Red-M

Case Study: Estimated changes to the number of 2G cell sites or sectors as a consequence of reduced spectrum holding at 900MHz

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Executive Summary

Red-M conducted a 'simulated' design exercise for two areas of the country in order to help Ofcom build a picture of the number of additional GSM900 Macro cell sites required as the amount of spectrum available is reduced. The areas chosen by Ofcom were:

- A 10km by 10km square of North London
- A 28km by 28km square centred around Burton-on-Trent in Staffordshire

The simulated design exercise was repeated five times for each scenario with reducing amounts of spectrum. Starting with a baseline, spectrum was removed in 2.5MHz blocks. Blocks of 2.5MHz, 5MHz, 7.5MHz and 10MHz of spectrum were removed and the network was re-designed to meet defined grade of service and coverage quality objectives. These objectives did not vary as the amount of spectrum was reduced.

The results show that the increase in the number of sites required is lower in the mostly rural scenario (Burton), where the cells are mostly coverage limited. In the London scenario, the cells are predominantly capacity limited and any reduction in spectrum requires additional sites to achieve the required capacity. The urban scenario is also more sensitive to the assumptions of offered traffic, grade of service and frequency re-use.

The results of the exercise are summarised in the table below.

Simulation Results	Site Count Summary		
	Sites	Transceivers	Sites %
Burton Baseline	32	197	100%
Burton -2.5MHz	32	200	100%
Burton - 5MHz	32	205	100%
Burton - 7.5MHz	33	211	103%
Burton - 10MHz	37	216	116%
London Baseline	70	742	100%
London - 2.5MHz	83	791	119%
London - 5MHz	98	872	140%
London - 7.5MHz	156	1016	223%
London - 10MHz	231	1172	330%

A spreadsheet parameterised model has been provided to allow the impact of changing input assumptions to be modelled rapidly and at a high level without recourse to a further modelling exercise. The limitations of the spreadsheet model mean that the results are likely to be most reliable for relatively small excursions around the initial conditions. If more than a cursory view of the impact of changing assumptions is required, then Red-M recommends further more detailed study.

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1. Introduction

Ofcom is currently considering how to implement liberalisation of 2G spectrum in the UK. Ofcom published a consultation in September 2007 which included a proposal that the existing holders of 900MHz spectrum (O2 and Vodafone) should be required to clear and release some of that spectrum so that it could be re-allocated to other parties. Ofcom's proposal was based upon their initial assessment of the costs that O2 and Vodafone would be likely to incur in clearing that spectrum.

Ofcom is currently considering the responses to that consultation and refining its estimates of the costs of clearing spectrum.

In updating their analysis Ofcom believes that a simulation exercise may be beneficial to ascertain the sensitivity of some of the costs associated with reducing the amount of 900 MHz spectrum O2 and Vodafone hold and use for their 2G networks. The outcome of the exercise would provide Ofcom with information about the number of additional sites that may be required to achieve the same capacity and coverage (i.e. maintain a broadly similar level of network quality) in sample areas of a 2G network when some amount of spectrum is cleared.

This document contains the results of the simulation exercise performed

2. Red-M's Approach to the Case Study

2.1 Outline

Red-M conducted a 'simulated' design exercise for two areas of the country in order to help Ofcom build a picture of the number of additional GSM900 Macro cell sites that may be required as a function of the amount of cleared spectrum. The areas chosen were

- A 10km by 10km square of North London, including mostly urban areas, but excluding the dense urban area of central London
- A 28km by 28km square centred on Burton on Trent in Staffordshire, including mostly rural areas, but including urban population centres and small towns and villages.

The simulated design exercise was repeated five times for each scenario with reducing amounts of spectrum. Starting with a baseline, with 14.2MHz[1] of spectrum in London and 17.2MHz of spectrum in Burton, spectrum was removed in 2.5MHz blocks. Blocks of 2.5MHz, 5MHz, 7.5MHz and 10MHz of spectrum were removed and the network was re-designed to meet defined grade of service and coverage quality objectives. The approach taken at each

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[1] See Appendix A. The reduced spectrum allocation in London is due to an allowance made for microcellular and picocellular layers which are not simulated in this exercise.

stage was to modify the baseline network, simulating a 'least cost minimum disruption' scenario where sites in the baseline network continue to exist in the reduced spectrum scenario. The sites are not moved, but some tuning of antenna down-tilt was used to control interference in extreme cases. In the 'London-10MHz' scenario, the existing network is impacted to such a considerable degree that this approach did not result in a feasible network. It was therefore decided to start from scratch and populate a network with large numbers of relatively low base stations.

Although the exercise was made as realistic as possible, it is a simulation, since it is not possible to capture real constraints such as issues with site acquisition. In order to make the process as realistic as possible, care was taken to identify a baseline scenario and then benchmarking the baseline against extracts of data supplied by Ofcom. Aspects of the benchmark that were examined included:

- Range of site heights
- Number of Sites
- Per Sector Transceiver Counts, as shown in Figure 1.

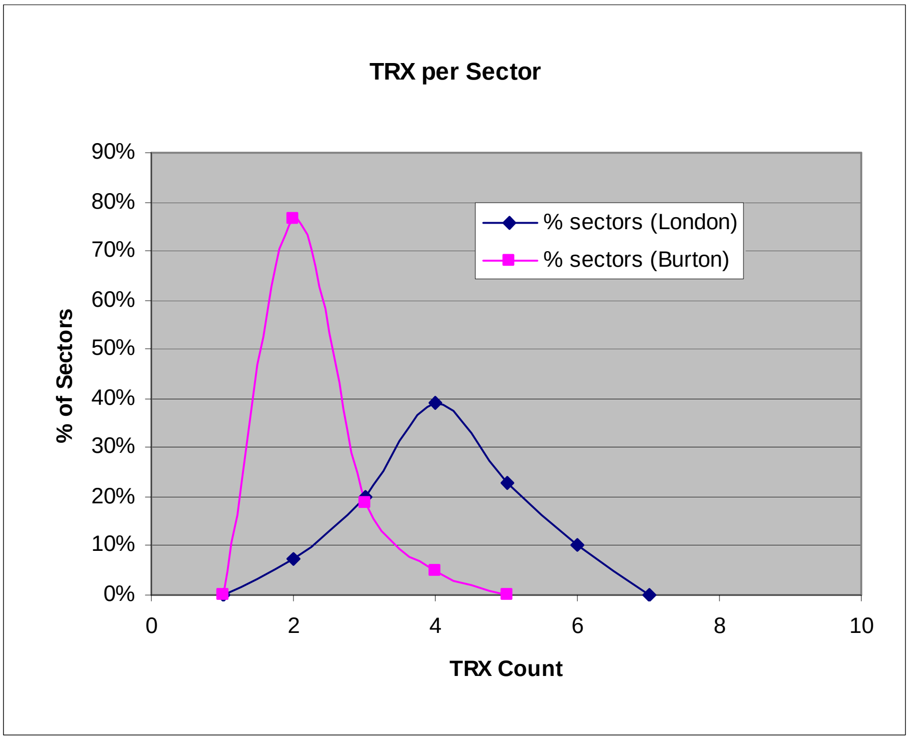

Figure 1: Example Benchmark Data (smoothed)

Of paramount importance in estimating the changes to the number of cell sites is the traffic model. 2G networks do not exhibit the 'cell breathing' phenomenon of 3G networks, and therefore cells are either:

- Coverage-Limited – a reduction in spectrum results in no change to the number of cells required, or
- Capacity-Limited – a reduction in spectrum results in an increase in the number of cells required

In practice both Burton and London baseline scenarios were designed with both capacity and coverage-limited sites, although sites were predominantly coverage-limited in Burton and capacity-limited in London.

In order to limit the impact of 'edge effects' on the simulation results, simulations were run on a larger area (the 'computation zone'), than that for which the results are reported (the 'focus zone').

2.2 Details of the Approach Taken

Red-M adopted the following process:

- A benchmark 2G network was designed using the 'ICS Telecom' planning tool. This network was designed to approximate a 'real' UK 2G network, with coverage probability as specified in Ofcom's technical parameters.
- In order to calculate this coverage, Red-M defined a representative link budget and planning level (see paragraph 3.3 below). Red-M used the COST231-Hata propagation model, and in order to make the planning more realistic the model was enhanced with the use of terrain and clutter data and a diffraction model[2].
- A traffic model was defined (see paragraph 4 below) by associating a traffic density (in Erl/km^2) with each type of clutter available in the clutter database. A separate traffic model was required for London and Burton.
- Results were recorded for the baseline networks. The results included coverage quality (at the respective planning levels), grade of service, site counts and transceiver counts. Graphical representations of coverage, grade of service and best server interference were produced using the planning tool.
- Once the baseline network was simulated, 2 x 2.5 MHz blocks of spectrum were cleared of GSM carriers. The network was then re-planned with additional sites as necessary and optimised to recover approximately the same capacity and coverage that it had before the spectrum was cleared. Within the constraints of the technical parameters given, re-planning/optimisation resulted in new sites rolled out, existing sites split, and the implementation of a new frequency plan[3]. Existing sites from the baseline plan were left in place, although some re-tuning of antenna down-tilt was done to help reduce interference. Further tuning would improve the network quality, but in the interests of time, this activity was kept relatively short.

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[2] 'Deygout 1994' method with coarse integration. Although previous work used the Epstein-Peterson method, this method is not available in ICS Telecom.
[3] ICS Telecom's automatic frequency planning facility was used. In the interests of time channel groups were defined, and the frequency planning algorithm was limited to '2 passes'.

- At the end of the optimisation activity the minimum number of additional sites and sectors to provide the same coverage and capacity as the baseline was recorded. Coverage quality, grade of service, site & transceiver counts and graphical representations were recorded for comparison with the baseline network.
- A summary table was produced for the number of additional macro base sites needed to reproduce the baseline capacity/coverage as a function of the reduced amount of spectrum available.

To rapidly explore the sensitivities of results to assumptions, Red-M also built a 'parameterised model' of the results. The parameterised model is a *simple* spreadsheet that allows sensitivity analysis to be performed on the following parameters:

- amount of spectrum
- number of GSM900 subscribers
- busy hour traffic per subscriber
- frequency re-use pattern
- target Grade of service

The spreadsheet model allows a sensitivity analysis of the results to the input assumptions to be rapidly tested at a *high level* without recourse to simulation and planning exercises which are relatively time-consuming.

3. Propagation Modelling

3.1 Modelling Process

The process used was

- Establish a reliable propagation model using COST231[2]
- Establish GSM link budgets using typical equipment parameters and conforming to the technical parameters stipulated by Ofcom (see Appendix A)

3.2 Propagation Model

Ofcom requested that the planning exercise used a COST231 derived propagation model. The formulation of the model available in ICS telecom is shown in equation (1):

$$\begin{aligned}Pathloss = {} & k_1 + k_2 \times \log(d) + k_3 \times h_{mobile} + k_4 \times \log(h_{mobile}) + k_5 \times \log(h_{eff}) + \\ & k_6 \times \log(h_{eff}) \times \log(d) + k_7 \times (diffraction\_loss) + clutter\_loss\end{aligned} \quad \text{........(1)}$$

Where

- d is the distance between transmitter and receiver in km
- the values k_1 to k_7 available from a previous exercise are shown in Table 1

- h_{mobile} and h_{eff} are the height of the mobile and effective height of the base-station in m respectively
- *diffraction_loss* is a loss term calculated using an approximation to the universal theory of diffraction using a terrain height database
- *clutter_loss* terms available from a previous exercise are shown in Table 2

Table 1: Values for k_1 to k_7

K1	140
K2	40
K3	-2.55
K4	0
K5	-13.82
K6	-6.55
K7	0.60

Table 2: Table of Clutter Loss Values

Clutter Category	*Clutter Loss* (dB)
Urban	0
Suburban	-2
Dense suburban	0
Rural / village centre	-5
Agricultural land	-7.5
Non-agricultural land	-4
Semi-natural vegetation	-2
Water features	-3
Wetlands	-2
Woods/forest	3
Isolated high-rise buildings	8
Road/motorway junctions	-3

For the purposes of the current exercise, a number of changes were imposed by the planning environment

- The Ofcom clutter database has fewer categories than shown in Table 2
- When using COST231 type semi-empirical models, it is desirable to ensure that the model is tuned with the resolution of data that is used for the simulation – 50m in this case.

In order to validate the model in equation (1), data from about 10 sites in mixed Urban and Rural/Village environments was selected at random. The mixture of clutter types and base-station environments related to the Ofcom clutter database is shown in Table 3.

Table 3: Clutter Types for Measurements

Terrain	Clutter Category	No. points
0	Rural	8569
1	Suburban	1998
2	Urban	15139
6	Water	-
8	Woodland	1847

These measurements were compared with the predictions from ICS Telecom[4] using the clutter categories available in the Ofcom database. Clutter types and offsets associated with them (taken from Table 2) are shown in Table 4.

Table 4: Clutter Categories in Ofcom Database

Clutter Category	*Clutter Loss (dB)*
Rural	-5.5
Suburban	-2
Urban	0
Water	-3
Woodland	3

The statistics of the difference between predicted field strength and measured field strength resulting from this comparison are given in Table 5.

