Annex 14

Less densely populated areas – site counts

Introduction

A14.1 This annex presents an update on the work carried out by Ofcom to estimate the total number of base stations needed to deploy a basic 3G service in less densely populated areas using 900MHz, 1800MHz and 2100MHz spectrum.

A14.2 The boundary used to define densely populated and less densely populated areas was set at the area containing 80% of the UK population. This level was chosen as the 2100MHz 3G operators have an obligation under their current licence to provide coverage to at least 80% of the UK population. It is noted that further network expansion is likely to take one of two forms: operators may choose to increase the extent of coverage and /or increase the depths of their existing coverage. In this annex we consider the extension of coverage in less densely populated areas.

A14.3 The baseline criterion used in this annex is a basic 3G service planned to provide voice and data service (of at least 64kbps) to a handset within a vehicle. This service level has been chosen on the assumption that operators would wish to provide at least a similar level of service that might be available presently from the 2G network.[1] Higher data rates than 64kbps are likely to be available within the coverage area, but may not be available at the edges of the coverage area and are not used as the primary design criterion for our network dimensioning. The coverage area is defined by replicating existing 2G network coverage beyond the 80% population area. The 2G network coverage has been defined based on the approach used in Ofcom's 2008 Nations and Regions Market report[2].

A14.4 The information supplied here supplements the technical analysis published in our September 2007 consultation[3] and the further information published in response to stakeholder questions in November 2007[4]. It also complements analysis in other parts of this consultation document:

- Annex 13 estimates the site numbers required in more densely populated areas
- Annex 15 calculates the costs differences arising from the site numbers estimates in this annex

A14.5 Initial questions on the methodology used were answered in Answers to stakeholder questions relating to cost modelling published in November 2007.

A14.6 It should be noted that the process of planning and designing a network at any particular frequency is complex and time consuming. We have therefore made a

[1] Note that is different from the 2007 Consultation, where we estimated the number of base stations needed by considering the 3G is dimensioned to provide a voice service to a handset within a vehicle at the edge of the coverage areas.
[2] http://www.ofcom.org.uk/research/cm/cmrnr08/
[3] http://www.ofcom.org.uk/consult/condocs/liberalisation/
[4] http://www.ofcom.org.uk/consult/condocs/liberalisation/app/supplement.pdf

number of assumptions and simplifications in order to produce our results. Consequently, the results of the study should be regarded as indicative of the direction and likely magnitude of the effects rather than as definitive quantifications on the number of base stations required.

A14.7 Within this annex we provide:

- a summary of the methodology used within the 2007 Consultation to estimate the number of base stations needed in the less densely populated areas;
- an estimate of the results within the 2007 Consultation;
- a breakdown of issues raised in response to the 2007 Consultation and how we have incorporated these into our analysis;
- a new baseline of results for the number of base stations that are estimated to be needed after we have taken into account the comments raised to Ofcom;
- analysis of the change in the number of base stations needed from the 2007 Consultation to our revised baseline values;
- a sensitivity analysis of the revised results to investigate the affect of individual assumptions on the baseline case.

Background

A14.8 In the 2007 Consultation Annex 6, 7 and 8 considered the technical issues involved in providing mobile broadband services using 3G technology at various frequency bands and explained how we captured the impact of these technical issues upon the cost of deploying 3G networks.

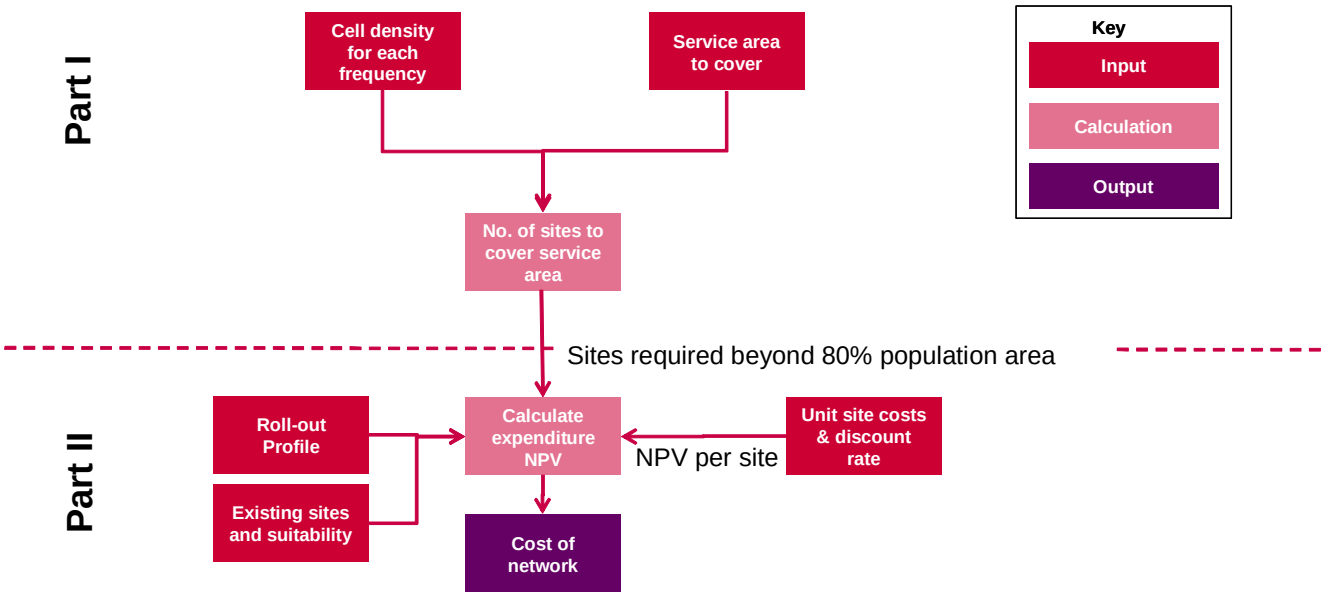
A14.9 The analysis considered the technical impact of deploying networks in the 900, 1800, and 2100 MHz bands using macro cells and assessed the resulting impact of the availability of different frequencies on network costs.

