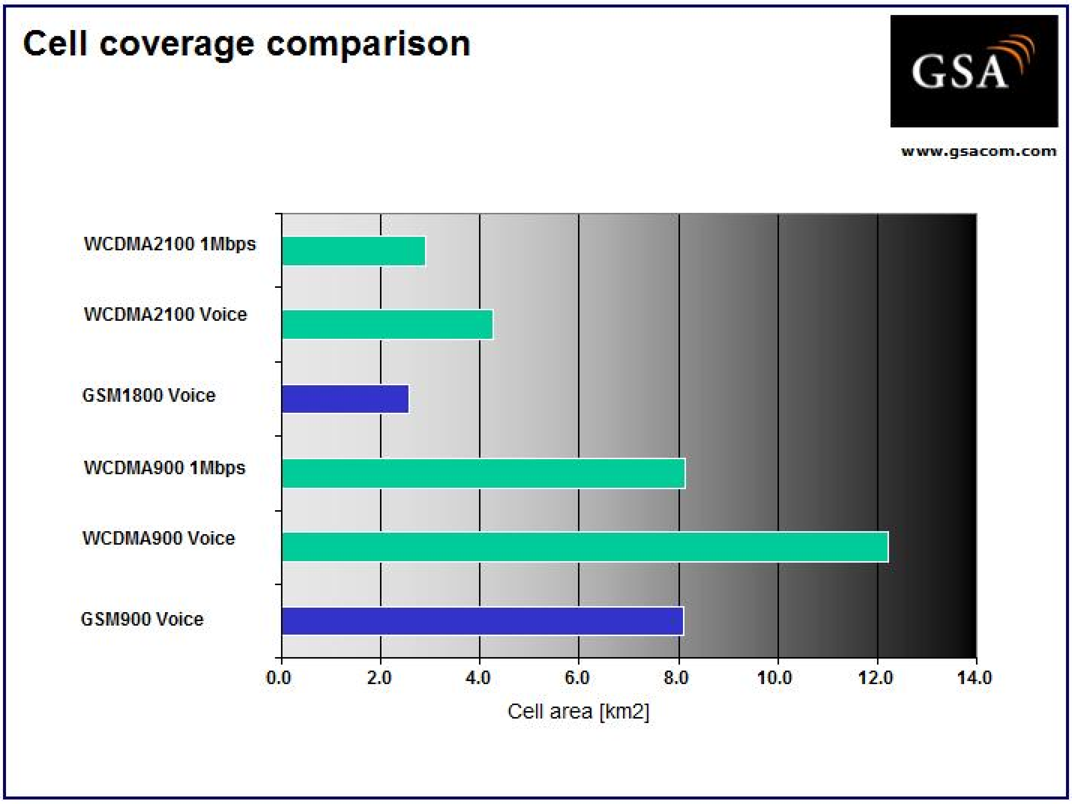


Figure 9: Cell coverage comparison by GSA.

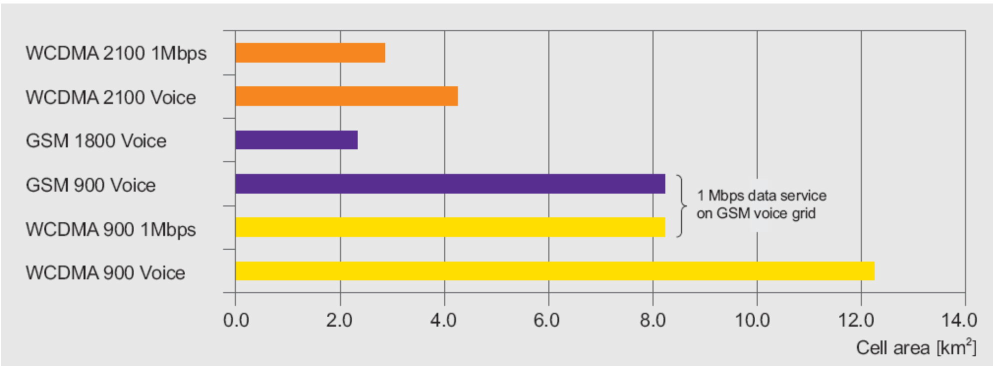


Figure 10: Comparison of coverage area per cell for various networks from [4].

A13.117 Nokia-Siemens Networks published a white paper comparing GSM and WCDMA coverage at various frequencies and service types[4]. Figure 10, reproduced from the paper, shows that a GSM900 network's voice coverage in a suburban area indoors is similar to the coverage obtained by the same network for 1 Mbps data service using WDCMA 900. It also indicated that approximately 2.8 times as many cells would be required to deliver the same coverage at 2100 MHz.

[4] "WCDMA Frequency Refarming: A leap forward towards ubiquitous mobile broadband coverage", Nokia Siemens Networks White Paper.

A13.118 Relevant work was conducted on behalf of Ofcom by Analysys Mason within the Digital Dividend Review project[5]. This compared cell counts at 2100 MHz and in the upper part of the digital dividend UHF spectrum between 790 and 862 MHz, close enough to the 900 MHz band to provide a valid comparison, shown in Figure 11. The site ratio is constant at around 2.4 times.

A13.119 Our previous consultation results are shown in Table 7, together with the consequent site ratios.

Figure 11: UMTS cell counts from digital dividend review project

Table 7: Site counts from September 2007 consultation.

	900 MHz	2100 MHz	Ratio
Low	6600	13900	2.11
Medium	7500	17900	2.39
High	8400	29000	3.45

Findings

A13.120 There is considerable variation amongst site counts indicated by various sources. This may arise from the wide range of possible parameters when comparing networks at various frequencies.

A13.121 However the ratio of site counts between frequency bands is typically found to be in a range from 2 to 3.5 times, depending on the source and the conditions. The results of the analysis in our previous consultation were in this range.

[5] "Digital Dividend – Mobile Voice and Data (IMT) issues", Study for Ofcom Digital Dividend Review, Mason Communications Ltd, October 2007.

A13.122 We therefore find that the results of our analysis are not inconsistent with other sources, as far as the broad behaviour is concerned.

Technical Issues

A13.123 Table 8 summarises the major technical issues raised by consultation responses from the mobile operators. The responses have been grouped into high-level issues.

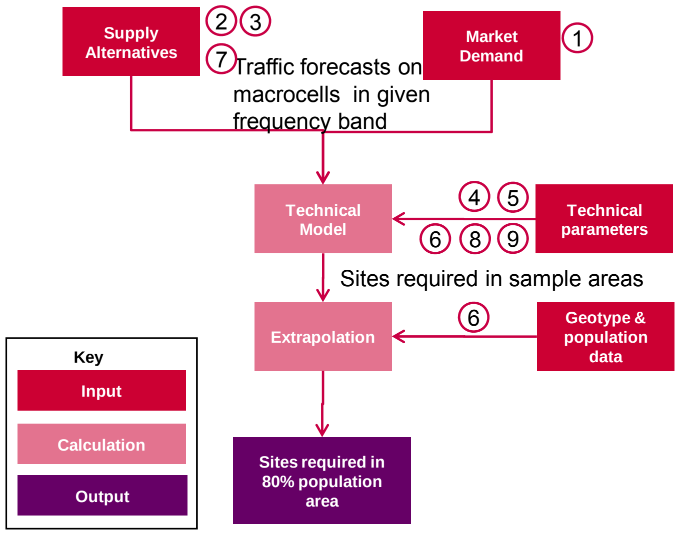
A13.124 This is not intended to be a comprehensive list of issues raised. Confidential responses are not included but have been considered in the refined analysis.

Table 8: Summary of technical issues raised by consultation responses.

Issue	O2	Vodafone	Orange	T-Mobile	Three
1. Mobile broadband demand, and traffic forecasts	Outdoor & rural coverage is the predominant requirement of users Absence of demand and absence of evidence to the contrary Capacity will be the binding constraint, not coverage	Too many 3G subscribers in 2010, especially due to handset availability – forecasts more relevant to long-run demand. Level of voice demand assumed is too high.		Ofcom's central demand forecast is relatively conservative	Very fast growth – up to 800% in throughput per year
2. Mixed frequencies planning issues	UMTS2100/UMTS 900 with different coverage leads to unacceptable amount of handover Blanket coverage at 900 MHz is inefficient - more efficient to build a few more 2100 MHz sites	Quality of inter-frequency handovers might be a major obstacle;			

Issue	O2	Vodafone	Orange	T-Mobile	Three
3. Alternative coverage techniques (e.g. UMA/Wi-Fi, femtocells, repeaters)	For indoor locations there would be substitute networks in most cases, namely Wi-Fi or fixed access				
4. Propagation differences of 900 MHz	Propagation benefits are illusory in the UK context	Negligible Building Penetration Loss differences	Well-known differences for rural and in-building coverage.	Large indoor and outdoor differences	Differences have been underestimated.
5. Handset sensitivity		Need to account for 3dB worse UE sensitivity at 900 MHz			
6. Simulation area & extrapolation		Area not representative, sensitive to assumptions, scaling not well justified			Area is unrepresentative
7. Quantity of spectrum and 1800 holdings	At high demand levels cell splitting is the binding constraint and 1800 MHz operators have an enduring advantage due to quantity of spectrum	2 carriers may not be available at 900 MHz – need to account for one carrier situation to avoid overstating benefits	Unlikely that 1800 MHz would offer an advantage over 2100 MHz. 1800 held by 4 operators so any benefits available to all of these	No significant cost difference between 1800 and 2100 MHz	Equipment is available; need to account for capacity differentials. 1800 MHz has better propagation characteristics than all other 3G-ready spectrum except 900 MHz

Issue	O2	Vodafone	Orange	T-Mobile	Three
8. HSDPA		More efficient multiplexing and less concurrent users will presumably tend to reduce the number of sites required			HSDPA at high rates implies larger differences
9. Site engineering	Confidential queries				



A13.125 Figure 12 identifies how these issues relate to Part I of our analysis methodology.

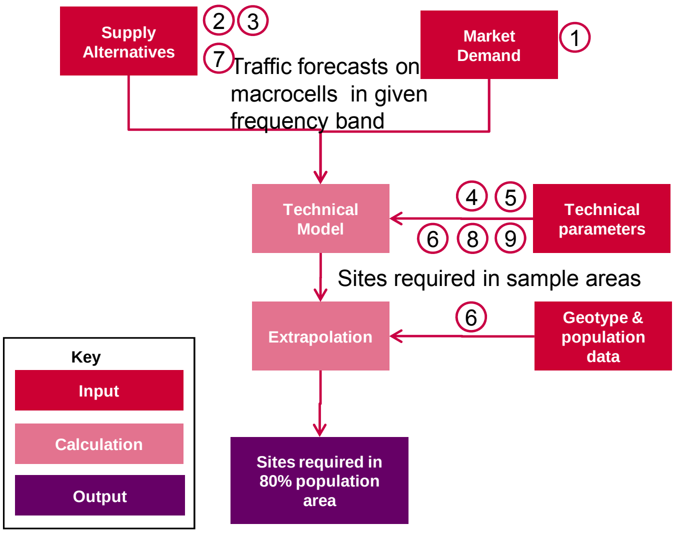


Figure 12: Identification of how issues raised by consultation responses relate to the site number evaluation methodology.

A13.126 In this investigation of issues, we have primarily chosen to fix all parameters, other than those being investigated, at the values indicated in the base case as specified in Table 19. Following investigation of these issues, we have modified the set of technical parameters and variables arising from the market scenarios to yield the refined results.

Issue 1 – Forecasts of mobile broadband demand

Issue

A13.127 Consultation responses indicated that recently the growth of mobile broadband demand has been strong, increasing the relevance of the cost of networks to serve this level of demand.

A13.128 Some responses indicated that, as the demand for data quantities rises, networks will become increasingly capacity constrained (rather than coverage constrained). Under these circumstances, the number of sites required at each frequency band will become more similar, thereby reducing the cost difference.

Analysis

A13.129 Given the potential for higher mobile broadband demand than considered in the previous consultation, we have conducted an analysis based on the technical model described earlier to examine the potential for capacity constraints to occur.

A13.130 We have varied the average data volume per user over the range 0.3 – 30 MB / user / day, for 900 MHz (1 and 2 carriers),1800 MHz (2 and 4 carriers) and 2100 MHz (2 carriers), yielding the results shown in Figure 13 for the number of sites required to provide service in the 80% population area subject to the parameters according to the base case as given in Table 19.

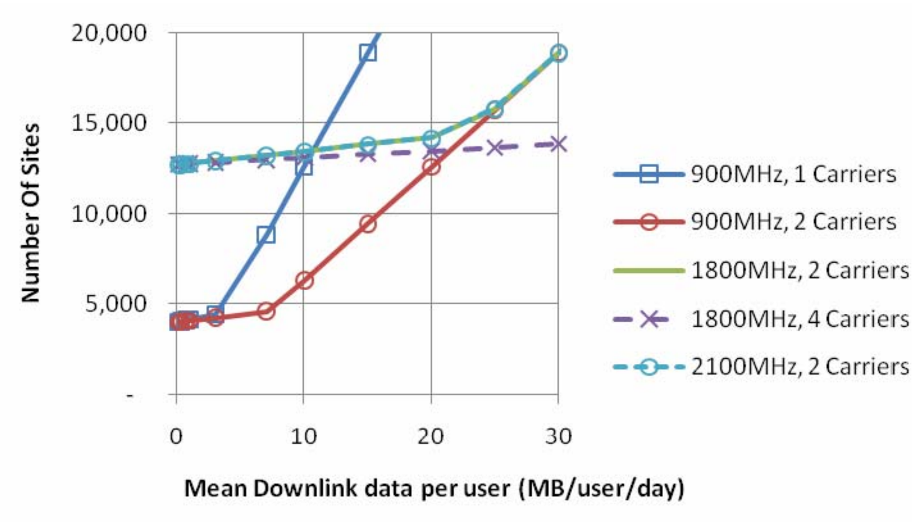


Figure 13: Results of theoretical analysis of capacity constraints.

A13.131 The results showed that, as asserted by some responses, the capacity of the sites does eventually become a limiting factor in the site coverage. The number of sites required to serve additional traffic is then independent of the additional traffic served.

A13.132 When a single carrier is available at 900 MHz, downlink interference constraints dominate at a relatively low data volume. When two carriers are available the number of simultaneous users causing mutual interference is halved, so the network remains coverage constrained up to higher traffic levels.

Findings

A13.133 We note that it is theoretically possible that, for high levels of required capacity, the differences in the numbers of sites required in different frequency bands may diminish substantially.

A13.134 For the parameters we have investigated, increases in data volume beyond several megabytes per user per day cause site differences to begin to diminish and to become reduced to zero between 10 and 25 MB per user per day. The point at which the site difference goes to zero is lowest when the smallest quantity of 900 MHz spectrum is available.

A13.135 A number of factors could offset the overall impact of such capacity constraints:

- Average demand could be lower than the level required for the network to exhibit significant capacity constraints.

- Although some areas of the network are capacity constrained, much of the network area could have much lower traffic densities, where the network is coverage-limited.
- Significant capacity constraints could occur late in the network lifetime, so for most of the near and medium term significant noise-limited coverage differences could dominate.
- Market requirements for deeper coverage levels over time could increase the extent of site differences.
- The use of small cells (such as microcells, picocells and femtocells) could be used to serve the areas of densest traffic, offloading the most challenging traffic from the network, leaving the remaining network as predominantly coverage-limited.

A13.136 Despite these offsetting factors, the potential for capacity constraints could significantly affect the overall impact of any site differences and must be carefully considered in assessing the overall impact in Annex 8. However these constraints are only significant if the volume of data likely to be transferred is high enough. In the case of the use of multiple frequency bands (see § A13.137 *ff*) or of the use of HSDPA (see §A13.332 *ff*) the data volume for capacity constraints will be seen to increase significantly compared to the volumes calculated in Figure 13.

Issue 2 – Mixed frequencies planning issues

Issues

A13.137 Some consultation responses indicated concerns that, given that today's 3G networks are all deployed at 2100 MHz, realising any site difference associated with access to lower frequencies would require a network with service provided using a combination of frequency bands.

A13.138 To achieve cost reductions associated with any difference in sites required between frequency bands, the network would need to provide different coverage areas for different frequency bands, while still delivering equivalent services everywhere, i.e. the 'coverage extension' approach illustrated in Figure 14.

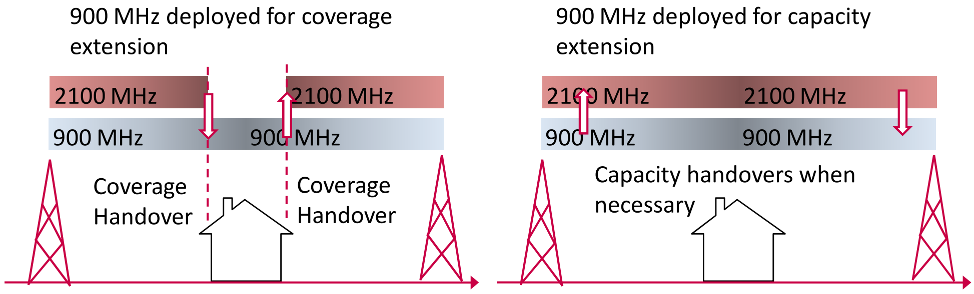


Figure 14: Deployment approaches for 3G networks using multiple frequency bands

A13.139 As a mobile handset moves around the network, inter-frequency hard handovers will be required when the less-extensive network does not provide adequate coverage. Some responses suggested that these handovers may seriously degrade quality of service and network efficiency.

A13.140 As a consequence, these responses suggested that operators would need to deploy all network layers with the same coverage, reducing the site differences and using 900 MHz mainly for capacity, i.e. the 'capacity extension' approach illustrated in Figure 14.

Analysis

A13.141 We have spoken to vendors and overseas operators regarding their expectations and experiences of such inter-frequency handovers. The responses indicate that:

10.141.1 Inter-frequency hard handover is fully supported by 3GPP standards from release 6 onwards (the relevant protocol extensions are specified in 3GPP technical specification TS 25.331).

10.141.2 Compliant equipment is available or in development and according to public data has been field-trialled and commercially deployed by operators including Elisa, Telstra, AT&T, SFR, Telefónica and Optus.

10.141.3 Efficient traffic management between 'layers' requires careful network optimisation to set handover thresholds and cell coverage areas to ensure traffic is on the 'correct' layer for coverage and capacity purposes.

10.141.4 Some temporary disruption of service may be involved during handover, with increased latency for packet services during the handover.

10.141.5 Inter-frequency hard handovers will be required even when using 900 MHz for capacity relief due to the need to balance traffic loading between carriers.

10.141.6 For many data services, some short-lived disruption will not be apparent to the user.

10.141.7 Users camped on 900 MHz need not handover until its capacity is exceeded.

10.141.8 The extension of coverage for improved indoor service using 900 MHz is widely envisaged by industry bodies - see for example [6] and [7]:

A13.142 The use of mixed-frequency networks will allow capacity constraints to be relieved by higher-frequency spectrum, freeing the lower frequency to provide coverage for more challenging traffic. The number of sites required in total will then be less than required for a single-frequency network with an equivalent quantity of spectrum. A method for accounting for this effect is described in §A13.147 *ff*.

Findings

A13.143 Inter-frequency handover is supported by equipment and standards and is required even for the use of 900 MHz for capacity extension.

A13.144 Achieving good network performance will require careful optimisation of the 900 and 2100 MHz network layers with respect to each other. Such optimisation is comparable to the requirements for optimising 900 and 1800 MHz GSM handovers, handover between 2100 MHz UMTS carriers or inter-radio-access technology (RAT) handover between GSM and UMTS.

A13.145 It does appear feasible, based on evidence received, to deploy 900 and 2100 MHz traffic on layers with different coverage levels and thereby realise any potential site difference.

A13.146 We will therefore continue to model use of 900 MHz as a means of coverage extension in combination with higher frequencies, since it appears reasonable that network operators would overcome the challenges of optimising a network layer to obtain any associated cost or quality benefits, just as they have in the past with GSM on multiple frequency bands.

Impact of mixture of frequency bands on site numbers

A13.147 The technical model described so far shows calculations for a single frequency band at a time.

A13.148 In practice, operators are likely to deploy a combination of the several different bands they possess. In particular, any UMTS 900 operator will also have UMTS 2100 bands.

A13.149 We are not aware of a widely accepted methodology for modelling site counts for an operator deploying a combination of bands. However, we present here a method to estimate a range for the impact of deployment of mixed frequencies.

Analysis

A13.150 The following description relates simply to the advantages in principle of mixed frequencies. It does not take into account existing operator deployments, but only focuses on the number of sites needed in principle as a function of spectrum portfolios. All effects relating to existing operator deployments are explored in Annex 16.

[6] UMTS900 – Benefits and issues, GSMA February 2007

[7] UMTS Forum Report No. 38

A13.151 Starting with the number of sites needed to achieve a given level of service with a single band according to the technical model and adding additional carriers, whether in the same band or not, we expect the following behaviour:

- If the network is purely coverage constrained, adding extra spectrum has no effect.

- Otherwise, the additional spectrum can carry some proportion of the traffic and allow expansion of cells.

A13.152 Going back to the specific example with a mix of frequencies, it is helpful to think, conceptually, that we are:

- starting from the lower frequency layer and

- adding to it a higher frequency layer, which allows an expansion of the lower frequency layer – i.e., a larger cell size.

A13.153 The above does not describe a sequence in time, but it is used to aid presentation.

A13.154 We present a method that:

- starts with a first order estimate;

- then refines the results in a second order estimate;

- we also present a simpler version of the calculation.

A13.155 The input used for these estimates is the cell size as a function of volume of data, for both the low frequency and high frequency bands. These are provided by the single frequency model, and take into account the number of carriers available at each band.

First order approximation

A13.156 For a first order approximation, we make the following assumptions:

i) Every square meter of the cell takes the same amount of resources to serve. This is not a realistic assumption: in practice, the outer edge of the cell (defined in terms of path loss) is harder to serve. We will come back later to the consequences of this assumption.

ii) The lower frequency layer is capacity constrained and will expand if the traffic load is lightened e.g. by transferring it to another band. We will refine this assumption later.

A13.157 We know from the inputs provided from the single layer modelling that:

a) The lower frequency carriers can cover an area of X m^2.

b) The higher frequency carriers can cover an area of Y m^2.

A13.158 Since the lower frequency layer is free to expand once traffic is lifted (assumption ii), it will expand when the higher frequency carriers are added to it.

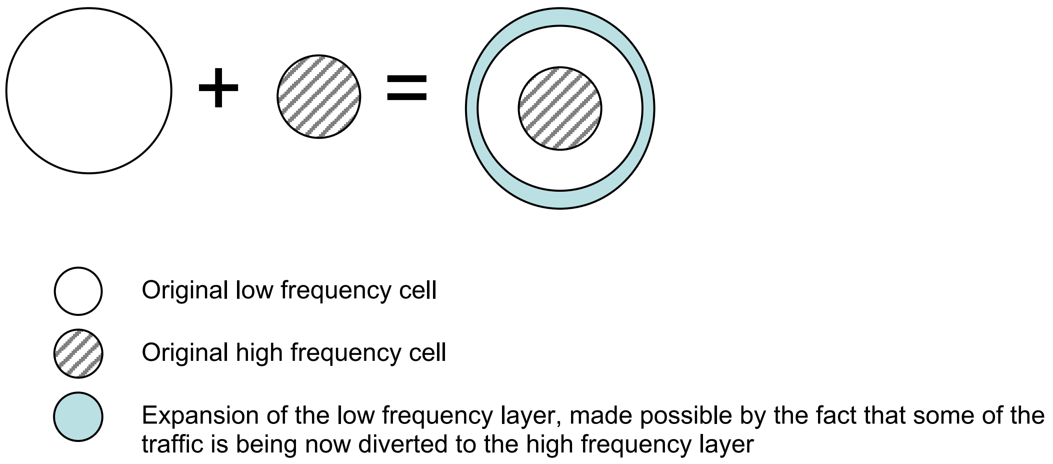


Figure 15: A mixed frequency cell can be larger than a single frequency cell

A13.159 How large will the expansion be? Given that:

- any m^2 of traffic is equally hard to serve (assumption i),
- the high frequency layer can cover an area of Y m^2

A13.160 It follows that the low frequency layer, assisted by the high frequency layer, can expand by Y m^2. The first order estimate for the mixed frequency cell size is simply X + Y. This is illustrated in Figure 15.

Second order approximation

A13.161 The second order approximation uses as an input an estimate of the proportion of traffic that the high frequency layer can carry, as part of a mixed frequency cell.

A13.162 Based on the first order approximation, and using assumption (i), the proportion of traffic in the high frequency layer is simply the ratio of the area covered by the high frequency layer over the area covered by the full cell size. This is

- Y/(X+Y).

A13.163 We therefore reduce the traffic carried in the lower frequency layer by the above amount, and use the single frequency modelling to calculate how much larger the lower frequency layer becomes. This illustrated in Figure 16.

A13.164 This method can also be generalised to cases where the number of higher frequency cells is larger than the number of lower frequency cells. This is likely to be the case in a transition period, when UMTS 900 will not have been fully deployed yet.

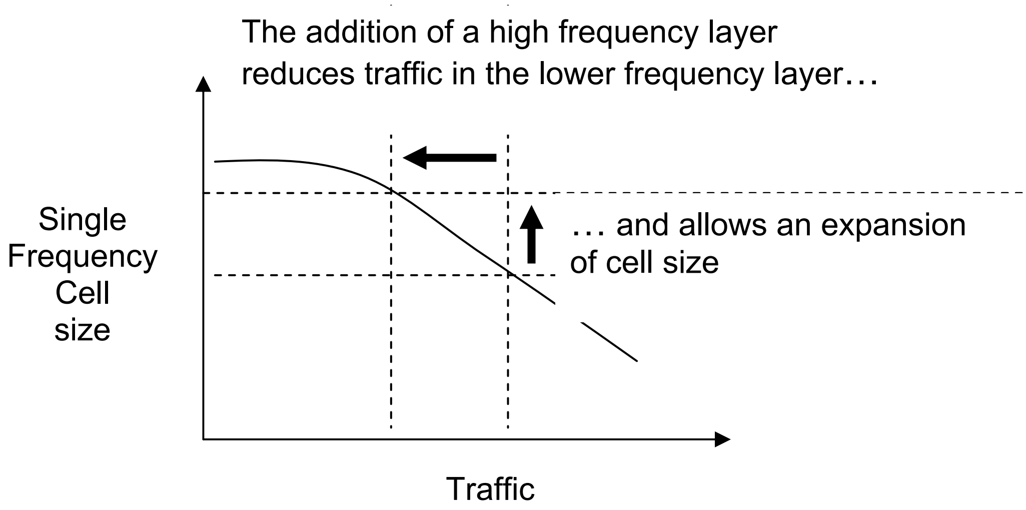


Figure 16: The second order estimate

A13.165 This generalisation can be done by simply adjusting the total area covered by the high frequency layer to account for the fact that there are more high frequency cells. Calling the ratio of high frequency cells to low frequency cells W, the equation in §A13.162 becomes:

- YW (X + YW).

A13.166 The usage of this estimator is illustrated in Figure 17 with an example. The chart was produced using the results for the scenario where data rates are 1.2 Mbps at 95% confidence and indoor penetration is at depth 2 as defined in section A13.255 *ff*.

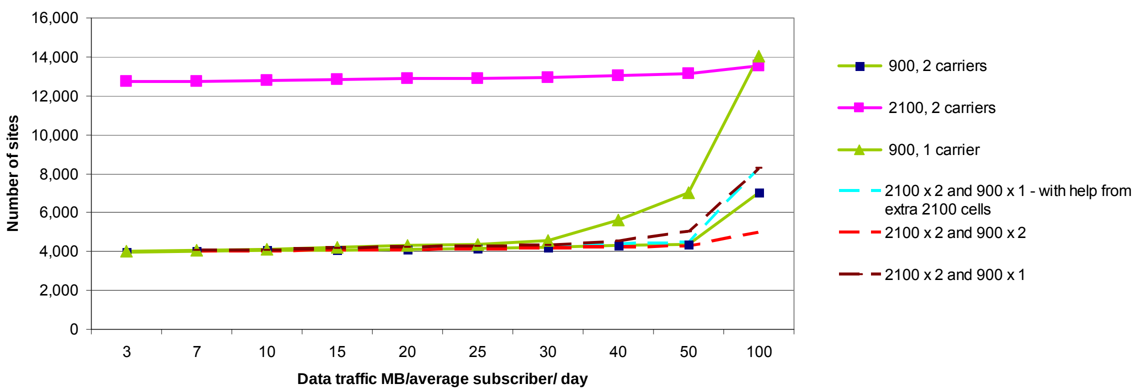


Figure 17: Example of the second order estimate.

A13.167 The solid lines above were all calculated using the single band model, and the legend shows frequency and number of carriers. The dotted lines show different mixed band estimates. These are:

- Two carriers at 2100 MHz, and one carrier at 900 MHz, with the help from additional 2100 MHz-only sites. This was calculated for the case where there are 50% more 2100 MHz cells than there are 900 MHz cells.

- Two carriers at 2100 MHz, and two carriers at 900 MHz, and all sites operate at both frequencies

- As above, but with only one carrier at 900 MHz

A13.168 We note that:

- For data traffic up to around 30 MB/user/day, the networks are largely coverage constrained and adding spectrum has no impact

- Between 40-50 MB / user / day, the single carrier 900 MHz network is capacity constrained, and all mixed band networks show similar results to that of a network with 2 carriers at 900 MHz

- At 100 MB / user / day, there is a visible advantage of a second 900 MHz carrier that cannot be replicated by a mixed frequency network with a single 900 MHz carrier

Limitations of this estimate

A13.169 When the lower frequency cell size is larger than the higher frequency cell size, this methodology overestimates the cell expansion possible. This is because the hardest traffic to serve is that closest to the cell edge. The higher frequency layer has limited reach, so it will not carry traffic close to the mixed frequency cell edge.

A13.170 In other words, the second order estimate is a maximum value for the impact of adding a high frequency layer to a lower frequency layer. The reduction of traffic afforded by the higher frequency cell cannot generate as much benefit as measured by the second order estimate, save for cases when both layers are capacity constrained to the point where both can reach the cell edge of the mixed frequency cell.

A simpler estimator

A13.171 The main results required for this analysis are those concerned with the service provided by a network that uses a single carrier at 900 MHz plus additional carriers at 2100 MHz.