Table 5: Measurements and Predictions Compared

Category	Mean Offset(dB)	Offset Std dev.(dB)
Rural	-4.3	10.1
Suburban	-4.9	8.4
Urban	-4.6	8.0
Water	-	-
Woodland	-3.6	8.8

The mean offset of the model in both rural/suburban and urban areas is approximately 4.5dB with a standard deviation of 8dB in Urban and 10dB in Rural areas. The factor of 4.5dB may be a combination of model

[4] Using the 'Deygout 1994' diffraction algorithm with coarse integration.

implementation, clutter database and bias between the measurements used to arrive at the original model and the measurements used for the confirmation exercise here.

It was therefore decided to change only the K1 intercept parameter from the original value of 140 (given in Table 1) down to a value of 135.5 dB. The urban measurements and predictions are shown superimposed in Figure 2, and the resulting model parameters for use in ICS Telecom are shown in Table 6.

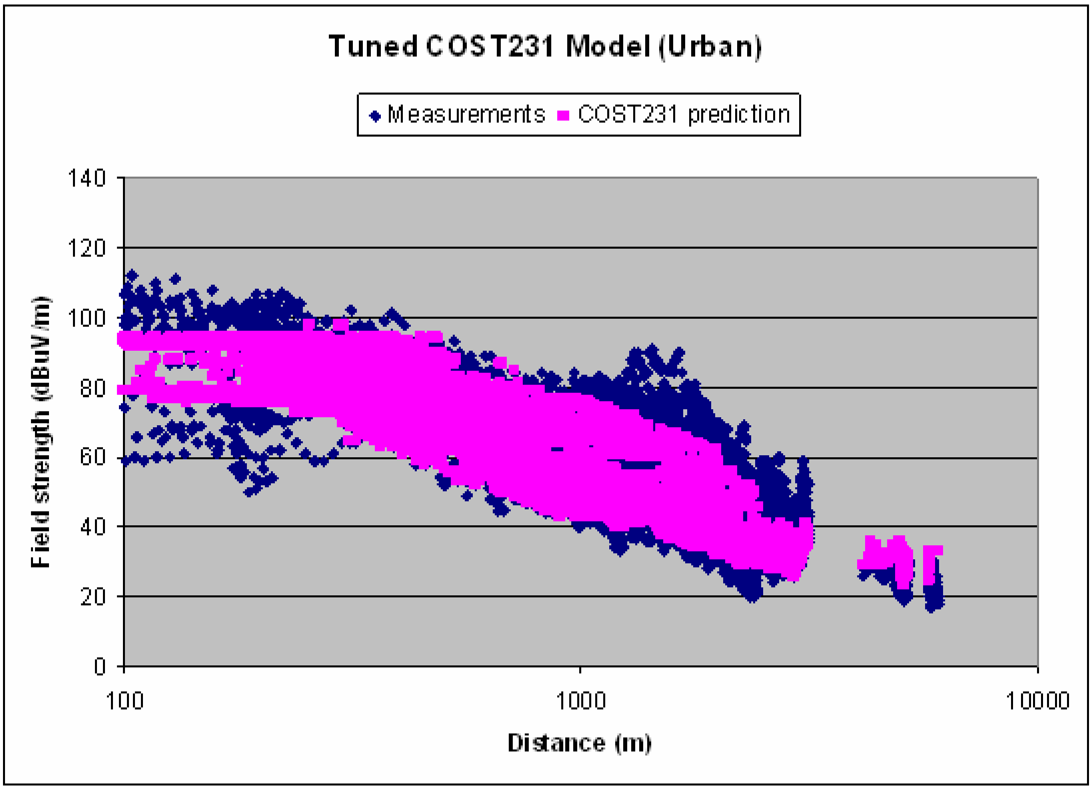

Figure 2: Propagation Model

For rural areas it seems that the model is not well-tuned as the standard deviation is higher than would be acceptable for normal planning purposes. It is important to emphasise that in the time and with the measurements available it was not intended to complete a model tuning exercise. In real planning exercises, the inaccuracy or uncertainty of a planning model can be accounted for by increased margins. Since the planning exercise is intended, as far as possible, to mirror a real exercise, and the standard deviation of rural measurements observed is greater than would normally be expected, we have chosen *not* to reflect the uncertainty in the rural model in increased planning margins in this case. Planning levels and margins are discussed in paragraph 3.3 below.

Despite not having increased margins to cope with the increased uncertainty, the benchmark design required slightly more sites in Burton than would have been expected from examination of reference data. This is, in part, ascribed to Ofcom's coverage quality requirements and the rural planning level chosen by Red-M (seen Appendix A below). In view of this observation we did not worry if the coverage area did not exceed the stated 90% at the rural planning level, as long as it was close, preferring this compromise to adding further sites or making one or two sites abnormally high to give the impression of additional coverage.

Table 6: Revised COST231 model parameters used in ICS Telecom

Parameter	Urban
K1	135.5
K2	40
K3	-2.55
K4	0
K5	-13.82
K6	-6.55
K7	0.60

3.3 Planning Levels

The following GSM Planning levels were chosen to take into account the technical parameters specified by Ofcom and recorded in Appendix A.

Planning Level Summary		
		Level / dBm
GSM 900	Rural	-84
	Urban	-75

Figure 3: Planning Level Summary

The associated link budgets are given in Appendix B.

4. Traffic Modelling

4.1 Modelling Process

The approach adopted for traffic modelling was to associate a traffic density (in Erl/km^2) with each type of clutter. It was originally hoped to retain a single traffic model for both simulation areas, but imposing this constraint led to unrepresentative transceiver and site counts, generally underestimating the number of sites needed in London and overestimating the number needed in Burton on Trent.

To produce representative results, different values of traffic density are required for the same clutter type in each simulation area. Five main clutter types were used, corresponding to the clutter types available in the Ofcom database. They are (with colours in the clutter map shown in brackets) – Rural (white), Suburban (dark blue), Urban (light blue), Water (green) and Woodland (orange).

4.2 Traffic Model

4.2.1 London

Figure 4 shows the clutter map for the London focus zone. Table 7 provides statistics of the London Area by clutter type and gives the derived traffic density results.

Figure 4: London Clutter Map showing areas classed as Rural (white), Urban (light blue), Water (green) and Woodland (orange)

Table 7: London Area by Clutter Type and Derived Traffic Density

Clutter Code	Clutter Type	Area, km^2	%	Derived Erl/km2 (900MHz)
0	Rural	11.0	11%	3.9
1	Suburban	0	0%	-
2	Urban	85.4	86%	37.5
6	Water	2.14	2%	0.0037
8	Woodland	0.45	0%	2.3

As there is only one 'Urban' clutter type, yet the computation zone extends from near the M25 to close to central London, the resulting traffic model is likely to under-estimate the levels of offered traffic close to central London whilst over-estimating the levels towards the M25. This artefact does have some impact on the baseline designs, by reducing the number of sites required near central London relative to those required further out. The impact of this assumption was minimised during the simulation exercise by

- Ensuring that the computation zone didn't extend right into Central London
- Biasing the design to have more sites/greater coverage towards the more southerly parts of the focus zone.

4.2.2 Burton

Figure 5 shows the clutter map for the Burton computation zone. Table 8 provides statistics of the Burton area by clutter type and gives the derived traffic density results.

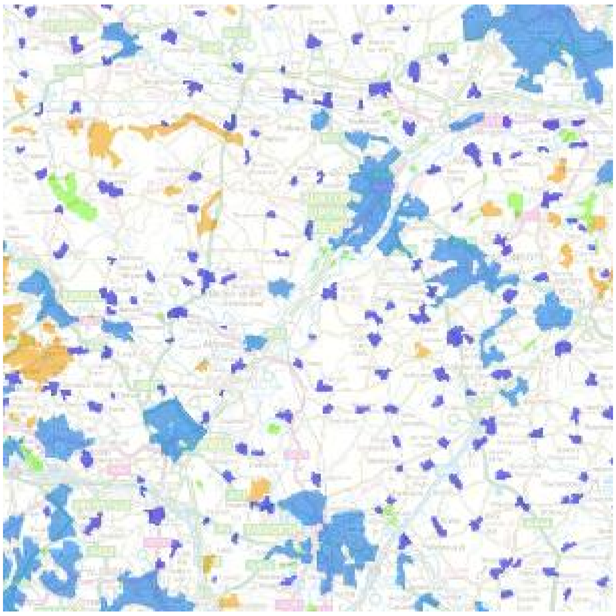

Figure 5: Burton Clutter Map showing areas classed as Rural (white), Suburban (dark blue), Urban (light blue), Water (green) and Woodland (orange).

Table 8: Burton Area by Clutter Type and Derived Traffic Density

Clutter Code	Clutter Type	Area, km^2	%	Derived 900MHz Erl/km2
0	Rural	670	85%	0.24
1	Suburban	39.1	5%	2.4
2	Urban	58.9	7%	8.5
6	Water	3.48	1%	0.0028
8	Woodland	13.4	2%	0.0028

5. Results for Baseline Scenario

5.1 Burton

The following figures give coverage quality, grade of service and interference plots for the Burton baseline scenario.

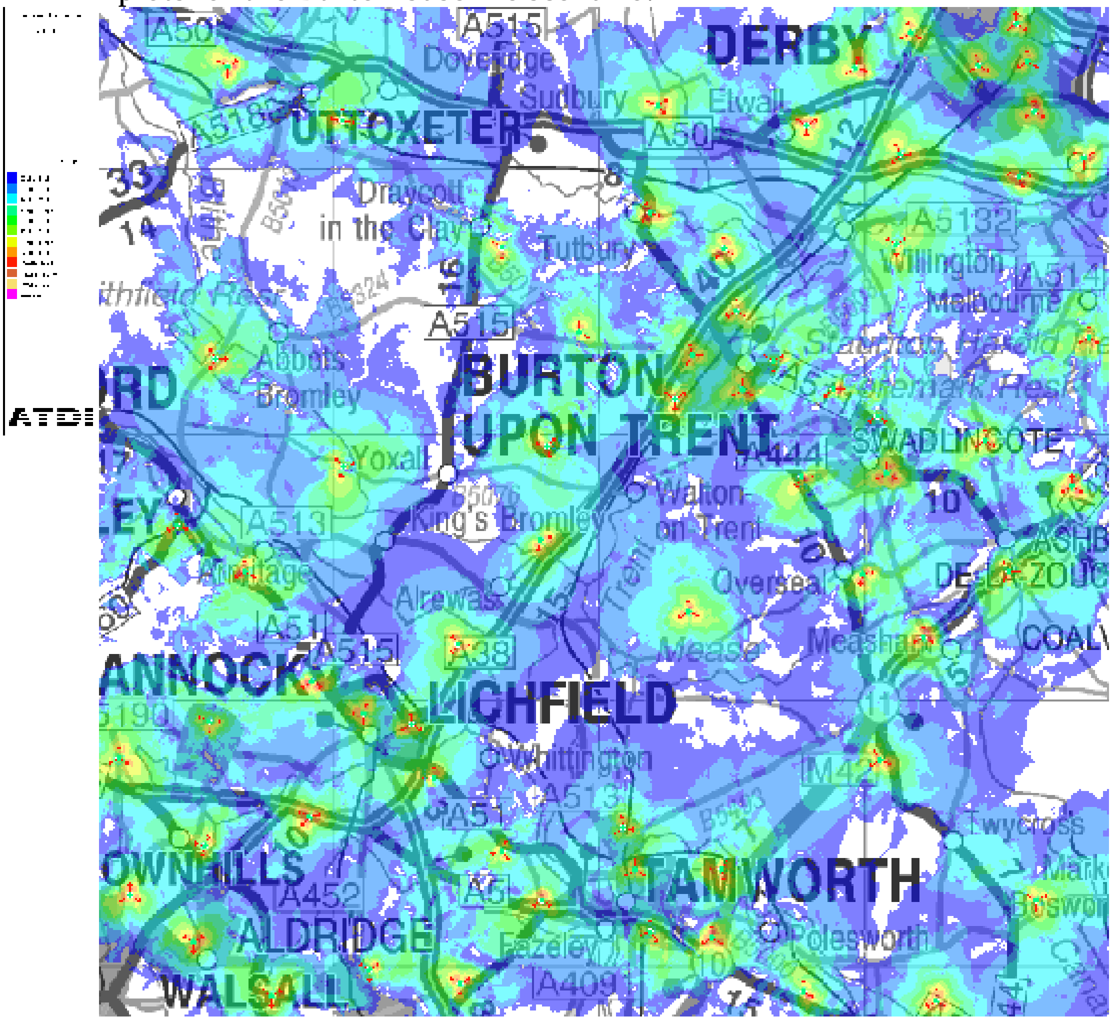

Figure 6: Base-Line Coverage for Burton (Rural Planning Level – Dark Blue)

Table 9: Baseline Coverage (Burton)

Clutter Code	Burton Clutter Types	Covered Area, km^2	% Coverage
0	Rural	590	88
1	Suburban	31	79
2	Urban	47	79 (at urban planning level)
6	Water	3.5	70
8	Woodland	3.6	27