A14.10 The analysis separately considered the technical impact of frequency in both densely populated and less densely populated areas, since the user traffic profiles and requirements for coverage in these two areas are different.

A14.11 For the less densely populated areas of the country, the primary aim of further investment is assumed to be increasing the extent of basic outdoor and in-vehicle coverage. The costs associated with extending the population covered by 3G networks beyond 80% were examined in Annex 7 of the 2007 consultation.

A14.12 The methodology used within the 2007 consultation to carry out the analysis is summarised in the Figure 1.

Figure 1: Overview of study methodology



A14.13 During the 2007 consultation period Ofcom received a number of questions from stakeholders which were related to Ofcom's methodology and underlying assumptions for some aspects of our calculations. To answer these questions Ofcom published 'Answers to stakeholder questions relating to cost modelling' on 19 November 2007.

A14.14 The following section, A14.15 to A14.18, summarises the methodology published in Annex 7 of the 2007 consultation together with the additional information supplied in November 2007.

A14.15 A link budget approach was used to calculate the maximum allowable propagation loss from each base station for each frequency band.

A14.16 Radio planning software was used to derive an estimate of the coverage footprint for each base station. The coverage footprint was different for each base station depending on the propagation considerations including terrain and land use. We took the average base station density for different environments that are relevant for less densely populated areas to find an average base station density.

A14.17 The resulting base station densities were then multiplied by the estimated coverage area to generate an estimate of the number of base stations needed.

The number of base stations needed was calculated from:

Equation 1

$$N = \text{Total Coverage Area} \times \text{Site Density}$$

A14.18 The associated costs were calculated from the number of base stations needed. We assumed a mixture of upgrade and new site builds, where the cost per site differs between these site types.

Summary of the 2007 Consultation results

A14.19 The analysis and results for less densely populated areas were described in Annex 7 of the 2007 consultation. The conclusions for the base case analysis to provide a 3G service to deliver voice to a handset within a vehicle to between 80-99% of the UK population are listed below:

- The results indicated that using 900MHz spectrum to provide 3G services in less densely populated areas entails deploying fewer base stations than providing similar services at 1800MHz or 2100MHz.
- Our base case results indicated that using 900MHz 2,300 base stations are required, whilst networks using 1800MHz and 2100MHz required 3,700 and 5,000 respectively.
- This amounts to 1800MHz requiring 60% more base stations, whilst 2100MHz requires 120% more base stations than 900MHz. This difference in the number of required base stations implies a lower cost of providing 3G services in less densely populated areas using 900MHz.

A14.20 The following section addresses the comments in response to our September 2007 consultation on the less densely populated analysis.

Issues raised in Consultation responses

A14.21 The following issues were raised in consultation responses relating to our estimates of the number of base stations needed in less densely populated areas.

- Link budget corrections
- Comment on the cell planning exercise
- Extent of coverage provided

Link budget corrections

2007 consultation link budget

A14.22 The link budgets used in the 2007 consultation for the less densely populated analysis were published in "Consultation on application of spectrum liberalisation and trading to the mobile sector: Supplementary information"[5].

Comments on the link budgets

A14.23 There were a number of questions on the link budget calculations some of which have been addressed in the densely populated analysis, Annex 13. The issues raised within the responses related to the less densely populated case are listed below, with our comments addressing each point in turn:

- **Response:** It is unclear what uplink bit rate has been assumed by Ofcom. Assuming a 128/384 UL/DL service, Vodafone believes that the downlink will be the limiting factor.

- **Ofcom comment:** The less densely populated analysis used in the 2007 Consultation was based on the coverage area for a 12.2kbps voice service. In this case our analysis shows that the uplink is the limiting factor.

- **Response:** 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.

- **Ofcom comment:** The link budgets were corrected for consistency; however as the service is uplink limited the UE receiver sensitivity is not relevant to this case.

- **Response:** The link budgets for 900 MHz, 1800 MHz and 2100 MHz include vehicle/in building penetration losses. These are inconsistent with outdoor coverage. The values should be 0 dB. Notwithstanding this, the values are also inconsistent with Ofcom's own assumptions in Annex 8.

- **Ofcom comment:** In the 2007 consultation the less densely populated area was planned assuming in-vehicle coverage. We have maintained this assumption as a baseline for this analysis. The effects on the base station count for providing an outdoor coverage target are shown in the Sensitivity Analysis in section A14.64 to A14.83. It should be noted that in the original link budget the penetration loss variability was set to 6dB but only applied to the 900MHz calculation. The 6dB penetration loss variability has been applied within this annex to all three frequency bands for our baseline case.

A14.24 The following issues were also raised and have been addressed in Annex 13 that analyses the densely populated areas.

- Inclusion of mast head amplifier

[5] http://www.ofcom.org.uk/consult/condocs/liberalisation/app/supplement.pdf

- Body loss value
- Soft handover gain value
- Coverage confidence (identified as probability of call success in 2007 Consultation document)

A14.25 The changes in these parameters are summarised below.

- To incorporate the effect of including a mast head amplifier the Node B noise figure and the cable and combiner losses have been altered. The Node B noise figure has been changed from 4dB to 2dB for all frequencies. The combiner and cable losses have been altered from 3dB to 0dB.
- Body loss for handset usage: A 3dB body loss is now used for all bands and is applied to both the mobile transmit and the mobile receive. It is assumed that the passenger is in the vehicle will be using the UE to access date services. Therefore the value of 3dB for body loss was chosen for handheld browsing as detailed in the densely populated analysis, Annex 13 Table 16.

Table 1 : Body loss for handset usage revised figures.

	900MHz	1800MHz	2100MHz
2007 Consultation body loss assumption	1.5dB	1.5dB	2dB
Revised body loss assumption	3dB	3dB	3dB

- Soft handover gain: Table 2 shows the changes made to this input parameter.