A13.172 We note that, if the 2100 MHz carriers are carrying exactly 50% of the traffic, then the calculation of the second order estimate (for a network with 1 carrier at 900 MHz plus 2100 MHz) will yield the same result as the calculation of a single band network with 2 carriers at 900 MHz.

- This is intuitive: the second order estimate works by reducing the total traffic into the single 900 MHz carrier. Adding a second 900 MHz carrier has the same effect.

A13.173 Another way of stating this is to say that the range between one and two carriers at 900 MHz will encompass the range of the second order estimate, except in the following case:

- When the second order estimate would attribute more than 50% of the traffic to the 2100 MHz carriers.

A13.174 This would only happen in two cases, according to the equation in paragraph:A13.165 :

i) either the cell size ratio is 1:1 (i.e. in capacity constrained scenarios where the differences between bands becomes unimportant);

ii) Or the cell size ratio is more than 1:1, but this is made up by 2100 MHz cells outnumbering 900 MHz cells by at least the same proportion.

A13.175 In some years of the roll out profiles described in Annex 15, 2100 MHz cells do outnumber 900 MHz cells significantly. However, in the main scenarios of interest, the cell size ratio is even more significant, around 3:1. Therefore, we do not expect cases (i) or (ii) to occur within most scenarios.

A13.176 Therefore, a simple estimate of the maximum impact of adding 2100 MHz to a single carrier UMTS 900 network is the estimate of the UMTS 900 network with two carriers. This is in most cases an even more optimistic estimator than the second order calculation.

A13.177 This can be illustrated again by referring back to Figure 8. All of the mixed band, single 900 MHz carrier results are contained within the bounds of the 900 MHz, 1 carrier result, and the 900 MHz, 2 carriers results.

Conclusions

A13.178 We estimate the maximum impact of adding 2 carriers at 2100 MHz to a 1 carrier 900 MHz network first via the simpler estimate described above. This uses the calculation for 2 carriers at 900 MHz as the upper limit for cell size of the mixed band network.

A13.179 Only if there is reason to find a narrower range for this result would we use the more complex second order estimate described above. However, we observe that, in most scenarios of interest, the results in between 1 and 2 carriers already provide a narrow range.

Issue 3 – Alternative coverage techniques

Issues

A13.180 The September 2007 consultation concentrated on meeting service targets based on the use of conventional macrocells and found that achievement of these service targets in densely cluttered environments and indoors requires a larger number of macrocells at lower frequencies.

A13.181 However, there are other means of achieving service based on alternative cell types and technologies. These include microcells, picocells, femtocells, repeaters & Wi-Fi/GAN.

A13.182 These alternative supply approaches may exhibit lower site differences associated with their operating frequencies.

A13.183 Concern was expressed in some responses that the consultation had dismissed such technologies without sufficient consideration of their potential impact.

Analysis

A13.184 We have further considered the technologies mentioned and their potential impact on alternative means of supplying mobile broadband services.

A13.185 Table 9 summarises the relevant network technologies for supplying mobile broadband services. The alternatives to macrocells can all be seen as variations on the concept of using small, cheaper cell types to deliver capacity and/or coverage.

Table 9: Description of potential alternative technologies for supporting mobile broadband services.

Technology	Description
Macrocell	Cells with antennas typically above the prevailing height of clutter on towers or rooftops. Typically the main means of delivering wide-area coverage in a cellular network.
Microcells & street furniture sites	Cells with antennas mounted below the prevailing height of local buildings, typically mounted on exterior walls or street furniture poles.
Wi-Fi / GAN[8] (UMA[9])	A technology to support dual-mode handsets which handover from 3G (or 2G) to Wi-Fi when in range of a Wi-Fi access point (public or private) which supports the service. These are typically deployed within the home.
Repeaters	Bi-directional off-air amplifiers, enhancing macrocell coverage by overcoming losses through walls.
Picocells and distributed antenna systems (active & passive)	Dedicated cells for in-building environments, providing capacity and coverage, typically within large enterprise buildings or high-density public environments (shopping centres, airports etc.)
Femtocells	Low-power, low-cost consumer (or small enterprise) access points, mainly for 3G, backhauled over DSL or cable and self-installed by the user and auto-configured while remaining under the control of the operator.

A13.186 In comparing these alternatives, we have considered the practicality of deploying them to meet the anticipated demand and associated limitations, compared to a macrocell 3G network. The findings are summarised in Table 10.

[8] Generic Access Network (3GPP-standardised UMA)
[9] Unlicensed/Universal Mobile Access

Table 10: Comparison of alternative technologies for delivering mobile broadband services

Technology	Practicality of Deployment	Limitations
Microcells & street furniture sites	• Widely deployed for 2G capacity, not typically used as a substitute for macrocell coverage. • Helpful for overcoming site acquisition difficulties in some areas. • Less widely deployed than for 2G to date.	• Provide capacity at reduced cost per site, but reduced coverage per site so many needed to cover wide area. • Challenges in interference management within limited UMTS carriers and high in-building penetration loss due to shallow angles of incidence on building walls.
Wi-Fi / GAN (UMA)	• Self-install at home or potentially enterprise. • Some operators deploying now for 2G –3G handsets in very limited supply. • Can be used to provide differentiated home services .	• Licence-exempt spectrum, subject to uncontrolled interference. • Requires users to change handsets – limited availability and cost of subsidies. • 3G GAN only recently standardised.
Repeaters	• Sparsely deployed to solve particular coverage holes where capacity is not a significant limitation.	• Do not add capacity – coverage only. • Noise rise in macrocell receiver limits numbers which can be deployed per sector. • Installation requires careful set-up to deliver adequate donor signal without feedback .
Picocells and distributed antenna systems (active & passive)	• Widely deployed for both 2G and 3G in large public environments and some enterprises.	• Requires expert installation and commissioning. • Challenging business case for small and medium environments.

Technology	Practicality of Deployment	Limitations
Femtocells	• Not yet commercially deployed for 3G. • Significant operator interest – trials in progress. • Avoid expert installation. • Can be used to provide differentiated home services.	• Mainly for home environments, though some interest in enterprise deployment. • Interference, management issues, network integration, costs and public concerns may limit rate of take-up. • Not yet proven.

A13.187 As a basis for assessing the potential financial impact of these solutions, we assess the difference in the number of sites required to deliver in-building coverage with the extensive use of small cell solution rather than with extra macrocell sites.

A13.188 We assume that penetration at depth 2 (defined in section A13.255 *ff*) is required, but that macrocells are used only to deliver coverage to depth 1 (5m less penetration depth given the assumptions in section A13.255 *ff*). Small cells are used to deliver the remaining coverage and it is assumed that such cells cost the same for an operator deploying at any frequency band.

A13.189 The comparison omits the costs of delivering such systems as these are common to operators for both frequency bands.

A13.190 This is only a representative comparison if the cost of the in-building systems is the same for both operators, **and** the cost is cheaper than delivering in-building coverage by macrocells in using either frequency

A13.191 Assuming the base case parameters defined in Table 19 the resulting site differences are illustrated in Figure 18.

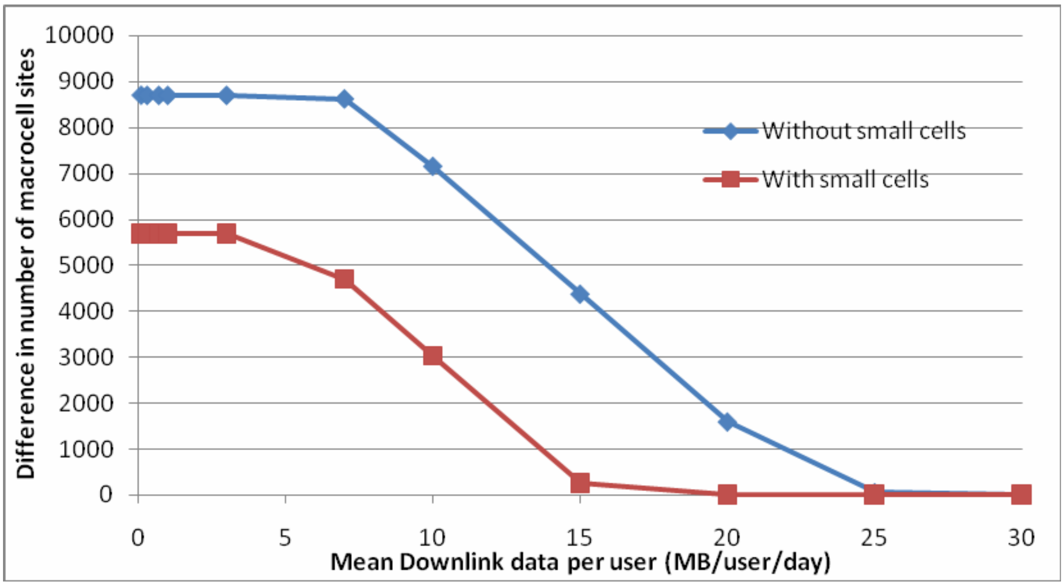


Figure 18: Comparison of site differences (2100 MHz vs. 900 MHz with 2 carriers) with and without the use of small cells to provide extensive deeper indoor coverage.

A13.192 It seems unlikely that such extensive deployment of alternative solutions would occur in practice. An operator cannot rely on users in all buildings to install small cells and so the number of macrocells required is unaffected until there is a very large population of such cells.

A13.193 It is also possible that:

- Macrocell in-building coverage is cheaper, for the UMTS 900 operator, in which case they can retain part of the original cost difference by avoiding the more expensive alternative.

- Macrocell in-building deployment is cheaper, for both operators, in which case the alternative solution is not used.

A13.194 As a result only a limited proportion of the reduction in the difference in site numbers will therefore occur. The comparison is useful as an additional sensitivity case, beyond our core range of scenarios, but we do not consider that this is a likely outcome.

A13.195 An alternative approach to considering the impact of small cells is to assume that they are primarily used to deliver increased capacity, avoiding the need to increase the number of macrocells in a capacity-limited scenario.

A13.196 If small cells are used primarily as a means of capacity relief then some proportion of the traffic volume would be carried on the small cells. If we again assume that the costs associated with these small cells are the same independent of spectrum holdings, then the effect is simply to reduce the volume of traffic that the macrocell network needs to carry. This increases the traffic volume at which the network begins to become capacity constrained.

A13.197 Figure 19 shows how the site difference increases as increasing proportions of data are offloaded from the macrocell network. For example, if 30% of the traffic is offloaded with a mean data volume of 10 MB / user /day, then the site difference increases by 1467 sites or a factor of 1.2.

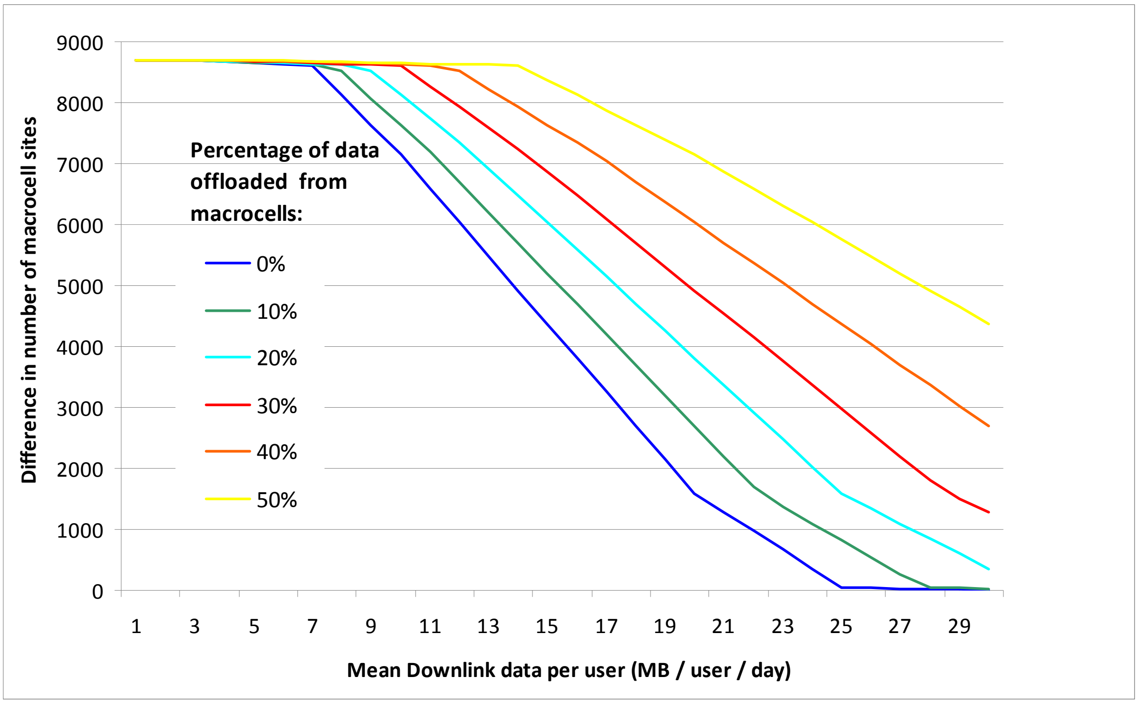


Figure 19: Impact of providing capacity relief via small cells on site differences between 900 MHz and 2100 MHz (base case parameters, 2 carriers per frequency band)

Findings

A13.198 Part of the mobile data traffic is likely to be carried via alternatives to macrocells.

A13.199 All of the alternative techniques exhibit reduced site difference with frequency for the areas and traffic which they serve.

A13.200 Microcells will still exhibit some variation with frequency, while the other approaches will exhibit almost none, requiring typically one cell per location served independent of frequency.

A13.201 The use of these alternatives is largely motivated by the challenges of deploying 3G at higher frequencies. They can therefore be considered as themselves constituting a partial means to mitigate cost differences and hence as a response to the existence of these differences.

A13.202 If such cells were very widely deployed, they could provide an alternative means of delivering deep indoor coverage.

A13.203 However, a significant part of the traffic is still likely to be carried via macrocells and it is expected that this will continue to act as the primary means – and largest cost driver – for delivering mobile broadband service using 3G technologies.

A13.204 Using alternative cell types to reduce the capacity carried in the macrocell network may actually increase the cost difference by reducing the cell loading and hence making the network more coverage constrained rather than capacity constrained.

A13.205 No alternative solutions appear to be a complete substitute for macrocell roll-out or to avoid the cost difference entirely as they are unlikely to be cost effective to universally deploy, but there may be some reduction in the site difference as a result.

A13.206 In selecting traffic ranges for the analysis of macrocells, we are reflecting the uncertainty about supply mechanisms including small cell techniques.

Issue 4 – Propagation differences between frequency bands

Issues

A13.207 Consultation responses raised a number of issues relating to the differences in propagation characteristics of different frequency bands and particularly relating to the behaviour of the building penetration loss (BPL).

A13.208 The variation of BPL between frequency bands assumed in the consultation was variously asserted by respondents to be both too low and too high. Some evidence was provided indicating losses which vary both positively and negatively with frequency. A need for further evidence was noted.

A13.209 Responses suggested that BPL varies with clutter type and that it was appropriate to consider the impact of this on the site difference.

A13.210 Responses noted that the overall size of the BPL depends on the depth of penetration into buildings considered and that the impact of both shallower and deeper penetration should be considered.

A13.211 The total fade margin allowed to provide adequate service consistency depends on the value of the coverage confidence assumed. The consultation assumed a coverage confidence of 90%, but respondents questioned that assumption, asserting that both higher (95%) and lower (80%) values were appropriate.

A13.212 Suggested values of BPL and some empirical evidence were provided in response to an information request.

Analysis

A13.213 In summary, the steps we have taken to address these issues are as follows.

10.213.1 We have examined the physical processes involved in propagation into and within buildings to determine the expected impact of frequency on BPL.

10.213.2 We have gathered a range of published evidence relating to BPL and compared this with the assumptions in the consultation (see Appendix A13.3: References regarding building penetration losses for the full set of literature used in this assessment).

10.213.3 We have proposed a set of BPL figures which vary with clutter type based on operator suggestions, both for cases where BPL varies with frequency and where it does not.

10.213.4 We have calculated the impact of these changes to determine the sensitivity of the site difference to these variations.

10.213.5 We have calculated the impact of situations where the depth of penetration is less than in the consultation.

10.213.6 We have examined situations where the coverage confidence is both less than and more than the level in the consultation.

A13.214 Note that this analysis is primarily concerned with site differences associated with delivering the same service quality using networks at different frequencies. This may not be the same objective as the fade margins used routinely by operators to plan at various frequencies, since such margins may include adjustments to deliver networks which are cost effective.

Definition

A13.215 In our analysis we use the following definition of the Building Penetration Loss:

> "The difference (in decibels) between the median of the location variability of the signal level at the building location, as predicted by the outdoor propagation model, and the signal level inside the building at the same height above ground, with multi-path fading spatially averaged for both signals".

A13.216 In common with models in the literature, we assume that the BPL (in decibels) is composed of two additive components, one associated with the external wall and the other associated with penetration into the building beyond the internal face of the external wall.

A13.217 If individual internal features of the building are not explicitly modelled, it is usual to assume that the internal loss is a linear function of distance.

A13.218 We also assume that the BPL is statistically independent from the outdoor propagation loss, so that the variances associated with each can be summed directly.

A13.219 This approach is illustrated in Figure 20, along with the resultant formulation of the total system fade margin. The fade margin forms a key element of the link budget in the calculations described in A13.82 since it directly reduces the maximum acceptable path loss and hence increases the required site density for a given depth of coverage.

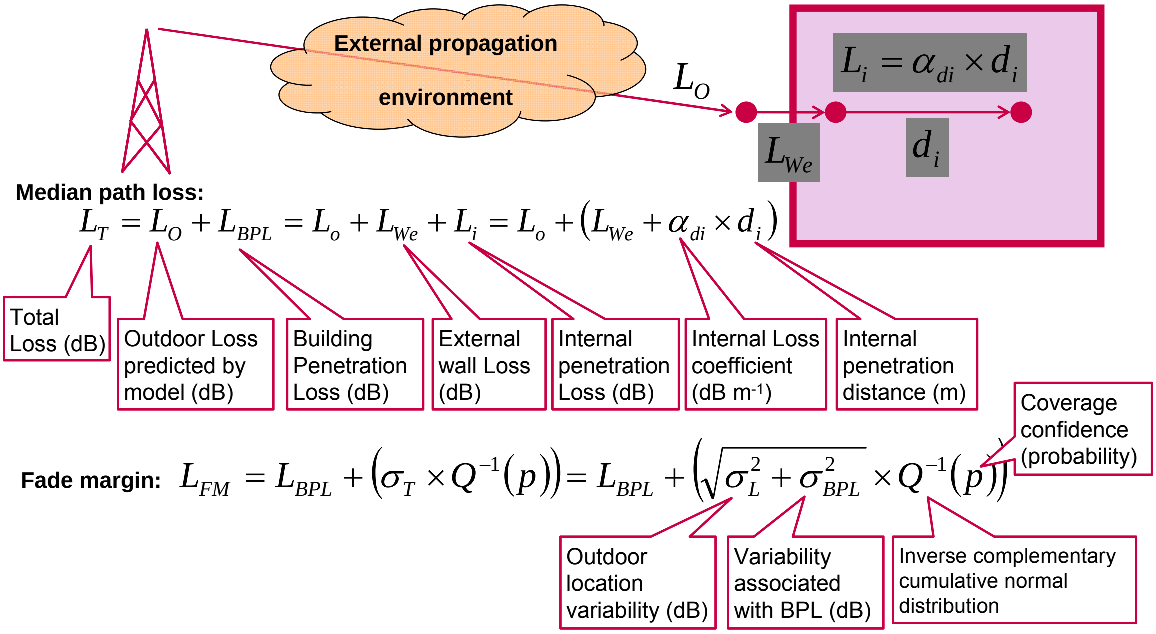


Figure 20: Definition of total loss and factors constituting the system fade margin.

Physics of propagation into and within buildings

A13.220 An overview of the physics affecting radiowave propagation into buildings is provided in this section to indicate the main factors which may affect the variation of the building penetration loss with frequency. Further research by Ofcom into this topic has informed this analysis [Ofcom_SES_07].

A13.221 The propagation loss for signals propagating into and within buildings (i.e. L_{We} and α_{di} in Figure 20) will be affected by:

- The types of materials used in building construction.
- The construction of a given building, including both its overall dimensions and the internal compositions of walls, floors and windows.
- The balance between various propagation mechanisms.

A13.222 Propagation mechanisms of particular relevance are:

- Absorption loss due to penetration through bulk materials (e.g. solid, homogeneous walls).
- Diffraction around edges (e.g. window frames, reinforcement rods etc.)
- Scattering from rough surfaces and objects small compared with a wavelength (e.g. furniture and rough walls).
- Multipath effects (e.g. from the combination of multiple reflections from internal walls).
- Waveguide effects (e.g. along long, straight corridors).

A13.223 These effects compound to create a complex set of factors which are components of the total BPL. Each mechanism is now examined individually with respect to its impact on the variation of BPL with frequency.

Absorption loss

A13.224 Absorption through bulk materials depends on the electromagnetic properties of the material, primarily its permittivity and conductivity.

A13.225 Permittivity and conductivity depend in general on frequency in a complex fashion and may exhibit increases or decreases over any particular frequency range due to the molecular structure of the materials and associated resonance and absorption effects. These effects are described in detail in references such as [Rizzi_88], [Ofcom_SES_07] and [Stone_97].

A13.226 For a given value of permittivity and conductivity, however, the loss due to absorption increases with frequency as a direct consequence of Maxwell's equations (this is known as the skin effect).

A13.227 An illustration of the variation of loss with frequency for common building materials is shown in Figure 21. In this case, where materials are assumed to be uniform and homogeneous, there is a clear tendency for loss to increase with frequency.

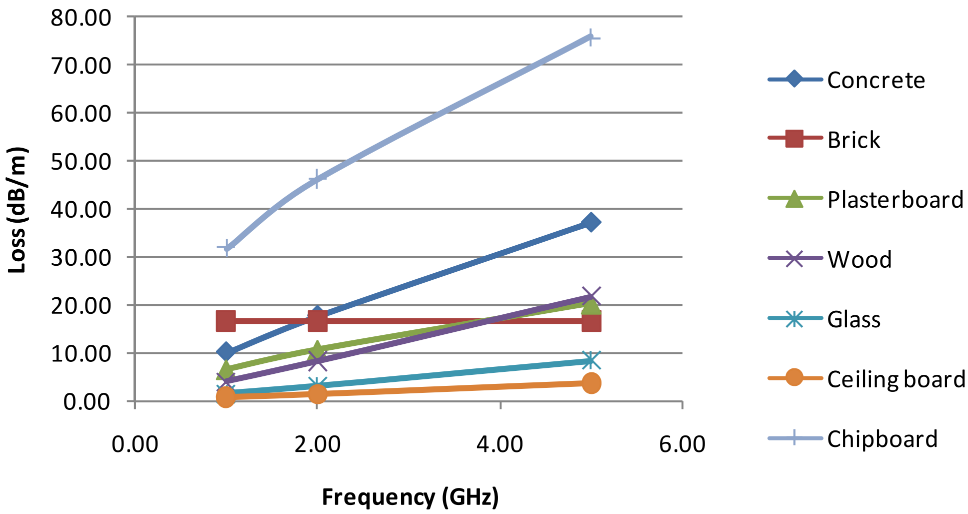


Figure 21: Frequency dependence of specific attenuation (loss per unit distance) for common building materials, based on values for material properties in [Ofcom_SES_07].

Diffraction loss

A13.228 Diffraction is a wave propagation phenomenon which allows energy to be received even when the direct path of the energy is blocked by an object such as a hill, rooftop or window edge. It is common to simplify the modelling of diffraction phenomena by assuming the diffracting obstacle can be modelled as a simple straight edge.

A13.229 Around a single edge, diffraction loss increases with frequency, typically at around 10dB per decade of frequency within the region obstructed by the edge (the ‘shadow zone’).

A13.230 In the visible region (e.g. through a window with diffraction occurring from all 4 edges), diffraction contributions from the edges combine, causing a complicated frequency dependence. The details of this frequency dependence are related to the size of a region around the direct path of the radio wave known as the Fresnel zone.

If the Fresnel zone is unobstructed, there will be relatively little diffraction loss. Since the size of the Fresnel zone reduces with frequency, the resulting loss may decrease with frequency if the aperture is of just the right size. For a very large aperture, the aperture loss will not vary with frequency. This effect is illustrated based on theoretical computations for a window in Figure 22.

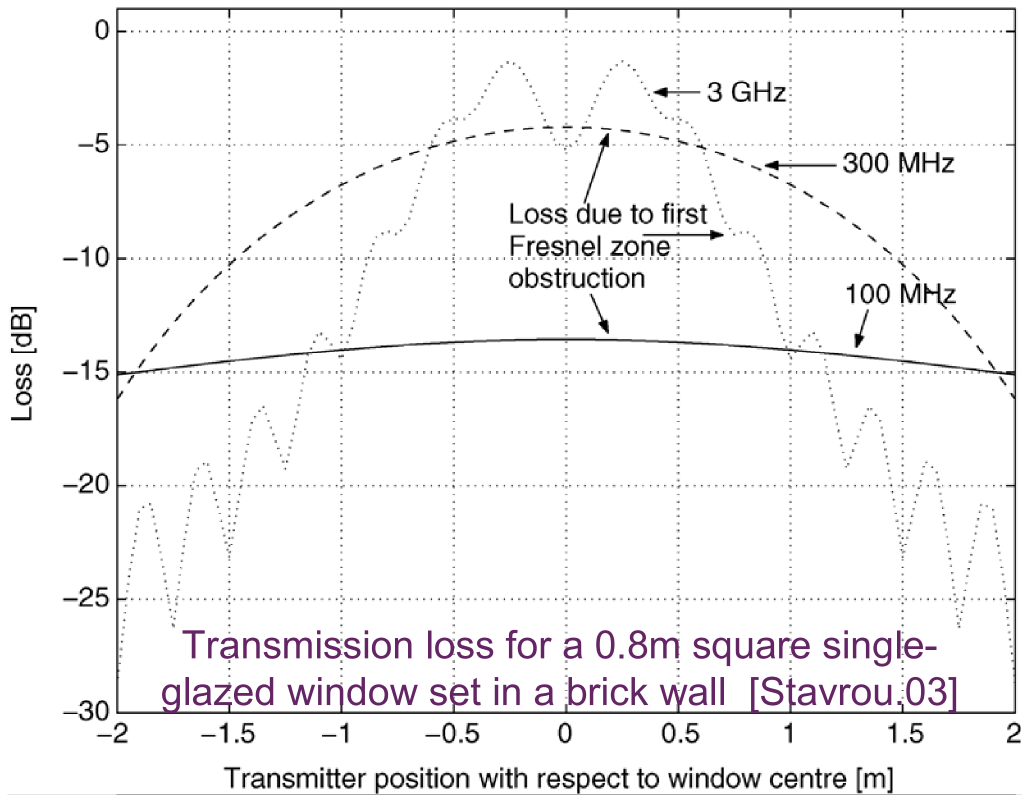


Figure 22: Example transmission loss for a 0.8m square single-glazed window set in a brick wall (from [Stavrou_03]).

Waveguiding

A13.231 At frequencies where the wavelength is low compared with the width of a corridor, waves are channelled along corridors and achieve greater penetration depth than would be expected based on conventional free space propagation, although the variation of loss with distance becomes of exponential form ($k \times d$ decibels where k is a constant and d is the penetration distance) rather than a power law ($10\ n \log d$ decibels where n is a characteristic constant).

A13.232 When waveguiding dominates, the associated losses may actually decrease with increasing frequency, assuming a straight, smooth, uniform waveguide. The amount of energy which actually travels down the waveguide depends significantly on incidence angle on the ‘mouth’ of the corridor, so large losses can be experienced at this stage.

Summary of expectations based on physics

A13.233 The discussion of propagation mechanisms described above is summarised in Table 11 .

Table 11: Expected variation of loss with frequency for various propagation mechanisms.

Effect	**Impact on loss at high frequency**
Loss through uniform external walls and metallised glass will increase with frequency	⇧
Loss through large apertures with minimal conductivity (plain glass windows)	=
Loss in regions dominated by diffraction and no line-of-sight	⇧
Losses through smaller windows may decrease with frequency if wavelength close to size (~25cm)	⇩
Loss at particular points in presence of strong multipath may increase or decrease with frequency over limited frequency ranges	⇳
Loss through internal walls and through floors will increase with frequency, so greater differences for greater target depths	⇧
Corridors may exhibit unusually low penetration loss	= or ⇩

A13.234 Any given building will be a mixture of these effects, so a large spread of values is anticipated relative to the overall trend. Nevertheless, the general trend of increasing loss with frequency arising from the skin effect and other mechanisms suggests an overall trend to increase with frequency, particularly when the penetration depth into a building is high. The frequency variation might thus take the form of Figure 23 for any given building.

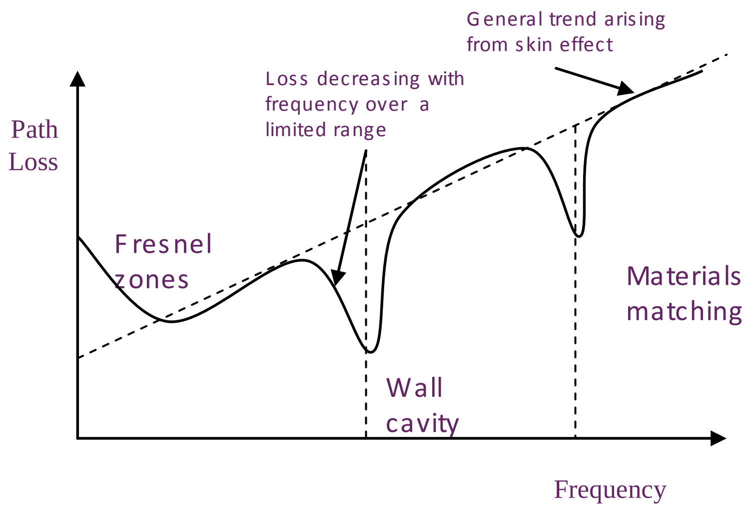


Figure 23: Illustrative variation of building penetration loss with frequency for a given building.