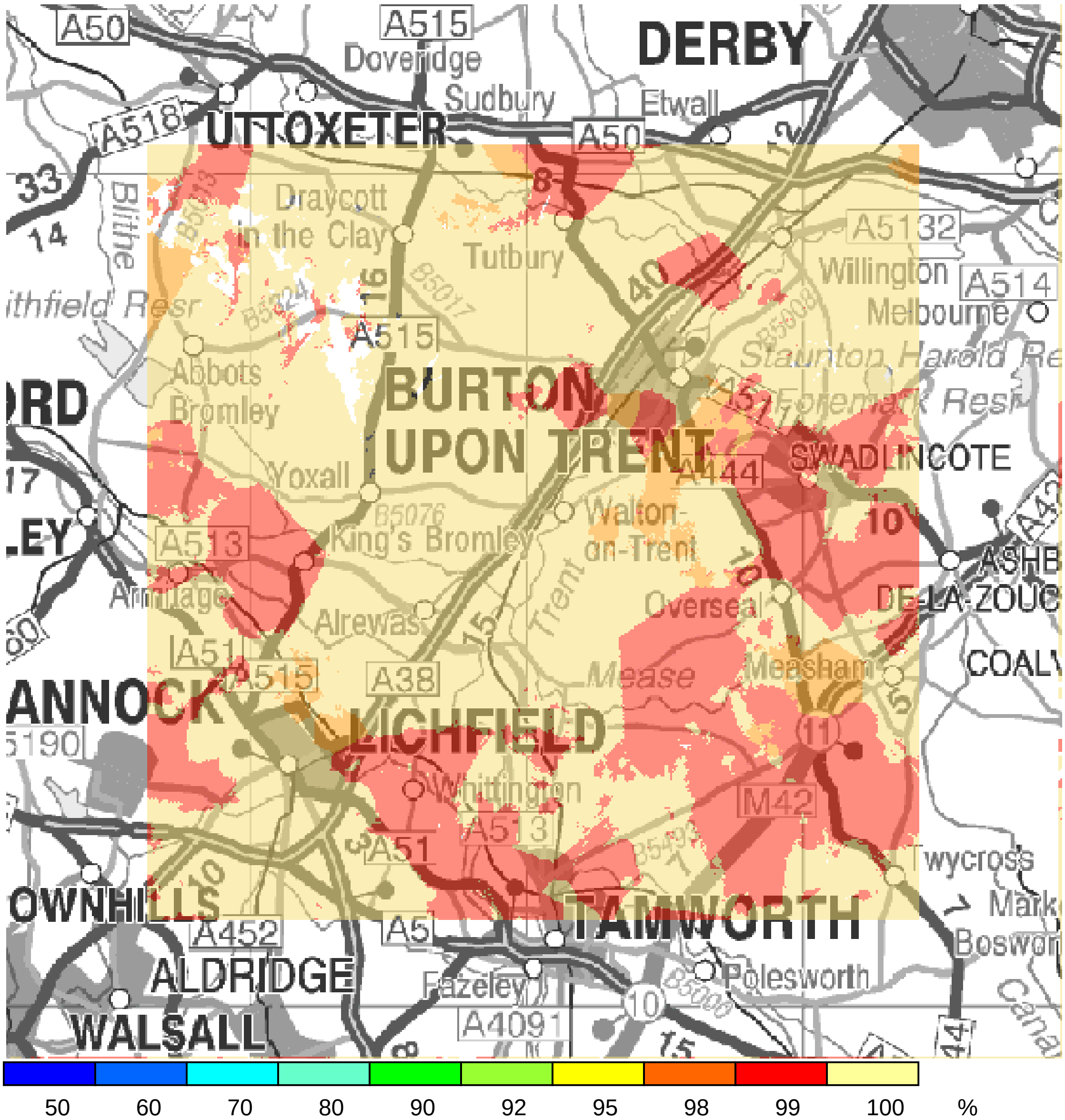

Figure 7: Baseline Grade of Service for Burton.

Figure 8: Baseline Interference for Burton (Pink = Best Server Interference. Interference to <0.5% of the area[5])

[5] As there very little interference, it is hard to see the isolated pink pixels, though the do exist in this diagram. See e.g. above the 'O' in Burton and superimposed on the 'n' in Walton-on-Trent

5.2 London

The following figures give coverage quality, grade of service and interference plots for the London baseline scenario.

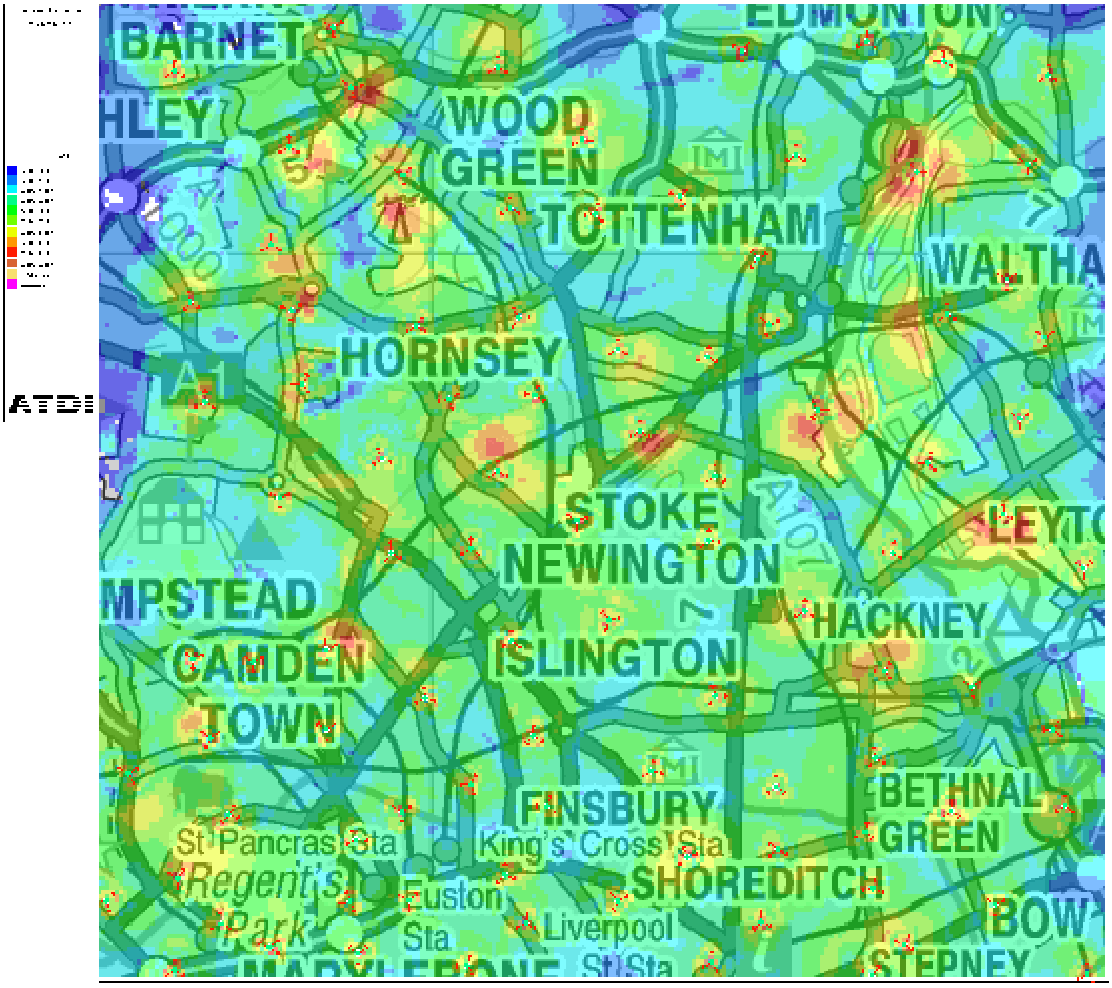

Figure 9: Base-Line Coverage for London (Urban Planning Level – Light Blue)

Table 10: Baseline Coverage (London)

Clutter Code	Burton Clutter Types	Covered Area, km^2	% Coverage
0	Rural	11	99.6
1	Suburban	-	-
2	Urban	85	99.4
6	Water	2.1	99.5
8	Woodland	0.43	96.6

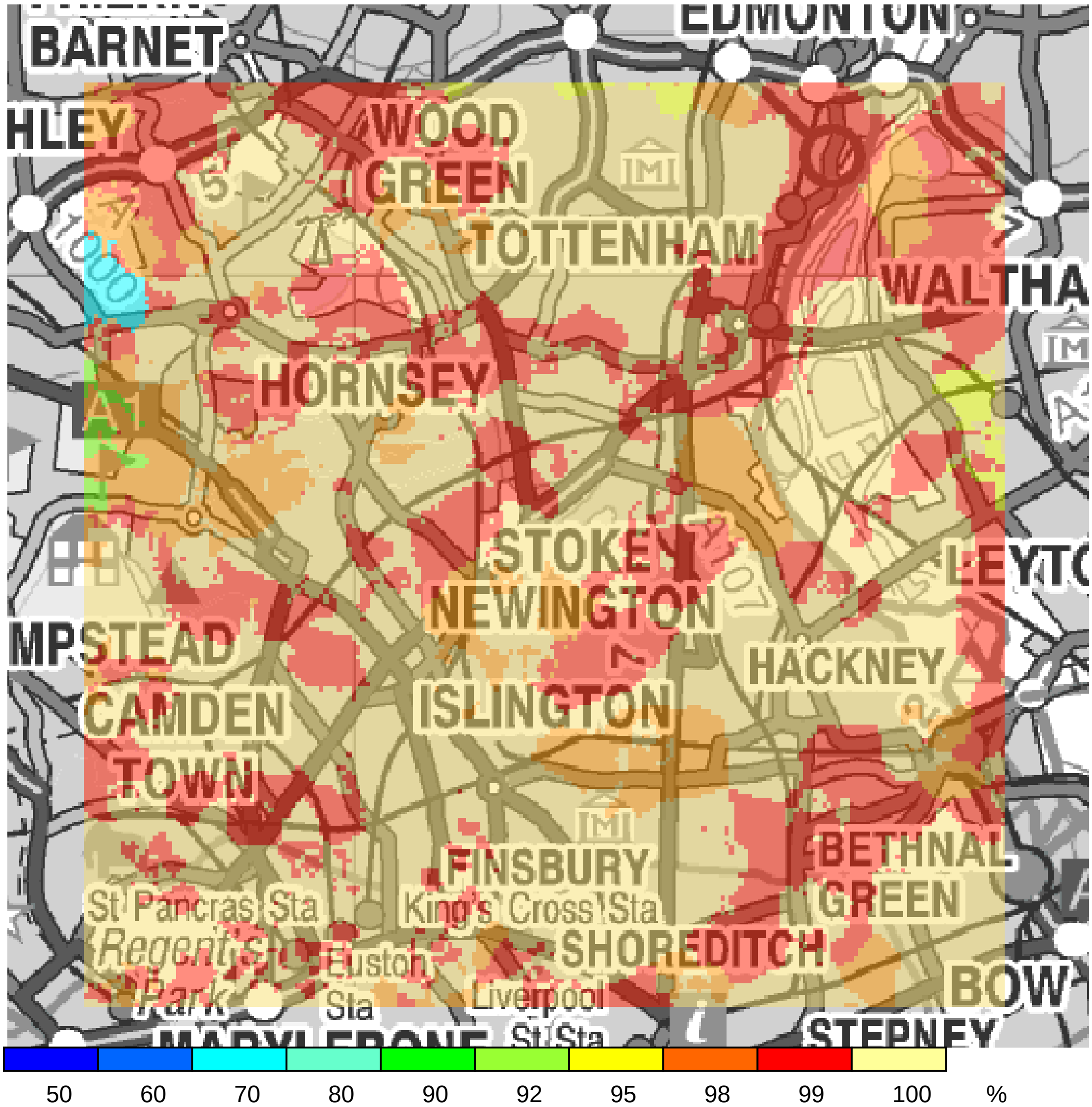

Figure 10: Baseline Grade of Service for London

The grade of service (GoS) drops slightly in hilly areas north-west of Hampstead / Hornsey.

Figure 11: Baseline Interference for London (Pink = Best Server Interference.)

The interference area is 3.5% of the focus zone. This could be reduced by fine-tuning powers and down-tilts. This was not done for the purposes of the simulation exercise, in the interests of time and as it was felt that this level o interference is acceptable for planning purposes.

5.3 Re-Planning with Reduced Spectrum

The graphs and plots for the plans with reduced spectrum are attached in Appendix D. The site and transceiver counts for these networks are summarised in Table 11. This table has been produced in Excel from the actual result files produced by ICS Telecom.

The results show that, as expected, the increase in the number of sites required is lower in the predominantly rural scenario (Burton), since in this scenario the cells are predominantly coverage-limited. Indications are that only 5 (16%) additional sites are required to cope with the loss of 10MHz of spectrum in Burton whereas in London the loss of 10MHz implies a complete redesign of the network and an additional 161 (230%) sites.

In the London scenario, the cells are predominantly capacity rather than coverage limited and any reduction in spectrum requires additional sites to be added to achieve the required capacity. The urban scenario is also most sensitive to the assumptions of offered traffic, grade of service and frequency re-use, as can be illustrated by observing the change in the number of sites required as these parameters are changed in the spreadsheet as discussed in paragraph 5.4 below.