Table 2: Soft handover gain revised figures

	Downlink	Uplink
2007 Consultation soft handover gain	3dB	3dB
Revised soft handover gain	2.5dB	2dB

- Coverage confidence: The coverage confidence across the cell area (identified as probability of call success in 2007 Consultation document) has been changed from 97% to 90%. This is equivalent to the coverage confidence at the cell edge changing from 90% to 78%[6].

Service provision

[6] Source reference: Reudink, D. O. Large-scale variations of the average signal. W.C. Jakes, Microwave Mobile Communications.

A14.26 The baseline criteria used in this annex is a basic 3G service planned to provide voice and data service (of 64kbps) to a handset within a vehicle. This service level has been chosen on the assumption that operators would wish to provide at least a similar level of service that might be available presently from the 2G network. Higher data rate services may still be available within the coverage area, but may not be available at the edges of the coverage area and are not used as the primary design criterion for our network dimensioning.

A14.27 To incorporate this change, the Eb/No value and the receiver processing gain have been changed for both the uplink and downlink.

A14.28 Eb/No is the signal energy bit divided by the noise spectral density and changes based on a number of factors including service type, multi-path fading channel, mobile speed and bit rate. Our revised Eb/No values, based on the figures from 3GPP TS 25.101 and TS 25.104, are:

Table 3: Revised Eb/No values

	Downlink[7]	Uplink[8]
2007 Consultation Eb/No	9.2dB	7.2dB
Revised Eb/No values	6.3dB	3.8dB

A14.29 The receiver processing gain changes to take into account differences in the information data rate and chip rate. Our revised receiver processing gain values are:

Table 4: Revised receiver processing gain values

	Downlink	Uplink
2007 Consultation receiver processing gain	25dB	25dB
Revised receiver processing gain	17.8dB	17.8dB

[7] Table 12.21, Holma and Toskala, "WCDMA for UMTS", Third Edition, John Wiley, 2002.
[8] Table 12.19, Holma and Toskala, "WCDMA for UMTS", Third Edition, John Wiley, 2002.

Revised link budgets

A14.30 The resultant link budgets that take into account all these changes proposed are shown below.

Table 5: UMTS 900 link budget revised baseline

Universal Parameters		Value		Units
Environment		Vehicle		
Mobile Velocity		120		km/h
Basic data		64		kbps
Carrier Frequency	F	900.0		MHz
Noise Bandwidth	B	3.84		MHz

		Downlink	Uplink	
Transmitter Parameters	Parameter	Value		Units
		BS_Tx	MS_Tx	
Body Loss	BL		3.0	dB
Equivalent Isotropic Radiated Power	EIRP	51.01	17.97	dBm

Eb/No Calculation		MS_Rx	BS_Rx	Units
Signal To Noise Ratio	Eb/No	6.3	3.8	dB

Receiver Limits		MS	BS	Units
Receiver Thermal Sensitivity	Srx	-110.2	-120.1	dBm

Receiver Parameters				
Body Loss	BL	3.0		dB
Minimum Required Isotropic Power	IPrx	-106.6	-120.1	dBm

Interference Calculation				
Load Factor	Ioth	50.00	50.00	%
Total Noise Rise	NR	3.01	3.01	dB

Variability Calculation		STD		Units
Total Variability	V	9.24		dB

Link Loss Calculation				
Soft Handover Gain	SHO	2.50	2.00	dB
Vehicle Penetration Loss	BPL	3.00	3.00	dB
Location Variability	V	9.24	9.24	dB
Coverage Target	Cov	78.00	78.00	%
Allowed Propagation Loss for Cell Range	PL	147.00	144.96	dB
Pilot Planning Level	PPLev	-93.95		dB

Table 6: UMTS 1800 link budget revised baseline

Universal Parameters		**Value**		**Units**
Environment		Vehicle		
Mobile Velocity		120		km/h
Basic data		64		kbps
Carrier Frequency	F	1800.0		MHz
Noise Bandwidth	B	3.84		MHz

		Downlink	Uplink	
Transmitter Parameters	Parameter	Value		Units
		BS_Tx	MS_Tx	
Body Loss	BL		3.0	dB
Equivalent Isotropic Radiated Power	EIRP	51.01	17.97	dBm

Eb/No Calculation		MS_Rx	BS_Rx	Units
Signal To Noise Ratio	Eb/No	6.3	3.8	dB

Receiver Limits		MS	BS	Units
Receiver Thermal Sensitivity	Srx	-109.6	-138.1	dBm

Receiver Parameters				
Body Loss	BL	3.0		dB
Minimum Required Isotropic Power	IPrx	-106.6	-138.1	dBm

Interference Calculation				
Load Factor	Ioth	50.00	50.00	%
Total Noise Rise	NR	3.01	3.01	dB

Variability Calculation	STD			Units
Total Variability	V	9.89		dB

Link Loss Calculation				
Soft Handover Gain	SHO	2.50	2.00	dB
Vehicle Penetration Loss	BPL	7.00	7.00	dB
Location Variability	V	9.89	9.89	dB
Coverage Target	Cov	78.00	78.00	%
Allowed Propagation Loss for Cell Range	PL	142.5	140.46	dB
Pilot Planning Level	PPLev	-89.45		dB

Table 7: UMTS 2100 link budget revised baseline

Universal Parameters		**Value**		**Units**
Environment		Vehicle		
Mobile Velocity		120		km/h
Basic data		64		kbps
Carrier Frequency	F	2100.0		MHz
Noise Bandwidth	B	3.84		MHz

		Downlink	Uplink	
Transmitter Parameters	Parameter	Value		Units
		BS_Tx	MS_Tx	
Body Loss	BL		3.0	dB
Equivalent Isotropic Radiated Power	EIRP	51.01	17.97	dBm

Eb/No Calculation		MS_Rx	BS_Rx	Units
Signal To Noise Ratio	Eb/No	6.3	3.8	dB

Receiver Limits		MS	BS	Units
Receiver Thermal Sensitivity	Srx	-112.6	-120.1	dBm

Receiver Parameters				
Body Loss	BL	3.0		dB
Minimum Required Isotropic Power	IPrx	-109.6	-138.1	dBm