Evidence from measurements

A13.235 We have examined various sources of literature in order to determine the actual observed building penetration loss in practice. As the preceding section makes clear, significant variation between buildings and locations within buildings is expected, so a large number of measurements in different buildings and frequencies is needed in order to make any significant findings. There are relatively few such studies in the open literature, so we have attempted to collate a large number of studies together in order to determine the overall trend.

A13.236 One relatively large study [Qualcomm_08] measured the loss through twelve buildings of varied construction at 900 and 2100 MHz. It found a mean penetration loss of 9.5 dB at 900 MHz and 12.8 dB mean at 2100 MHz, i.e. a mean difference of 3.3 dB, with these measurements conducted just inside the buildings through a single external wall (i.e. comparable to L_{We} in Figure 20). The measurements are shown in Figure 24. Note that in one case the loss is larger at 2100 MHz and there is substantial variation in the BPL amongst buildings.

A13.237 This mean difference in penetration loss increased by an additional 5.5 dB for points 'deep' inside building (to 8.5 dB). Such points were the deepest which could be measured within the dynamic range limits of measurement equipment. Measurements were made mostly in open spaces, avoiding internal walls where possible.

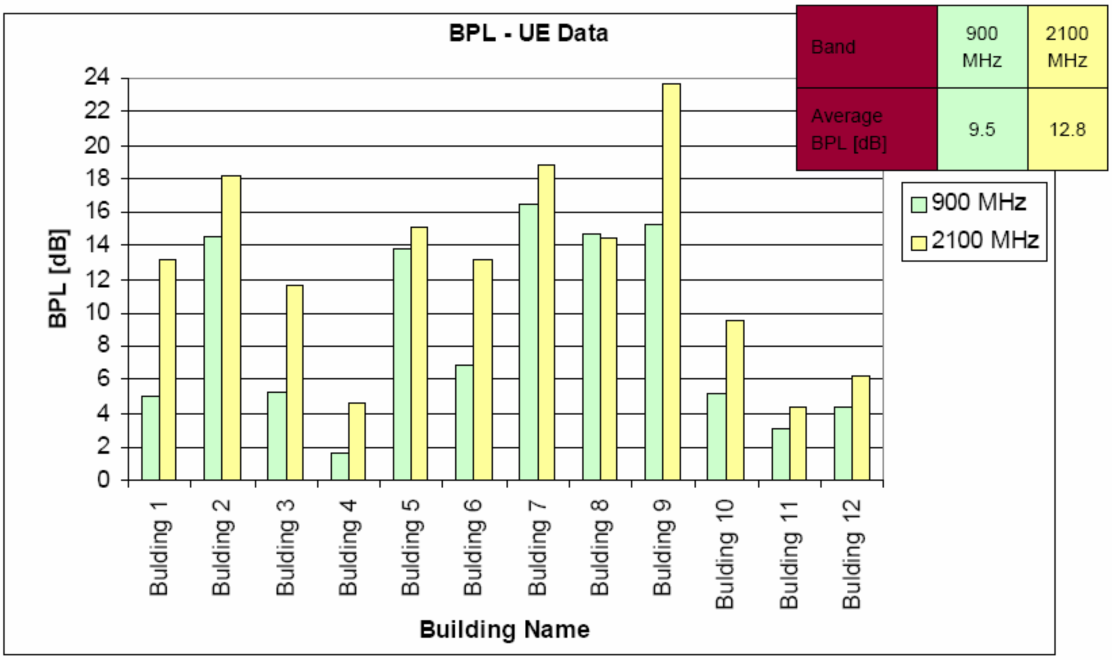


Figure 24: Measurements of penetration loss through a single external wall from [Qualcomm_08].

A13.238 The widely-quoted European research project COST 231 compiled measurements and models from a number of sources relating to the difference between propagation at 900 and 1800 MHz, with relevant statements including the following [COST_231]:

- “In some measurements it has been found that the floor penetration loss increases 2 dB at 1800 MHz compared to 900 MHz.”
- “The floor height gain is lower at 900 MHz, but the difference is small.”
- “Floor penetration losses…at 900 MHz were found to be about 2 dB lower.”
- “The path loss difference between the frequency bands is typically slightly higher than would be predicted in free space. Considering the Multi-wall model, a difference of 1.5 dB in the light wall loss and a difference of 3.5 dB in the floor loss were reported.”

A13.239 We have also compiled individual results from a wide variety of sources in the public literature, listed in Appendix A13.3.

A13.240 Figure 25 shows the compiled values for all buildings, together with a best-fit line and the values assumed in the previous consultation. Figure 26 shows a subset of the data applicable to urban multi-storey buildings and Figure 27 shows the data relevant to residential environments.

A13.241 There is a clear trend for BPL to increase based on this data, but the variability of data amongst buildings at a given frequency is substantially larger than the variation of the mean with frequency. Noting that some of this variation may also be due to methodological differences amongst authors, this makes it difficult to assert a firm value for the variation in the mean.

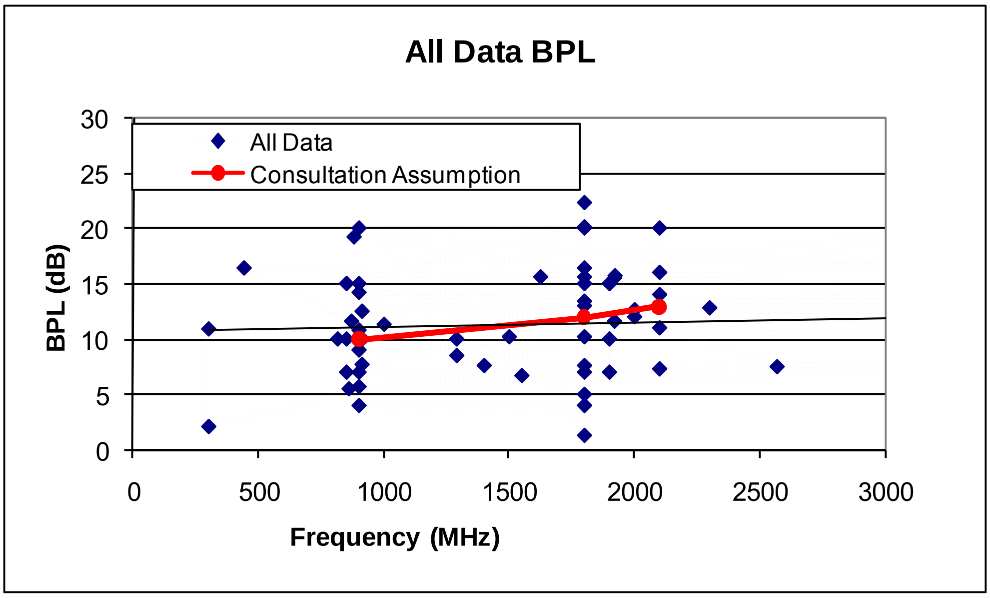


Figure 25: Building penetration loss data for urban multi-storey buildings from public sources.

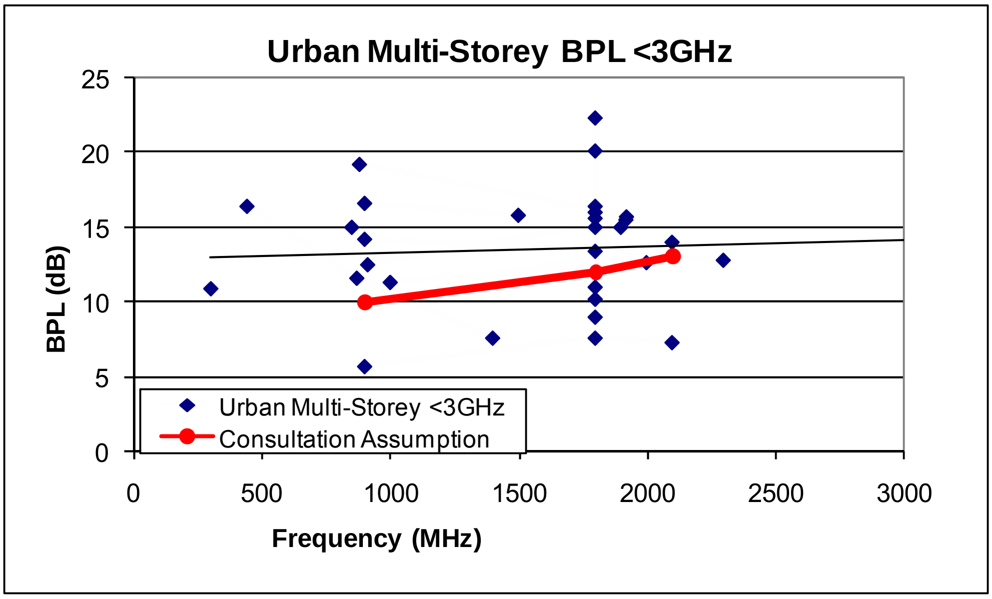


Figure 26: Building penetration loss data for urban multi-storey buildings from public sources.

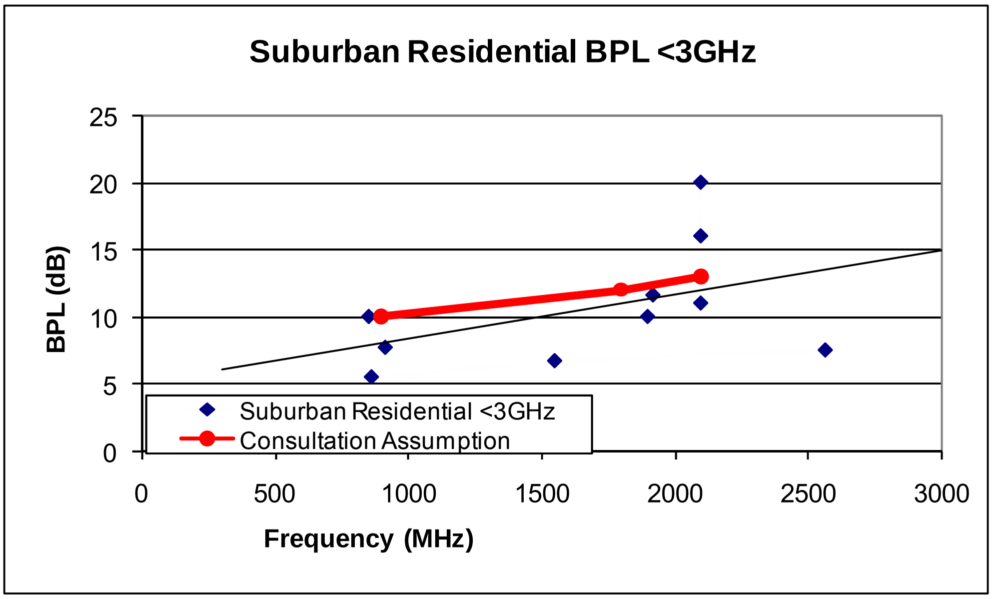


Figure 27: Building penetration loss data for suburban residential buildings from public sources.

A13.242 In response to information requests from Ofcom, the mobile operators have provided evidence based on their planning assumptions and on their own measurements. The specific details of this responses are confidential, but a general summary can be made as follows:

- All operators make a distinction in their BPL assumptions between clutter types, with BPL rising with increasing urban density as implied by clutter type within their radio planning tools.
- Some operators assert that there is no significant variation in building penetration loss between 900 MHz and 2100 MHz, while others assert a tendency for BPL to increase substantially with frequency.
- The central case assumption in the September 2007 consultation shows the following behaviour by comparison with responses from MNOs:
  - Low BPL compared with all MNO values for dense urban clutter.
  - Lower BPL than all but one set of MNO values for urban clutter.
  - Approximately in the middle of the range of BPL values for suburban clutter.
  - Lower than all but one set of MNO values for rural clutter.
  - Similar trend with frequency to those who asserted any variation.

A13.243 The assumptions in our previous consultation are summarised as follows. Three distinct cases were considered:

- A central case where BPL rises by 3dB from 900 MHz to 2100 MHz.
- A lower case where BPL does not change with frequency.

- An upper case where BPL rises by 5 dB from 900 MHz to 2100 MHz.

A13.244 In all cases, BPL was assumed constant for all clutter types and the standard deviation of BPL was assumed to be 6dB in all cases. This standard deviation is considered to include all relevant variations in BPL when using it to predict performance over the whole coverage area of a mobile network, including variations amongst buildings and across potential measurement locations within the building.

A13.245 These assumptions are summarised in Table 12.

Table 12: Assumptions regarding mean building penetration loss for previous consultation.

	Lower Assumption	Central Assumption	Upper Assumption
Frequency	**Mean BPL (dB)**	**Mean BPL (dB)**	**Mean BPL (dB)**
900MHz	**10**	**10**	**10**
1800MHz	**10**	**12**	**12**
2.1 GHz	**10**	**13**	**15**

A13.246 Given the wide range of measurements and views regarding BPL, we consider it appropriate to continue to consider a range of cases. However we have further refined the cases considered, in particular to include a variation with clutter type in line with the assertions of all operators, and to reflect a wider range of variations in mean building penetration loss with frequency.

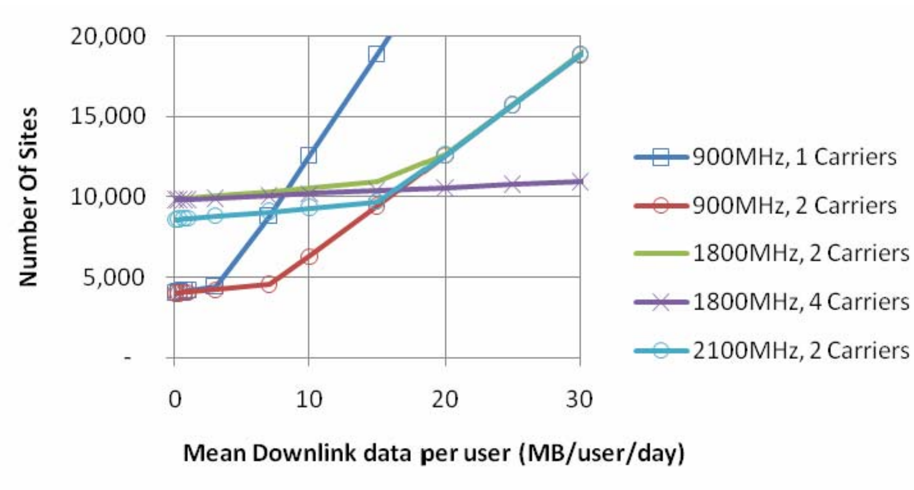
A13.247 New assumptions have been created to represent the range of views expressed by MNOs regarding frequency variability of BPL and the variability in BPL with clutter type. We have taken BPL to increase by 2dB from suburban to urban and again by 2dB from urban to dense urban.

A13.248 We are again considering three cases. A base case, where the suburban BPL rises in the same way as the previous consultation, a constant case where there is no variation with frequency and a case where the BPL rises by 10 dB from 900 MHz to 2100 MHz. and by 8 dB from 900 MHz to 1800 MHz Note that these variations relate to differing opinions regarding the physics of in-building penetration, rather than to different service levels. Differing service levels are considered in §A13.255*ff*. The resulting values are shown in Table 13.

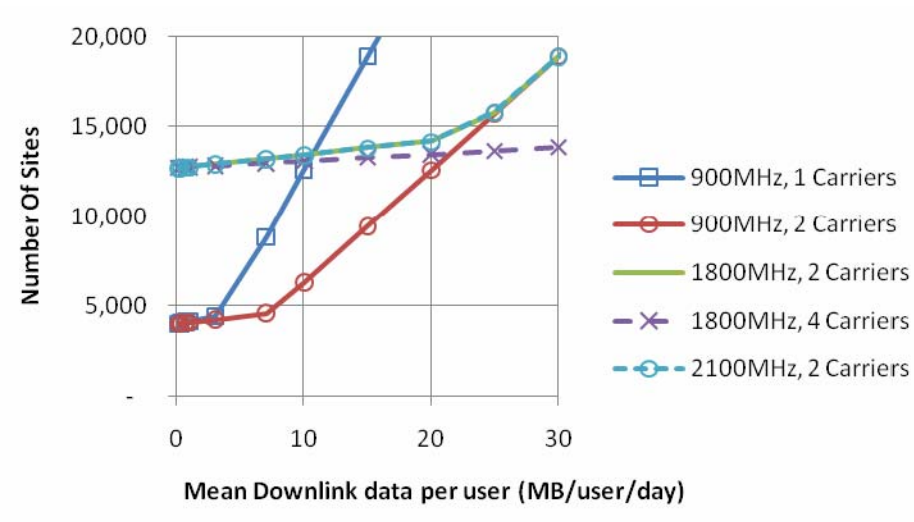
Table 13: Mean building penetration loss assumptions (decibels) for investigations in this consultation (Depth 2).

Depth 2	No Variation with Frequency (Constant)			Increasing with Frequency (Rising) (Base case)			Increasing with Frequency (Rising at higher rate)		
Frequency	**Dense Urban**	**Urban**	**Subur -ban**	**Dense Urban**	**Urban**	**Subur -ban**	**Dense Urban**	**Urban**	**Subur -ban**
900 MHz	14	12	10	14	12	10	14	12	10
1800 MHz	14	12	10	16	14	12	22	20	18
2.1 GHz	14	12	10	17	15	13	24	22	20

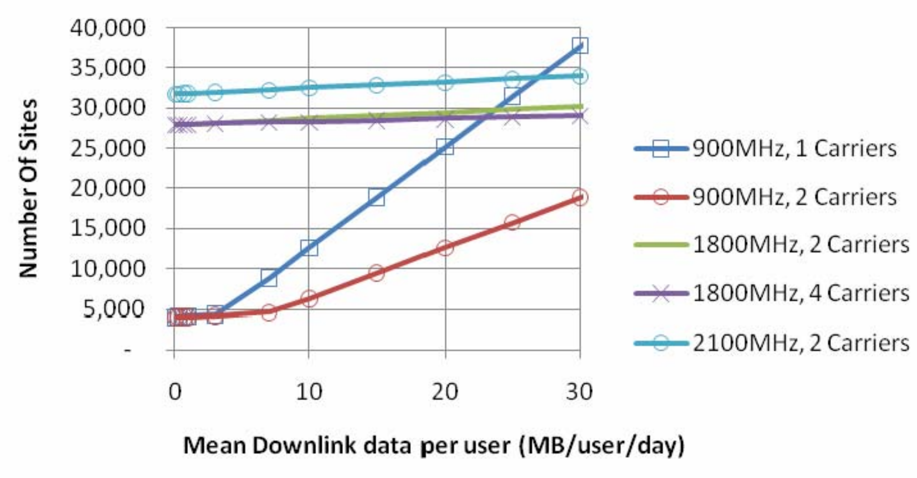
A13.249 The resulting site number predictions are shown in Figure 28 (a)-(c). All other parameters are the same as the base case.



Mean building penetration loss constant with frequency.



Mean building penetration loss rising with frequency (same as base case).



Mean penetration loss rising with frequency at higher rate than base case. Note change of scale in y-axis.

Figure 28: Impact of varying the rate of change of mean building penetration loss with frequency.

Findings regarding building penetration loss

A13.250 From physics theory:

- Expectations based on physics includes mechanisms where BPL may vary both positively and negatively with frequency, with the balance depending on the building construction and the depth of penetration.
- A substantial variability in BPL amongst building types at fixed frequency is anticipated, probably more than the variation in the mean BPL versus frequency.

A13.251 From measurement data:

- The overall trend in published measurements is for BPL to increase with frequency.
- Measurements of deeper penetration tend to exhibit greater increase in BPL with frequency.

A13.252 From operator evidence:

- Some assert negligible variation in mean BPL with frequency.
- Other assert substantial increase with frequency.
- All suggest greater BPL in denser areas.
- Simulation results indicate that changes to the assumptions in the consultation tend to increase the site differences.

A13.253 We accept the need to vary the BPL with clutter and to examine a wide range of cases of the variation of BPL with frequency, but note that there is an overall trend in published evidence for BPL to increase with frequency.

A13.254 The range of values examined for BPL can vary the site ratio for 3G service from as little as two times (no variation of BPL with frequency) to over seven times (large variation of BPL) for coverage-limited scenarios. The data volume at which capacity limitations reduce the site difference to zero is also substantially affected, from around 10 MB per user per day (no variation of BPL) to around 30 MB (large variation of BPL).

Shallower building penetration

A13.255 It is desired to examine the impact of coverage being provided to a reduced depth than previously examined, representing different views on the importance of deep in-building coverage to mobile broadband users in the future. In order to do so, the total building penetration loss (BPL) is taken to comprise the sum of two components, as illustrated in Figure 29:

- The loss in the external wall of the building which is encountered when providing any indoor service (L_{W_e} in Figure 29).
- The additional attenuation encountered as signals penetrate deeper inside the building, arising from propagation through and around internal walls, furniture & fixtures and people within the building. (L_i in Figure 29). The ground floor of buildings is taken as the reference environment for comparison.

A13.256 The internal loss L_i (decibels) is modelled as depending on the penetration distance into the building d_i (metres) and a specific attenuation rate α_{di} (decibels per metre) according to $L_i = \alpha_{di} \times d_i$.

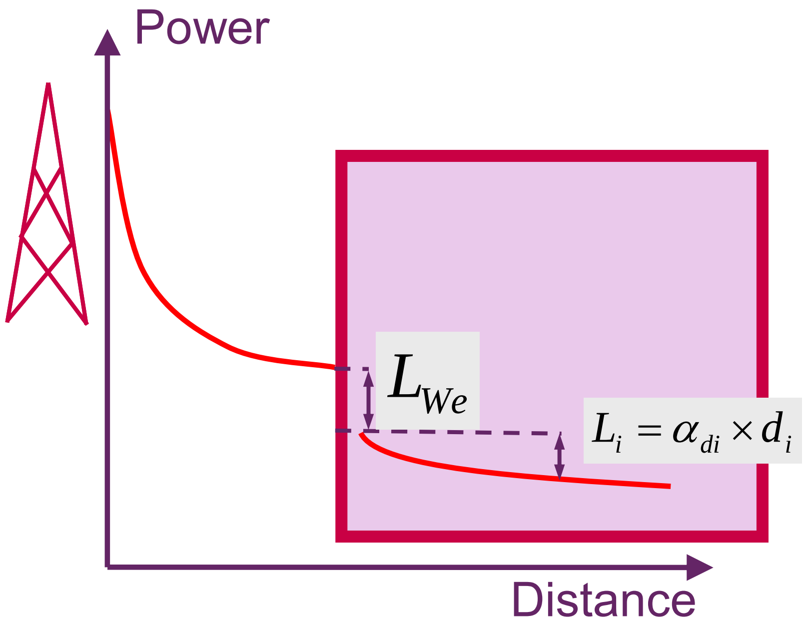


Figure 29: Illustration of the separation of total building penetration loss into two components.

A13.257 One source of parameters for such modelling is [COST_231]. This study is based on measurements and is widely quoted in the industry. It indicates a value of α_{di} = 0.6 dB/m approximately. Another project was based on detailed electromagnetic modelling [Ofcom_SES_07] which suggests values of α_{di} = 0.5 - 0.6 dB / m for urban environments.

A13.258 The loss for the external wall L_{W_e} varies substantially according to the material type and thickness. [COST_231] suggests values in the range 4 – 10 dB as typical, while [Ofcom_SES_07] gives 2.5 and 3.5 dB for 1 and 2 GHz respectively in dense urban environments and 2.0 and 3.0 dB respectively in urban environments.

A13.259 To examine the impact of reduced depth, we have assumed L_{W_e} = 2.5, 3.3 and 4.0 dB for 900, 1800 and 2100 MHz respectively and α_{di} = 0.5, 0.58 and 0.6 dB / m for 900, 1800 and 2100 MHz respectively.

A13.260 The specific depth corresponding to the depth 2 case is uncertain given the wide variation in potential losses associated with given buildings. For illustration, for the specific case of the parameters assumed in A13.259 the depth 2 losses would correspond to a penetration depth of 15m. However we consider that the values assumed are in a reasonable and realistic range for good in-building coverage given the comparison with MNO evidence cited in A13.242.

A13.261 We have then adjusted the mean penetration loss values relative to the depth 2 values by reducing the penetration depths by 14m relative to depth 2 (depth 0), and by 5m relative to depth 2 (depth 1). The same variation with clutter type is assumed as previously. The resulting mean BPL values are given in Table 14.

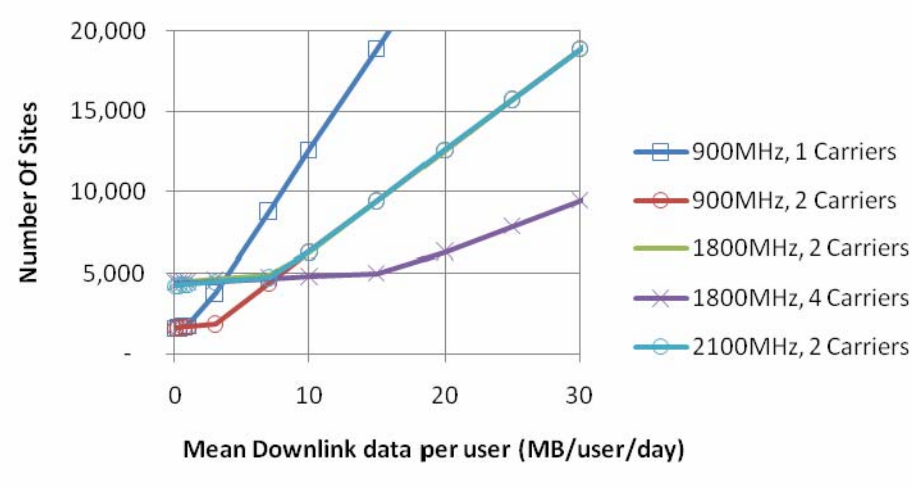
Table 14: Variation of mean building penetration loss for reduced coverage depth scenarios.

Depth 0	**Increasing with Frequency (Rising) (Base case)**		
Frequency	**Dense urban**	**Urban**	**Suburban**
900 MHz	7.0	5.0	3.0
1800 MHz	7.9	5.9	3.9
2.1 GHz	8.6	6.6	4.6

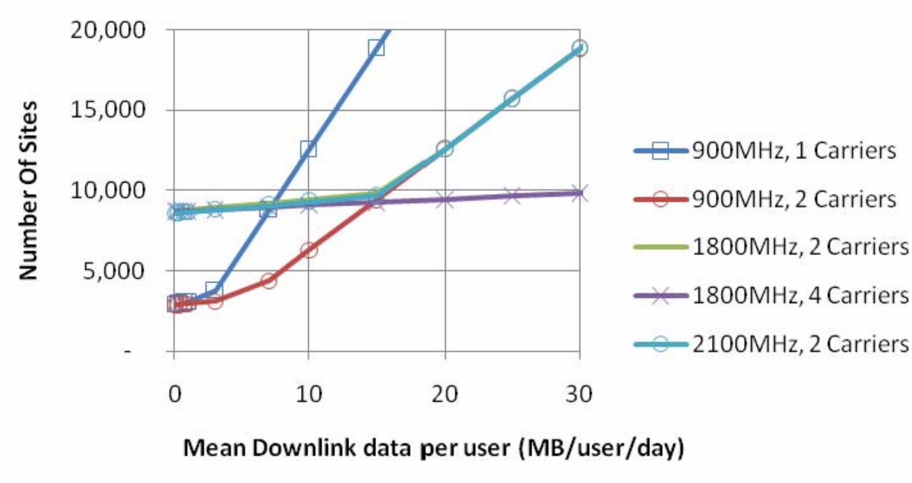
Depth 1	**No Variation with Frequency (Constant)**			**Increasing with Frequency (Rising) (Base case)**			**Increasing with Frequency (Rising at higher rate)**		
Frequency	**Dense urban**	**Urban**	**Suburban**	**Dense urban**	**Urban**	**Suburban**	**Dense urban**	**Urban**	**Suburban**
900 MHz	11.5	9.5	7.5	11.5	9.5	7.5	11.5	9.5	7.5
1800 MHz	11.5	9.5	7.5	13.1	11.1	9.1	19.5	17.5	15.5
2.1 GHz	11.5	9.5	7.5	14.0	12.0	10.0	21.5	19.5	17.5

Simulation Results

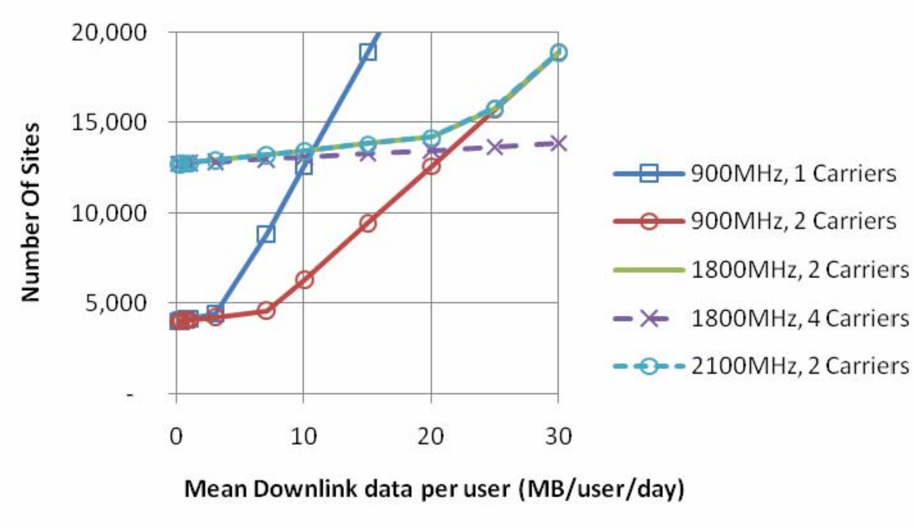
A13.262 The site numbers resulting from varying the coverage depth are shown in Figure 30 (a)-(c).



(a) Depth 0.



(b) Depth 1.



(c) Depth 2 (i.e. base case).

Figure 30: The impact of varying coverage depth.

Findings

A13.263 In the shallowest scenario (Depth 0), with substantially lower penetration depths than the consultation central case, the site difference is reduced substantially.

A13.264 However, the resulting assumptions related to a lower total BPL than most operator responses and do not relate to a market scenario in which coverage quality is important to most consumers.

A13.265 Hence evidence based on operator submissions indicates that Depth 1 or Depth 2 are more credible scenarios. We have used Depth 2 as the basis of our base case, with Depth 1 as the lower end of the range for investigation. The relevant choice relates to how important consistent in-building coverage is to future mobile broadband consumer. This is one particular dimension considered as part of the market scenarios specified in Annex 11.