Table 11: Results of Planning Simulation Exercise in the Focus Zone

Simulation Results	Site Count Summary		
	Sites	Transceivers	Sites %
Burton Baseline	32	197	100%
Burton -2.5MHz	32	200	100%
Burton - 5MHz	32	205	100%
Burton - 7.5MHz	33	211	103%
Burton - 10MHz	37	216	116%
London Baseline	70	742	100%
London - 2.5MHz	83	791	119%
London - 5MHz	98	872	140%
London - 7.5MHz	156	1016	223%
London - 10MHz	231	1172	330%

5.4 Parameterised Spreadsheet

To rapidly explore the sensitivities of results to assumptions at a higher level, Red-M also built a 'parameterised model' of the results. The parameterised model is a *simple* spreadsheet that allows sensitivity analysis to be performed on the following parameters:

- amount of spectrum
- number of GSM900 subscribers
- busy hour traffic per subscriber
- frequency re-use pattern
- target grade of service

The spreadsheet model allows a sensitivity analysis of the results to the input assumptions to be rapidly tested at a *high level* without recourse to simulation and planning exercises which are relatively time consuming.

The spreadsheet also contains all the details of the inputs and assumptions for

- the traffic models, including the derivation of the Erl/km^2 values for clutter types based on based on population counts
- the Urban and Rural Planning levels

- the definition of the channel groups used for automatic frequency assignment in both London and Burton.

The spreadsheet contains the results for the planning simulation exercises through .csv export of sites in the focus zone. It does not contain all the sites in the computation zone, though these are accessible by opening the simulation projects that have been defined within the ICS Telecom tool. A copy of all of these files has been provided on a CD.

The model for sensitivity analysis has been built up using knowledge of the coverage and capacity of cells in Burton and London. It uses a simplified model, where a cell is defined as occupying one of three clutter types (Burton: Rural, Suburban or Urban; London: Urban, Rural or Woodland), allowing the traffic offered to this cell to be calculated. Knowing the number of frequency groups needed for acceptable C/I (from the planning simulation), and with an implementation of the ErlangB formula, the spreadsheet estimates the number of additional sectors needed to serve the offered traffic at the desired grade of service. An additional site is counted as three additional sectors. The results are aligned with the simulation results for the same inputs.

The simplifications used to produce the spreadsheet do mean that it will not produce accurate results when the inputs are moved a long way from the baseline assumptions. For example, if the offered traffic is reduced to zero, the spreadsheet should produce the minimum number of sites necessary to cover the area in under coverage limited scenarios. The result aligns to the nearest site for Burton (which is coverage limited), but overestimates the number of sites required to cover London by approximately 25. This is because all of the London simulations are capacity limited and the extrapolation is done from this baseline.

The spreadsheet also attempts to calculate the national impact of removal of spectrum in terms of number of sites, given an estimate of total site count and the *site count weighted* percentage of the UK that resembles Burton and London. The default estimate provided by Red-M for the site count weighted percentage is 60% Rural, 40% Urban, derived from examining baseline data within MapInfo.

If more than a cursory view of the impact of changing assumptions on the site counts is required, then Red-M recommends further more detailed study.

6. Summary and Conclusions

A simulation exercise has been performed to estimate the impact of reduced spectrum on existing GSM900 networks on the assumption that the traffic handling capacity of the network needs to be maintained despite the reduced spectrum. This study focussed on two zones chosen to be representative of urban and predominantly rural areas. As expected, the impact of the reduction in spectrum is greater in the urban areas.

7. References

[1] ETSI EN 300 910 V8.5.1 (2000-11) Digital cellular telecommunications system (Phase 2+) Radio transmission and reception (GSM 05.05 version 8.5.1 Release 1999)

[2] Digital Mobile Radio – Towards Future Generation Systems Cost 231 Final Report, Chapter 4.4 – Propagation Models for Macro-Cells, Thomas Kurner, E-Plus Mobilfunk GmbH, Germany

Appendix A Ofcom Technical Parameters

A.1 North London

The Following technical parameters were supplied by Ofcom for area 1 (North London):

- Only Macrocell sites need to be considered.
- 15 GSM carriers need to be reserved for micro and pico-cell layers and hence need to be subtracted from the spectrum available to the Macro layer as used in the simulations.
- All Cell sites use base band frequency hopping.
- Only voice capacity need be considered.
- Antennas are assumed to have variable electrical down-tilt.
- Maximum licensed transmit EIRP power 32dBW per carrier.
- The antenna bore-sight gain should be 16.0 dBi at 900 MHz and the horizontal beam-width approximately 65°.
- The outdoor propagation model used to determine the coverage area from each site should be a COST231-Hata model .
- 90% coverage probability at the cell edge
- 2% blocking probability
- Spectrum is assumed to be contiguous.
- National Grid coordinates for the zone

Focus zone (10km x 10km)	x = 527050 – 537050 y = 182100 – 192100
Computation zone (11.6km x 11.2km)	x = 526250 – 537850 y = 181700 - 192900

A.2 Burton

The Following technical parameters were supplied by Ofcom for area 2 (Burton Upon Trent):

- Only Macrocell sites need to be considered.
- All the available spectrum channels can be used for the simulations.
- All Cell sites use base band frequency hopping.
- Only voice capacity need to be considered.
- Antennas are assumed to have variable electrical down-tilt.
- Maximum licensed transmit EIRP power 32dBW per carrier.
- The antenna bore-sight gain should be 16.0dBi at 900 MHz and the horizontal beam-width approximately 65°.
- The outdoor propagation model used to determine the coverage area from each site should be a COST231-Hata model .
- 90% coverage probability at the cell edge
- 2% blocking probability
- Spectrum is assumed to be contiguous.

- National Grid coordinates for the zone

Focus zone (28km x 28km)	x = 406250 – 434250
	y = 303100 – 331100
Computation zone (38km x 38km)	x = 401250 – 439250
	y = 298100 – 336100

Appendix B Planning Level Link Budgets

B.1 Urban Planning Level

Transmitter Parameters		**Downlink**	**Uplink**		
		BS	**MS**	**Units**	
Transmitter RF Peak Output Power	Ptx	20.0	2.0	W	max power (GSM 900 BTS Class 5 | GSM 05.05 Mobile Power Class 4)
as above in dBm	PdB	43.0	33.0	dBm	=10*log Ptx
Combiner + Cable + Connector Losses	Lcc	3.0	0.0	dB	Red-M Estimate
Tx Antenna Gain	Gtx	16.0	0.0	dBi	Red-M Estimate
Body Loss	BL		1.5	dB	1.5dB head (phone) 4.5dB waist (laptop) - ITU-R P.1238-3
Equivalent Isotropic Radiated Power	**EIRP**	**56.0**	**31.5**	**dBm**	**= Pctx + Gtx - BL**
Receiver Parameters		**MS**	**BS**	**Units**	
Receiver Sensitivity	Rx_c	-104.0	-108.0	dBm	2dB & 4dB better than GSM 5.05 reflects equipment development
Combiner + Cable + Connector Losses	Lcc	0.0	3.0	dB	Red-M Estimate
Rx Antenna Gain	Grx	0.0	16.0	dBi	Red-M Estimate
Diversity Gain	DG	0.0	3.0	dB	3dB = 2-branch MRC in AWGN environment
Body Loss	BL	1.5		dB	1.5dB head (phone) 5.5dB waist (laptop) - ITU-R P.1238-3
Required Isotropic Power	**Prx**	**-102.5**	**-124.0**	**dBm**	=Rx+Lcc-Grx-DG+BL
Maximum Allowed Path Loss	**PLmax**	**158.5**	**155.5**	**dB**	**=Tx EIRP - Prx**
Link Loss Calculation		**D/L**	**U/L**	**Units**	
Interference Degradation Margin	IDM	3.0	3.0	dB	Estimate ('Cellular Network Planning…' A.R. Mishra)
Fast Fade Margin	FFM	0.0	0.0	dB	Not Required for Rural Environment (TU50)
Building Penetration Loss	BPL	10.0	10.0	dB	Vehicle penetration loss
BPL Standard Deviation	SDbp	6.0	6.0	dB	Red-M Estimate
Location Variabilty	LV	7.0	7.0	dB	Antennas & Propagation..., S. Saunders
Total Variability	Vt	9.2	9.2	dB	=Sqrt(a^2+b^2….)
Coverage Target	Cov	90	90	%	Ofcom Technical Parameter
Shadowing Fade Margin	SFM	11.8	11.8	dB	=NORMINV(percentile/100,0,LV)
Total Planning Uncertainty	U	24.8	24.8	dB	=IDM + FFM + BPL + SFM
Allowable Propagation Loss		**133.7**	**130.7**	**dBm**	**=Plmax - U**
Planning Level	**Lev**	**-74.7**		**dBm**	**=EIRP - PL**

B.2 Rural Planning Level

Transmitter Parameters		**Downlink**	**Uplink**		Notes
		BS	**MS**	**Units**	
Transmitter RF Peak Output Power	Ptx	20.0	2.0	W	max power (GSM 900 BTS Class 5 | GSM 05.05 Mobile Power Class 4)
as above in dBm	PdB	43.0	33.0	dBm	=10*log Ptx
Combiner + Cable + Connector Losses	Lcc	3.0	0.0	dB	Red-M Estimate
Tx Antenna Gain	Gtx	16.0	0.0	dBi	Red-M Estimate
Body Loss	BL		1.5	dB	1.5dB head (phone) 4.5dB waist (laptop) - ITU-R P.1238-3
Equivalent Isotropic Radiated Power	**EIRP**	**56.0**	**31.5**	**dBm**	**= Pctx + Gtx - BL**
Receiver Parameters		**MS**	**BS**	**Units**	
Receiver Sensitivity	Rx_c	-104.0	-108.0	dBm	2dB & 4dB better than GSM 5.05 reflects equipment development
Combiner + Cable + Connector Losses	Lcc	0.0	3.0	dB	Red-M Estimate
Rx Antenna Gain	Grx	0.0	16.0	dBi	Red-M Estimate
Diversity Gain	DG	0.0	3.0	dB	3dB = 2-branch MRC in AWGN environment
Body Loss	BL	1.5		dB	1.5dB head (phone) 5.5dB waist (laptop) - ITU-R P.1238-3
Required Isotropic Power	**Prx**	**-102.5**	**-124.0**	**dBm**	=Rx+Lcc-Grx-DG+BL
Maximum Allowed Path Loss	**PLmax**	**158.5**	**155.5**	**dB**	**=Tx EIRP - Prx**
Link Loss Calculation		**D/L**	**U/L**	**Units**	
Interference Degradation Margin	IDM	3.0	3.0	dB	Estimate ('Cellular Network Planning…' A.R. Mishra)
Fast Fade Margin	FFM	0.0	0.0	dB	Not Required for Rural Environment (TU50)
Vehicle Penetration Loss	BPL	3.0	3.0	dB	Vehicle penetration loss
BPL Standard Deviation	SDbp	1.5	1.5	dB	Red-M Estimate
Location Variabilty	LV	7.0	7.0	dB	Antennas & Propagation..., S. Saunders
Total Variability	Vt	7.2	7.2	dB	=Sqrt(a^2+b^2….)
Coverage Target	Cov	90	90	%	Ofcom Technical Parameter
Shadowing Fade Margin	SFM	9.2	9.2	dB	=NORMINV(percentile/100,0,LV)
Total Planning Uncertainty	U	15.2	15.2	dB	=IDM + FFM + BPL + SFM
Allowable Propagation Loss		**143.3**	**140.3**	**dBm**	**=Plmax - U**
Planning Level	**Lev**	**-84.3**		**dBm**	**=EIRP - PL**

Appendix C Relevant Radio Planning Assumptions and their Models

C.1 Traffic Channels

A GSM system is characterised by carriers each with eight timeslots. For this planning exercise we have assumed that one timeslot on the BCCH channel is used for signalling and the remaining timeslots are used for speech. We have not assumed the use of half-rate or AMR modes which allow more than one call per timeslot.

The resulting number of available speech channels is shown in Table 12.

Table 12: Speech Channels

Number of TRXs	Number of Speech Channels
1	7
2	15
3	23
4	31
5	39
6	47
7	55
n	n*8-1

In practice a signalling dimensioning exercise is necessary to determine the number of signalling timeslots required, taking into account and balancing such events as RACH bursts, paging requests and location updates. In the current exercise this level of detail would not enhance the accuracy of the result which would remain dominated by the accuracy of the traffic models developed.

C.2 Reference Interference Limits

Reference interference limits have been taken from reference [1]. The are

- for cochannel interference : C/Ic = 9 dB
- for adjacent (200 kHz) interference : C/Ia1 = -9 dB
- for adjacent (400 kHz) interference : C/Ia2 = -41 dB
- for adjacent (600 kHz) interference : C/Ia3 = -49 dB

C.3 DTX and Power Control

C/I improvements from the use of DTX or Power control were not assumed on either the uplink or the downlink.