Interference Calculation				
Load Factor	Ioth	50.00	50.00	%
Total Noise Rise	NR	3.01	3.01	dB

Variability Calculation	STD			Units
Total Variability	V	10.04		dB

Link Loss Calculation				
Soft Handover Gain	SHO	2.50	2.00	dB
Vehicle Penetration Loss	BPL	8.00	8.00	dB
Location Variability	V	10.04	10.04	dB
Coverage Target	Cov	78.00	78.00	%
Allowed Propagation Loss for Cell Range	PL	144.38	139.34	dB
Pilot Planning Level	PPLev	-88.33		dB

A14.31 Table 8 shows the changes in the maximum allowable propagation loss that have resulted from the changes in the link budgets for our target to in-vehicle basic 3G service.

Table 8: Summary of the calculated propagation loss

	Frequency (MHz)		
	900	1800	2100
Allowed propagation loss, PL (dB) Consultation September 2007	141.55	139.33	137.57
Revised allowed propagation loss (dB)	144.96	140.46	139.34
Difference in allowed propagation loss (dB)	3.41	1.14	1.77

Comment on the cell planning exercise

Overview of the original planning exercise

A14.32 The planning exercise was carried out using the following procedure:

- We analysed a sample area to examine the characteristics of networks in a typical less densely populated area. The area chosen was around Horsham in West Sussex.
- A 2G 900 MHz network was analysed within this area by drive testing to find the base station footprint and user density levels over the area.
- This exercise was carried out by a third party using an experienced radio planner who manually planned the networks taking into account the existing 2G base station footprint and user density levels obtained from drive tests.
- Networks were re-planned for coverage according to the link budgets originally published for UMTS 900, UMTS 1800 and UMTS 2100 and using a calibrated modified Okumura Hata propagation model[9][10]. The positions of existing base stations were used where appropriate.
- By considering the existing base station footprint and user density levels the area was re-planned for 3G using 900 MHz, 1800MHz and 2100MHz spectrum. The resulting base station densities were calculated and are reported in Table 9.

Table 9: Base station densities in less densely populated areas (as published in Table 20, September 2007 consultation)

Base stations per km^2	UMTS 900	UMTS 1800	UMTS2100
Less densely populated area	0.017	0.027	0.037

[9] Field Strength and its variability in VHF and UHF Land Mobile Radio Service, Y Okumura et. al., Rev. Electr. Commun. Lab. 16, 825-873,1968.
[10] Empirical formula for Propagation Loss in Land Mobile radio Services. Masaharu Hata. IEEE Transactions on Vehicular Technology Vol VT-29, No 3, August 1980

Comments on the cell planning exercise

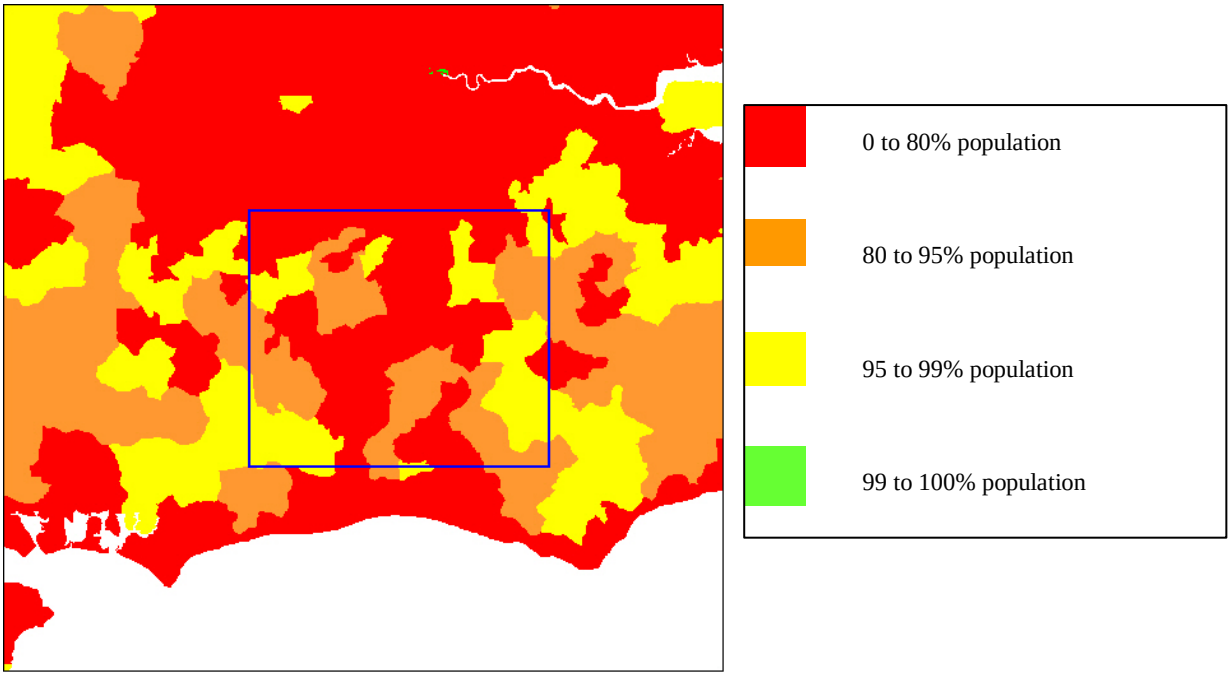
A14.33 The following point was raised on the cell planning exercise:

- **Response**: It is inappropriate to seek to draw conclusions on rural base station densities from the West Sussex drive tests. There are a number of specific constraints and local population density issues in this area which differ from the rest of the UK.

  Ofcom comment: The area around Horsham was cell planned using 900MHz, 1800MHz and 2100MHz spectrum. The sites classified in the less densely populated areas were used to obtain an estimate of respective site densities for different frequency networks.