Coverage confidence

A13.266 The consultation assumed a constant coverage confidence of 90% at cell edge, i.e. there is 90% confidence that locations at threshold noise-limited signal levels would be delivered adequate service.

A13.267 Consultation responses indicated that other values should be considered to represent differing user expectations of quality.

Analysis

A13.268 The impact of varying the coverage confidence is to vary the fade margin for indoor users as shown in Table 15 (fade margins are quoted excluding the mean BPL). The general behaviour is then expected to be similar to that encountered when varying the mean building penetration loss or the coverage depth.

Table 15: Impact of varying coverage confidence on system fade margins.

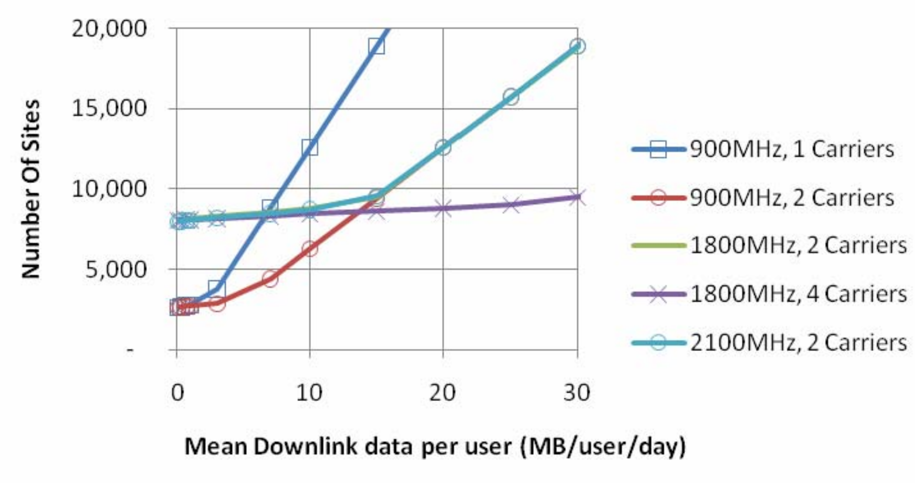
Confidence Level (cell edge)	Indoor Fade Margin (dB)		
	900	1800	2100
80%	7.8	8.3	8.5
85%	9.6	10.3	10.4
90%	11.8	12.7	12.9
95%	15.2	16.3	16.6

A13.269 It is common to relate the cell edge coverage confidence to that which would be experienced over the whole cell area, assuming that in-building users are uniformly distributed across the cell. Responses from operators indicated that their target levels for this cell-area coverage confidence varied between 80% and 95%.

A13.270 We have therefore examined the variation in the site numbers with cell area confidence, translating between edge and area cases using a standard transformation from [10]. Figure 31 and Figure 32 show the outcome for 78% and 69% cell edge confidence, corresponding approximately to 90% and 85% cell area confidence respectively.

A13.271 We have also varied the coverage confidence over a wider range to determine the number of sites required when coverage-limited. The result is shown in Figure 33.

A13.272 We have additionally investigated a case where operators deploy to a different coverage confidence in different areas, with 90% by area in suburban environments and 95% by area in urban, open-in-urban and dense urban areas. The outcome is shown in Figure 34.



[10] "Microwave Mobile Communications", ed. W.C. Jakes, IEEE Press, 1974, pp. 126-127.

Figure 31: Sites required at 78% cell edge confidence, corresponding approximately to 90% cell area confidence.

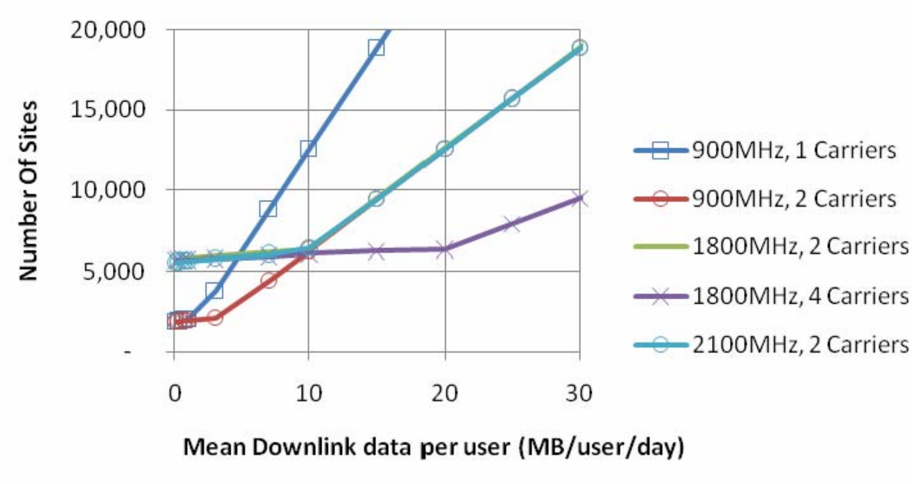


Figure 32: Sites required at 69% cell edge confidence, corresponding approximately to 85% cell area confidence.

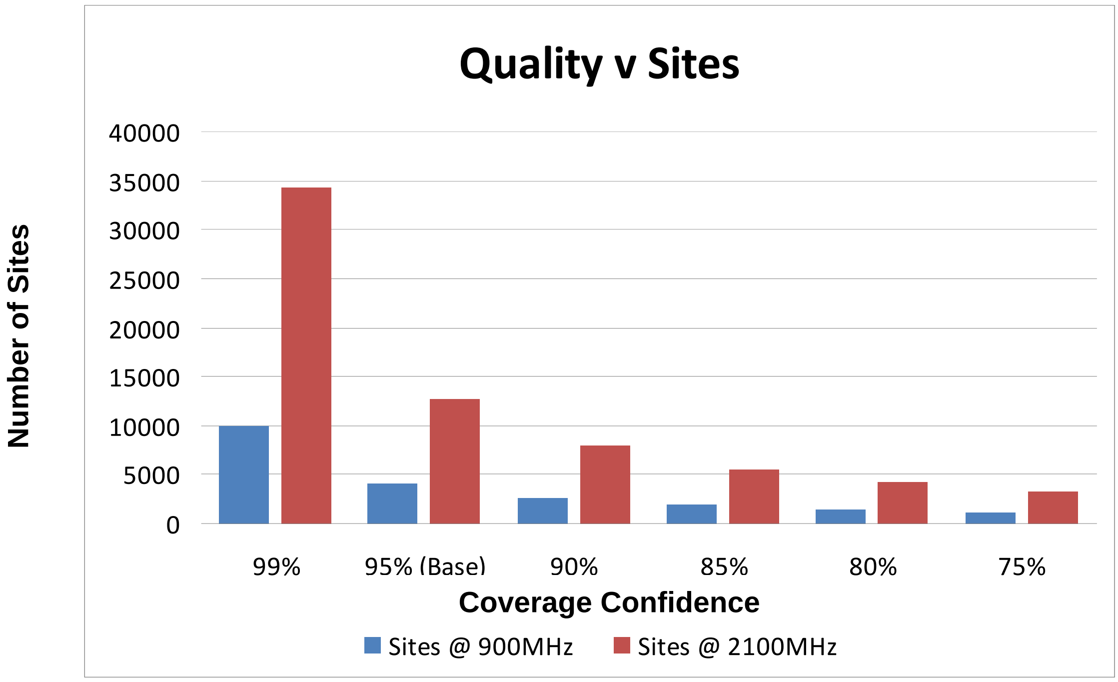


Figure 33: Impact of varying coverage confidence (over entire coverage area) when coverage limited.

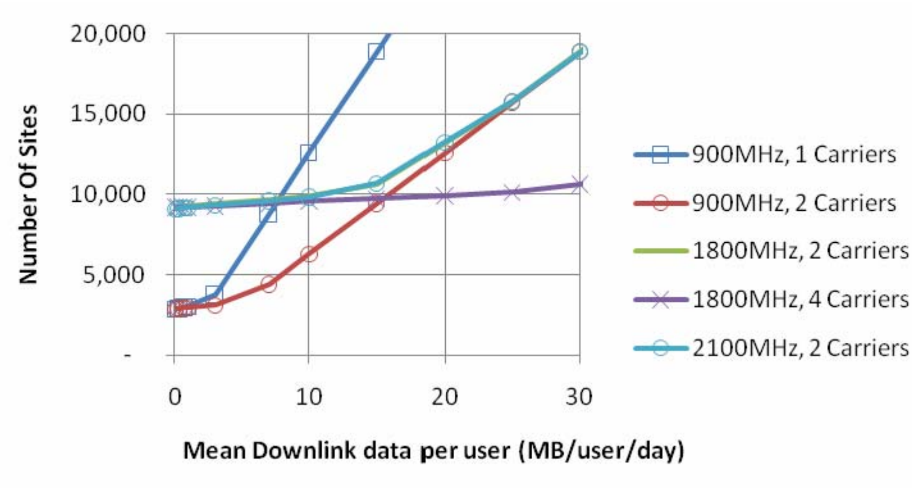


Figure 34: Impact of coverage confidence targets of 90% (suburban) and 95% (urban, open-in-urban and dense urban).

Findings

A13.273 The coverage confidence has a significant impact on site difference results, comparable with varying the penetration depth.

A13.274 For subsequent analysis we will use 87% cell edge confidence as our base case (c.f. 90% at cell edge used as the central case in our previous consultation), corresponding approximately to 95% over the cell area. This corresponds to the level used by many operators in the most built-up areas. We note, however, the significant impact of varying the coverage confidence on the results.

Issue 5 – User Terminal Performance

Issues

Receiver Sensitivity

A13.275 Consultation responses pointed out that the September 2007 modelling used the same receiver sensitivity for user devices at all frequencies, while the 3GPP specification allows for a 3dB reduced sensitivity at 900 and 1800 MHz compared with 2100 MHz.

A13.276 This could partially offset the advantages associated with improved propagation at lower frequencies, potentially reducing the site advantage.

Transmit Power

A13.277 The modelling in the first consultation assumed a mobile station transmit power of 21 dBm, while the specification 3GPP TS 25.101 allows two distinct classes: class 3 which has a maximum power output of 24dBm and class 4 which has a maximum power output of 21dBm.

A13.278 Higher output power will give increased uplink range and could affect the cost difference if the network is coverage limited to a different degree at each frequency.

A13.279 The issue is to quantify the effect of this difference and to determine whether there is any information in the public domain to suggest whether UEs of one power class will tend to predominate.

Body Loss

A13.280 The consultation assumed that the total mobile station antenna gain was 0 dBi and did not explicitly consider an allowance for body loss. Discussions with mobile operators indicated that it would be appropriate to consider usage of mobile terminals close to the human body where the effective mobile antenna gain was substantially reduced due to signal losses in the human body.

A13.281 Responses variously indicated that appropriate values for the body loss could be as high as 7 dB and as low as 0dB.

Analysis

Receiver sensitivity

A13.282 The focus of our previous consultation was on the intrinsic differences in the characteristics of different frequency bands rather than on the specific of the associated equipment.

A13.283 Examination of the UMTS user equipment specification TS 25.101 confirms that there is a 3dB difference in the minimum receiver sensitivity, being 3dB higher (reduced sensitivity) at 900 MHz and 1800 MHz compared with 2100 MHz. Discussions with manufacturers indicate that this arises due to the smaller duplex spacing in the 900 and 1800 MHz bands, which leads to an increased insertion loss in the duplexer and hence a 3dB degradation in the noise figure and sensitivity.

A13.284 While it is open to manufacturers and operators to implement devices with better performance than this, it is reasonable that a direct comparison of the characteristics of the different bands should incorporate effects associated with the fixed duplex spacing.

A13.285 As a result, our base case now includes this difference in sensitivity.

Transmit power

A13.286 Although early 3G handsets tended to be of the +21 dBm power class, it appears that newer devices are more usually capable of +24 dBm output power.

A13.287 We have surveyed manufacturers' data for a range of devices which support HSDPA and find that these almost all support +24 dBm. It is apparent that +24 dBm is now common in devices intended for data applications.

A13.288 For investigation purposes and in our base case we have therefore selected +24 dBm for data, +21 dBm for speech.

Body Loss

A13.289 In considering values of body loss which may be appropriate for our studies, it is relevant to distinguish a number of usage cases leading to a range of body loss values. Figure 35 shows a number of positions in which mobile terminals of various types may be used, each of which may affect the body loss in different ways.

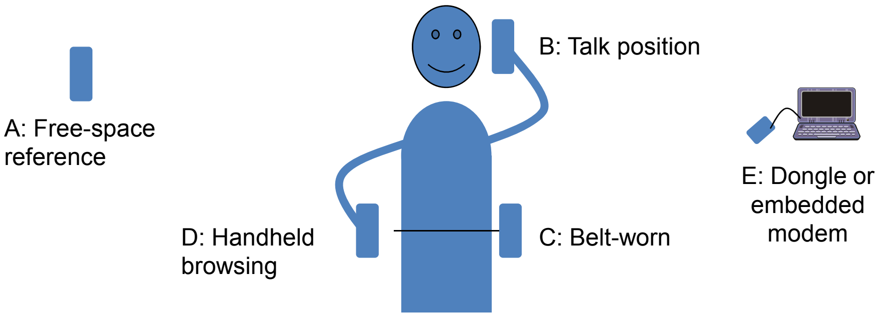


Figure 35: User device configurations lead to a range of body loss values.

A13.290 The positions are summarised as follows:

10.290.1 Position A is an idealised free-space situation, in which the body loss is zero decibels by definition.

10.290.2 Position B is the 'talk position', where a mobile phone is normally located for speech services. Here the mobile antenna is subject to loss due to the head and hand of the user.

10.290.3 Position C is a belt-worn situation, where the mobile device is likely to reside for idle mode operation and when autonomously synchronising/uploading/downloading data. Here the device is subject to loss due to the user's torso and due to the reduce height of the device.

10.290.4 Position D is a browsing mode, where the device is held in the user's hand and is subject to loss due to the hand and reduced height but is held away from the body.

10.290.5 Position E represents a mobile broadband data 'dongle' (i.e. external modem) or embedded modem used with a laptop or similar computer. Losses due to the body directly are low, but are replaced by losses from the surface on which the laptop rests and losses due to the case and components of the laptop in the case of an embedded device.

A13.291 Positions B, C and D are of most relevance to the operation of handheld devices with substantial mobile data capability in addition to speech (e.g. "smartphones"), while position E is of most relevance to data dongles and mobile-embedded devices.

A13.292 The overall device antenna gain is taken as the nominal antenna gain (assumed to be 0 dBi) minus the difference between the loss in position A and the position of interest.

A13.293 One source of measurement data relating to these positions is the COST 273 which compiles the results of several studies together[11].

A13.294 In talk position (position A), COST 273 reports that the loss is a combination of head and hand losses. Studies tended to show a lower head loss at 900 MHz (4.2 to 5.1 dB) compared with GSM 1800 (2 to 2.6 dB), based on measurements using standard head 'phantoms'. Similarly, measurements on a sample of six GSM handsets indicated an average head loss of about 5 dB at 900 MHz and about 2 dB at 1800 MHz.

A13.295 The hand loss in talk position averaged over 12 handsets varies with frequency to a similar extent but in the opposite direction, being around 1.7 dB at 900 MHz and 3.7 dB at 1800 MHz. A separate study showed no significant variation in hand loss with frequency.

A13.296 An average of 12 handsets in browsing position (position D) produced mean hand loss of 1.7 dB at 900 MHz and 2.5 dB at 1800 MHz.

A13.297 Another source of data for positions C and B is ITU-R recommendation P.1238[12], which states :

> "*At 900 MHz with a dipole antenna, measurements show that received signal strength decreased by 4 to 7 dB when the terminal was held at the waist, and 1 to 2 dB when the terminal was held against the head of the user, in comparison to received signal strength when the antenna was several wavelengths away from the body."* (*ITU-R P.1238*)

A13.298 Link budget calculations for 3G systems at 2100 MHz often assume 0 dB body loss for a data terminal (corresponding to position E) and 3dB for speech in position B (e.g. see [13]).

A13.299 There is little clear evidence in the literature for values applicable to dongles and embedded modems. However, studies such as [14] do indicate that the laptop components surrounding the antenna and the presence of the user's body and hands can significantly affect the radiation efficiency and pattern relative to the free space values.

A13.300 Following review of this evidence and of values indicated by mobile operators, we have selected the values shown in Table 16 for study. Although values shown in the literature do vary with frequency, there does not appear to be sufficient consistent data available to assert a specific variation with frequency.

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[11] Mobile Broadband Multimedia Networks, Ed. Luis Correia, Elsevier 2006. pp. 230-238.

[12] Recommendation ITU-R P.1238-4 "Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900 MHz to 100 GHz", 2005, §8.

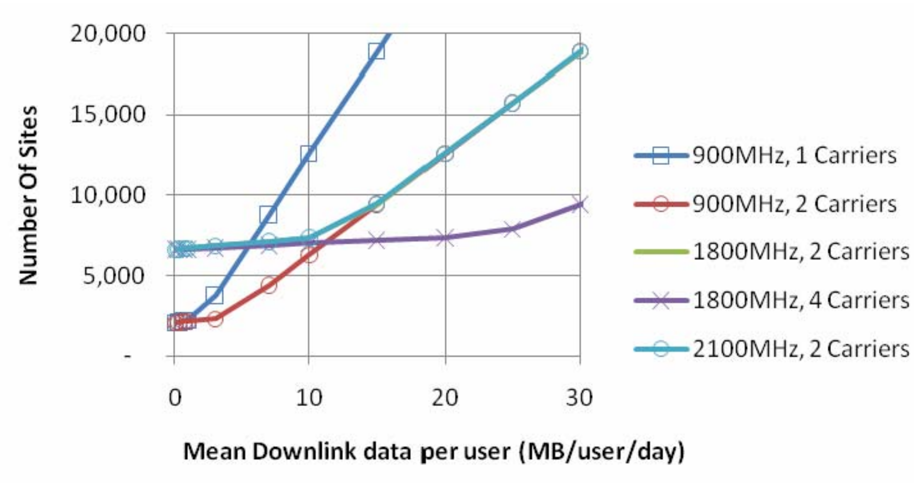
[13] WCDMA for UMTS: Radio Access for Third Generation Mobile Communications, Harri Holma (Editor), Antti Toskala (Editor), John Wiley & Sons, 3rd Edition, 2004, ISBN 0470870966

[14] Modern Antenna Handbook, Balanis, Wiley, 2008, chapter 22.

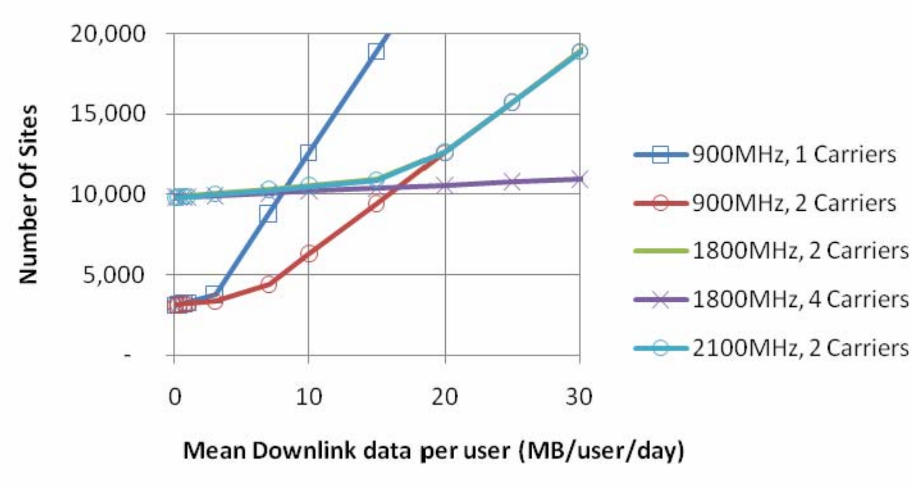
Table 16: Values used for investigation of impact of body loss

Position	Range of body loss values for investigation
A: Free space reference	0 dB
B: Talk position	3 - 5 dB
C: Belt-worn	5 - 7 dB
D: Handheld browsing	3 - 5 dB
E: Dongle or embedded modem	0 - 3 dB

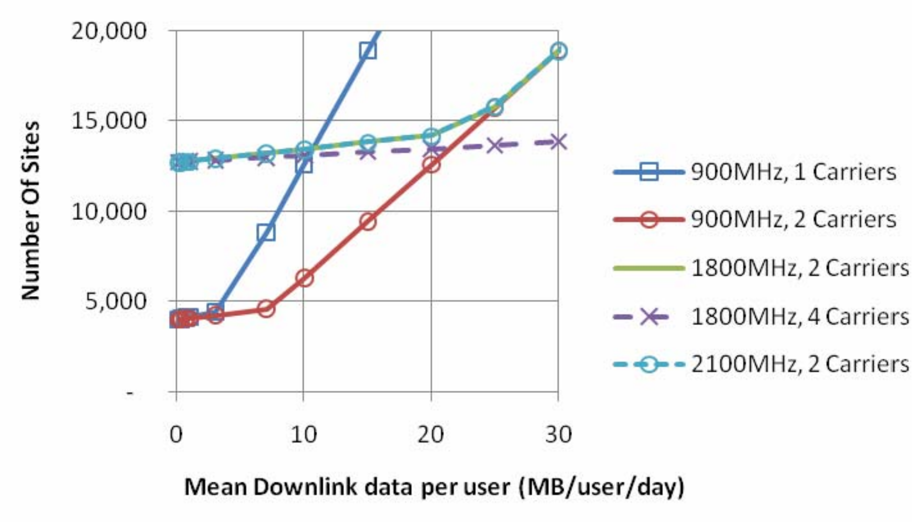
A13.301 Results are shown in Figure 36 (a)-(d). Only the body loss is varied: all other parameters are as for the base case.



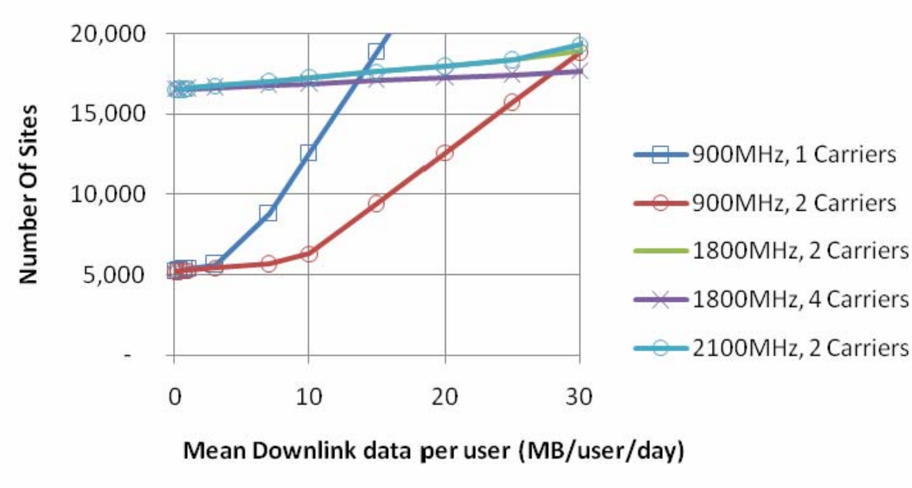
(a) Impact of 0dB body loss.



(b) Impact of 3 dB body loss.



(c) Impact of 5 dB body loss (i.e. base case).



(d) Impact of 7dB body loss.

Figure 36: Impact of varying user device body loss from 0 dB to 7 dB.

Findings

A13.302 Consultation simulations were concentrated on determining intrinsic propagation differences between bands and maintained equipment specifications equal between bands.

A13.303 User equipment which just meets the 3GPP specification is subject to performance degradation at 900 and 1800 MHz relative to 2100MHz, partially offsetting the propagation differences. We have now accounted for these specified differences according to 3GPP specifications, but note that practical equipment may exceed the specification to a different degree in different frequency bands.

A13.304 Variations in body loss according to device type and usage position can significantly affect the number of sites required to deliver adequate service. In some cases this could limit the service which can be delivered by an operator with high frequency spectrum. We have included predictions of a range of body loss to identify the impact of such effects.

A13.305 In summary, we are using 5 dB as our base case body loss for data and 3 dB as our base case for speech, but we have examined the sensitivity of the results to this value for body losses of up to 7 dB and as low as 0 dB for data.

Issue 6 – Simulation Area and Extrapolation

Issues

A13.306 The September 2007 consultation used a 100 km^2 area of North London as the basis for the simulation work and then extrapolated the site count from this area to the whole of the 80% population area.

A13.307 Responses indicated several concerns relating to the selection of this area:

- The simulation area has a relatively high percentage of built-up areas compared with the 80% population area as a whole.

- A planning efficiency factor (40% of site difference of 2100MHz sites over 900 MHz) has been applied to the site numbers derived from the North London simulations to account for the differences with the 80% population area, but this extrapolation approach may not be robust or fully justified.

- The extrapolation effectively includes the impact of sites required to cover open and forested areas within the 80% population area, which an operator would normally cover incidentally as part of serving the populated regions (except for specific locations such as major roads). This may cause the calculations of site numbers to exaggerate the total number of sites required.

A13.308 The methodology applied in the previous consultation is summarised as follows:

- An area of North London was planned using an optimisation tool for a given traffic demand and subscriber density.

- The North London area was initially chosen to explore issues associated with densely populated areas with dense numbers of buildings and many different clutter types, not to be fully representative in itself.

- Site numbers established for the North London area based on simulation results at 900, 1800 and 2100 MHz.

- The low adoption 900MHz scenario was taken as a baseline (simulation results indicated 37 sites were required in this case).

- National Low Adoption, 900MHz requirement was assumed to be 6600 sites based on existing 3G site details provided by operators.

- National site counts were calculated by multiplying the national baseline (6600 sites) by the ratio of the relevant North London result with the North London baseline, e.g. for the medium adoption scenario at 2100MHz the North London result indicated a requirement for 194 sites. This would require 194 / 37 × 6600 = 34,600 sites nationally.

- A planning efficiency factor is then included to account for the fact that North London is more densely populated and built up than the rest of the UK 80% population area. The factor was applied to the number of sites in excess of those at 900MHz to account for the practical placement of sites in population centres and to account for terrain variations. The value of the planning efficiency factor was taken to be 40%.

- This reduces the additional site number in the example to a site count of 17,800.

A13.309 We have now adopted a different technical model, which allows direct calculation of the density of sites required in a given clutter environment. This permits the total number of sites to be calculated for the whole area of interest directly based on an assessment of the area of each clutter type within required service area.

A13.310 We have also calculated site counts based on only the sites required according to the technical model in the populous clutter types (suburban, urban, open-in-urban and dense urban).

Impact of Varying Population density

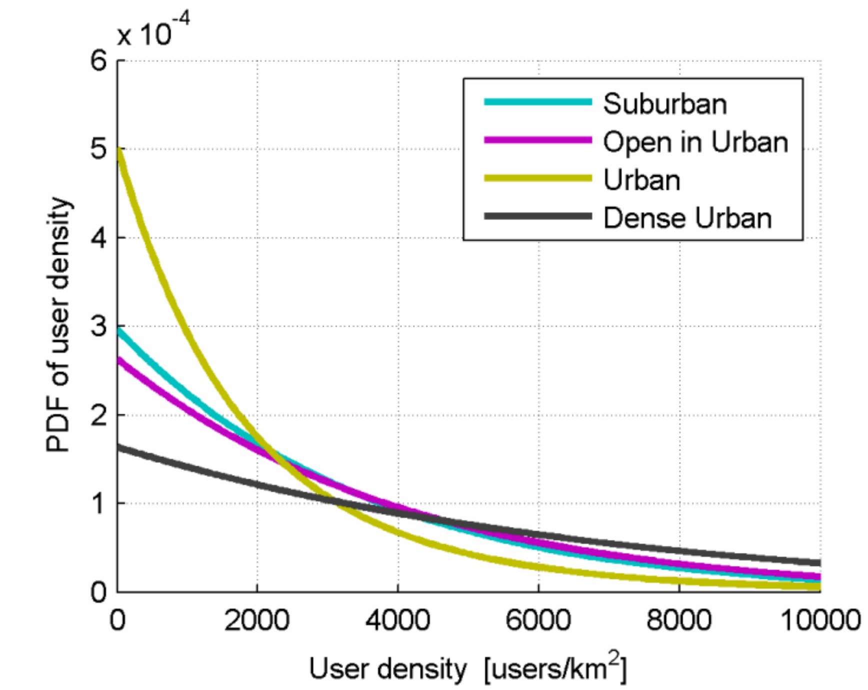
A13.311 The distribution of user densities selected for modelling is shown in Table 17. Taken together with the area for the clutter types in the 80% area, the implied subscriber count is around 16.2 million. Taken together with UK mobile subscriptions of 73.5m at the end of 2007[15], this implies a market share amongst the population living in the 80% area of 22%.

Table 17: Assumed distribution of subscriber densities by clutter type.

Clutter type	Subscriber density (km^{-2})	Area (km^2)	Implied total subscribers
Water	0	514.6	-
Open	0	17565.6	-
Forest	0	2392.2	-
Suburban	1,261	8985.0	11,330,035
Open In Urban	1,261	1387.1	1,749,136
Urban	5,183	572.7	2,968,460
Dense Urban	6,369	26.7	169,909
Undefined	0	1,145.6	-
total		45,247.5	16,217,539

A13.312 In most of our calculations we have taken the subscriber density to be constant at the average values expressed in Table 17. However, in practice the subscriber density will vary widely within a clutter category, so we have also examined the impact of such variation on the site numbers.

A13.313 In order to model this effect, we have used the Pareto distribution to relate the probability density of a given user density in each clutter type, applying the same mean values as in Table 1. The resulting distributions are shown in Figure 1. Note that, although suburban and open in urban have the same mean (as per Table 17) the shape of the curve is different.



[15] Ofcom Mobile Sector Assessment "Mobile citizens, mobile consumers" 2008, §3.16.

Figure 37: User density probability density functions

A13.314 In order to calculate the impact of these distributions on the site numbers predicted by our technical model, an analytical calculation was used to integrate the site numbers predicted for a given user density over the range and probability of each user density according to the distributions in figure 1. Details of this method are given in Appendix A13.2: Site Numbers From Pareto Distributed User Populations in Section A13.429 *ff*.