Appendix D Figures for Re-Planning Exercise

D.1 Burton

D.1.1 Removal of 2.5MHz Spectrum

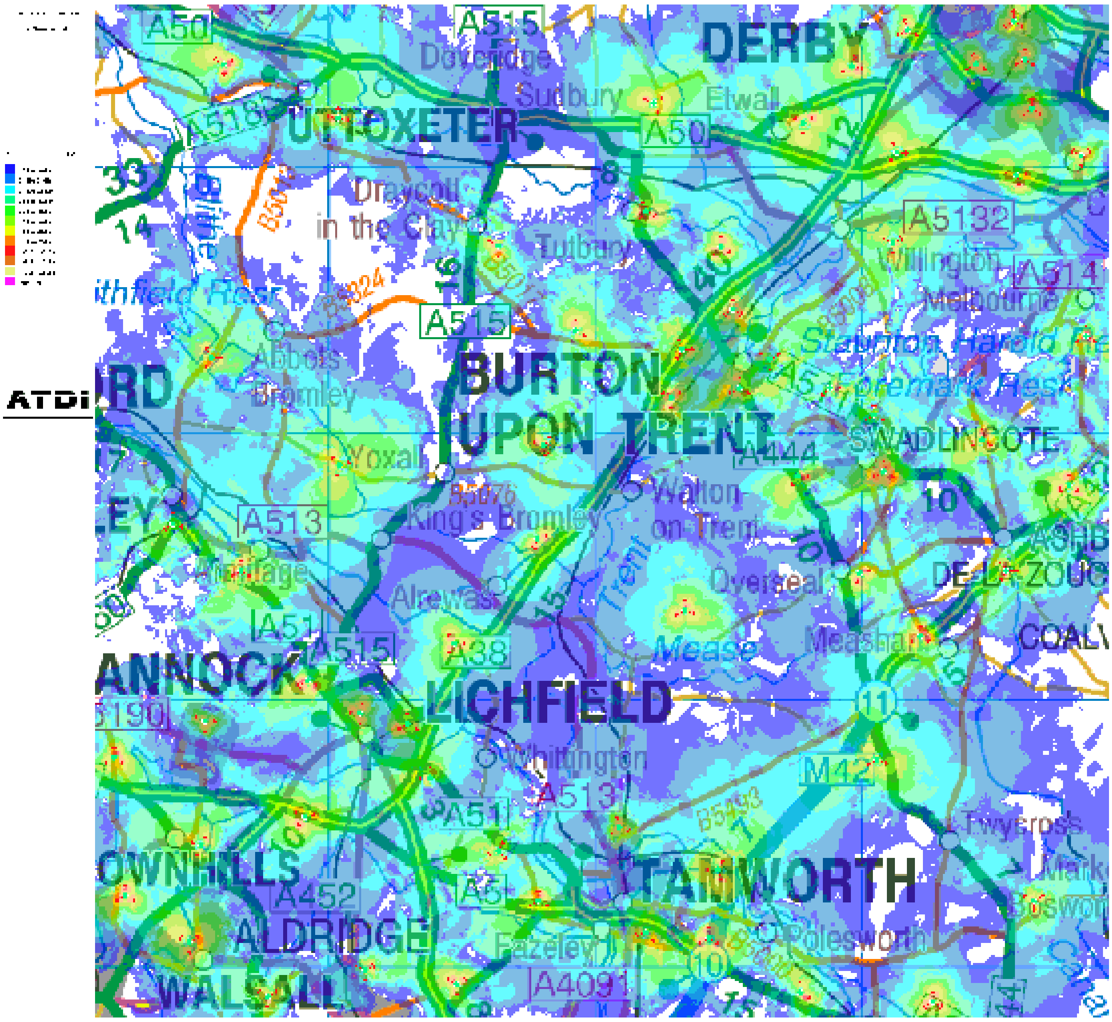

Figure 12: Coverage for Burton with 2.5MHz Spectrum Removed (Rural Planning Level – Dark Blue)

Table 13: Coverage (Burton -2.5MHz)

Clutter Code	Burton Clutter Types	Covered Area, km^2	% Coverage
0	Rural	613.2525	91.5
1	Suburban	33.295	85.2
2	Urban	48.0	81.5 (to urban planning level)
6	Water	3.85	77.3
8	Woodland	4.1	30.6

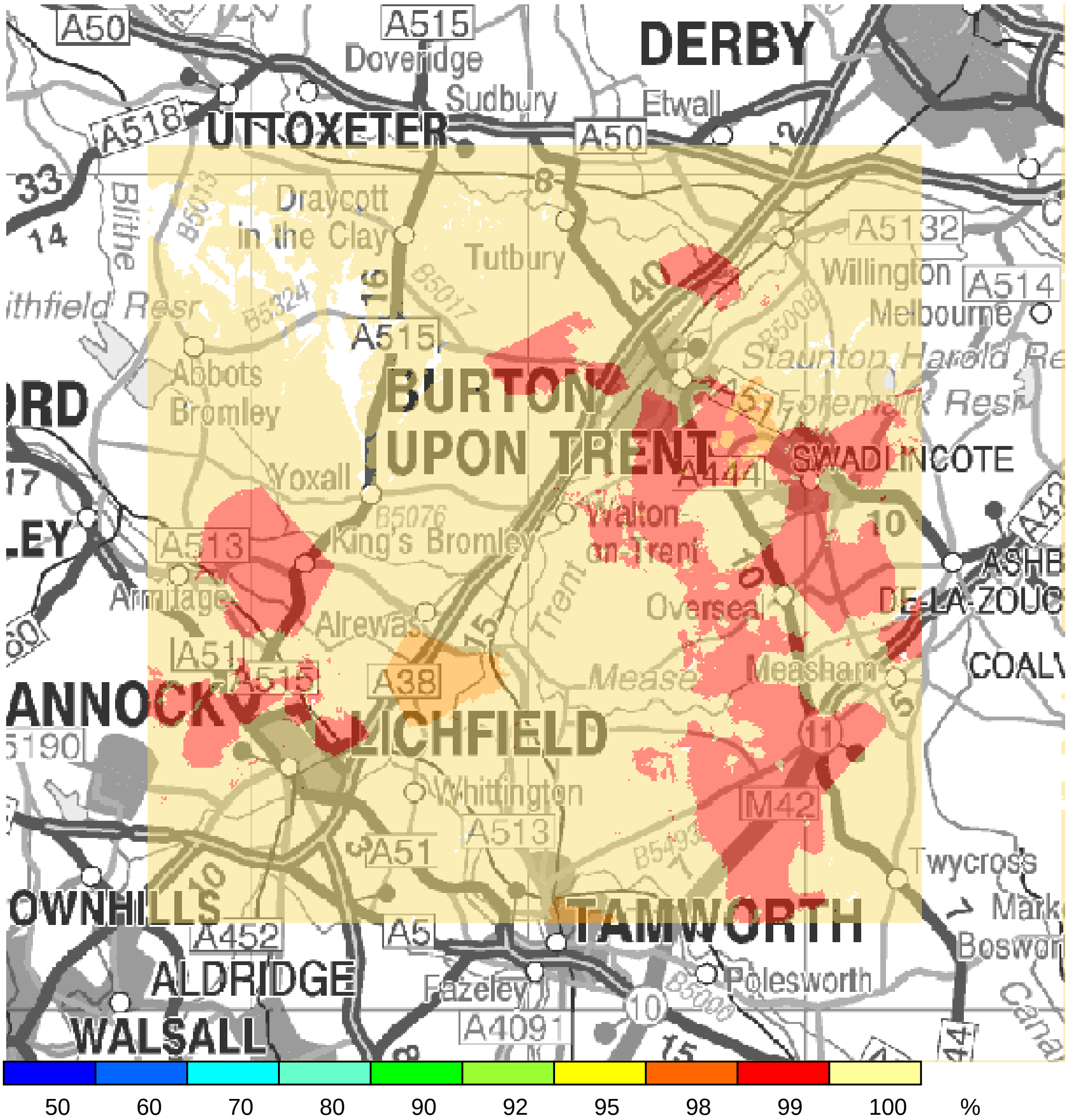

Figure 13: Grade of Service for Burton with 2.5MHz Spectrum Removed

Figure 14: Interference for Burton with 2.5MHz Spectrum Removed (Pink = Best Server Interference)

The interference area is less than 1% of the focus zone.

D.1.2 Removal of 5MHz Spectrum

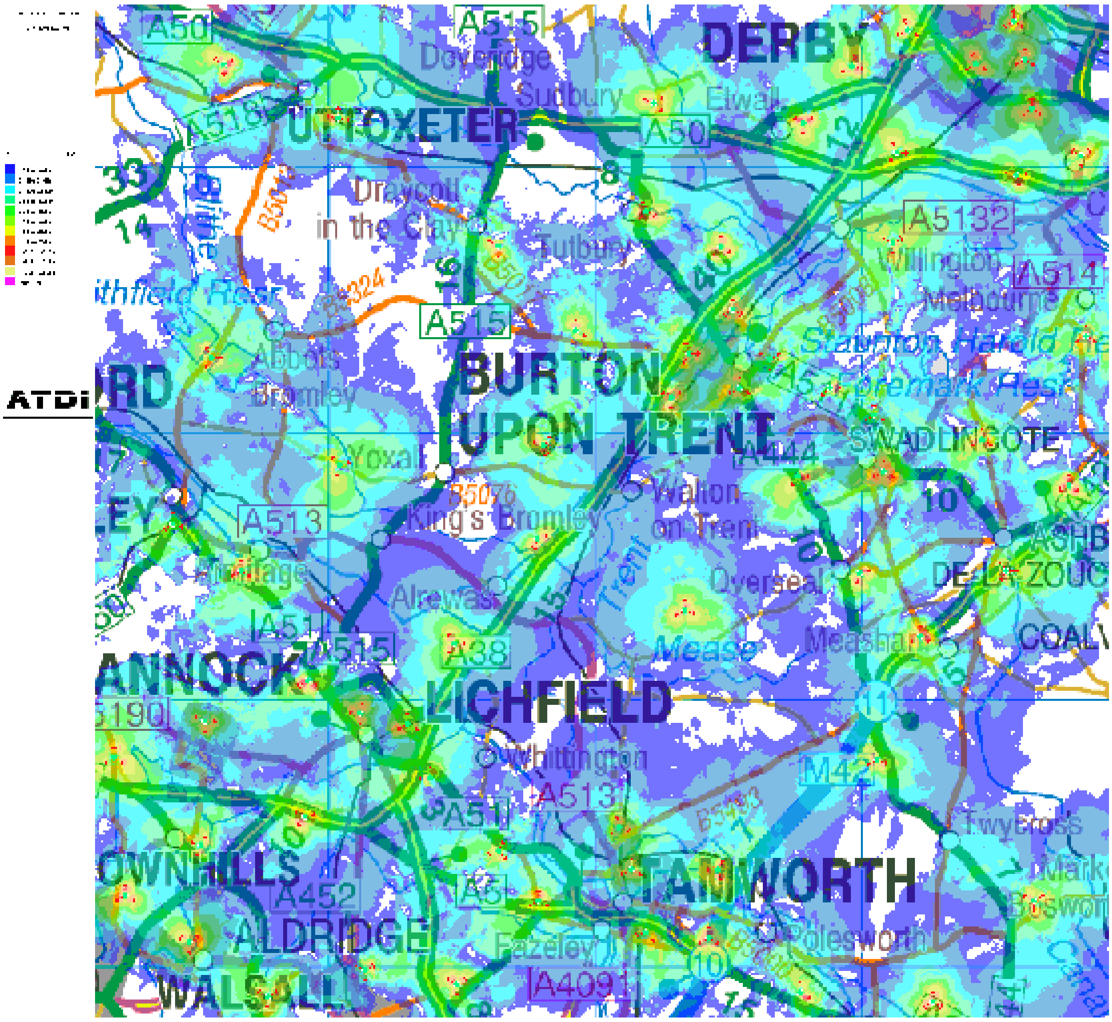

Figure 15: Coverage for Burton with 5MHz Spectrum Removed (Rural Planning Level – Dark Blue)

Table 14: Coverage (Burton -5MHz)

Clutter Code	Burton Clutter Types	Covered Area, km^2	% Coverage
0	Rural	585.5525	87.4
1	Suburban	30.73	78.6
2	Urban	48.0	81.5 (to urban planning level)
6	Water	3.48	69.8
8	Woodland	3.6275	27.1