A14.34 Figure 2 shows that the planned area has a range of population densities.

Figure 2: Analysis of the population density for the area around Horsham



A14.35 We consider that it is appropriate to consider the cell planning of rural areas around Horsham as an indicative measure of potential advantages of the availability of 900MHz spectrum over other access to 1800MHz or 2100MHz to understand the potential scale of the cost differences.

A14.36 In the September 2007 consultation we considered that it was appropriate to consider the site density values with a tolerance of ±30%.

Extent of coverage

Overview of the methodology used in the 2007 Consultation for estimating the extent of coverage

A14.37 For our base case in the 2007 Consultation document, we considered the cost differences that would arise due to holding different frequencies if an operator rolled

out a 3G network from 80% to 99% of the UK population. We also considered cases where rollout was less extensive than this to 90% and 95% of the population.

A14.38 The coverage area was defined by selecting postcode sectors based on their population densities. The 80% of the most densely populated postcode sectors areas were not considered for the analysis of the less densely populated areas. The postcode sectors were then chosen until 80 to 99% (or 90%, 95% for the other cases) of the UK population was selected. It was assumed that 100% of the area of these selected postcode sectors would have 3G coverage. This resulted in the less densely populated areas having a coverage area of:

- 137,085km^2 for 80-99% population coverage.
- 73,134 km^2 for 80-95% population coverage
- 35,244 km^2 for 80-90% population coverage

Overview of comments received in responses

A14.39 Vodafone in their response assumed for their example calculation that it would be more reasonable to assume a 3G coverage level of 95% for 3G services and 90% for mobile broadband.

A14.40 O2 stated that they considered that there is unlikely to be a UMTS900 (or UMTS2100) deployment by any player in rural areas, as there is no payback on the investment purely on the basis of mobile broadband. This view was supported by the comments of one other stakeholder.

A14.41 Orange stated a desire to provide national 3G coverage.

A14.42 The Council of National Parks commented that maximum use should be made of existing equipment in any extension of 3G services to rural areas so that environmental impacts are minimised.

Ofcom comment

A14.43 We have reviewed our estimated areas for the extent of coverage to ensure they represent plausible scenarios.

A14.44 Firstly, we note that in countries where 900MHz has been made available, such as Finland, Australia and New Zealand operators have made public declarations of their intention to use UMTS900 to extend 3G service to a high percentage of the population over the next few years. Whilst UK circumstances will differ to those counties, this does illustrate that extension of 3G coverage is a plausible outcome of liberalisation.

A14.45 Secondly, we have reviewed our approach to estimating coverage areas using postcode sectors (outlined above). We believe that the original approach risked overstating the area to be covered. As an alternative means of estimating future 3G coverage area, we have considered the area that is currently served by 2G. It seems reasonable to believe that if operators do extend their 3G coverage in the future it will be to the areas where they currently provide 2G coverage, rather then to places where no GSM coverage is provided at all.

A14.46 We have carried out further analysis to identify a typical coverage area for the less densely populated areas (outside the 80% population area), that is currently served by 2G. The results of this analysis will be used to identify the coverage area required for the new 3G service.

A14.47 In May 2008 Ofcom published *The Nations & Regions Communications Market 2008*[11] report, a review of the markets for television, radio, and telecommunications, showing detailed data for the nations and regions of the UK. Within this report the extent of mobile coverage in Q1 2008 was evaluated across the UK for both 2G and 3G. This was carried out by examining the number of mobile networks with coverage in each postcode district. For an operator to be counted as having coverage, its network footprint has to cover at least 75% of the postcode district area.

A14.48 Our revised approach is to align our methodology in determining the typical coverage area for the less densely populated with that used in the Nation and Regions report. The following details how this was calculated.

- We obtained the GSM Association and Europa Technologies data which was used in Ofcom's 2008 Nations and Regions Market report and performed further analysis to assist our work on the future coverage provision in less densely populated areas.

- The 80% of the most densely populated district areas were not considered for this analysis on the less densely populated areas. The proposed coverage area was identified by choosing the postcode district areas with at least 75% area coverage for at least three of the four 2G cellular operators. For our analysis, we assumed that 3G coverage will eventually replicate the current 2G coverage provision; we have assumed that 90% of the area of these postcode districts will have 3G coverage provision. The identified size of this coverage area within these postcode districts is 91,857 km^2.

Table 10: Comparison of total coverage area

Estimate of total coverage area	Total coverage area, km^2
Method originally published in the September 2007 Consultation document	137,085
Revised approach	91,857

A14.49 This revised coverage area is used to define the less densely populated area that an operator will provide a 3G service to in the baseline. The sensitivity analysis contains results for the provision of 3G coverage to 75% and 100% of the area for the selected postcode districts.

Revised methodology for the number of base stations needed

A14.50 This section shows how the changes to our original assumptions and modelling are taken into account to get new estimates for the number of base stations needed.

[11] http://www.ofcom.org.uk/research/cm/cmrnr08/

A14.51 The revised assumptions that are detailed in this annex are summarised in Table 8 and Table 10. Table 8 shows the changes in the allowed propagation loss, these have resulted from the changes made to the link budgets. Table 10 shows the changes in the assumption of the total 3G coverage area in the less densely populated areas that an operator would offer.

A14.52 The number of base stations needed is calculated from:

Equation 2

$$N = \text{Total Coverage Area} \times \text{Site Density}$$

A14.53 The following steps provide an outline of how the changes in the link budgets were accounted for to estimate the revised number of base stations needed.

A14.54 The new base station site density, taking into account the changes in the link budgets, is found by multiplying the base station site density before the changes have been made to the link budgets by a correction factor. This correction factor is shown below.

Equation 3

$$\text{Site Density}_{new} = \text{Correction Factor} \times \text{Site Density}$$

A14.55 Sections A14.57 to A14.61 show the derivation of this correction factor.