A13.315 Figure 38 plots the results of assuming a distribution of user densities for the baseline parameters with two carriers at each of 900MHz and 2100MHz (solid curves). The results of assuming an average user density are also plotted for comparison (dashed curves).

A13.316 The distribution curves indicate that a greater number of sites is required at either frequency for a given average user demand. This is because, although for a certain demand level the average user density may be within the coverage limited region, the Pareto distribution for the same mean density will include some proportion of areas with much higher user densities. For very small and very large traffic demand levels the average and distribution curves converge because the Pareto distribution is contained entirely in either the coverage or capacity limited regime respectively.

A13.317 At 2100MHz this increase in the number of sites is bigger, because the active user density number in pole capacity raises, which explicitly affects the ratio of the active-user-density over the census-population-density. This ratio causes a flattening of the Pareto distribution curve towards greater user densities.

A13.318 The overall effect of assuming a distribution of user densities drives the point where site differences between 900 and 2100 MHz to much greater demand levels.

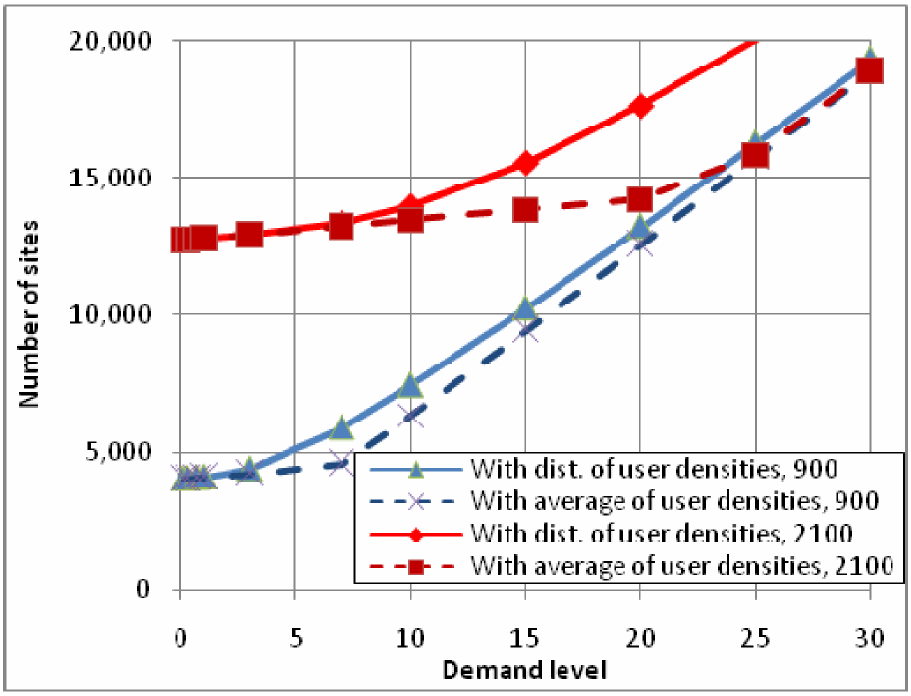


Figure 38: Comparison between the baseline site numbers given an average active user density (dashed lines) or Pareto distributed user densities (solid lines).

Impact of extent of service

A13.319 It could be that service quality is more important in some parts of the densely populated area than others.

A13.320 For example, quality could be significantly more important in the commercial districts.

A13.321 To explore this we have examined the number of sites which would be required to deliver service in only the areas corresponding to urban and dense urban areas, as shown in Figure 39.

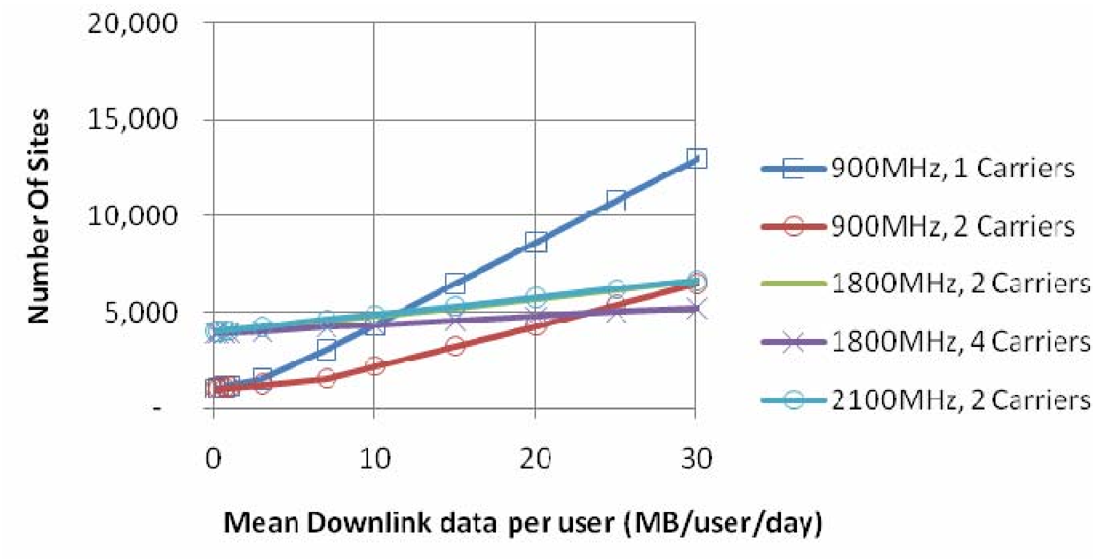


Figure 39: Sites required to deliver service in urban and dense urban areas alone

Findings

A13.322 The removal of targeted coverage of open areas as a driver for site counts reduces the number of sites required for covering the densely populated area. We note that some sites would be required to target areas of high traffic away from residential population centres – e.g. major highways – but in the main we consider it appropriate that the most important regions for site deployment would be those which are densely populated.

A13.323 Selectively covering business districts alone significantly reduces site count, but we do not consider this a likely scenario.

Issue 7 - Quantity of Spectrum

Issues:

A13.324 The consultation evaluated site costs based on the availability of two carriers per network in each frequency band.

A13.325 However, the costs of spectrum clearance and some policy options included consideration of cases where only 1 carrier would be available to some operators in 900 MHz. The site differences may be less in this case.

A13.326 1800 MHz operators have more spectrum available than 900 MHz operators. This could offset site differences associated with improved propagation at 900 MHz.

Analysis:

A13.327 The main role of the cost difference analysis in the consultation was to show what happens in the counterfactual, where spectrum is liberalised in the hands of incumbents. We then considered a central case where 2 carriers were used to provide service in each frequency band.

A13.328 However, as described in Annex 8, it is also relevant to consider the impact of reducing the available spectrum to one carrier at 900 MHz and increasing it to 4 carriers at 1800 MHz.

A13.329 For the base case, the outcome of this variation is shown in Figure 40.

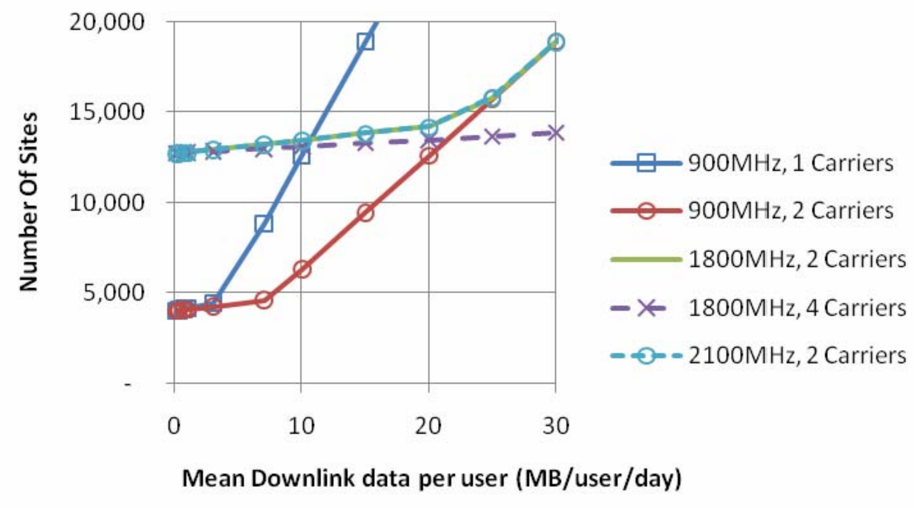


Figure 40: Impact of varying quantity of spectrum (base case)

Analysis

A13.330 As illustrated in Figure 40, variations in the available quantity of spectrum can substantially affect the volume of data at which site differences reduce. For the various policy considerations described in Annex 10 different comparisons of spectrum quantities are of most relevance.

A13.331 As a result we have calculated the impact of a single carrier at 900 MHz and of four carriers at 1800 MHz in addition to our two carrier results throughout our analysis of site differences.

Issue 8 – Use of HSDPA

Issues

A13.332 Responses pointed out that HSDPA is now widely deployed by operators and that HSDPA operates in a different way to Release 99 (R99) traffic, which could potentially affect the size of any site differences

A13.333 Some responses suggested that these issues would decrease the number of sites required due to the increased efficiency of handling data traffic.

A13.334 Other responses suggested that planning for higher data rates would increase the number of sites required.

Analysis

A13.335 HSDPA differs from R99 downlink data traffic in two main ways:

10.335.1 A wider range of higher theoretical maximum data rates are supported (up to 14.4 Mbps in release 5 and 6). These are achieved using a fixed spreading factor (SF=16) but using adaptive modulation and coding techniques according to the signal quality of each user. As a result a wide range of possible data rates can be delivered to users with sufficiently good quality signals – see Table 18.

10.335.2 User traffic is served on a shared channel (HS-DSCH) whose capacity is allocated flexibly, with packets belonging to users being transmitted according to decisions made by the network in each 2ms according to the quality and bandwidth demand of each user. The share of downlink power available to HS-DSCH can be set by the operator, and may be dynamically varied according to demand in some systems.

Table 18: HSDPA modulation and coding schemes yielding variable data rates

Category	Max. number of HS-DSCH codes	Modulation scheme	Max. data rate [Mbps]
1	5	QPSK and 16-QAM	1.2
2	5	QPSK and 16-QAM	1.2
3	5	QPSK and 16-QAM	1.8
4	5	QPSK and 16-QAM	1.8
5	5	QPSK and 16-QAM	3.6
6	5	QPSK and 16-QAM	3.6
7	10	QPSK and 16-QAM	7.3
8	10	QPSK and 16-QAM	7.3
9	15	QPSK and 16-QAM	10.2
10	15	QPSK and 16-QAM	14.4

11	5	QPSK only	0.9
12	5	QPSK only	1.8

A13.336 The impact of deploying HSDPA compared with R99 may include the following:

10.336.1 The delivery of higher data rates requires the use of lower spreading gains and higher-order modulation schemes. These require a higher signal-to-noise ratio than lower-rate services. Such services, if designed to be delivered over a large proportion of the service area, will cause an increase in the impact of propagation differences and hence a higher site difference.

10.336.2 The efficient packet scheduling and ability to deliver the same data volumes in a shorter period will reduce capacity constraints on the network. However, capacity constraints are still present, including the limited number of available codes at a given rate and the need to share the HS-DSCH power amongst codes.

10.336.3 If the net effect is to reduce capacity constraints, the network is more likely to be coverage-limited, thereby exhibiting larger coverage differences arising from propagation difference between different frequencies.

A13.337 To analyse the extent of these effects, an extension to the technical model was constructed to account for HSDPA traffic. Details of this extension are provided in Appendix A13.1.

A13.338 Two deployment scenarios are considered:

10.338.1 Dedicated HSDPA carriers, where all of the available capacity is used for HSDPA traffic.

10.338.2 Shared carriers, where HSDPA shared with Release 99 traffic, with Release 99 traffic modelled as a reduction in the power available for HSDPA.

A13.339 In practice operators may use a blend of these two approaches, such as one shared carrier and one dedicated carrier. The result would be expected to be between the results for all-dedicated or all-shared operation.

A13.340 The other assumptions used in the modelling are specified in Table 19 and Appendix A13.1.

A13.341 Results are shown in Figure 41 to Figure 50 for base case parameters (except those specified in the figure captions). The data rates referred to in the figures are the target values for per-user throughputs. This is a more appropriate measure for HSDPA than the bearer bit rates used in the earlier calculations for release 99 due to the shared nature of the HSDPA resource. Throughput is typically used the relevant metric in literature regarding HSDPA.

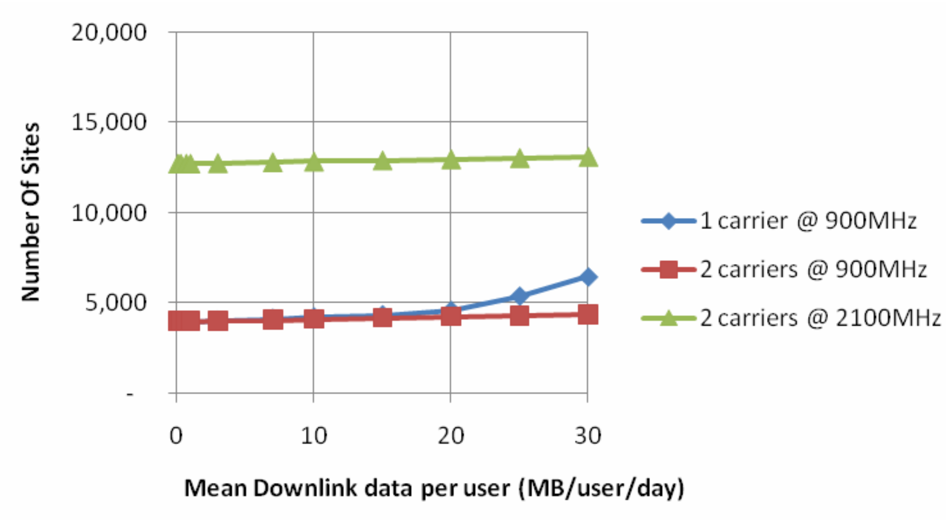


Figure 41: HSDPA 700 kbps, dedicated channel

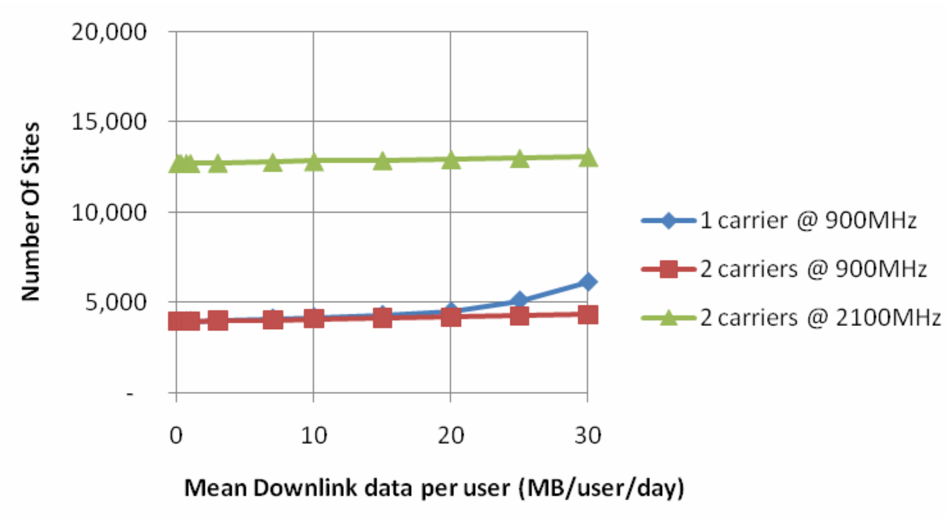


Figure 42: HSDPA 1.2 Mbps, dedicated channel (95% coverage confidence by area)

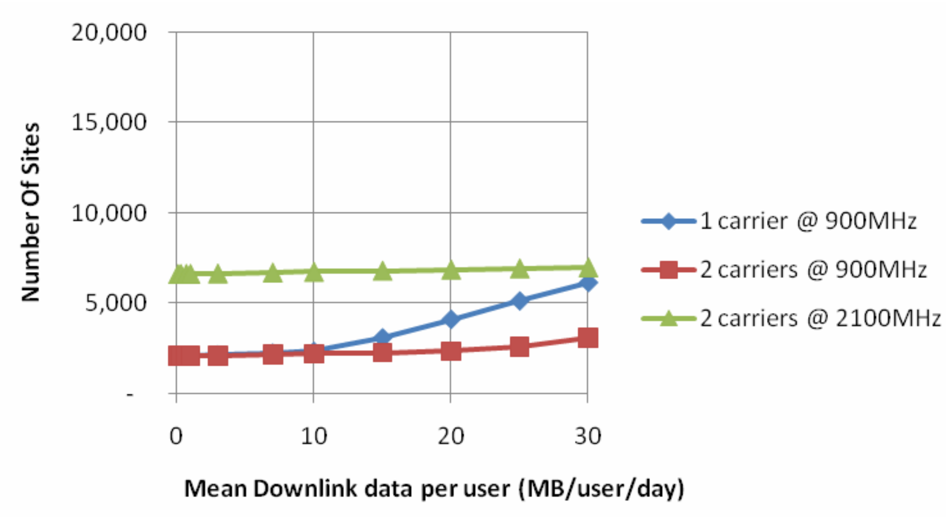


Figure 43: HSDPA 1.2 Mbps, dedicated channel ([0 dB] body loss)

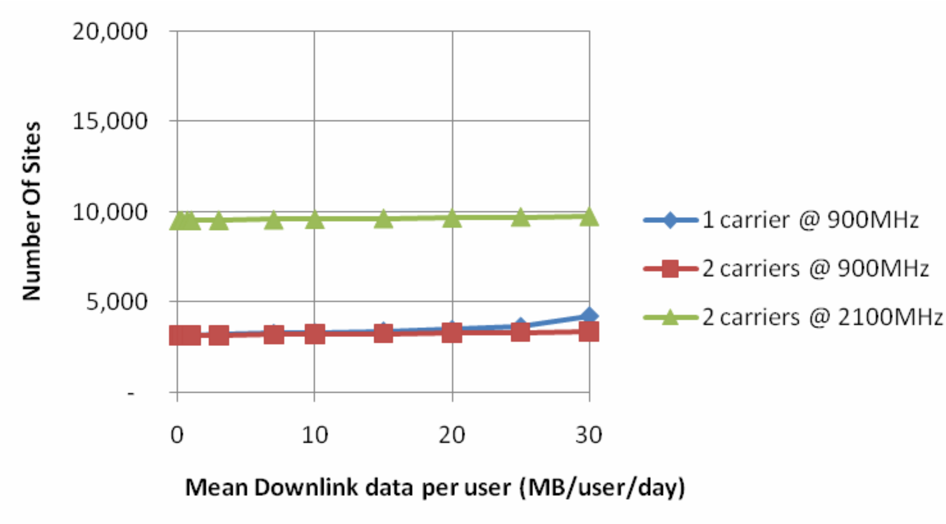


Figure 44: HSDPA 1.2 Mbps, dedicated channel (90% coverage confidence by area)

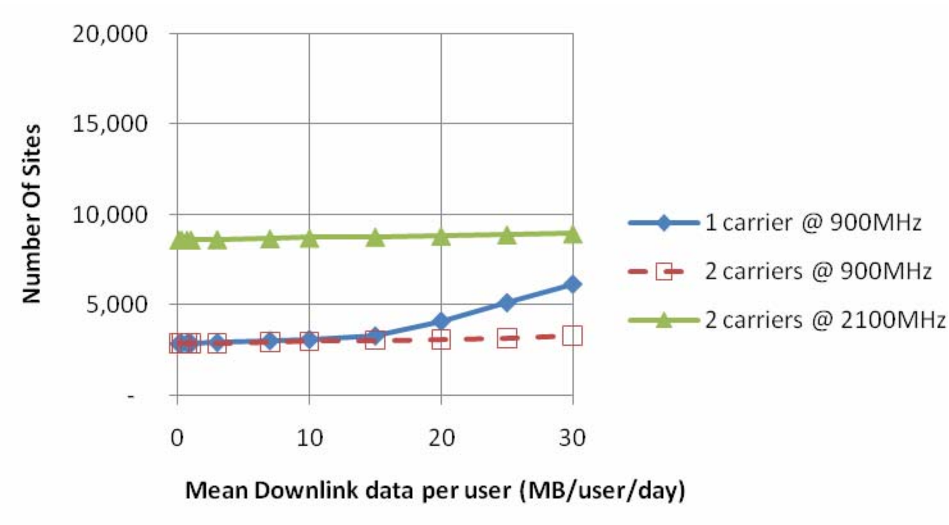


Figure 45: HSDPA 1.2 Mbps, dedicated channel (shallow coverage depth – depth [1])

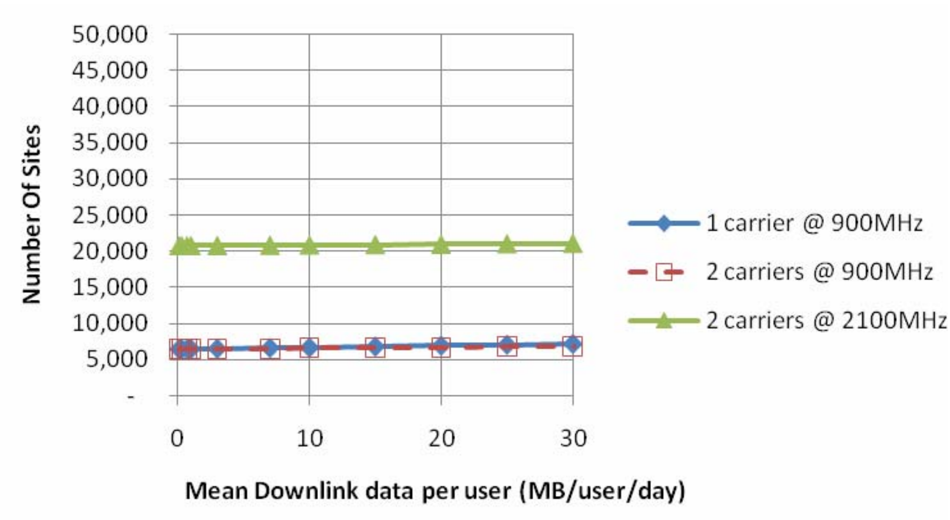


Figure 46: HSDPA 2.4 Mbps, dedicated channel (95% coverage confidence by area)

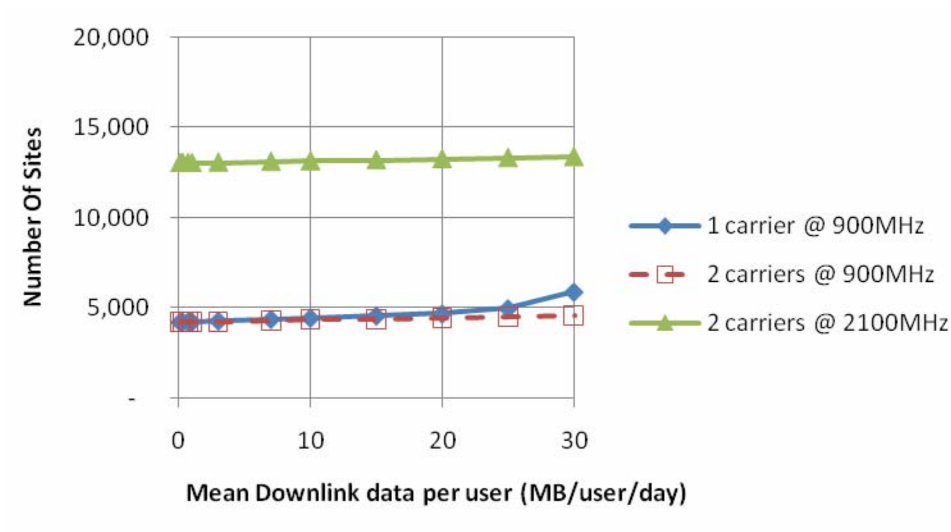


Figure 47: HSDPA 2.4 Mbps, dedicated channel (90% coverage confidence by area)

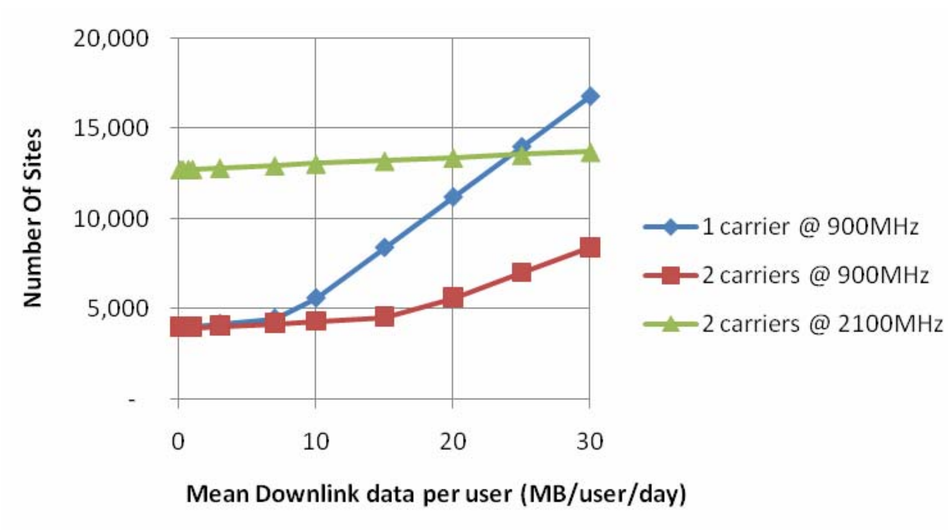


Figure 48: HSDPA 700 kbps, shared channel

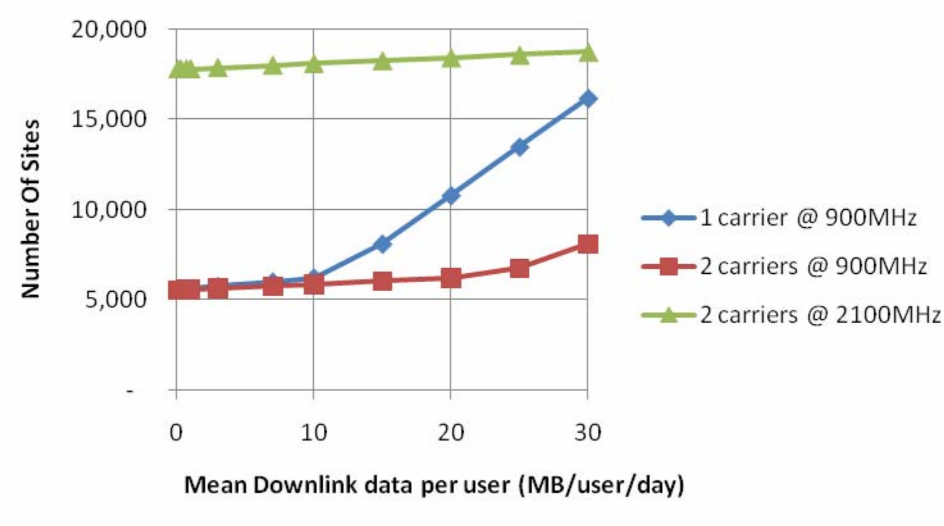


Figure 49: HSDPA 1.2 Mbps, shared channel

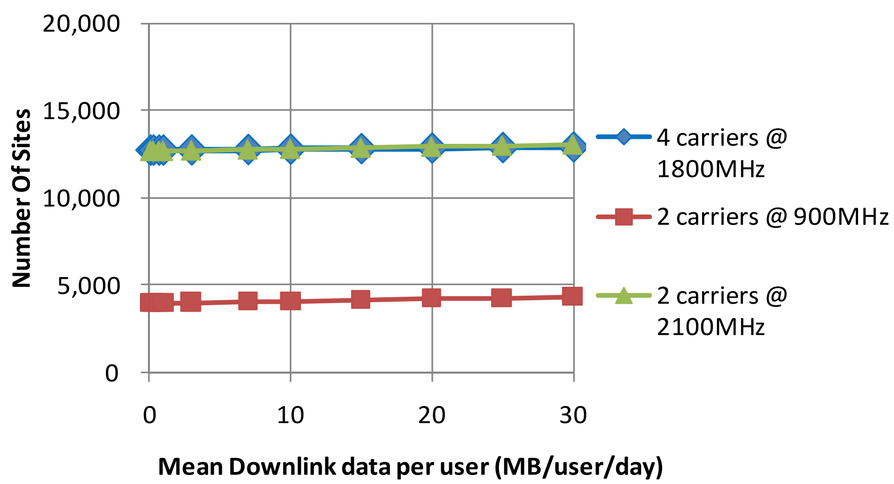


Figure 50: HSDPA 1.2 Mbps, dedicated channel, result with 4 carriers at 1800 MHz

Findings

A13.342 HSDPA carries downlink traffic in a different manner to R99 traffic, and can deliver such traffic more efficiently, in principle reducing the number of sites in a capacity-constrained network.

A13.343 However, offering higher data rates from the same sites as those designed to deliver consistent R99 rates will increase the data throughput for those users in areas of good signal quality. This will substantially reduce capacity constraints in the network, increasing the likelihood that the network is coverage-limited. Frequency differences are therefore more likely to produce site differences in such a network than in a capacity-limited release 99-dominated network, thus site differences are increased. This is confirmed by the calculations from our technical model, where the traffic volume at which capacity limitations become evident is increased in proportion to the increase in mean throughput available to HSDPA users.

A13.344 Offering higher data rates to customers over a large proportion of the network area will create more challenging link budgets, which will increase the absolute number of sites required, increasing the differences in sites between frequencies in the coverage limited range of data volumes.

Issue 9 - Site Engineering Issues

A13.345 Some consultation responses suggested that the use of antenna sharing on sites which are shared between frequencies and technologies, e.g. GSM 900/1800 and UMTS 900, would result in greater losses at the signal combiner equipment which may reduce site differences and limit scope for independent down-tilts. The site configuration is illustrated in Figure 51, where the insertion loss of the 2G/3G signal combiner is the relevant parameter.