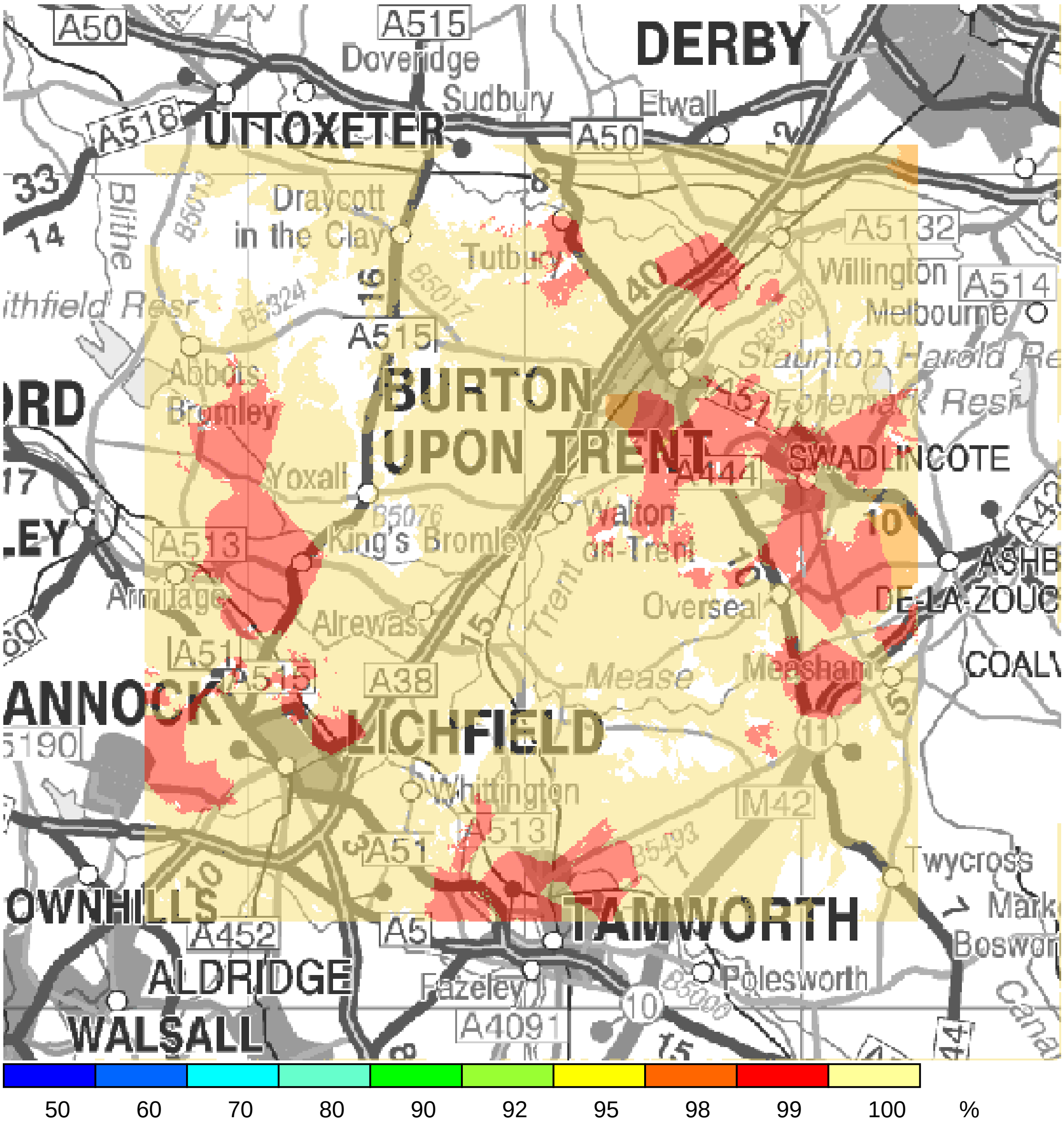

Figure 16: Grade of Service for Burton with 5MHz Spectrum Removed

Figure 17: Interference for Burton with 5MHz Spectrum Removed (Pink = Best Server Interference)

The interference area is approximately 1% of the focus zone.

D.1.3 Removal of 7.5MHz Spectrum

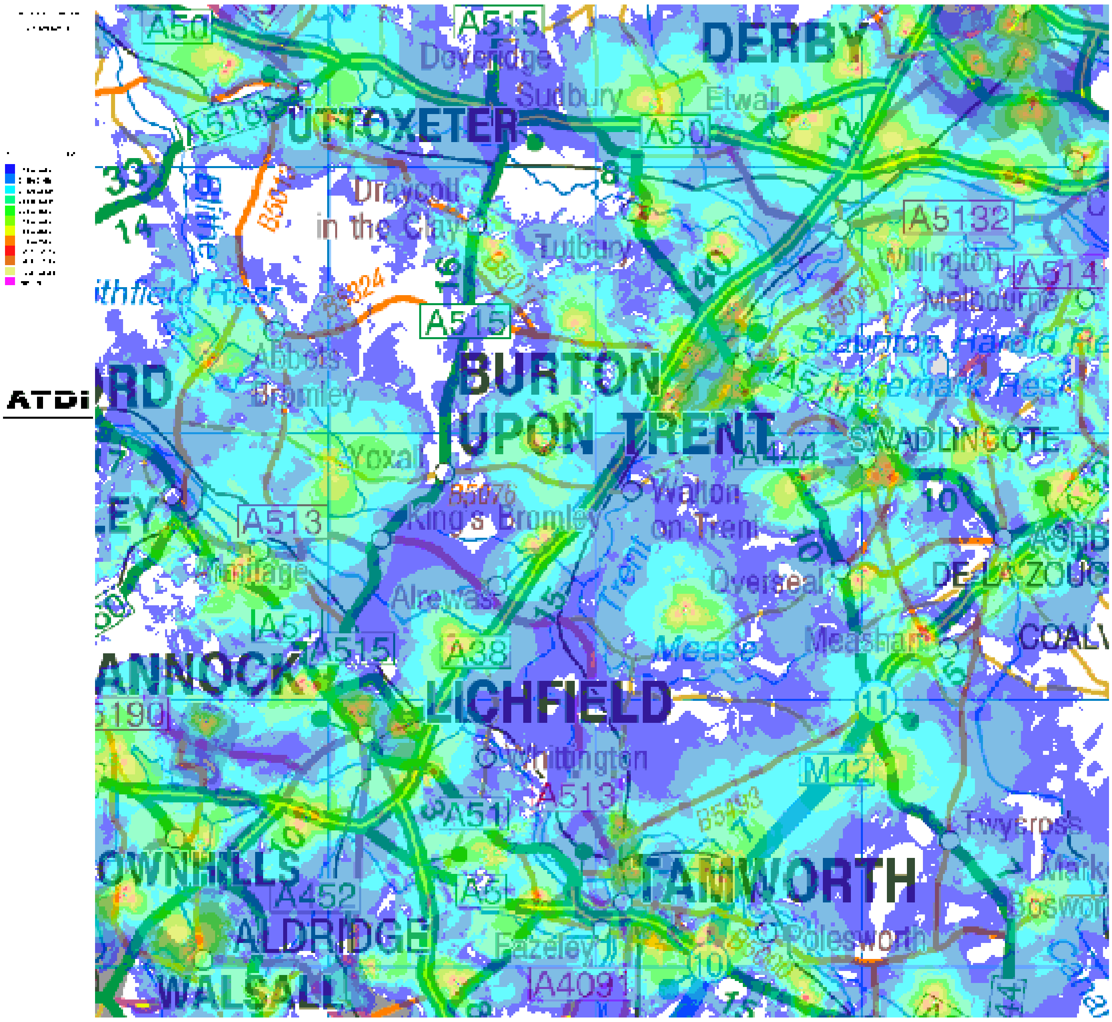

Figure 18: Coverage for Burton with 7.5MHz Spectrum Removed (Rural Planning Level – Dark Blue)

Table 15: Coverage (Burton -2.5MHz)

Clutter Code	Burton Clutter Types	Covered Area, km^2	% Coverage
0	Rural	606.9525	90.5
1	Suburban	32.675	83.6
2	Urban	47.7075	81.0 (to urban planning level)
6	Water	3.5075	70.4
8	Woodland	3.875	28.9

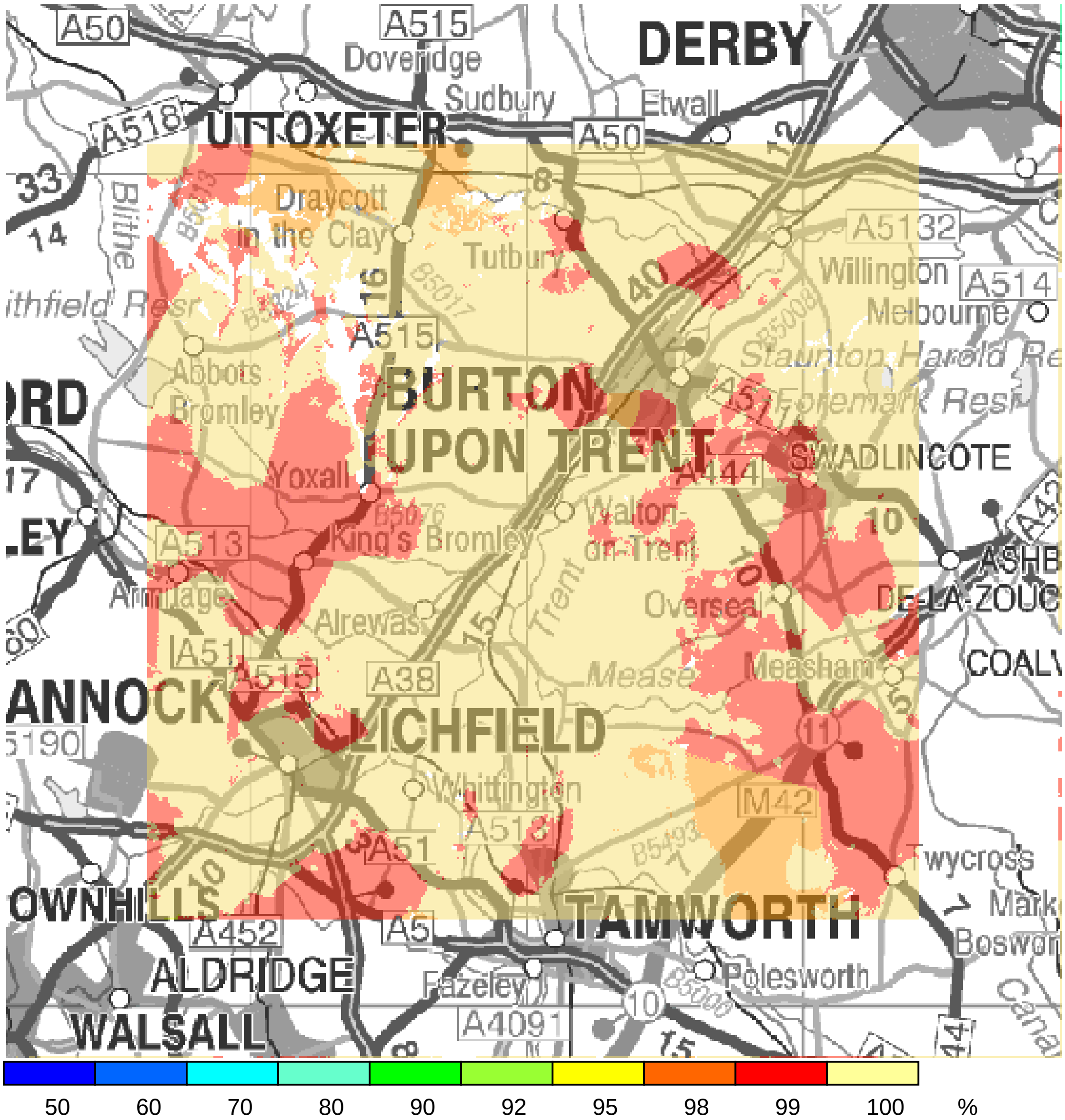

Figure 19: Grade of Service for Burton with 7.5MHz Spectrum Removed

Figure 20: Interference for Burton with 7.5MHz Spectrum Removed (Pink = Best Server Interference)

The interference area is approximately 0.3% of the focus zone.

D.1.4 Removal of 10MHz Spectrum

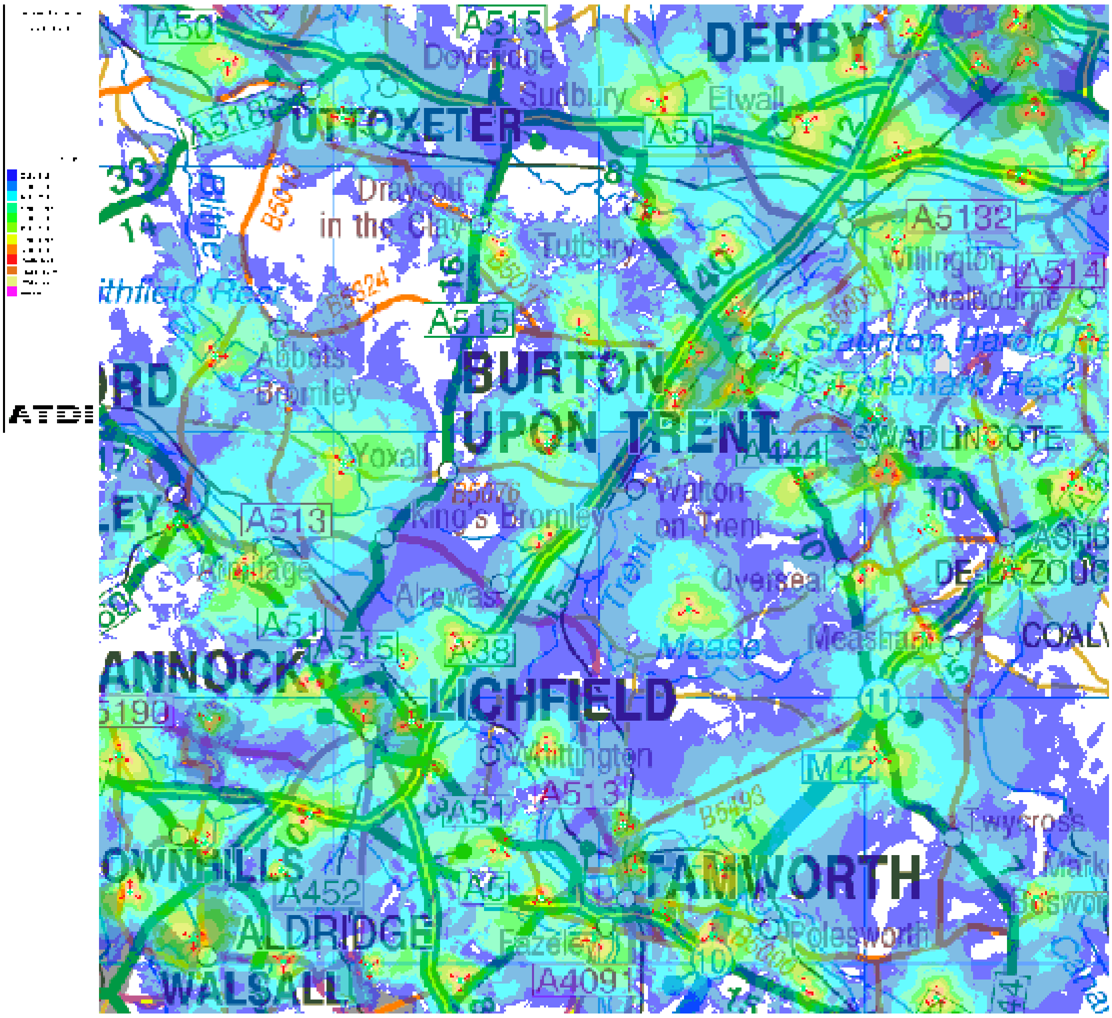

Figure 21 Coverage for Burton with 10MHz Spectrum Removed (Rural Planning Level – Dark Blue)