A14.56 There are a number of implicit assumptions in our methodology:

- We assume that the area is coverage and not capacity limited.
- Our propagation model assumes that the terrain is fairly flat and gently rolling.
- We also assume that coverage is reasonably contiguous for example our baseline case assumed our 3G coverage area covers 90% area of the selected postcode districts.
- Our methodology is more suitable for smaller net changes, than larger net changes in the allowable path loss. This is due to the use of a link budget correction being applied to a result from a cell planning exercise.

A14.57 The equation below approximates the path loss for the cell radius, d. This equation uses the allowable path loss from a base station, as derived within the 2007 Consultation.

Equation 4

$$PL = K + (10.\alpha).\log_{10}(d)$$

PL = Path loss (dB)
K = Constant, depending on clutter type and antenna height
d = distance, km
α = path loss exponent, depending on frequency and antenna height

A14.58 The equation below approximates the revised path loss, PL_{new} , from considering the changes in the link budgets for the new cell radius, d_{new}.

Equation 5

$$PL_{new} = K + (10.\alpha).\log_{10}(d_{new})$$

A14.59 These equations are combined to estimate the affect of a change in the link budget.

Equation 6

$$(PL - PL_{new}) = \Delta PL = (10.\alpha).\log_{10}\left(\frac{d}{d_{new}}\right)$$

A14.60 This equation can be rearranged to give the proportional relationship of the original cell radius and the new cell radius.

Equation 7

$$\frac{(\Delta PL)}{(10.\alpha)} = \log_{10}\left(\frac{d}{d_{new}}\right)$$

Equation 8

$$\left(\frac{d}{d_{new}}\right) = 10^{\frac{(\Delta PL)}{(10.\alpha)}}$$

A14.61 This relationship can be used to calculate the proportional relationship between the original cell coverage area and the new cell coverage area.

Equation 9

$$\left(\frac{d}{d_{new}}\right)^2 = \left(10^{\frac{(\Delta PL)}{(10.\alpha)}}\right)^2$$

Equation 10

$$\left(\frac{\pi.d^2}{\pi.d^2_{new}}\right) = \frac{\pi}{\pi}.\left(10^{\frac{(\Delta PL)}{(10.\alpha)}}\right)^2$$

Equation 11

$$\left(\frac{\pi.d^2}{\pi.d^2_{new}}\right) = \left(10^{\frac{2.(\Delta PL)}{(10.\alpha)}}\right)$$

Equation 12

$$\left(\frac{\text{Cell Area}}{\text{Cell Area}_{new}}\right) = \left(\frac{\text{Site Density}_{new}}{\text{Site Density}}\right) = \left(10^{\frac{2.\Delta PL}{(10.\alpha)}}\right)$$

The new site density estimate becomes:

Equation 13

$$\text{Site Density}_{new} = \left(10^{\frac{2.\Delta PL}{(10.\alpha)}}\right).\text{Site Density}$$

Where α = path loss exponent. (These have been derived from the modified Okumura Hata propagation model used in the radio planning exercise. For 900MHz α = 3.1, for 1800MHz α = 2.9 and for 2100MHz α = 2.9).
ΔPL = Change in allowable path loss.

Results from analysis

A14.62 Table 11 shows a revised estimate for the 3G base station densities after taking into account comments received from the September 2007 Consultation.

Table 11: The estimate of 3G base station densities (per km^2) for different spectrum bands

UMTS 900	UMTS 1800	UMTS 2100
0.010	0.022	0.028

Table 12 shows the baseline estimate for the total number of 3G base stations after taking into account comments received from the September 2007 Consultation.

Table 12: The total estimate of 3G base stations required for different spectrum bands

UMTS 900	UMTS 1800	UMTS 2100
949	2074	2568

A14.63 In the September 2007 Consultation, we estimate use of 1800MHz spectrum required 60% more base stations, whilst 2100MHz required 120% more base stations than use of 900MHz to provide coverage to less densely populated areas. For the baseline 2008 case we estimate use of 1800MHz spectrum requires 120% more base stations, whilst 2100MHz requires 170% more base stations than 900MHz.

Figure 3: Comparison of base station requirement estimates to less densely populated areas.

Analysis of the change in the number of base stations needed from the 2007 Consultation to our new baseline value

A14.64 The affect of each change from the 2007 Consultation is assessed in turn, in the order introduced within this document. The table below shows the cumulative affect of each iteration on the estimate of the number of base stations needed for each frequency band. The final iteration, baseline 2008, takes all changes into account.

Table 13: The cumulative affect of each changed assumption on the estimate of the number of base stations needed for each frequency band from the 2007 Consultation to our revised baseline case.

Cumulative change in assumptions	Number of base stations needed		
	900MHz	1800MHz	2100MHz
2007 Consultation base case	2331	3702	5073
Adjustment of UE receiver sensitivity	2331	3702	5073
Adjustment of penetration loss	2331	5588	7596

variability			
Inclusion of a mast head amplifier	1122	2531	3441
Adjustment of body loss value	1397	3210	4032
Adjustment of the soft handover gain	1617	3761	4724
Adjustment of the coverage confidence	812	1696	2100
Adjustment of network dimensioning of voice to network dimensioning of low data rate services	1416	3095	3833
Adjustment of the size of the coverage area	949	2074	2568
Baseline 2008	949	2074	2568

Sensitivity Analysis on baseline case

A14.65 This subsection, A14.66 to A14.83, varies some of the major assumptions and input parameters that underlie the baseline results presented above in Table 13. We examine in turn:

Table 14: Assumptions altered from the revised baseline for the Sensitivity analysis

Sensitivity	Description
Case 1	Network dimensioning for voice only
Case 2	No mast head amplifiers
Case 3	Network dimensioning for outdoor provision
Case 4	95% call success
Case 5	Different antenna gains at the base stations
Case 6a	75% of each post code district has coverage
Case 6b	100% of each post code district has coverage
Case 7a	3G coverage for the area with current 2G coverage for at least 2 operators.
Case 7b	3G coverage for the area with current 2G coverage for at least 4 operators

Case 1: Network dimensioning for voice

A14.66 This analysis considers the scenario where an operator chooses to plan their 3G service to deliver voice to a handset within a vehicle. Data services at various bit rates may still be available within the coverage area, but may not be available at the edges of the coverage area and are not used as the primary design criterion for our network dimensioning.