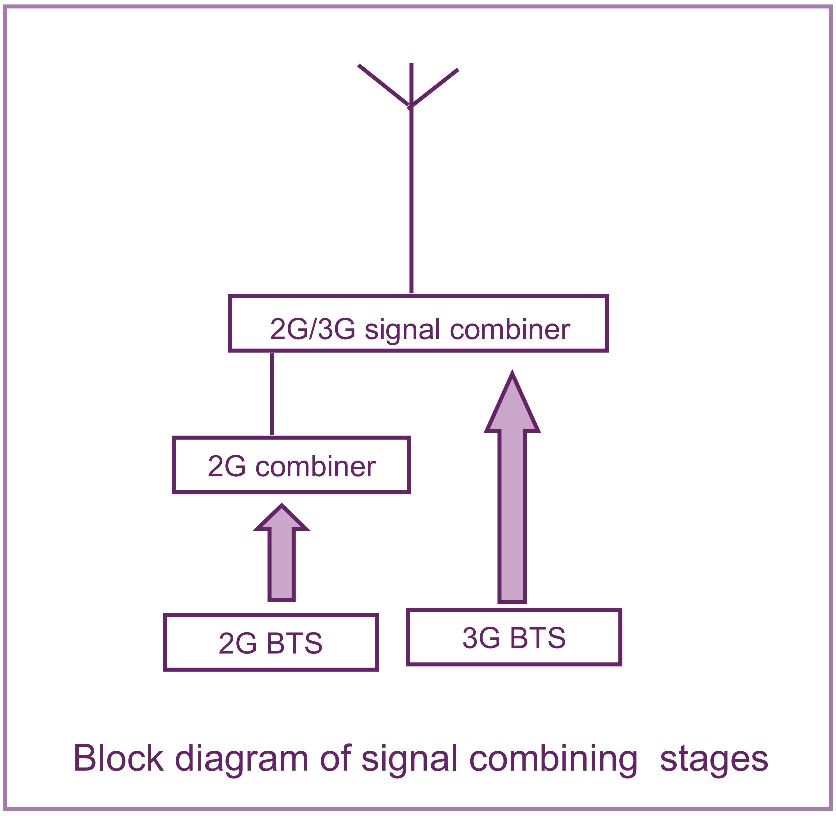


Figure 51: Signal combining at a 2G/3G base station site

A13.346 Another issue raised relating to site engineering is the potential use of masthead amplifiers, which can substantially reduce the noise figure of the base station receive system. The previous consultation assumed conventional operation where there the base station receiver and transmitter is entirely located away from the antenna, typically in a cabin or cabinet away from the structure supporting the antenna. Depending on the distance between the base station and the antennas, substantial feeder loss between the base station and the antenna may be incurred in the connecting cables. This loss increases the base station receiver noise figure and reduced the available base station transmit power.

Analysis

Combiner Losses

A13.347 We have discussed combiner equipment with base station manufacturers and with specialist combiner manufacturers. These manufacturers have been engaged in trials of UMTS 900 equipment in overseas operator networks.

A13.348 These manufacturers advised that the current design techniques allow commercial operation of combiners with an insertion loss of almost 0dB for the uplink path and a maximum of 0.6 dB in the downlink path. At these levels the impact of the additional combiner loss on site counts would be negligible.

A13.349 The cost of such devices is several hundreds of pounds per unit. In comparison with the overall costs of a base station site, these figures are negligible, and anyway are encompassed well within the range of costs considered in Annex 15.

A13.350 Conventional shared antennas are sometimes limited in their applicability due to the need for different downtilts between antennas for different frequency bands and technologies to account for the differing interference conditions. For some sites this will limit the option for site sharing due to space constraints. However, more than one manufacturer is now offering integrated antennas with the capability to produce independent downtilts. Additionally, discussions with an overseas operator who has deployed UMTS and GSM in the same low frequency band indicated that for many sites it was possible to use the same downtilt for both technologies when frequency hopping by making use of the increased sensitivity of measurement reports from the UMTS equipment.

Masthead Amplifiers

A13.351 Achievement of low receiver noise figures using masthead amplifiers requires the mounting of powered electronics on the top of tower. Historically and particularly for GSM, this has not been a favoured approach for operators on the grounds of cost, reliability and maintainability. Also, some sites will not permit due to space and other restrictions.

A13.352 It is plausible, however, that any saving in site cost could offset the additional costs involved in purchasing and installing the equipment and the associated maintenance costs.

A13.353 Operators have indicated that masthead operation, where low noise amplifiers and potentially power amplifiers are placed close to the antenna, is increasingly common and helpful in reducing the number of sites required.

Findings

Combiner Losses

A13.354 Combiner equipment with negligible insertion loss is available at low cost compared with the overall site costs (new or upgrade).

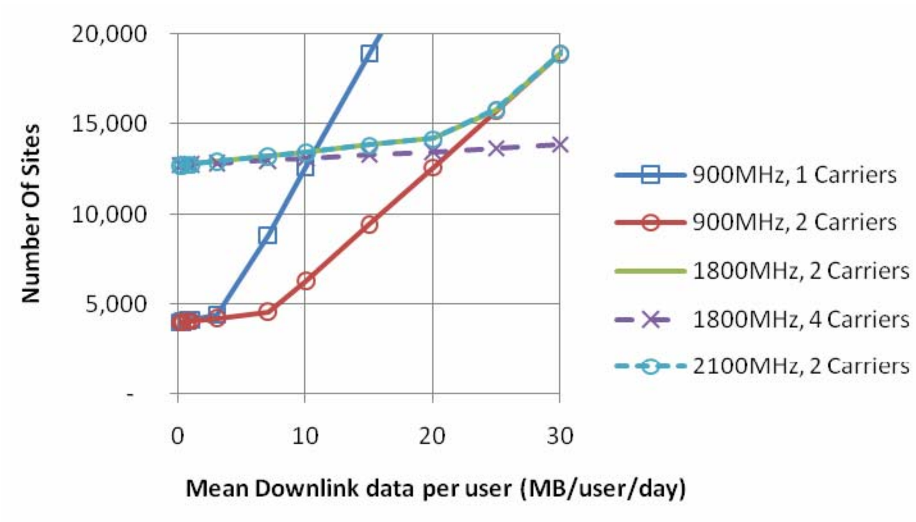
A13.355 Antenna downtilts can be independently controlled when necessary, but the need for independent downtilts appears to be less than anticipated based on industry feedback.

A13.356 Our current view is therefore that the site engineering issues raised are not major and can be addressed at relatively low cost compared to overall site costs.

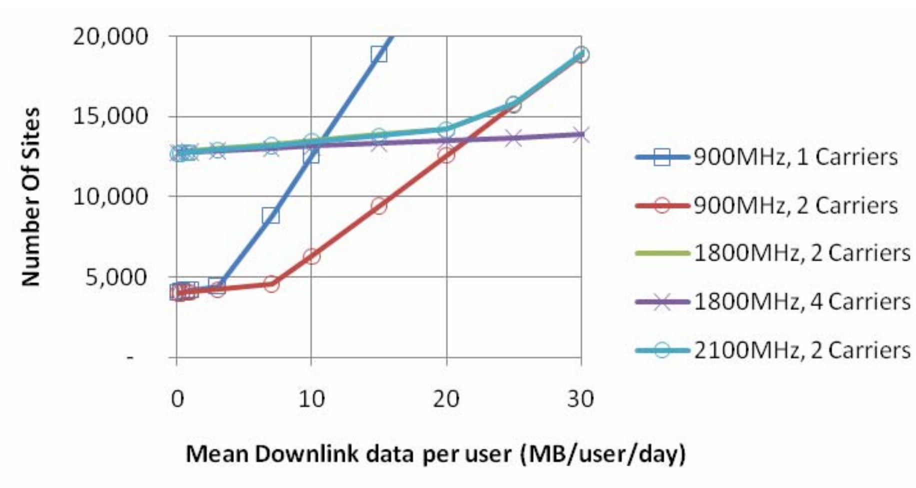
Masthead Amplifiers

A13.357 The impact of including and excluding such amplifiers is shown in Figure 52. Since the number of sites is limited by downlink Ec/Io performance with the parameters chosen, the MHA makes little or no difference in this particular case. However the differences would be more apparent if a lower threshold value of Ec/Io was chosen or if the uplink performance were separately assessed.

A13.358 Since masthead amplifiers could in some cases substantially reduce the number of sites required, we consider that this would be adopted by operators even if the per-site costs were increased. Therefore we have adopted the use of masthead amplifiers, with a system noise figure of 2dB, for our base case.



(a) With MHA (base case)



(b) Without MHA

Figure 52: The impact of the use of masthead amplifiers

Other Technical Issues and Variations Examined

Pilot Signal Quality

A13.359 As described in A13.103 and in more detail in Appendix A13.1, one constraint on the number of sites is the requirement to deliver adequate pilot signal quality, to avoid the phenomenon of 'pilot pollution', where the mobile is unable to reliably decode signals from each cell. We have modelled this constraint within the technical model using a base case assumption of a required threshold value of Ec/Io = - 8dB under unloaded conditions and have confirmed with MNOs that this is a reasonable value to assume.

A13.360 However, the factors affecting the performance of a network to Ec/Io include the detailed propagation geometry, the configuration (especially downtilt) of the base station antennas, plus the cell-specific setting of the proportion of the downlink power which is allocated to the pilot channel. While account these factors is included in the technical model on an average basis, the model is not able to account for the fine detail of optimisation which an operator might conduct to improve the performance of the network in respect of this parameter.

A13.361 To investigate the potential impact of this parameter, we have varied the threshold value over a wide range, for 2 carriers at 900 and 2100 MHz for a data quantity of 3MB / user /day with the other parameters at the base case. The outcome is shown in Figure 53. It is apparent that the coverage-limited site counts are affected significantly by the value of this parameter for the parameters considered in the base case and given the modelling approach adopted.

A13.362 In order to account for this sensitivity in the results, we have examined the range of market scenarios for Ec/Io from -6 to -10 dB as shown in Figure 53.

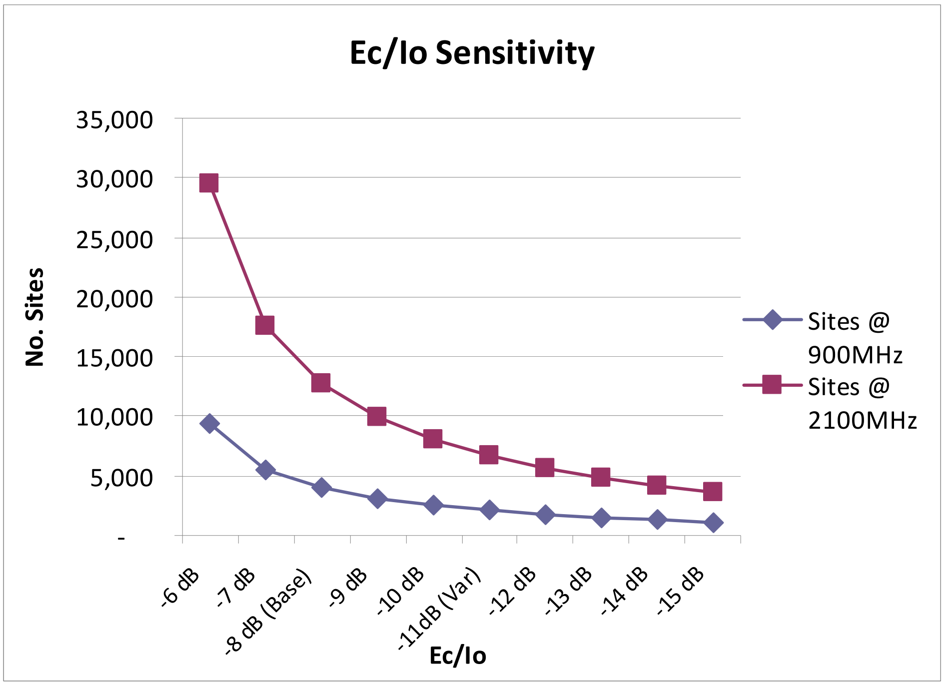


Figure 53: Impact of varying the unloaded Ec/Io threshold (data quantity 3MB / user / day, 2 carriers at 900 and 2100 MHz)

Uplink receiver diversity

A13.363 Our base case assumes the use of uplink receiver diversity via appropriate assumptions concerning the required uplink Eb/No. The results shown in Figure 54 indicate the result where such diversity is considered impractical or ineffective. The outcome is not greatly affected, particularly because of the limitation on site numbers arising from the threshold values of Ec/Io adopted.

A13.364 Uplink receiver diversity is widely adopted and may yield savings in site numbers where the uplink is the limiting factor. We therefore continue to include its impact in our base case.

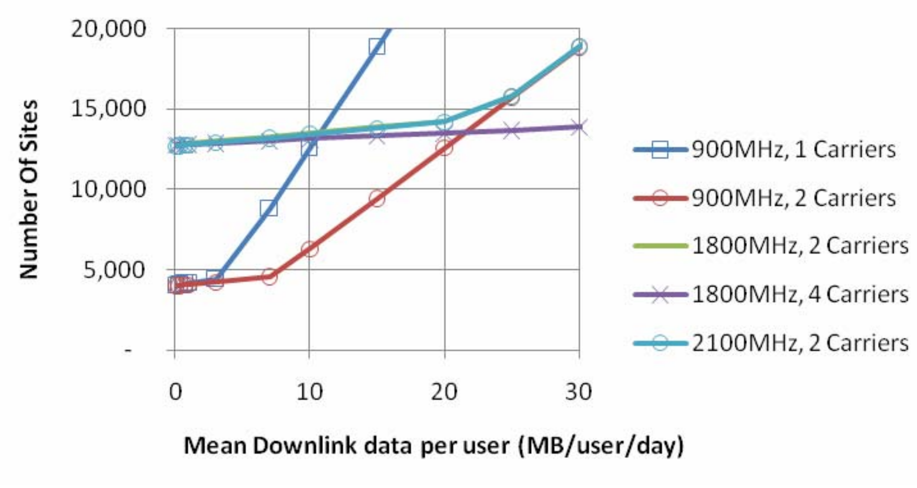


Figure 54: Impact of assuming no uplink receiver diversity

Sectorisation

A13.365 Most cellular sites divide their coverage area into three distinct sectors to limit the interference caused amongst users and between sites. When a network is capacity constrained, an alternative to deploying extra sites ('cell splitting') is to increase the sectorisation per site from the usual three sectors to six. This does not quite double the capacity, but does increase the data volume at which cell splits are required as shown in Figure 55. Nevertheless this is not a commonly deployed technique, partly due to physical constraints on site space, so we have continued to utilise three sectors in our base case.

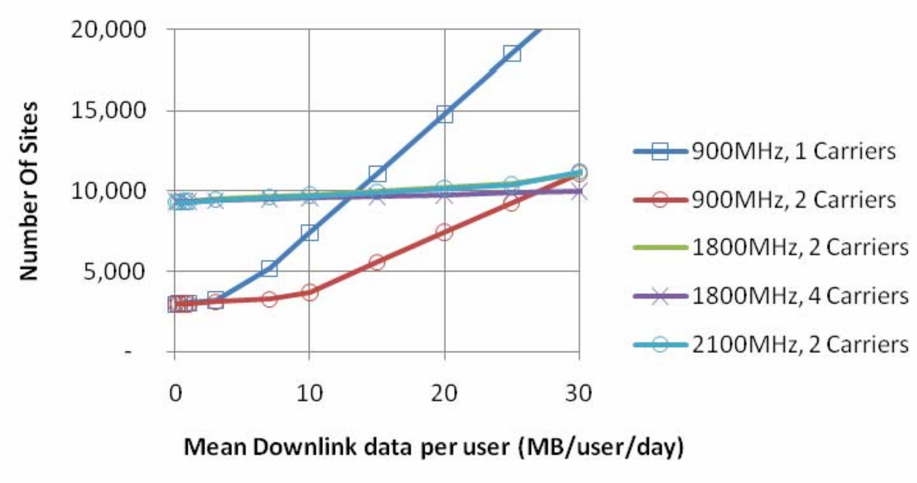


Figure 55: Impact of six-sector operation

Proportion of users in soft handover

A13.366 When users are located at the overlap area between sites, they will be in 'soft handover' where two or more sites communicate with the user to limit interference effects. However, this also increases the required system resources and hence limits the available system capacity. For our base case we have assumed that 20% of users are in soft handover on average across the network.

A13.367 In some areas particularly urban areas, the overlap between sectors and sites may increase due to the increased level of multipath scattering. To estimate the impact of this we have assumed that 40 % (rather than 20%) of users are in soft handover, occupying extra system resources for the same capacity. The outcome is shown in Figure 56.

A13.368 This hastens the onset of capacity limitations, reducing the data volume at which the site difference reduces. This is probably an overestimate of the impact since this assumes this effect is present on all sites.

A13.369 We have continued to assume 20% as the base case since this is widely quoted in the literature and has been confirmed as a planning assumption in consultation with the MNOs, but we note that this creates an additional variation in the potential onset of capacity limitations.

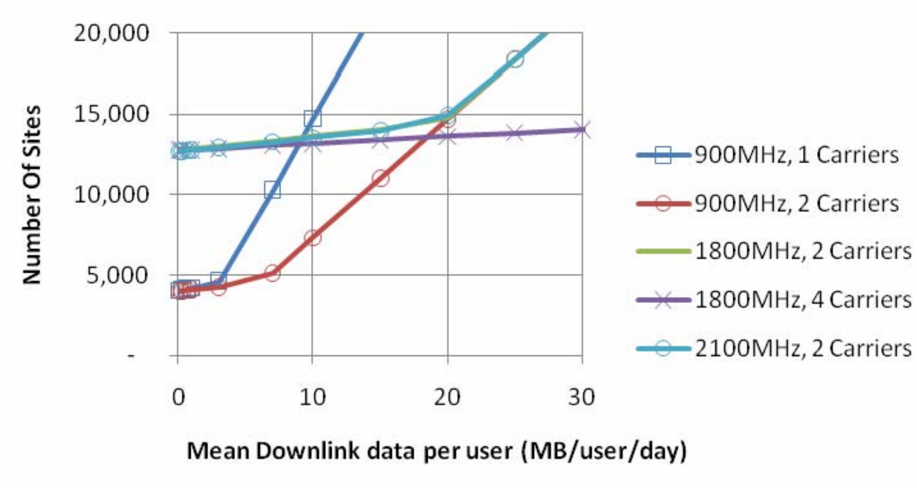


Figure 56: Impact of increasing proportion of users in soft handover

Maximum Load Factor for Cell Splitting

A13.370 In our base case we have assumed that cells are split when the load factor exceeds 75%. For some services this could lead to poor signal quality, so in Figure 57 we have examined the impact of a 50% maximum load factor. Again this reduces the onset volume for capacity limitations.

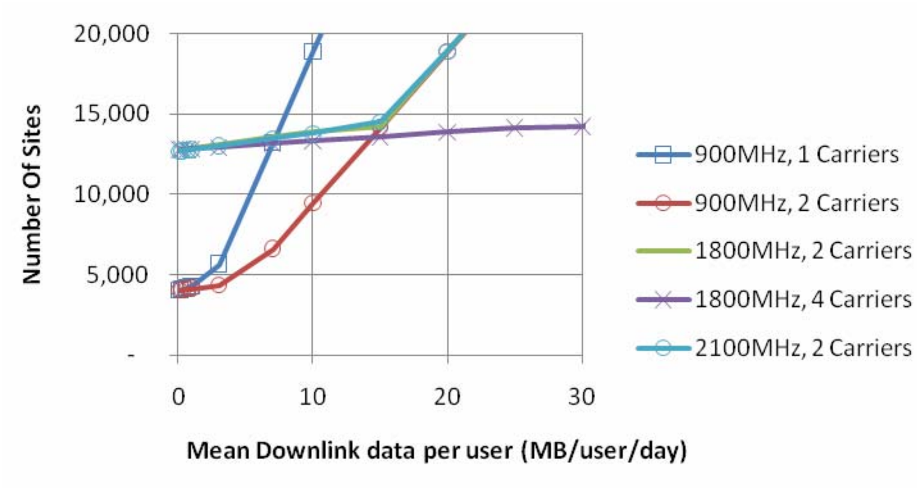


Figure 57: Impact of reducing maximum load factor to 50%

Summary of parameters for analysis

A13.371 The parameters which are considered relevant to our analysis following the refinements described in earlier sections are summarised in Table 19, which includes the values defined for the base case and the range of values examined relative to this base case.

Table 19: Parameter ranges used for analysis

Ref.	Paramete r	Value for base case	Range for analysis	Units		Source
Base station parameters						
1	Sectors Per Site	3	3, 6			Industry practice
2	Carriers per sector	2	1, 2 (900 MHz) 2, 4 (1800 MHz) 2, 3 (2100 MHz)			Scenarios relevant to policy considerati ons

3	Total transmit power per carrier	20	20	watts		Industry data
4	Pilot channel power	10%	10%	Proportion of total transmit power		Holma[16] Table 8.18
5	Power in other common downlink channels	10%	10%	Proportion of total transmit power		Holma Table 8.18
6	Boresight antenna gain	16.0 (900 MHz) 17.8 (1800 MHz) 18.3 (2100 MHz)	16.0, 19.0 (900 MHz) 17.8, 20.8 (1800 MHz) 18.3, 21.3 (2100 MHz)	dBi	The larger values are to be used to represent the six-sector case	Kathrein 742 265 multi-band antenna (3 sector case)
7	Antenna height	25.0 (dense urban) 15.0 (suburban) 20.0 (all other areas)	25.0 (dense urban) 15.0 (suburban) 20.0 (all other areas)	m		
8	Cable, combiner and connector losses	0.0	3.0 (conventional operation) 0.0 (masthead operation)	dB	The use of masthead amplifiers (LNA and PA) is now included in the base case	Masthead operation

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

9	Receiver noise figure	2.0	5.0 (conventional operation) 2.0 (masthead operation)	dB	The use of masthead amplifiers is now included in the base case	Holma Table 8.2 (base case) Industry suggestions (masthead)
User equipment (mobile device) parameters						
10	Transmit power (at antenna input)	21.0 (speech services) 24.0 (data services)	21.0 (speech services) 24.0 (data services)	dBm		3GPP TS 25.101 and Holma table 8.1
11	Antenna gain (mean effective gain)	0.0	0.0	dBi		Holma Table 8.3
12	Antenna height	1.5	1.5	m		Standard assumption
13	Body loss (relative to free space)	3.0 (speech) 0.0 (data – dongle/embedded modem) 5.0 (data – smartphone)	3.0 (speech) 0.0, 3.0 (data – dongle/embedded modem) 5.0, 7.0 (data – smartphone)	dB		Holma Table 8.1
14	Receiver noise figure	10.0 (900 MHz) 10.0 (1800 MHz) 7.0 (2100 MHz)	10.0 (900 MHz) 10.0 (1800 MHz) 7.0 (2100 MHz)	dB		Holma Table 8.1 and 3GPP TS 25.101
System Parameters						

15	Coverage Confidence (at cell edge)	87% at cell edge, i.e. 95% over cell area.	69% (corresponds approximately to 85% confidence over cell area) 78% (corresponds approximately to 90% confidence over cell area) 87% (corresponds approximately to 95% confidence over cell area) Also 90% by area (dense urban, urban, open-in-urban clutter) together with 95% by area (suburban)	%	Values of 85-95% over the whole cell area are common in the industry	Industry Data
16	Location variability (outdoor)	7.0 (900 MHz) 7.9 (1800 MHz) 8.1 (2100 MHz)	7.0 (900 MHz) 7.9 (1800 MHz) 8.1 (2100 MHz)	dB		Estimated from curves provided in [17]
17	Building penetration loss variability	6.0	6.0	dB		As September 2007 Consultation

[17] "Microwave Mobile Communications", ed. W.C. Jakes, IEEE Press, 1974.

18	Mean building penetration loss	See Table 13 and Table 14.	- Constant with frequency at 900 MHz values - Increasing with frequency by 10 dB between 900 and 2100 MHz - Depth 1 - Depth 0	dB		
19	Other-to-own cell interference power ratio	0.65	0.65 for 3 sector sites 0.85 for 6 sector sites	ratio	Higher value for six sector sites to account for additional inter-sector overlap due to multipath and antenna pattern	Holma table 8.7 Holma table 8.6 See reference [18], p. 237
20	Orthogonality factor	0.5 (downlink) 0 (uplink)	0.5 (downlink) 0 (uplink)	ratio		Holma table 8.7

[18] Understanding UMTS Radio network modelling, planning and automated optimisation theory and practice, Nawrocki, Dohler & Aghvami, Wiley, 2006.

21	Proportion of users in soft handover	20	20, 40	%	Some evidence that a higher value may be encountered in more densely built-up areas	Holma p. 59
22	Fast fading margin	2.0 (pedestrian)	2.0 (pedestrian) 0.0 (vehicular)			Holma p. 187
23	Maximum load factor	75	50, 75	%	50% is often used as a basis for coverage planning, though we use 75% as a driver for cell splitting due to air interface capacity limitations	Assumption
24	Soft handover gain	2.5 (DL) 2.0 (UL) 0.0 (DL for HSDPA)	2.5 (DL) 2.0 (UL) 0.0 (DL for HSDPA)	dB		Holma figure 9.21 Holma figure 9.20
25	Ec requirements	-114 (900 MHz) -114 (1800 MHz) -117 (2100 MHz)	-114 (900 MHz) -114 (1800 MHz) -117 (2100 MHz)	dBm		3GPP TS 25.101 Rel. 7

26	Ec / Io requirements	-8 (unloaded)	-8, -11 (unloaded)	dB		Industry data
27	Max: mean path loss ratio	6 dB	6 dB (uniform user distribution)	dB		Holma p195,
28	Data rates	See Table 18 and Table 22	For HSDPA, assume 15 codes and vary cell edge throughput target from 384 kbps to 2.4 Mbps.			
29	Eb/No requirements	See Table 22 – with uplink receive diversity	See Table 22 – with and without uplink receive diversity		Uplink receive diversity is commonly used	Holma Table 8.2 (with UL receive diversity) Holma table 12.21 (DL) Holma table 12.19 (without UL receive diversity)
30	Activity factor for speech	0.58 (DL) 0.67 (UL)	0.58 (DL) 0.67 (UL)			Holma table 8.7 (DL) Holma table 8.6 (UL)
31	Average data volume per user (downlink)	3	3 - 30	MB/user/day		Likely range in 2015 based on market analysis – see Annex 11

32	Speech traffic	20	20 0 (for data-only networks)	mE per subscriber in busy hour		Operator data
33	Proportion of daily traffic in busy hour	10	10	%		Based on market analysis (Annex 11).
34	Subscriber density	See Table 17.				Based on 2001 census data.
35	Extent of coverage	Most densely populated area containing 80% of population, including only urban, suburban, dense urban and open-in-urban clutter	1) 80% area 2) Reduced area to exclude residential areas			Based on 2001 census data.
36	Proportion of offered traffic successfully connected	95	95	%		Assumption based on industry data

37	Proportion of users indoors	Speech 70% indoors / 30% outdoors Medium rate data (80% indoors, 20% outdoors) High rate data (90% indoors and 10% outdoors)	Speech 70% indoors / 30% outdoors Medium rate data (80% indoors, 20% outdoors) High rate data (90% indoors and 10% outdoors)	%		Assumptions based on industry data
38	Outdoor propagation models	SE21-Hata Model (see Table 20 and Table **21**).				CEPT ERC REPORT 68[19]

Table 20: SE21-Hata propagation model

Urban	$f \le 1500$MHz	$L = 49.2 + 26.2 \log f + 35.2 (\log d)^{\alpha} - a(h_m) - b(h_b)$
	$1500 < f \le 2000$MHz	$L = 25.9 + 33.9 \log f + 35.2 (\log d)^{\alpha} - a(h_m) - b(h_b)$
	$f > 2000$MHz	$L = 25.9 + 33.9 \log f + 10 \log(f/2000) + 35.2 (\log d)^{\alpha} - a(h_m) - b(h_b)$
Dense urban		$L = L(\text{urban}) + 3$
Suburban		$L = L(\text{urban}) - 2[\log(\min\{f,2000\}/28)]^2 - 5.4$
Open in urban		$L = L(\text{urban}) - 4.78 [\log(\min\{f,2000\})]^2 + 18.33 [\log(\min\{f,2000\})] - 40.94$

where

$a(h_m) = 0.09 \log f - 0.25$

$b(h_b) = \min [0, 20 \log(h_b/30)]$

$$\alpha = \begin{cases} 1 & , d \le 20\text{km} \\ 1 + (0.14 + 0.87 \times 10^{-4} f + 1.07 \times 10^{-3} h_b)(\log \frac{d}{20})^{0.8} & , 20 < d < 100\text{km} \end{cases}$$

[19] European Conference of Postal and Telecommunications Administrations (CEPT), European Radiocommunications Committee (ERC), REPORT 68, "Monte-Carlo Simulation Methodology For The Use In Sharing And Compatibility Studies Between Different Radio Services Or Systems", Appendix 1 to Annex 2 (b),Naples, February 2000, revised in Regensburg, May 2001 and Baden, June 2002.

Table 21: UL and DL frequencies[20]

Frequency band	900	1800	2100	MHz
UL frequency	897	1747	1950	MHz
DL frequency	942	1842	2140	MHz

Table 22: Service data rates and Eb/No requirements

	Downlink		**Uplink**		
Service	Bearer data rate[21] (kbps)	Eb/No [22]	Bearer data rate (kbps)	Eb/No (dB)[23] (No Rx Div)	Eb/No (dB)[23] (With receive diversity)
Speech	12.2	9.2 dB	12.2	9.8 dB	6.2 dB
Medium-rate data	144.0	5.3 dB	64.0	6.7 dB	2.8 dB
High-rate data	384.0	5.3 dB	144.0	5.7 dB	2.2 dB
HSDPA	See Table 18				

[20] The value of the parameter α was assumed to be 1 to facilitate the modeling process so as the inverse function to be expressed in an algebraic way. This assumption was verified to introduce minimal error.