Table 16: Coverage (Burton -2.5MHz)

Clutter Code	Burton Clutter Types	Covered Area, km^2	% Coverage
0	Rural	608.24	90.8
1	Suburban	33.6875	86.2
2	Urban	48.152	81.7 (to urban planning level)
6	Water	3.84	77.13
8	Woodland	3.9625	29.6

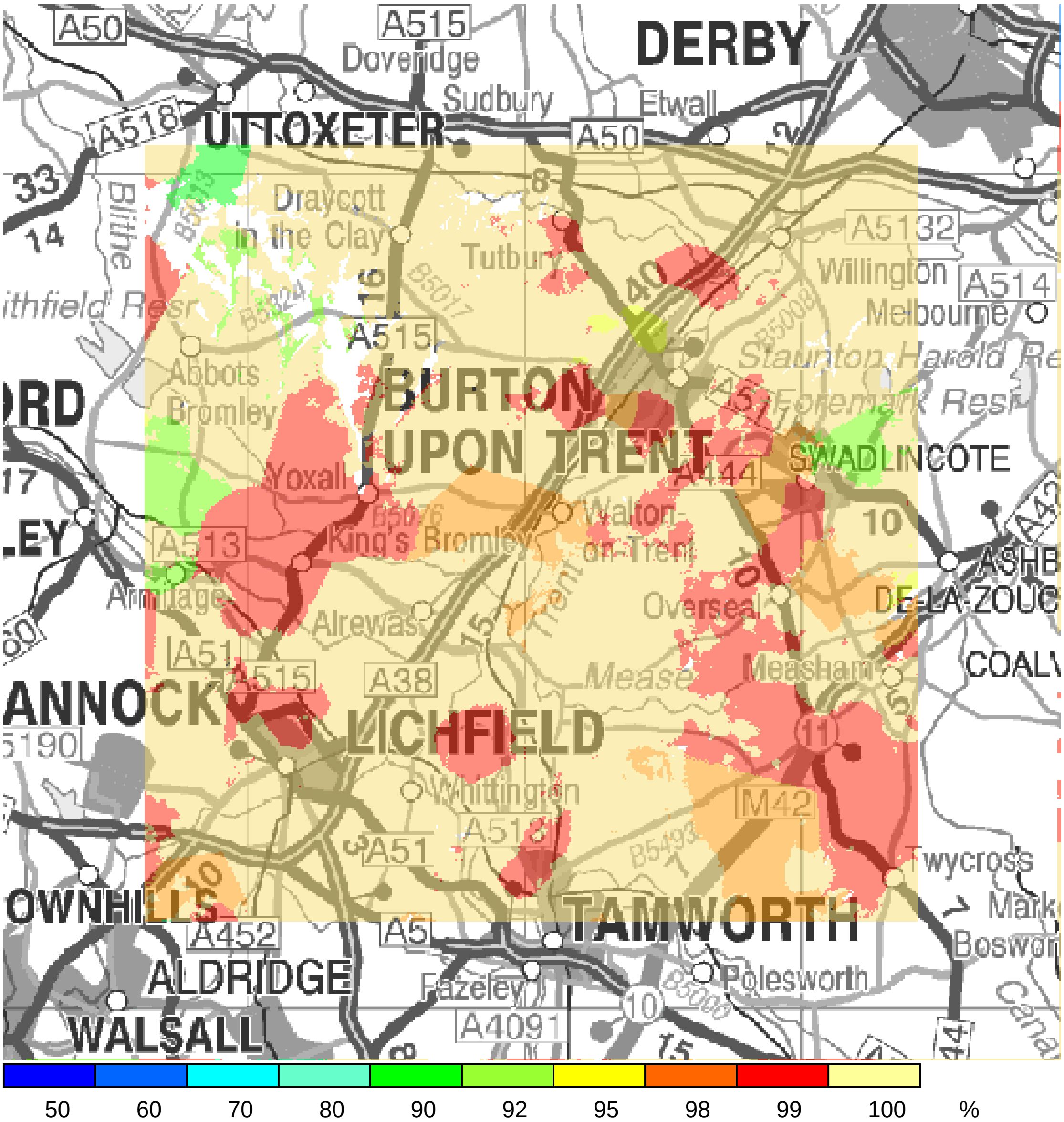

Figure 22: Grade of Service for Burton with 10MHz Spectrum Removed

Figure 23: Interference for Burton with 10MHz Spectrum Removed (Pink = Best Server Interference)

The interference area is approximately 0.6% of the focus zone.

D.2 London

D.2.1 Removal of 2.5MHz Spectrum

Figure 24: Coverage for London with 2.5MHz Spectrum Removed (Urban Planning Level – Light Blue)

Table 17: Coverage (London, -2.5MHz)

Clutter Code	London Clutter Types	Covered Area, km^2	% Coverage
0	Rural	11	99.8
1	Suburban	-	-
2	Urban	85	99.5
6	Water	2.1	100
8	Woodland	0.43	96.6

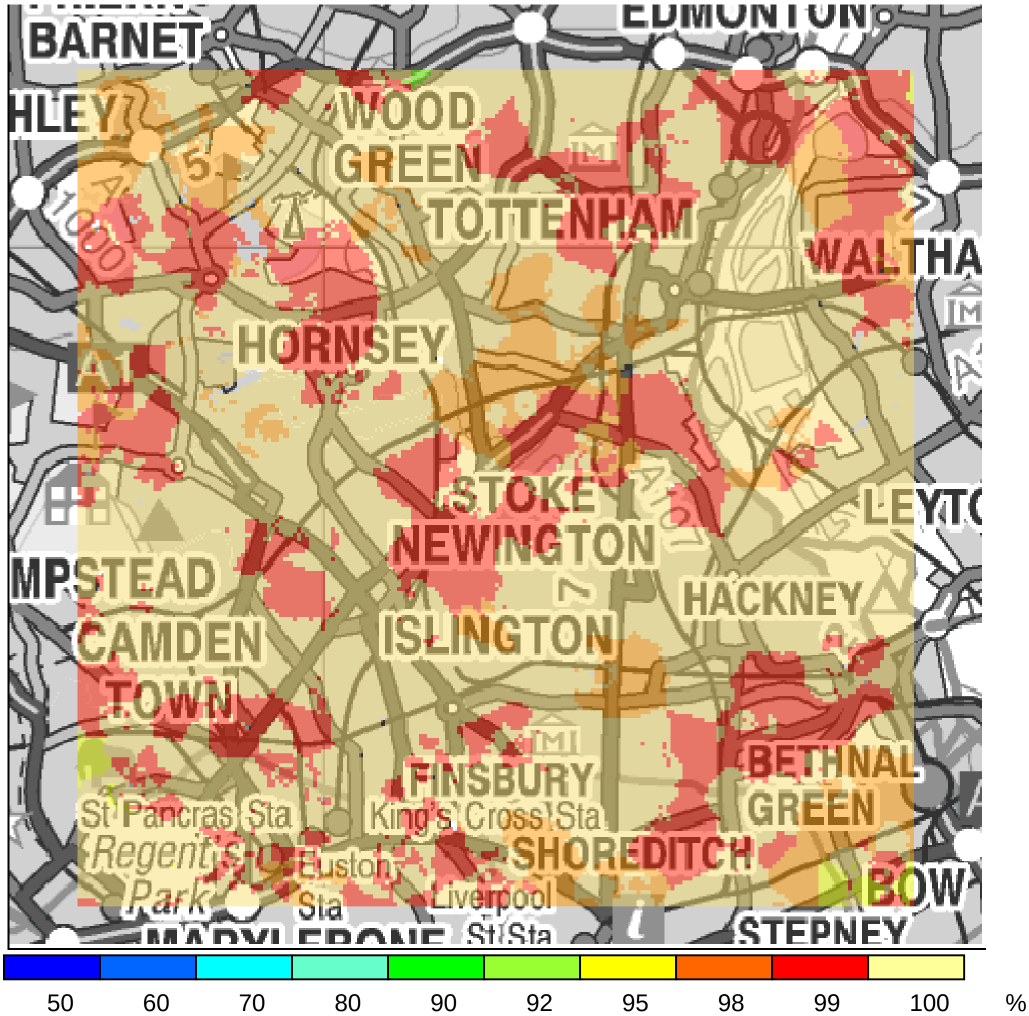

Figure 25: Grade of Service for London with 2.5MHz Spectrum Removed

Figure 26: Interference for London with 2.5MHz Spectrum Removed (Pink = Best Server Interference)

Interference area is 4.7% of the focus zone which could be reduced by fine-tuning powers and down-tilts.

D.2.2 Removal of 5MHz Spectrum

Figure 27: Coverage for London with 5MHz Spectrum Removed (Urban Planning Level – Light Blue)

Table 18: Coverage (London, -2.5MHz)

Clutter Code	London Clutter Types	Covered Area, km^2	% Coverage
0	Rural	11	99.9
1	Suburban	-	-
2	Urban	85	99.6
6	Water	2.1	100
8	Woodland	0.43	96.6

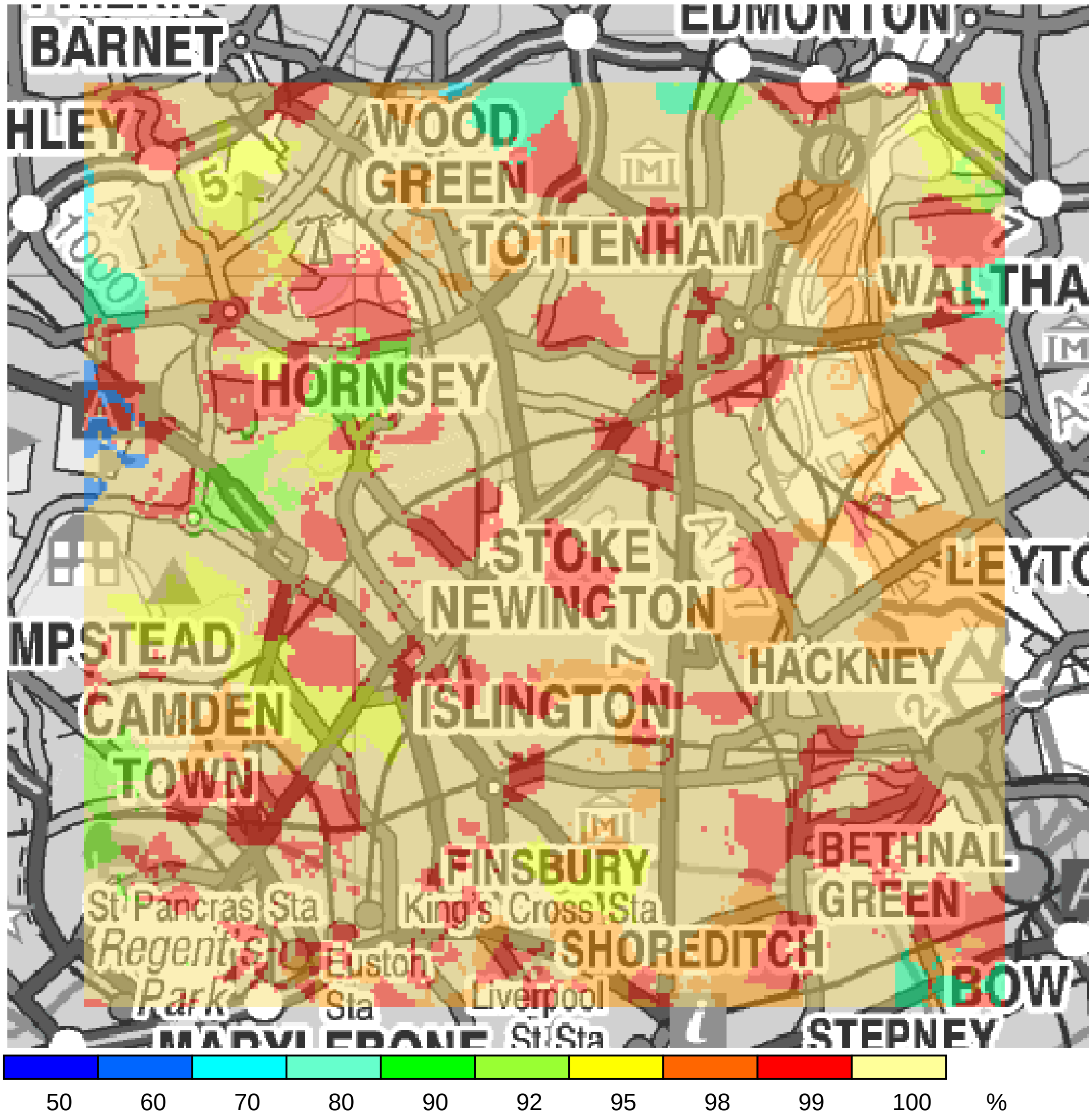

Figure 28: Grade of Service for London with 5MHz Spectrum Removed

Figure 29: Interference for London with 5MHz Spectrum Removed (Pink = Best Server Interference)

Interference area is 3.9% of the focus zone which could be reduced by fine-tuning powers and down-tilts.