A14.67 To consider the scenario where an operator chooses to dimension their network for coverage only, we have made some changes to the link budget assumptions which are detail below.

A14.68 To consider the scenario where an operator chooses to target voice coverage only, we have made some changes to the Eb/No values and the receiver processor gain in the link budget assumptions which are detailed below Table 15 and Table 16.

A14.69 For this analysis it is assumed the UE will be used in the talk position as detailed in the densely populated analysis, Annex 13 Table 16 and a value of 3dB has been chosen the for body loss.

Table 15: Sensitivity analysis changes to Eb/No values for the planned provision of voice services

	Baseline	Case 1
Uplink Eb/No	7.2dB	3.8dB
Downlink Eb/No	9.21dB	6.3dB

Table 16: Sensitivity analysis changes to receiver processor gain values

	Baseline	Case 1
Receiver processor gain	17.8dB	25dB

Case 2: No mast head amplifiers

A14.70 This analysis considers the scenario where an operator chooses not deploy mast head amplifiers on their base stations.

A14.71 To consider the scenario where an operator chooses not to use mast head amplifiers, we have made some changes to the link budget assumptions which are detail below.

Table 17: Sensitivity analysis changes to parameters relating to mast head amplifiers

	Baseline	Case 2
Receiver noise figure in the BTS	2dB	5dB[12]
Cable and Combiner loss in the BTS	0dB	3dB

Case 3: Network dimensioning for outdoor provision

A14.72 This analysis considers the scenario where an operator chooses to deploy a network that is targeted to provide outdoor pedestrian coverage only at the edge of coverage. In our baseline we have considered that an operator would plan to an in-vehicle coverage target.

A14.73 To consider the scenario where an operator chooses to target outdoor pedestrian coverage only, we have made some changes to the link budget assumptions which are detail below.

Table 18: Sensitivity analysis changes to penetration loss

	Penetration loss, dB	
Frequency (MHz)	Baseline	Case 3
900	3	0
1800	7	0
2100	8	0

- A figure of 6dB penetration loss variability was used for all frequency bands for the in-vehicle coverage target. For this sensitivity analysis, penetration loss variability is assumed to be 0 dB.

- A fast fading margin of 2dB was added for this sensitivity analysis, this value aligns with the one used in the densely populated analysis, Annex 13.The fast fading margin is the power control headroom which is needed to maintain adequate closed loop power control. This margin applies to slow moving mobiles where the power control compensates for fast fading.

- The Eb/No values were changed from Multi-path Case 3 to Multi-path Case 1. Eb/No is discussed in A14.28 and this change was carried out to accommodate the change in the multi-path environment from vehicular to pedestrian open coverage area for this sensitivity analysis. A description of the different Multi-path cases can be found in various books[13] [14].

[12] In the 2007 consultation the less densely populated area link budgets used a value of 4dB for receiver noise figure in the BTS; this has now been changed to 5dB for non MHA operation to match the value used in Annex 13.

[13] Holma and Toskala, "WCDMA for UMTS", Third Edition, John Wiley, 2002.
[14] Laiho, Wacker and Novosad, "Radio network Planning and Optimisation for UMTS", John Wiley, 2002.

Table 19: Sensitivity analysis changes to Eb/No values for the planned provision of **64kps to a pedestrian open coverage area.**

	Baseline	Case 3
Uplink Eb/No	7.2dB	9.2dB[15]
Downlink Eb/No	9.2dB	9.7dB[16]

Case 4: 95% coverage confidence

A14.74 This analysis considers scenario where an operator plans to a different level for the probability of coverage confidence, than we have assumed in our baseline case.

A14.75 The table below shows the baseline values assumed for probability of call success and an alternative suggestion.

Table 20: Sensitivity analysis changes to coverage confidence

	Baseline	Case 4
Cell call success	90%	95%
Equivalent call success at the cell edge[17]	78%	88%

Case 5: Different antenna gains at the base stations

A14.76 This analysis considers different antenna gains at the base station. This scenario could occur when there is limited space available to fit antennas on to base stations to achieve the higher gains at the lower frequencies.

A14.77 Table 21shows the baseline values assumed for antenna gain and the alternative vales modelled.

Table 21: Sensitivity analysis changes to base station antenna gain values

Case	Frequency (MHz)		
	900	1800	2100
Baseline	18.0dBi	18.0dBi	18.0dBi
Case 5	16.0dBi	17.8dBi	18.3dBi

Case 6: Change the percentage of postcode district with coverage

[15] Table 8.3, 3GPP TS 25.104 V8.2.0 (2008-03)
[16] Equation 12.24, Holma and Toskala, "WCDMA for UMTS", Third Edition, John Wiley, 2002.
[17] Reudink, D. O. Large-scale variations of the average signal. W.C. Jakes, Microwave Mobile Communications.

A14.78 Our baseline case assumes that an operator will plan a basic level of 3G coverage to 90% area of the postcode districts where there is currently at least three cellular operators with 2G coverage. This analysis considers the scenario where a different percentage of the postcodes have coverage.

A14.79 The table below shows the baseline values assumed for the percentage postcode districts and the alternative values modelled.

Table 22: Sensitivity analysis changes to percentage of postcode districts with coverage

Case	Percentage of selected post code districts with coverage	Total coverage area, km^2
Baseline	90%	91,857
Case 6a	75%	76,547
Case 6b	100%	102,063

Case 7: Change the extent of coverage

A14.80 Our baseline case assumes that an operator will plan a basic level of 3G coverage to 90% area of the postcode districts where there is currently at least three cellular operators with 2G coverage. This analysis considers the scenario where an operator chooses to match a different extent of 2G coverage.

A14.81 The table below shows the baseline values assumed and alternative values modelled.