[21] These are the rates assumed for network dimensioning based on the limiting case of service for users, not the maximum rates available

[22] Holma table 12.21

[23] 3GPP TS 25.104, table 8.5 with a 1dB reduction for 3km/h rather than 120km/h (after Holma table 12.19)

Table 23: Parameter ranges used for HSDPA analysis

Ref.	Parameter	Value for base case	Range for analysis	Units	Source
1	Number of codes	15	15	Codes	15 can only be used for dedicated HSDPA
2	Pilot Power	10%			Assumption based on industry data
3	R99 OH Power Allocation	0%	0%		Assumption based on industry data
4	R99 DCH Power Allocation	0%	0%		Assumption based on industry data
5	Power for HS-SCCH & R99 common channels	15%	15%		Assumption based on industry data
6	Planned DL Load	80%			Assumption based on industry data
7	Service Processing Gain	10log(16)			HSDPA Spreading Factor
8	DL Fast Fading Margin	0		dB	Assumption based on industry data
9	DL Soft Handover Gain	0		dB	Assumption based on industry data
10	Rel. 99 UL Rate	144		kbps	Assumption based on standard uplink data rates. “Radio Network Planning and Optimisation for UMTS”, Laiho, Wacker & Novosad, 2002, table 7.2, p.282.
11	Throughput vs. SINR				Use curves from “HSDPA/HSUPA for UMTS”, Holma & Toskala, John Wiley 2006, figure 7.5, p.130.

Results of site counts calculated using refined analysis techniques

A13.372 Earlier sections of this annex related to the examination of a range of sensitivities in response to comments from stakeholders and additional evidence gathered since our previous consultation. Note that the diagrams and figures presented in those sections were derived for 3GPP UMTS Release ’99, while this section focuses on HSDPA.

A13.373 In this section we present the outcome of our analysis for variations with the main dimensions of the market scenarios specified in Annex 11, namely:

a) The depth of indoor coverage (varying between Depth 1 and Depth 2).

b) The per-user throughput (varying between 384 kbps, 1.2 Mbps and 2.4 Mbps for HSDPA with dedicated carriers).

c) Downlink data volumes between 0.1 MB / user /day and 30 MB / user / day.

A13.374 The logic for examining HSDPA traffic rather than R99 is examined in Annex 10 and Annex 11.

A13.375 The range of results arising from this variation for the base case parameters is provided in Table 25 and Figure 58.

A13.376 Note that the results presented in this section are given only for 900MHz and 2100MHz. This is due to the fact that the results of the 1800MHz analysis are very close to the results for 2100MHz. The difference in path loss due to frequency is countered by the difference in the assumed UE noise figure in each band as given by parameter 14 in Table 19. For the R99 scenario using the base case parameters the differences at some example demand levels are given below:

Table 24: Difference in site count between 1800MHz and 2100MHz

Demand	# sites for 2x1800MHz	# sites for 2x2100MHz	Difference
1 MB / user / day	12,818	12,776	0.3%
10 MB / user / day	13,490	13,448	0.3%
30 MB / user / day	18,911	18,914	0.02%

A13.377 Additionally, given the sensitivities to technical parameters examined earlier, we also recalculate this range for two other sets of technical parameters, corresponding to parameters which have a particularly large impact on the outcomes:

i) As the base case but with Ec/Io = -10 dB and building penetration loss constant with frequency as specified in the ‘constant’ case in Table 13 (“low-end technical parameters”).

ii) As the base case but with Ec/Io = -6 dB and building penetration loss rising with frequency as specified in the ‘rising at higher rate’ case in Table 13 (“high-end technical parameters”).

A13.378 The results for the low-end technical parameters are provided in Table 26 and Figure 59.

A13.379 The results for the high-end technical parameters are provided in Table 27 and Figure 60.

A13.380 Table 28 contains entries from Table 25, Table 26 and Table 27 that have been taken forward to the modelling of cost differences described in Annex 15. Figure 61 allows a visual comparison of the sensitivities of the site counts across the range of parameters from the low-end, and base case to the high-end values.

A13.381 Additionally, 3 other special cases have been evaluated in order to provide supplementary information for the cost difference analysis. These are also given in Table 28. All are for the base case only. (g) & (h) consider demand volumes above the existing maximum of 30MB / user / day and case (i) considers relaxing the coverage confidence targets in suburban areas to 90% whilst maintaining the target in the urban, open in urban and dense urban areas at 95%.

Table 25: Site counts for market scenario ranges with base case technical parameters

	Data Volume (MB/user/day):		0.1	0.3	0.7	1	3	7	10	15	20	25	30
Depth 2	384kbps	1 carrier @ 900MHz	4,020	4,022	4,033	4,041	4,095	4,202	4,282	4,416	4,647	5,656	6,787
		2 carriers @ 900MHz	4,020	4,020	4,024	4,028	4,054	4,108	4,148	4,215	4,282	4,349	4,416
		2 carriers @ 2100MHz	12,712	12,712	12,712	12,715	12,742	12,795	12,836	12,903	12,969	13,036	13,103
	1200kbps	1 carrier @ 900MHz	4,020	4,022	4,031	4,039	4,087	4,184	4,257	4,379	4,521	5,131	6,157
		2 carriers @ 900MHz	4,020	4,020	4,023	4,026	4,051	4,099	4,136	4,197	4,257	4,318	4,379
		2 carriers @ 2100MHz	12,712	12,712	12,712	12,714	12,738	12,787	12,823	12,884	12,945	13,005	13,066
	2400kbps	1 carrier @ 900MHz	6,566	6,566	6,572	6,579	6,626	6,719	6,789	6,905	7,022	7,138	7,254
		2 carriers @ 900MHz	6,566	6,566	6,566	6,568	6,591	6,638	6,673	6,731	6,789	6,847	6,905
		2 carriers @ 2100MHz	20,761	20,761	20,761	20,761	20,779	20,826	20,861	20,919	20,977	21,035	21,094
Depth 1	384kbps	1 carrier @ 900MHz	2,901	2,903	2,914	2,922	2,975	3,083	3,163	3,395	4,525	5,656	6,787
		2 carriers @ 900MHz	2,901	2,901	2,904	2,908	2,935	2,989	3,029	3,096	3,163	3,230	3,395
		2 carriers @ 2100MHz	8,591	8,591	8,591	8,594	8,621	8,674	8,715	8,782	8,849	8,916	8,983
	1200kbps	1 carrier @ 900MHz	2,901	2,902	2,912	2,919	2,968	3,065	3,138	3,296	4,105	5,131	6,157
		2 carriers @ 900MHz	2,901	2,901	2,904	2,907	2,932	2,980	3,017	3,077	3,138	3,199	3,296
		2 carriers @ 2100MHz	8,591	8,591	8,591	8,593	8,617	8,666	8,702	8,763	8,824	8,885	8,945
	2400kbps	1 carrier @ 900MHz	4,738	4,738	4,745	4,752	4,798	4,891	4,961	5,077	5,194	5,349	5,896
		2 carriers @ 900MHz	4,738	4,738	4,738	4,740	4,763	4,810	4,845	4,903	4,961	5,019	5,077
		2 carriers @ 2100MHz	14,031	14,031	14,031	14,031	14,049	14,096	14,131	14,189	14,247	14,305	14,363

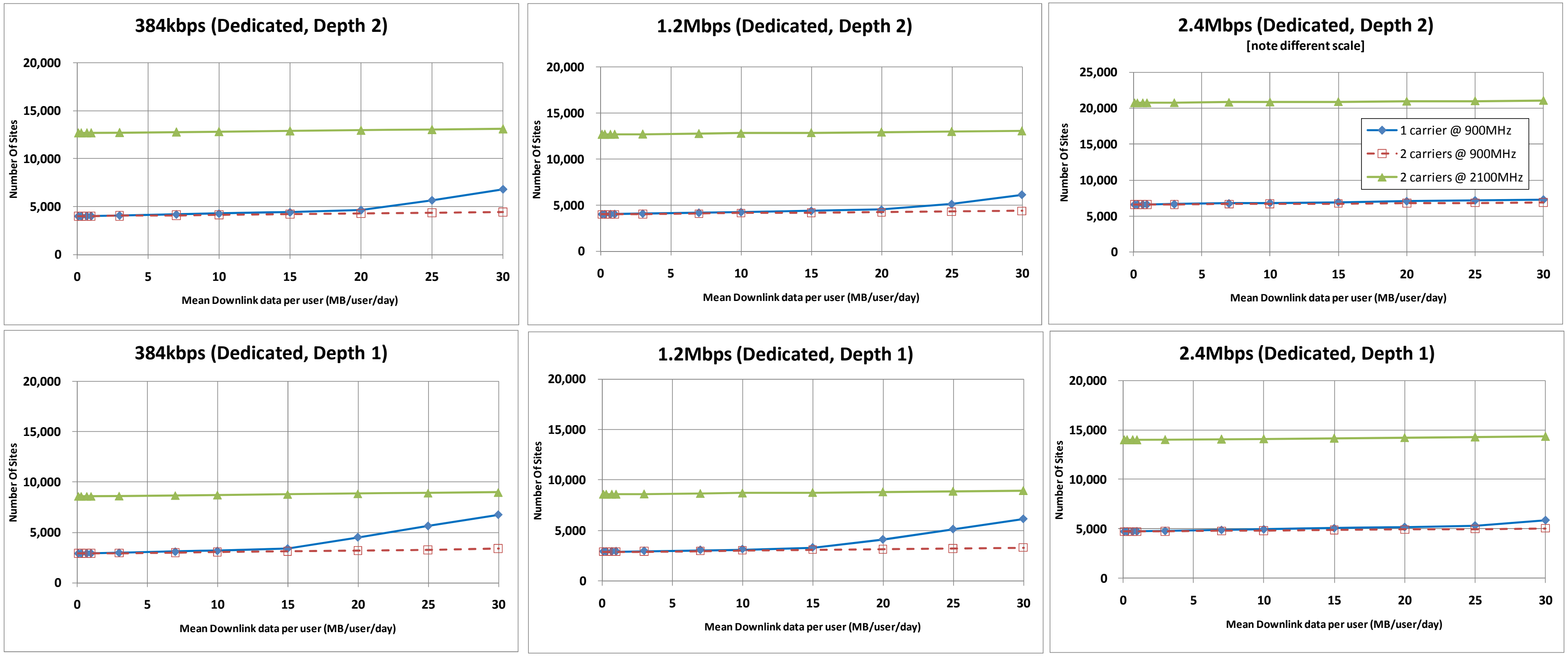


Figure 58: Graphs corresponding to site counts in Table 25 (base case technical parameters)

Table 26: Site counts for low-end technical parameters (Ec/Io = -10 dB and building penetration loss constant with frequency)

	Data Volume (MB/user/day):		0.1	0.3	0.7	1	3	7	10	15	20	25	30
Depth 2	384kbps	1 carrier @ 900MHz	2,552	2,556	2,567	2,575	2,629	2,736	2,816	3,394	4,525	5,656	6,787
		2 carriers @ 900MHz	2,552	2,552	2,558	2,562	2,589	2,642	2,682	2,749	2,816	2,937	3,394
		2 carriers @ 2100MHz	5,454	5,454	5,457	5,461	5,487	5,541	5,581	5,648	5,715	5,782	5,849
	1200kbps	1 carrier @ 900MHz	3,714	3,716	3,725	3,733	3,781	3,878	3,951	4,073	4,270	5,131	6,157
		2 carriers @ 900MHz	3,714	3,714	3,717	3,720	3,745	3,793	3,830	3,891	3,951	4,012	4,073
		2 carriers @ 2100MHz	7,936	7,936	7,936	7,939	7,963	8,012	8,048	8,109	8,170	8,231	8,291
	2400kbps	1 carrier @ 900MHz	6,566	6,566	6,572	6,579	6,626	6,719	6,789	6,905	7,022	7,138	7,254
		2 carriers @ 900MHz	6,566	6,566	6,566	6,568	6,591	6,638	6,673	6,731	6,789	6,847	6,905
		2 carriers @ 2100MHz	14,031	14,031	14,031	14,031	14,049	14,096	14,131	14,189	14,247	14,305	14,363
Depth 1	384kbps	1 carrier @ 900MHz	1,842	1,846	1,857	1,865	1,918	2,025	2,262	3,394	4,525	5,656	6,787
		2 carriers @ 900MHz	1,842	1,842	1,847	1,851	1,878	1,932	1,972	2,039	2,262	2,828	3,394
		2 carriers @ 2100MHz	3,935	3,935	3,938	3,942	3,969	4,022	4,063	4,130	4,196	4,263	4,330
	1200kbps	1 carrier @ 900MHz	2,680	2,682	2,691	2,699	2,747	2,845	2,917	3,115	4,105	5,131	6,157
		2 carriers @ 900MHz	2,680	2,680	2,683	2,687	2,711	2,759	2,796	2,857	2,917	2,978	3,115
		2 carriers @ 2100MHz	5,726	5,726	5,726	5,729	5,753	5,802	5,838	5,899	5,960	6,021	6,081
	2400kbps	1 carrier @ 900MHz	4,738	4,738	4,745	4,752	4,798	4,891	4,961	5,077	5,194	5,349	5,896
		2 carriers @ 900MHz	4,738	4,738	4,738	4,740	4,763	4,810	4,845	4,903	4,961	5,019	5,077
		2 carriers @ 2100MHz	10,124	10,124	10,124	10,124	10,142	10,188	10,223	10,282	10,340	10,398	10,456

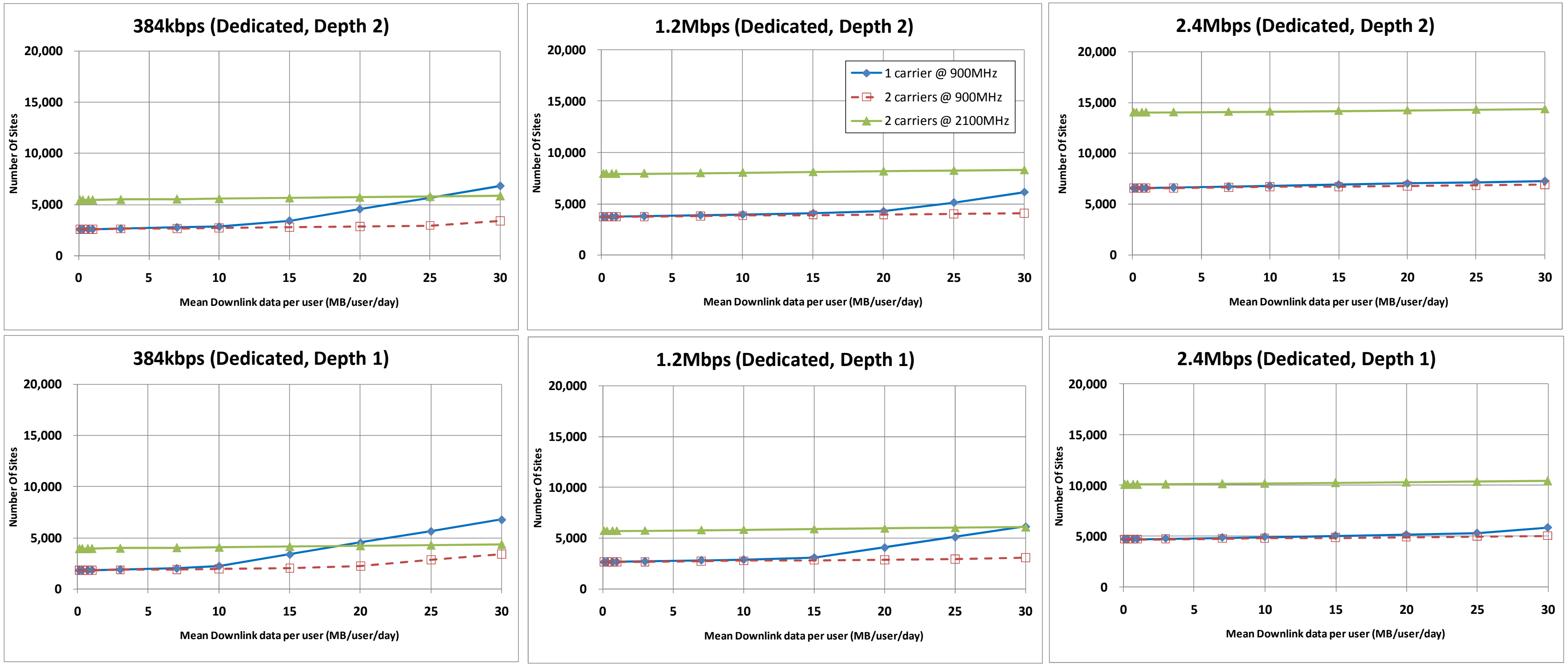


Figure 59: Graphs corresponding to site counts in Table 26 (low-end technical parameters)

Table 27: Site counts for high-end technical parameters (Ec/Io = -6 dB and building penetration loss rising with frequency at higher rate)

	Data Volume (MB/user/day):		0.1	0.3	0.7	1	3	7	10	15	20	25	30
Depth 2	384kbps	1 carrier @ 900MHz	9,347	9,347	9,351	9,359	9,413	9,520	9,600	9,734	9,868	10,002	10,136
		2 carriers @ 900MHz	9,347	9,347	9,347	9,347	9,373	9,426	9,467	9,533	9,600	9,667	9,734
		2 carriers @ 2100MHz	73,764	73,764	73,764	73,764	73,780	73,833	73,873	73,940	74,007	74,074	74,141
	1200kbps	1 carrier @ 900MHz	9,347	9,347	9,350	9,357	9,405	9,503	9,576	9,697	9,819	9,940	10,062
		2 carriers @ 900MHz	9,347	9,347	9,347	9,347	9,369	9,418	9,454	9,515	9,576	9,636	9,697
		2 carriers @ 2100MHz	73,764	73,764	73,764	73,764	73,776	73,824	73,861	73,922	73,982	74,043	74,104
	2400kbps	1 carrier @ 900MHz	9,347	9,347	9,349	9,356	9,402	9,495	9,565	9,682	9,798	9,914	10,031
		2 carriers @ 900MHz	9,347	9,347	9,347	9,347	9,367	9,414	9,449	9,507	9,565	9,623	9,682
		2 carriers @ 2100MHz	73,764	73,764	73,764	73,764	73,774	73,821	73,856	73,914	73,972	74,030	74,089
Depth 1	384kbps	1 carrier @ 900MHz	6,745	6,745	6,749	6,757	6,811	6,918	6,999	7,132	7,266	7,400	7,552
		2 carriers @ 900MHz	6,745	6,745	6,745	6,745	6,771	6,824	6,865	6,932	6,999	7,066	7,132
		2 carriers @ 2100MHz	53,205	53,205	53,205	53,205	53,221	53,275	53,315	53,382	53,449	53,516	53,583
	1200kbps	1 carrier @ 900MHz	6,745	6,745	6,748	6,755	6,804	6,901	6,974	7,095	7,217	7,338	7,460
		2 carriers @ 900MHz	6,745	6,745	6,745	6,745	6,767	6,816	6,852	6,913	6,974	7,034	7,095
		2 carriers @ 2100MHz	53,205	53,205	53,205	53,205	53,217	53,266	53,302	53,363	53,424	53,485	53,545
	2400kbps	1 carrier @ 900MHz	6,745	6,745	6,747	6,754	6,800	6,894	6,963	7,080	7,196	7,313	7,429
		2 carriers @ 900MHz	6,745	6,745	6,745	6,745	6,766	6,812	6,847	6,905	6,963	7,022	7,080
		2 carriers @ 2100MHz	53,205	53,205	53,205	53,205	53,216	53,262	53,297	53,355	53,414	53,472	53,530

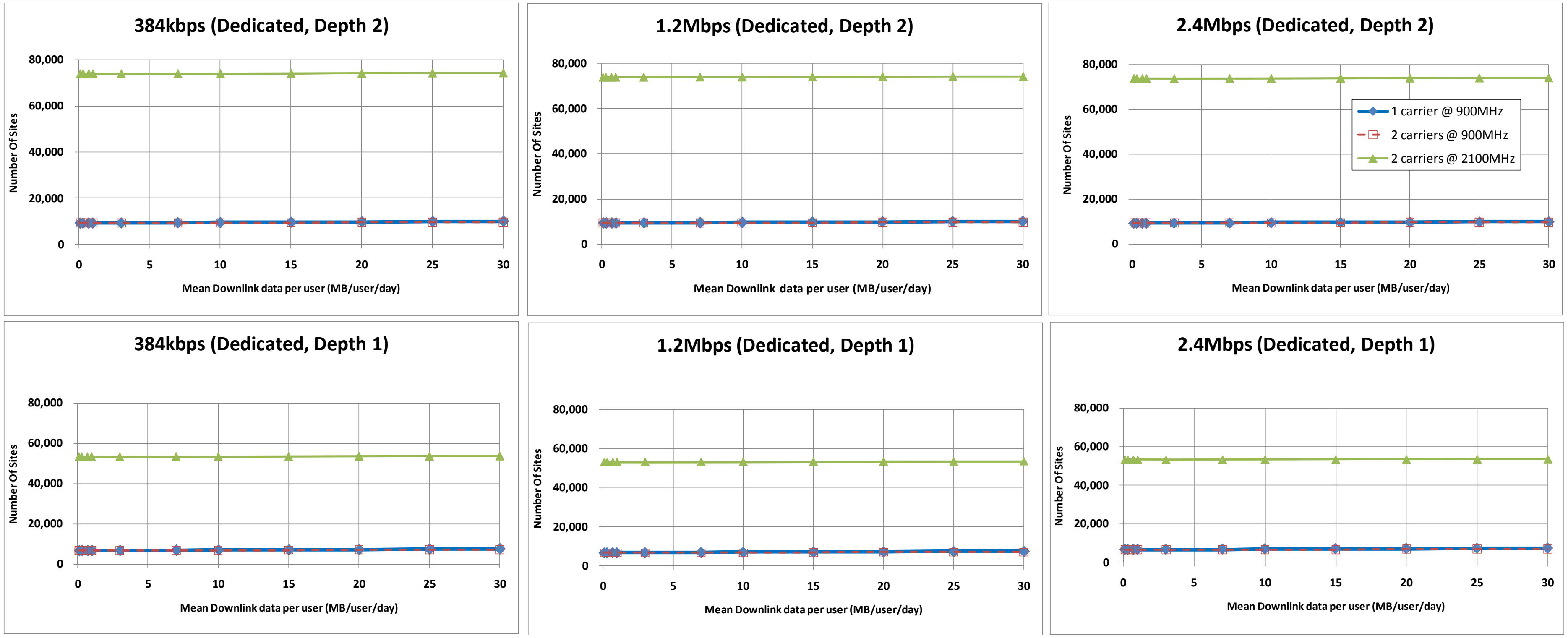


Figure 60: Graphs corresponding to site counts in Table 27 (high-end technical parameters)

Table 28: Site count sensitivities for selected scenarios

Scenario		Parameters			900MHz, 1 carrier	2100MHz, 2 carriers
		Data rates	Indoor Depth	Volume		
a	Lower demand	384 kbps	Depth 1	1 MB / user / day	2,900	8,600
b	As "lower demand" but high volume	384 kbps	Depth 1	30 MB / user / day	6,800	9,000
c	As "lower demand" but deep indoor coverage	384 kbps	Depth 2	1 MB / user / day	4,000	12,700
d	Higher demand	2.4 Mbps	Depth 2	30 MB / user / day	7,300	21,100
e	As 'higher demand' but low data rates	384 kbps	Depth 2	30 MB / user / day	6,800	13,100
f	As 'higher demand' but low indoor depth	2.4 Mbps	Depth 1	30 MB / user / day	5,900	14,400
g	As 'higher demand' but higher volume (40MB)	2.4 Mbps	Depth 2	40 MB / user / day	7,900	21,200
h	As 'higher demand' but higher volume (60MB)	2.4 Mbps	Depth 2	60 MB / user / day	11,800	21,400
i	As 'higher demand' but poorer suburban coverage (90%)	2.4 Mbps	Depth 2	30 MB / user / day	5,900	13,400

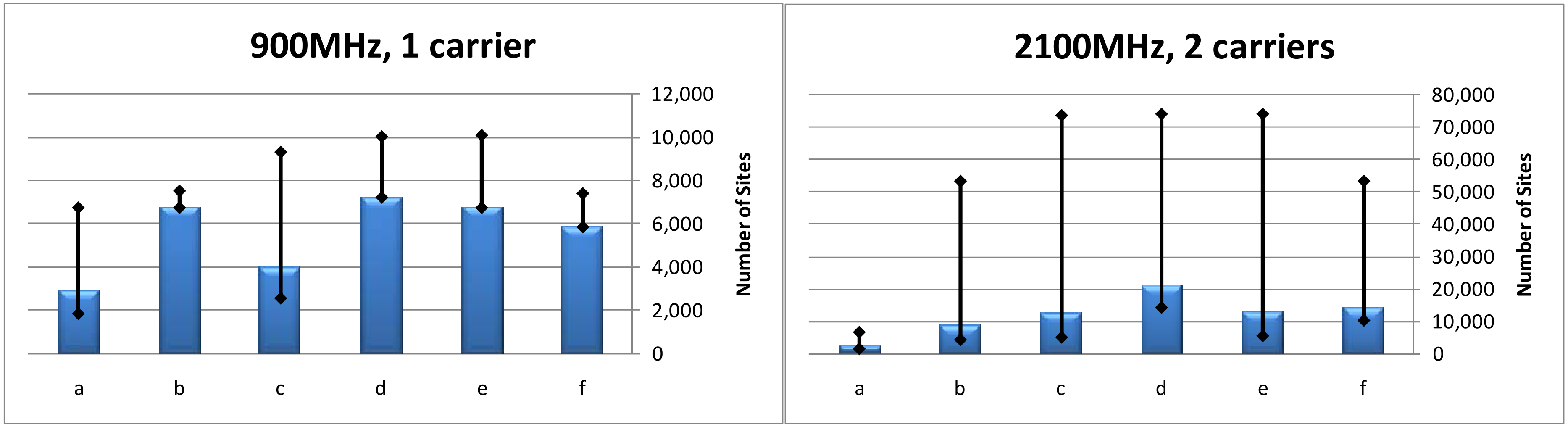
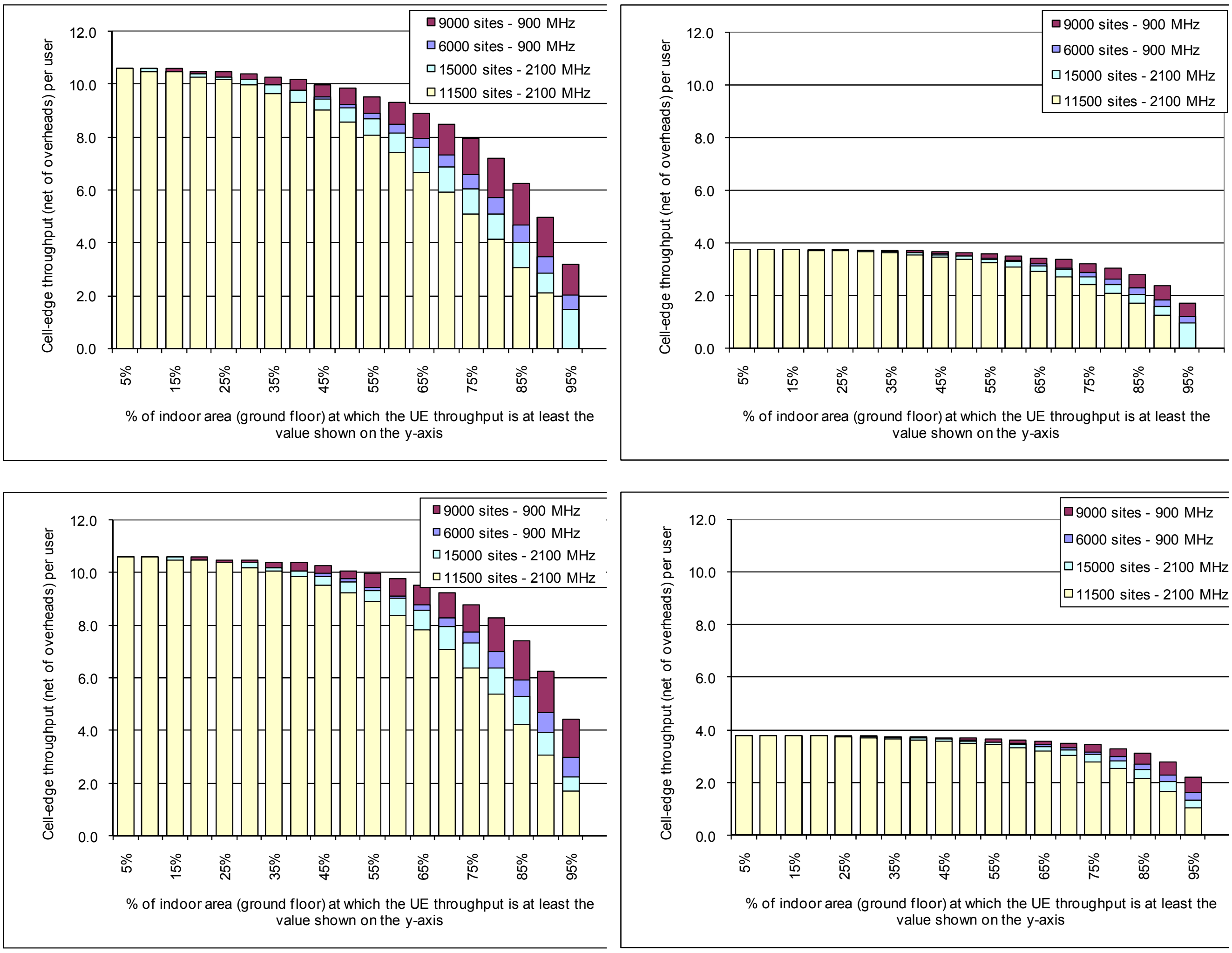


Figure 61: Graphs corresponding to site counts in Table 28. The bars correspond to the base case, whereas the lines show the variation between low- and high-end.

A13.382 In order to understand how different spectrum resources with particular site counts may impact on the service experienced by users we examine the proportion of the area at which given user throughputs are attained. These percentages correspond to the throughput experienced by users on the inside of buildings, at ground floor level, over the whole coverage area.

A13.383 A comparison is shown in Figure 62 (a) and (b) between dedicated and shared HSDPA carriers respectively. The upper two charts are for the base case parameters with an average data volume of 3MB / user / day. The lower two charts are for the case of lower body loss due to the assumption of dongle use rather than smartphones.

A13.384 The horizontal axis in Figure 62 represents the proportion of the area at ground floor level at which indoor users access data throughputs, in the busy hour, which are at least the value shown on the vertical axis. The vertical axis represents data throughput delivered over the air to these users in Mbps, taking account of overheads due to coding and other effects according to the method described in Appendix A13.1: Details of Technical Model.

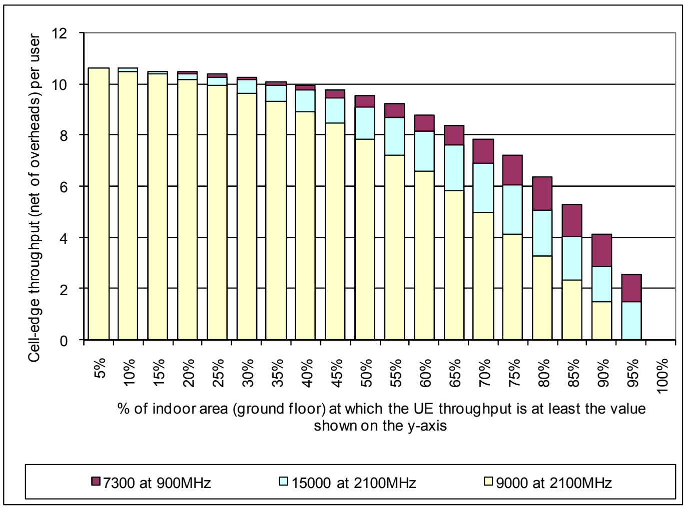


(a) Dedicated carriers

(b) Shared carriers

Figure 62: Per-user throughput versus percentage of area for various fixed site number networks (6,000 and 9,000 sites at 900MHz, 11,500 and 15,000 at 2100 MHz)

A13.385 Additionally, four specific variations have been compared directly as these are used elsewhere in this consultation. These cases are for dedicated carriers using the base case parameters but for the site numbers indicated in Figure 63 below.



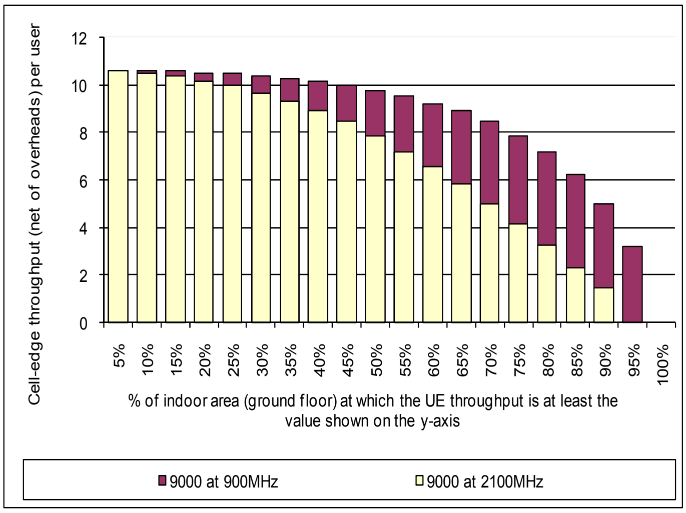


Figure 63: Per-user throughput versus indoor coverage for various fixed site number networks

Appendix A13.1: Details of Technical Model

Overview

A13.386 This appendix describes the technical model used for comparison purposes below. An overview flowchart is shown in Figure 64 for the case of Release 99 traffic. Differences from this calculation used in modelling HSDPA services are specified in §A13.412*ff*.

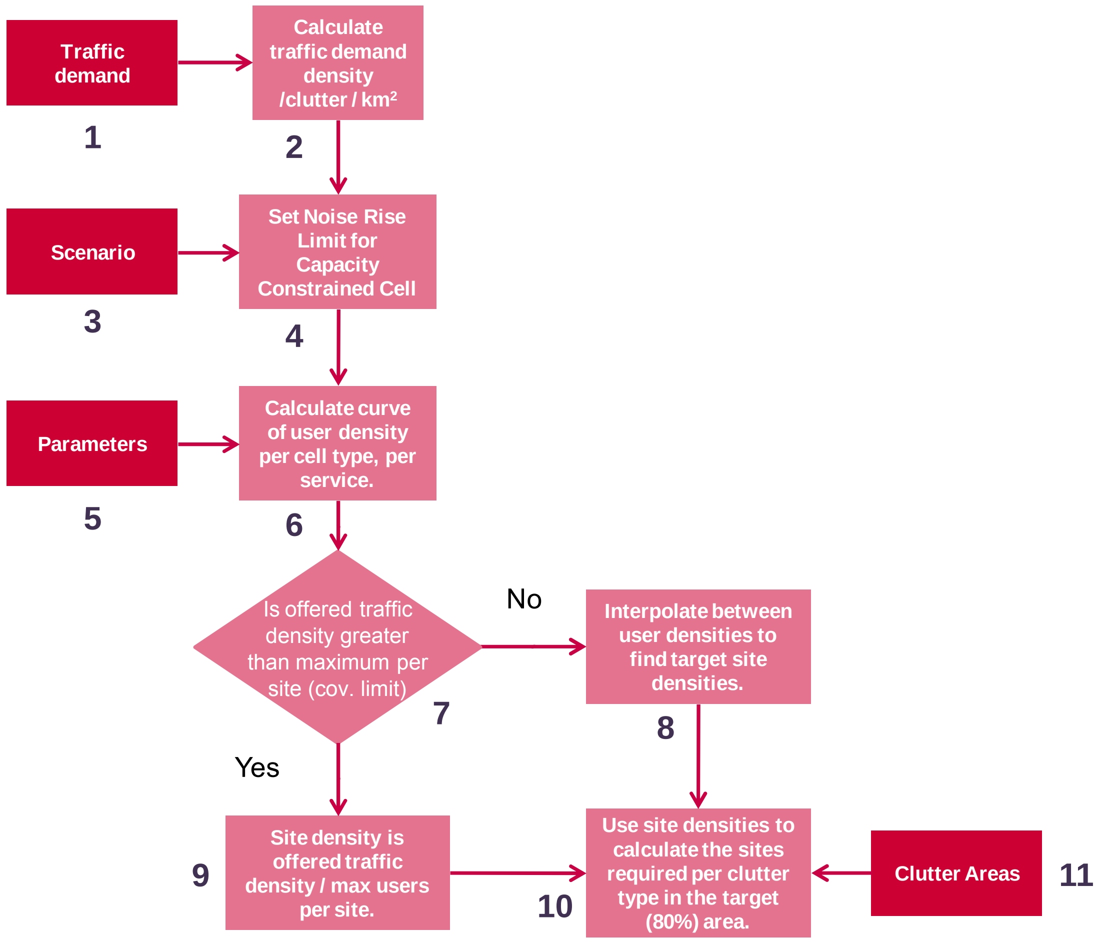


Figure 64: Technical Model Flowchart

Traffic Demand

A13.387 To calculate the number of simultaneously active users for a given services, in a given clutter type, the process shown in Figure 65 is applied.

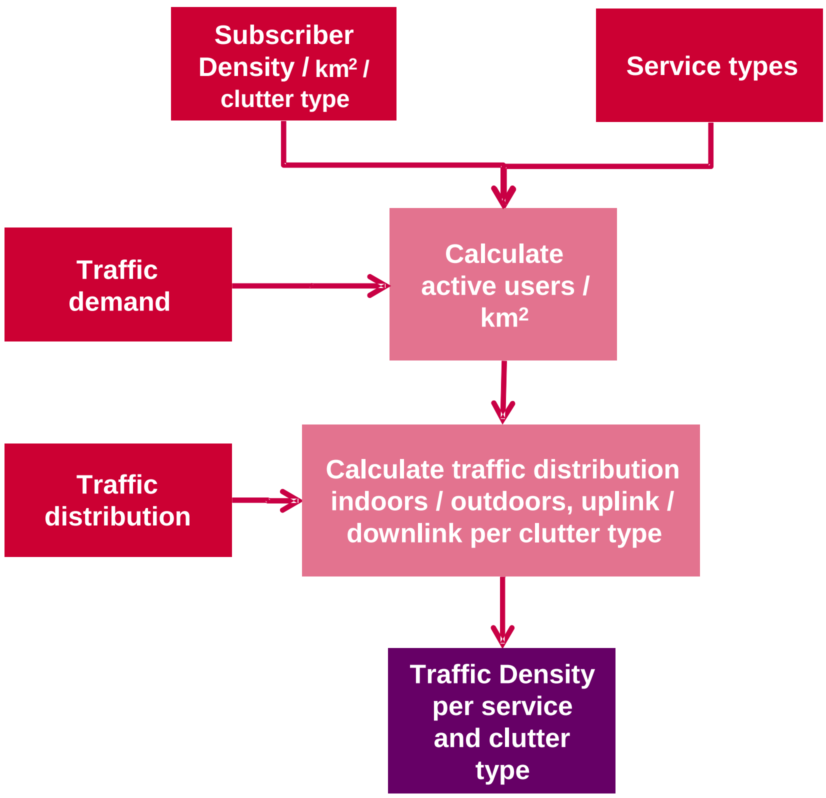


Figure 65: Calculation of active user density

A13.388 In each clutter class, the density of subscribers is assumed to be as in Table 17. The next step is to establish the number of simultaneous users per unit area.

A13.389 For speech traffic the demand is specified in milli-Erlangs within the busy hour, so the density of simultaneous users can be calculated directly:

Number of concurrent voice users (users per km^2) =
Total voice users (per km^2) × Busy hour traffic per user (Erlangs) × call success rate (%) / 100

The call success rate is assumed to be 95%.

A13.390 For data services the demand is specified in terms of the total average volume of data transferred by a user per day in the downlink. The data usage during the busy hour is assumed to be 10% of this total. The uplink data volume is assumed to be 20% of the downlink volume.

A13.391 The proportion of time a device is transmitting in the downlink (DL) and uplink (UL) respectively during the busy hour is then given by:

$$f_{DL} = \frac{Volume_{DL}(kbytes) \times 8}{Data\_rate_{DL}(kbps) \times 3600}$$

$$f_{UL} = \frac{Volume_{UL}(kbytes) \times 8}{Data\_rate_{UL}(kbps) \times 3600}$$

A13.392 The generation of data to and from the user device is assumed to be a uniform random process during the busy hour. At any instant in time, the probability that the device is:

Transmitting in the uplink only $p_{UL} = f_{UL}(1 - f_{DL})$

Transmitting in the downlink only $p_{DL} = f_{DL}(1 - f_{UL})$

Transmitting simultaneously in the uplink and downlink $p_{DL+UL} = f_{UL} f_{DL}$

A13.393 Hence the overall probability that a device is active in each link is:

Downlink: $p_{DL} + p_{DL+UL} = f_{DL}(1 - f_{UL}) + f_{UL} f_{DL} = f_{DL}$

Uplink: $p_{UL} + p_{DL+UL} = f_{UL}(1 - f_{DL}) + f_{UL} f_{DL} = f_{UL}$

A13.394 The number of active users in the busy hour is thus calculated as:

Downlink:

$$No.\_of\_concurrent\_data\_users_{DL}(km^{-2}) = User\_density_{DL}(km^{-2}) \times f_{DL}$$

Uplink:

$$No.\_of\_concurrent\_data\_users_{UL}(km^{-2}) = User\_density_{UL}(km^{-2}) \times f_{UL}$$

A13.395 For data services the activity factor in both uplink and downlink is assumed to be 1.

A13.396 Having determined the density of simultaneous users for a given service, the number of users covered by a single site is determined by assuming that the site provides a hexagonal coverage area according to $A = \frac{3\sqrt{3}}{2} r^2$ $A = \frac{3\sqrt{3}}{2} r^2$ where r is the radius of a circle that just encloses the hexagon. The user density is multiplied by this coverage area to give the number of users covered by the site. The number of users active on a given sector and is determined by dividing the number of users in the site by the number of sectors per site and by the number of carriers per sector. The number is also increased by a factor corresponding to the proportion of users in soft handover.

Traffic Channel Coverage

A13.397 The noise rise in the system is calculated following the approach described in [24]. The noise rise is defined by the ratio of the total system interference power over the total thermal noise power referred to the receiver input. Thus:

$$Noise\_rise = \frac{I_{total}}{P_N} = \frac{1}{1-\eta}$$

where η is the load factor, which is expressed as a fraction of the maximum or 'pole' capacity of the cell.

A13.398 The noise rise is calculated individually for the downlink and uplink based on the following equations, after [25].

Uplink:

$$\eta_{UL} = (1+i)\cdot\sum_{j=1}^{N}\frac{1}{1+\dfrac{W}{\left(E_b/N_0\right)_j\cdot R_j\cdot v_j}}$$

Downlink:

$$\eta_{DL} = \sum_{j=1}^{N} v_j\cdot\frac{\left(E_b/N_0\right)_j}{\dfrac{W}{R_j}}\cdot\left[(1-\alpha_j)+i_j\right]$$

where the quantities are defined as shown below:

η_{UL}	Uplink load factor (power ratio)
η_{DL}	Downlink load factor (power ratio)
N	Number of simultaneous users in the cell
i, i_j	Other to own cell interference power ratio. In the uplink *i* is the level seen by the base station receiver, while in the downlink in principle this varies for each user having a value ij for the jth user. (power ratio)
W	Chip rate = 3.84 × 10^6 chips per second

[24] WCDMA for UMTS: Radio Access for Third Generation Mobile Communications, Harri Holma (Editor), Antti Toskala (Editor), John Wiley & Sons; 3rd Edition, 2004, 478 pages, ISBN-10: 0470870966 , Chapter 8.
[25] WCDMA for UMTS Third Edition, Holma & Toskala, Wiley, 2004.

v_j	Activity factor of *j* th user (fraction)
$\left(E_b / N_0\right)_j$	Required signal energy per bit to noise power spectral density for *j* th user (power ratio)
R_j	Bit rate of *j* th user (bits Hz^{-1})
α_j	Orthogonality of *j* th user (power ratio)

A13.399 The loading reduces the maximum acceptable path loss for the system by increasing the effective noise floor by the noise rise, i.e. by $10\log\left(\frac{1}{1-\eta}\right)$ decibels.

A13.400 In the downlink, the cell range is additionally constrained by the requirement to deliver sufficient power to all users, so the maximum acceptable path loss is determined from :

$$L_{MAPL} = \overline{L} + L_{\max\_mean} = 10\log\left[P_{ded}\cdot\frac{\left(1-\eta_{DL}\right)}{N_{rf}W\sum_{j=1}^{N} v_j \frac{\left(E_b / N_0\right)_j}{W / R_j}}\right] + L_{\max\_mean}$$

where:

L_{MAPL}	Maximum acceptable path loss (power ratio)
$\overline{L}$	Mean path loss over the cell (power ratio)
$L_{\max\_mean}$	Ratio of maximum to minimum path loss (power ratio)
P_{ded}	Maximum transmit power available for dedicated (traffic) channels (W)
N_{rf}	Receiver noise power spectral density. $N_{rf} = kT + F$ (W Hz^{-1})
kT	Thermal noise power spectral density (W Hz^{-1})
F	Receiver noise figure (power ratio)

A13.401 The maximum acceptable path loss is taken to consist of a distance-dependent component determined from a path loss model and a fade margin:

$$L_{MAPL} = L(r) + L_{FM}$$

where L_{FM} is the fade margin, calculated in the same way as in our September 2007 consultation and $L(r)$ is the loss at distance *r* calculated from the path loss model.

A13.402 In principle the traffic should be distributed between multiple services in an appropriate ratio. However, this would cause considerable complexity and requires the selection of additional parameters. Instead the traffic volume of interest in a given scenario is allocated to the highest bearer rate being considered in that scenario.

Pilot Channel Coverage

A13.403 In order for the mobile to successfully monitor and handover between cells in the network, the common pilot channel must be received with sufficient quality.

A13.404 There are two key measures of pilot channel availability. One is simply the received signal strength of the pilot channel designated E_c and must be above a certain threshold as defined in the standards in order to be heard above the thermal noise. The second is the $\frac{E_c}{I_0}$, which relates to interference on the pilot channel from other pilot channels on other cells and is an indication of whether a mobile can detect its home pilot signal above that of the other cells. For site number dimensioning purposes we examine the unloaded $\frac{E_c}{I_0}$, i.e. that observed by a mobile in the presence of only common channel power which is transmitted by the base stations even in the absence of traffic.

A13.405 The Ec coverage is calculated from a basic link budget as follows: a) the pilot EIRP is calculated from the downlink pilot power and the transmitter gain and losses, and b) the maximum path loss allowed for the required E_c strength is calculated from the pilot EIRP, the receiver gain and losses (inclusive of body losses), and the E_c threshold value.

A13.406 The calculation of the unloaded $\frac{E_c}{I_0}$ coverage follows the approach in [26] and [27], and considers interference to the wanted pilot signal arising from the overhead powers in other base stations including the home base station. The overhead powers include other pilot signals and any other common channels.

A13.407 The $\frac{E_c}{I_0}$ as seen by a 'probe' mobile is given as:

$$\frac{E_c}{I_0} = \frac{\alpha_0 P_0 L(r_0) G_m}{I_h + I_0 + N}$$

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[26] W-CDMA Mobile Communication Systems Keiji Tachikawa (Editor); Wiley and Maruzen, 2002, 418 pages, ISBN 0-470-84761-1

[27] CDMA RF System Engineering (Mobile Communications Library), Samuel C. Yang (Author), Artech House, 1998, 304 pages, ISBN 0890069913

where:

α_0	Fraction of base station radiated power allocated to pilot
P_0	Total maximum base station radiated power
$L(r_0)$	Path loss to probe mobile at a distance r_0 from base station
G_m	Mobile antenna gain
I_h	Interference power received from home base station (=0 for the unloaded case)
I_0	Sum of interference power received from other base stations
N	Thermal noise power

A13.408 It is assumed that the other-cell interference power is proportional to the own cell interference I_h with a constant of proportionality i, the other cell to own cell interference ratio as used in the traffic link budget. Thus $I_0 = i \times I_h$.

Maximum Load Factor

A13.409 A maximum load factor per cell is specified as a parameter to the model. If this load would be exceeded by the simultaneous users accessing the cell then the cell is judged capacity constrained and the cell density is increased until the maximum load factor is attained. The number of cells thus rises linearly with the traffic volume beyond the point of onset of capacity constraints. See [28] §11.4.2.

A13.410 In order to ensure that the user density per cell given from the specification of the relevant traffic scenario matches the traffic per cell for a given load factor, the site density is calculated for a wide range of user numbers per cell. For each site density the corresponding number of users is calculated and matched against the market scenario, and the matching site density is calculated by simple interpolation.

A13.411 The final site density calculation is the result of calculations for all relevant services, for the uplink and downlink and for E_c, $\frac{E_c}{I_0}$ and load factor calculations. The relevant site density is the largest arising from all these constraints for a given user density.

HSDPA Calculation

A13.412 The calculation of the number of sites to deliver HSDPA coverage broadly follows the approach for release 99 traffic, but with some important differences specified in this section. An overview of the process is given in Figure 66.

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[28] Wideband CDMA for Third Generation Mobile Communications, Tero Ojanpera (Editor), Ramjee Prasad (Editor), Artech House, 2001, 468 pages, ISBN 089006735X

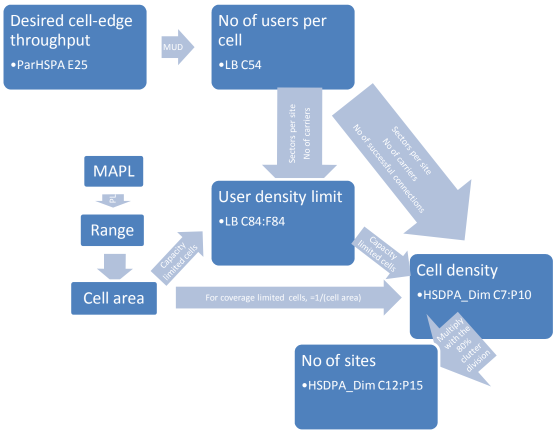

Figure 66: The process of calculating site numbers for HSDPA traffic .

A13.413 The user data throughput in HSDPA is determined from the signal-to-interference-plus-noise ratio (SINR) on the HS-DSCH channel via relationships given in [29] . This is the result of link level simulations and takes into account various coding overheads and retransmissions to yield the true throughput available to the users, as distinct from the data rate over the air. Link adaptation and HARQ are assumed. The reference curves are valid for user speeds of 3 km/h and of the channel being subject to flat (not frequency selective) Rayleigh fading. This assumption is perfectly appropriate to be used as the basis for the calculations, since the analysis is dealing predominantly with indoor users.

A13.414 The curves in reference [29] are implemented for the purpose of the model via a function of the following form:

$$SINR = c - \frac{\ln\left(\frac{a}{th} - 1\right)}{b}$$

where th is the single user throughput in Mbps and the coefficients a, b, and c are given in Table 29. Figure 67 plots the resulting curves.

Table 29: Coefficients used to model HSDPA performance

No of codes	a [Mbps]	b [dB^{-1}]	c [dB]
5	3.8	0.19	13.9

[29] "HSDPA/HSUPA for UMTS", Holma & Toskala, John Wiley 2006, figure 7.5 p.130.

10	7.5	0.2	18.3
15	10.7	0.19	19.3

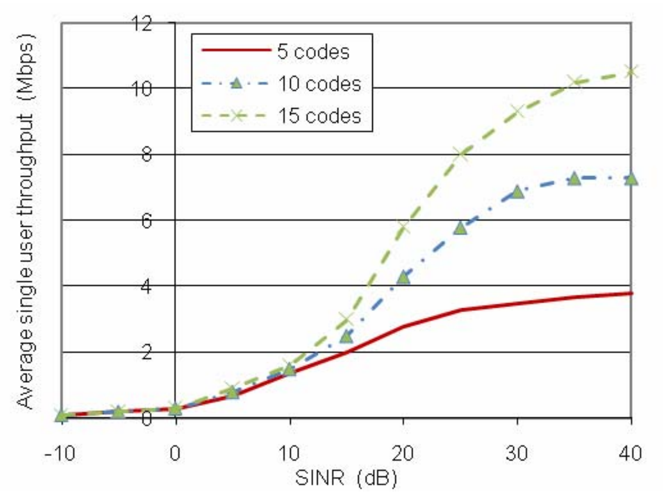

Figure 67: Average single user throughput versus average HS-DSCH SINR

A13.415 A multi-user diversity gain is applied via a function also given in figure 7.13 of reference [29] which applies for a pedestrian mobility model. The gain is modelled by the following empirical function:

$$p = 56\left(1 - e^{-0.66351(N-1)}\right)$$

where p is the multi user diversity gain expressed in %, e is Euler's constant, and N is the number of users. The function is plotted in Figure 68. The multiuser diversity gain modifies the total sector throughput th_s given by:

$$th_s = th(1 - p)N$$

The two above equation are used together in the analysis in order to calculate the maximum number of users N. Given that the user throughput *th* and maximum sector throughput th_s are known, the maximum number of users N is found via an iterative approach.

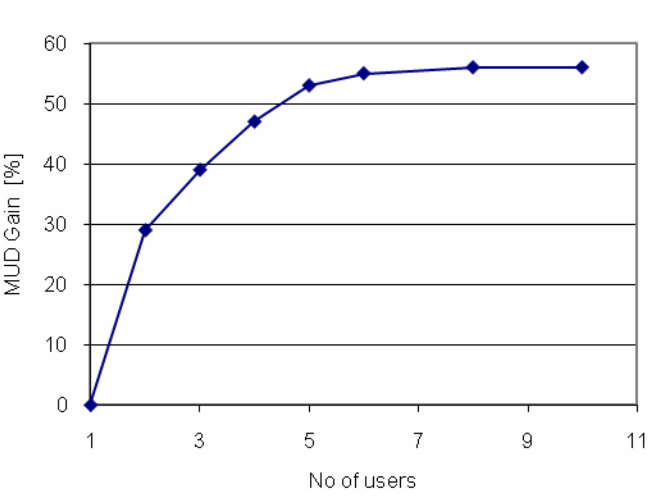

Figure 68: Variation of the multiuser diversity gain with respect to the number of users

A13.416 The HSDPA link budget is consisted of two parts: a) a common calculation for all clutter types, and b) a separate calculation for each clutter type. The link budget output is the cell-edge which can be converted to cell-area and number of sites per clutter type. The latter is achieved by employing the 80% UK area clutter proportion-breakdown information. The total number of sites can be found by summing the number of sites per clutter type.

A13.417 The link budget is calculated for the higher user density without the cell becoming capacity limited. For lower user densities than this limit, the cell-area (and number of sites per clutter type accordingly) is a constant value, whereas, for higher user densities, the cell-area increases linearly with the user density. Note that, different user-density limits are effective for each clutter type, so that the total number of sites vs. demand-level curve has 5 slopes, corresponding to the 4 user density limits imposed by the 4 different clutter types.

A13.418 The common part includes the following calculations: a) the cell-edge SINR is calculated by using the SINR curves given the desired cell-edge throughput is known, b) the EIRP is calculated from the available power for the data channel, the transmit antenna gain and cable loss, c) the receiver sensitivity is calculated from the receiver noise figure and noise rise interference margin, d) the maximum path loss (exclusive of shadow fading margin) is calculated for the downlink-data, downlink-Ec/Io and uplink, e) the maximum path loss is relaxed by the mean-to-max margin to derive the path loss of the average user location (exclusive of shadow fading margin), f) the average user SINR is calculated from the average path loss, g) the average user throughput is calculated from the average user SINR by using the SINR curves, and h) the number of users per sector is calculated from the multiuser diversity gain curves, as described in the respective section.

A13.419 The separate part includes the following calculations: a) the fade margin, b) the maximum path loss (inclusive of shadow fading margin), c) the cell-range and d) the cell-area that correspond to the cell becoming capacity limited, and e) the user density that the cell can serve without becoming capacity limited.

A13.420 6dB margin is assumed for the average to maximum path loss, as also done in R99.

A13.421 The maximum path loss is then calculated as the minimum of the uplink, downlink, and Ec/Io maximum path loss values.

A13.422 The user density which corresponds to the cell being coverage limited is found by dividing the number of active users, which was found from the multiuser diversity curves, by the cell-area, which was calculated above.

A13.423 Two scenarios were considered: dedicated channels, where a carrier is used for HSDPA traffic only, and shared-channel HSDPA where a proportion of power is available for Release 99 and the remainder is used for HSDPA.

A13.424 In the case of dedicated channels, this is translated in 15 codes. In the case of deployment in a dedicated carrier, the power is apportioned to: a) HS-SCCH and Release 99 common channels (15%), b) CPICH (10%), and c) HS data channels (75%).

A13.425 In the case of shared channel 5 available codes were assumed. The power is apportioned to: a) HS-SCCH and Release 99 common channels (15%), b) CPICH (10%), c) Release 99 DCH (25%), and d) HS data channels (50%). Less power is therefore available in the shared carrier case to support total HS traffic.

A13.426 The network is planned for 80% loading level (7dB interference rise margin) in the downlink. The higher value in comparison to the R99 case is due to the HS technical advantage to use more efficiently the available power in the channel.

A13.427 No soft handover is assumed, since soft handover is not available in HSDPA systems and no margin is allowed for fast fading due to the absence of power control in HSDPA.

A13.428 The uplink data rate is assumed 144kbps [Rel99]. The following cell-edge throughputs were examined: 384, 700, 1200 and 2400kbps.

Appendix A13.2: Site Numbers From Pareto Distributed User Populations

A13.429 The Generalised Pareto (GP) distribution was selected to model the actual PDF curves. The user population is not distributed with equal probability everywhere, but exhibits strong spatial correlations (i.e. settlements).The GP distribution is appropriate for this case, as it exhibits this correlation (few cities, many hamlets/villages).

A13.430 The GP PDF coefficients (scale $\sigma > 0$, shape $\xi \in \Re$, see GP PDF in Equation 1) for each clutter type were determined by maximum-likelihood fitting to the census data distributions subject to the mean being held at the values assumed elsewhere in the analysis. Several censored-data estimations were performed that yielded the same GP coefficients as with the uncensored, which proves the approximation rigidness.

$$f_X(x) = \frac{1}{\sigma}\left(1+\frac{\xi x}{\sigma}\right)^{\left(-\frac{1}{\xi}-1\right)} \quad , \quad \begin{array}{ll} 0 \le x \le -\dfrac{\sigma}{\xi} & \text{for } \xi < 0 \\ x \ge 0 & \text{for } \xi > 0 \end{array}$$

Equation 1

A13.431 Let *u* be the active user density, *m* the respective total number of sites and *g*(·) the function between them, so that *m* = *g*(*u*). If the active user density *u* becomes a random variable *U*, then *m* is also a random variable *M* with an expectation E[*M*] given by E[*M*]=E[*g*(*u*)], where E[*g*(*u*)] is:

$$\mathrm{E}(M) = \int_{-\infty}^{+\infty} g(u) f_U(u) du$$

Equation 2

A13.432 where $f_U(\cdot)$ is the active user density PDF. The $f_U(\cdot)$ can be easily found by rescaling the population density PDF by a factor so that the distribution mean matches the one that was used in the previous analysis that used the average user density values, so as to have comparable results.

A13.433 For each clutter type the function of the number of sites *g* is taken to have the following general form:

$$g(x) = \begin{cases} c_1 & , x < x_b \text{ (coverage limited)} \\ c_2 x & , x \ge x_b \text{ (capacity limited)} \end{cases}$$

Equation 3

A13.434 For any given scaling factor $\alpha > 0$ ($U = \alpha T$), where T is the random variable of the population density distribution) the following equation applies:

$$f_U(u) = \frac{1}{\alpha} f_T\left(\frac{u}{a}\right)$$

Equation 4

A13.435 Combining Equation 1, Equation 2, Equation 3 and Equation 4, we obtain the average number of sites E[*M*] for the specific clutter type from:

$$\mathrm{E}[M] = \begin{cases} c_1 - \dfrac{\left(\dfrac{\alpha\sigma}{x_\mathrm{b}\xi + \alpha\sigma}\right)^{\frac{1}{\xi}} \left(c_1(-1-\xi) + c_2(x_\mathrm{b} + \alpha\sigma)\right)}{-1-\xi} & \text{, if } x_\mathrm{b} < -\dfrac{\alpha\sigma}{\xi} \text{ and } \xi < 0, \text{ or } \xi > 0 \\ c_1 & \text{, if } x_\mathrm{b} \geq -\dfrac{\alpha\sigma}{\xi} \text{ and } \xi < 0 \end{cases}$$

Equation 5

A13.436 Finally, the total number of sites can be calculated by repeating the same analysis and summing the number of sites that were obtained for each clutter type.

Appendix A13.3: References regarding building penetration losses

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