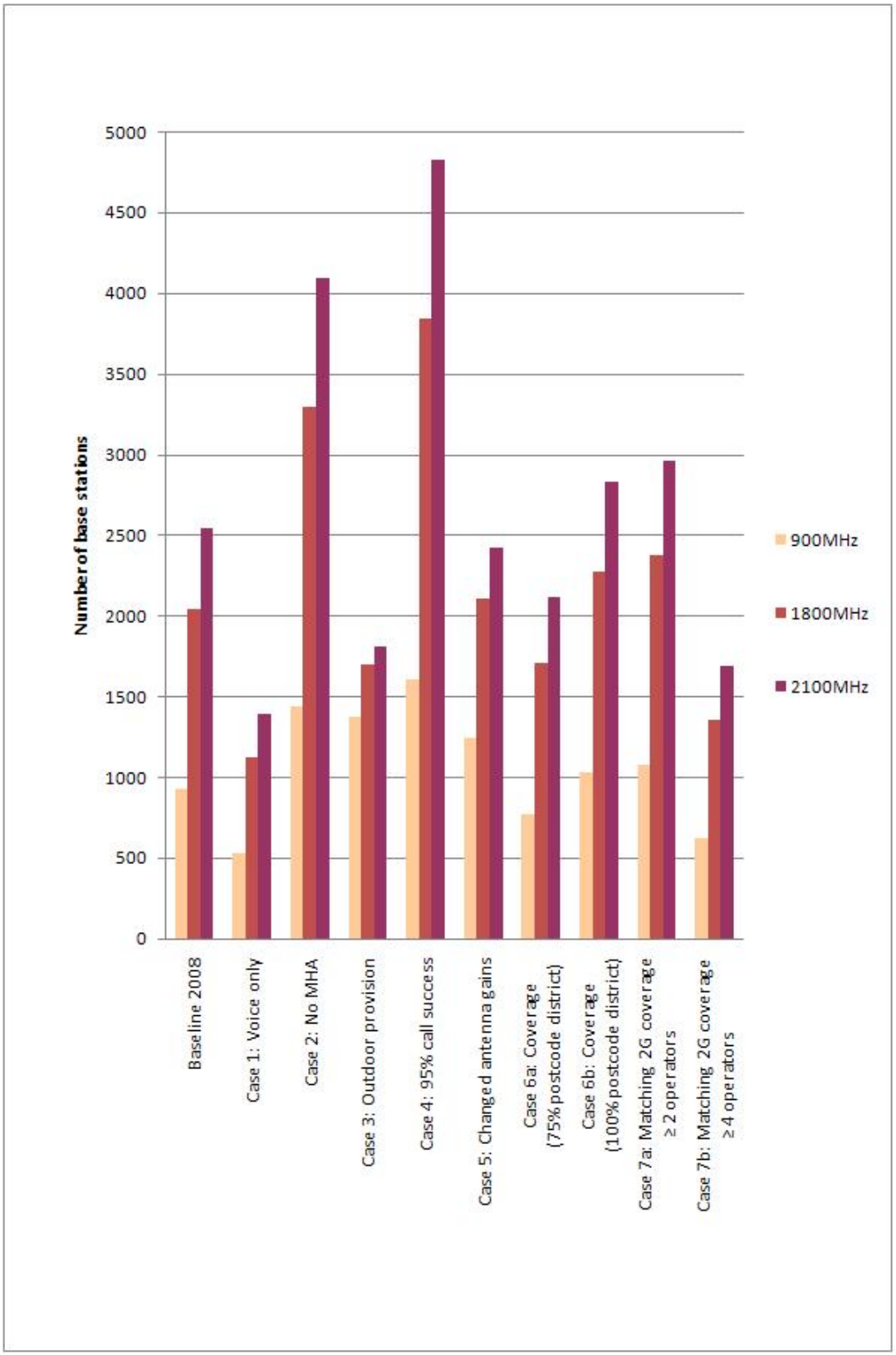
Table 23: Sensitivity analysis changes to the choice of 3G coverage area within the post code districts

Case	3G coverage area within Post code districts	Total coverage area, km^2
Baseline	Where there are currently at least three cellular operators with 2G coverage.	91,856
Case 7a	Where there are currently at least two cellular operators with 2G coverage.	128,057
Case 7b	Where there are currently four cellular operators with 2G coverage.	61,050

Sensitivity analysis results

A14.82 The results for each case of the sensitivity analysis are shown in Figure 4.

Figure 4: Estimates of the number of base stations needed from the sensitivity analysis



A14.83 These results show that fewer base stations are required for the case where an operator has access to 900MHz spectrum to extend their basic 3G coverage to less densely populated areas. This has been shown for all the cases modelled.

Summary

A14.84 In response to comments made on the analysis of less densely populated areas in the September 2007 consultation we have made a number of refinements to our methodology. The main changes are:

- Changes to the allowable propagation loss for all frequencies. The parameters that have been revised are: the provision of a basic data service to the edge of the coverage area, the soft handover gain value, body loss value, coverage confidence, the penetration loss variability and the inclusion of a mast head amplifier. The changes result in a difference in the allowable propagation loss in the baseline case of 3.41dB for 900MHz, 1.14dB for 1800MHz and 1.77dB for 2100MHz.

- Reduced estimate of the extent of coverage provided. The changes result in a reduction of the coverage area difference from 137,087km^2 to 91,857 km^2.

A14.85 As a result our baseline show that a reduced number of base stations will be required for the less densely populated area than were calculated in the 2007 Consultation. In addition, there is a smaller difference in the number of base stations needed using 1800MHz spectrum and 2100MHz spectrum due to the changes made in the allowable propagation loss.

A14.86 Our baseline case from our revised analysis indicates that using 900MHz 949 base stations are required, whilst networks using 1800MHz and 2100MHz required 2,074 and 2,568 respectively.

A14.87 In all cases the sensitivity analysis results indicates that fewer base stations are required where an operator has access to 900MHz spectrum to extend their basic 3G coverage to less densely populated areas.