D.2.3 Removal of 7.5MHz Spectrum

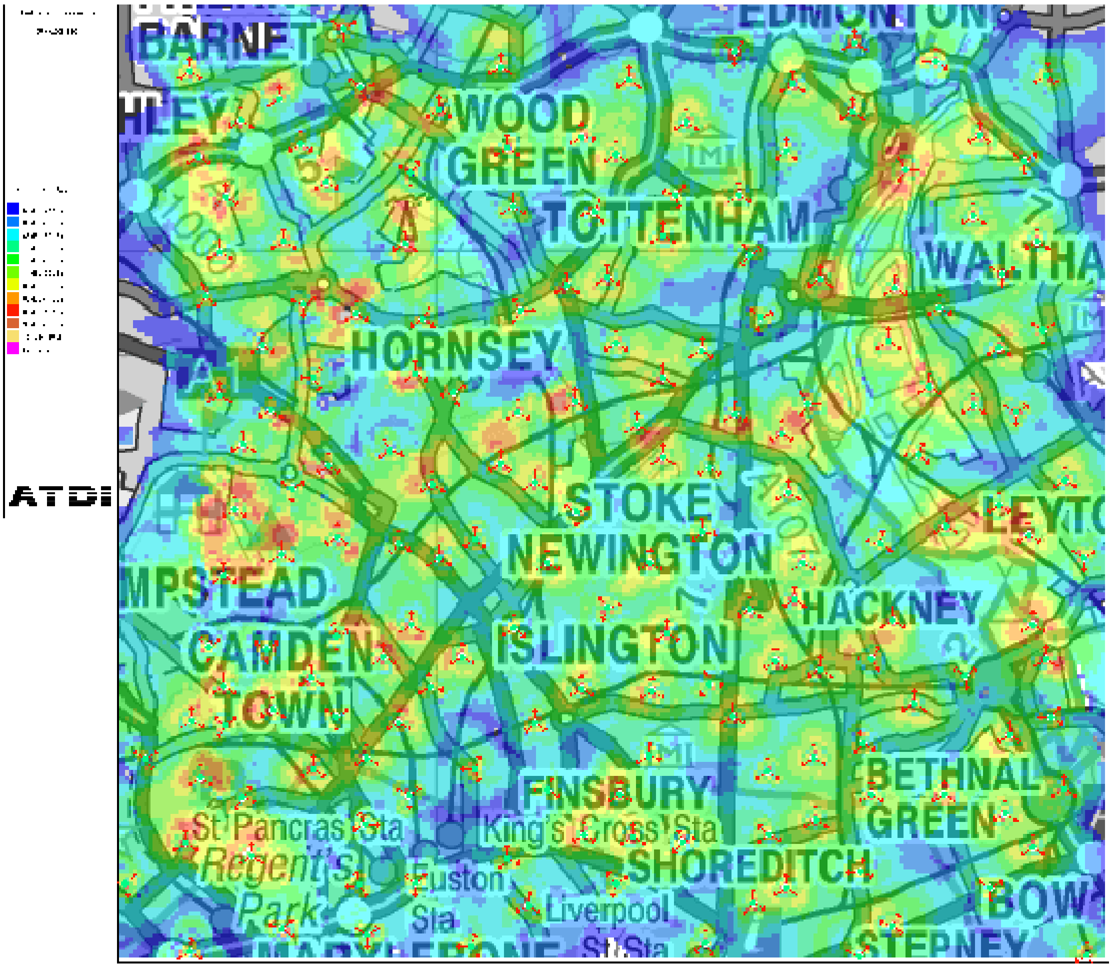

Figure 30: Coverage for London with 7.5MHz Spectrum Removed (Urban Planning Level – Light Blue)

Table 19: Coverage (London, -7.5MHz)

Clutter Code	London Clutter Types	Covered Area, km^2	% Coverage
0	Rural	11	99.8
1	Suburban	-	-
2	Urban	85	99.9
6	Water	2.1	100
8	Woodland	0.44	98.3

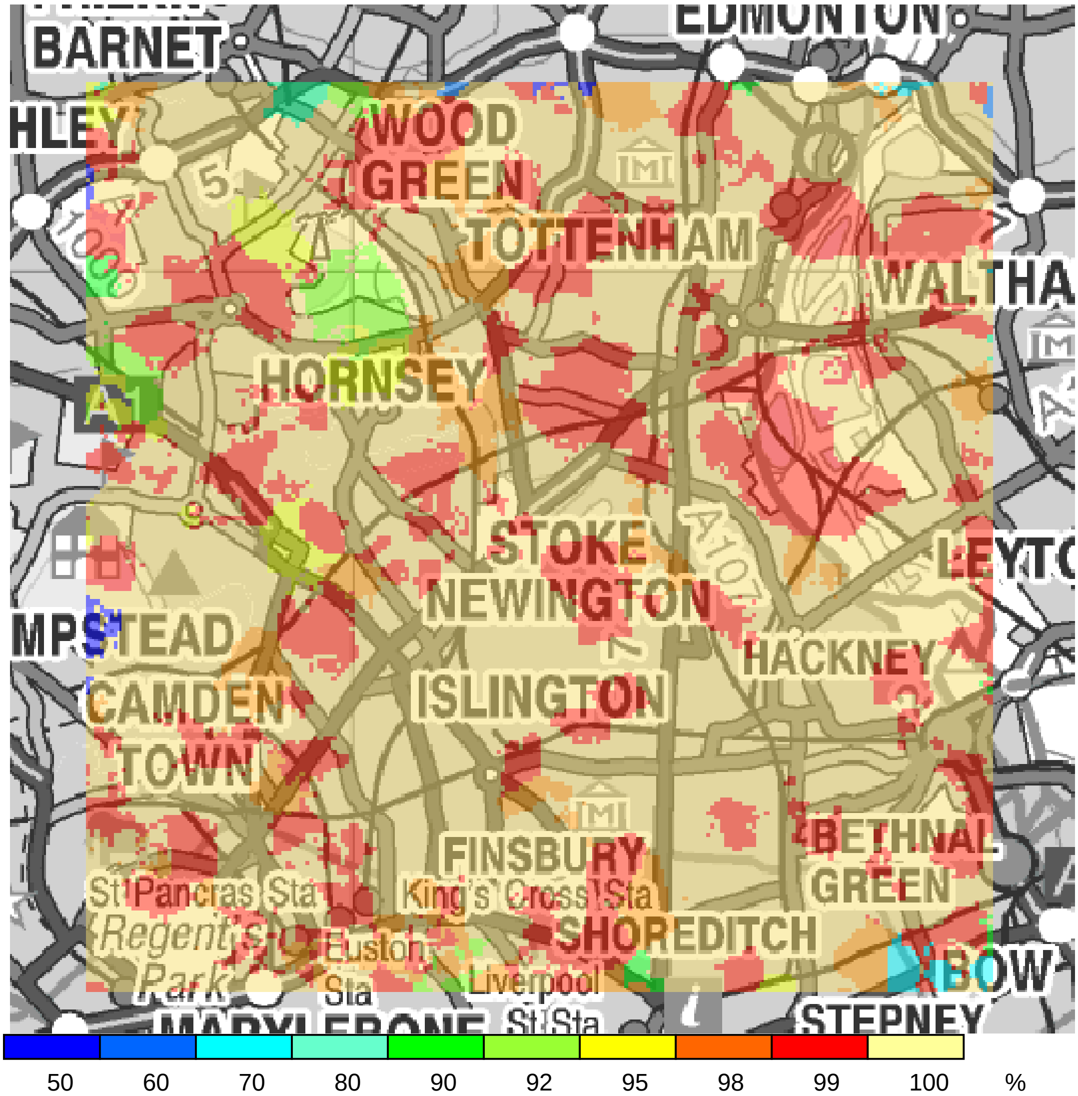

Figure 31: Grade of Service for London with 7.5MHz Spectrum Removed

Figure 32: Interference for London with 7.5MHz Spectrum Removed (Pink = Best Server Interference)

Interference area is 4.9% of the focus zone which could be reduced by fine-tuning powers and down-tilts.

D.2.4 Removal of 10MHz Spectrum

With the number of additional sites required for a reduction in 10MHz of spectrum, retaining the baseline sites is a constraint which prevents achieving acceptable grade of service with the minimum number of sites. We therefore chose to lay out sites in a regular pattern with a spacing determined by the capacity limits for the network. The sites were arranged in a regular grid with a spacing of about 750m for base-stations. No sites were placed over water, and additional sites were deployed in the urban hilly area to the west near Hampstead Heath in order t0 meet the coverage objective.

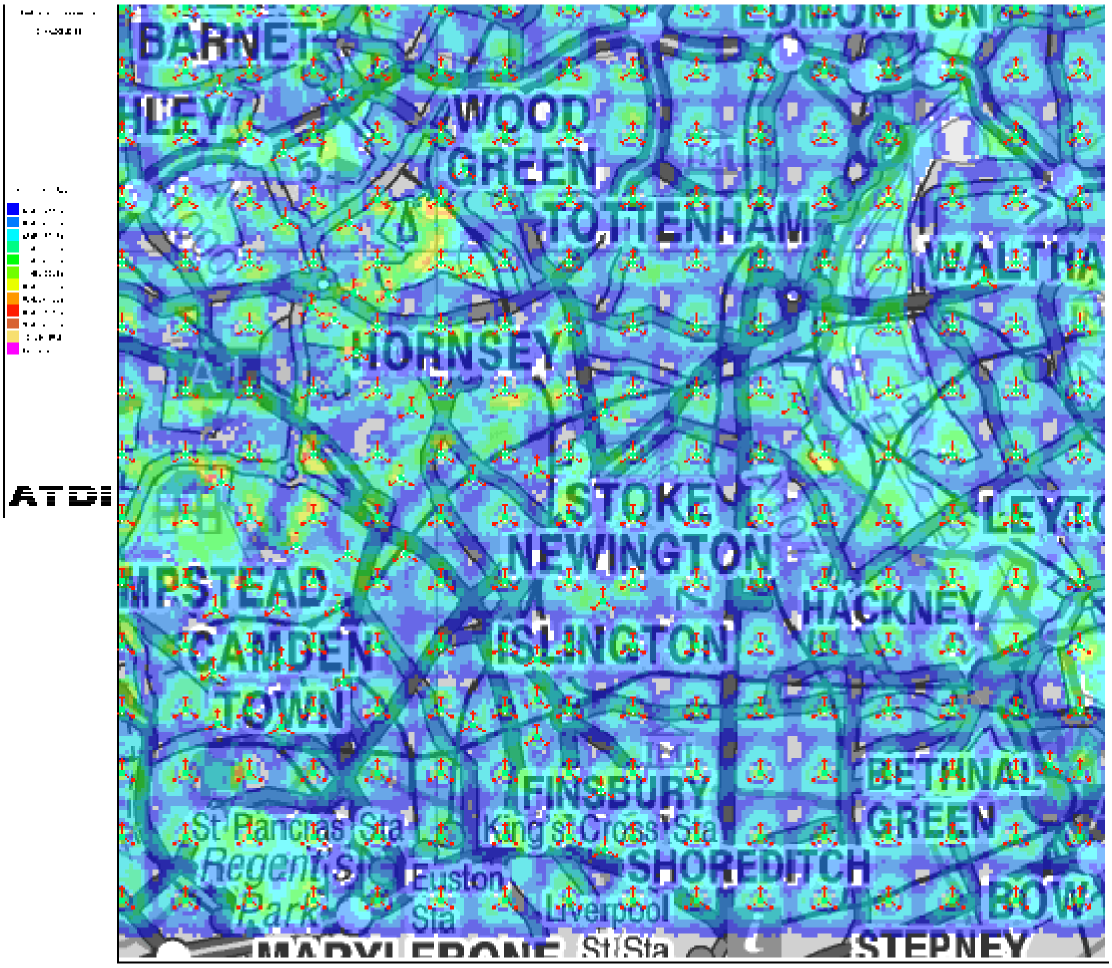

Figure 33: Coverage for London with 10MHz Spectrum Removed (Urban Planning Level – Light Blue)

Table 20: Coverage (London, -10MHz)

Clutter Code	London Clutter Types	Covered Area, km^2	% Coverage
0	Rural	11	99.2
1	Suburban	-	-
2	Urban	85	93.7
6	Water	2.1	89.34
8	Woodland	0.43	87.7

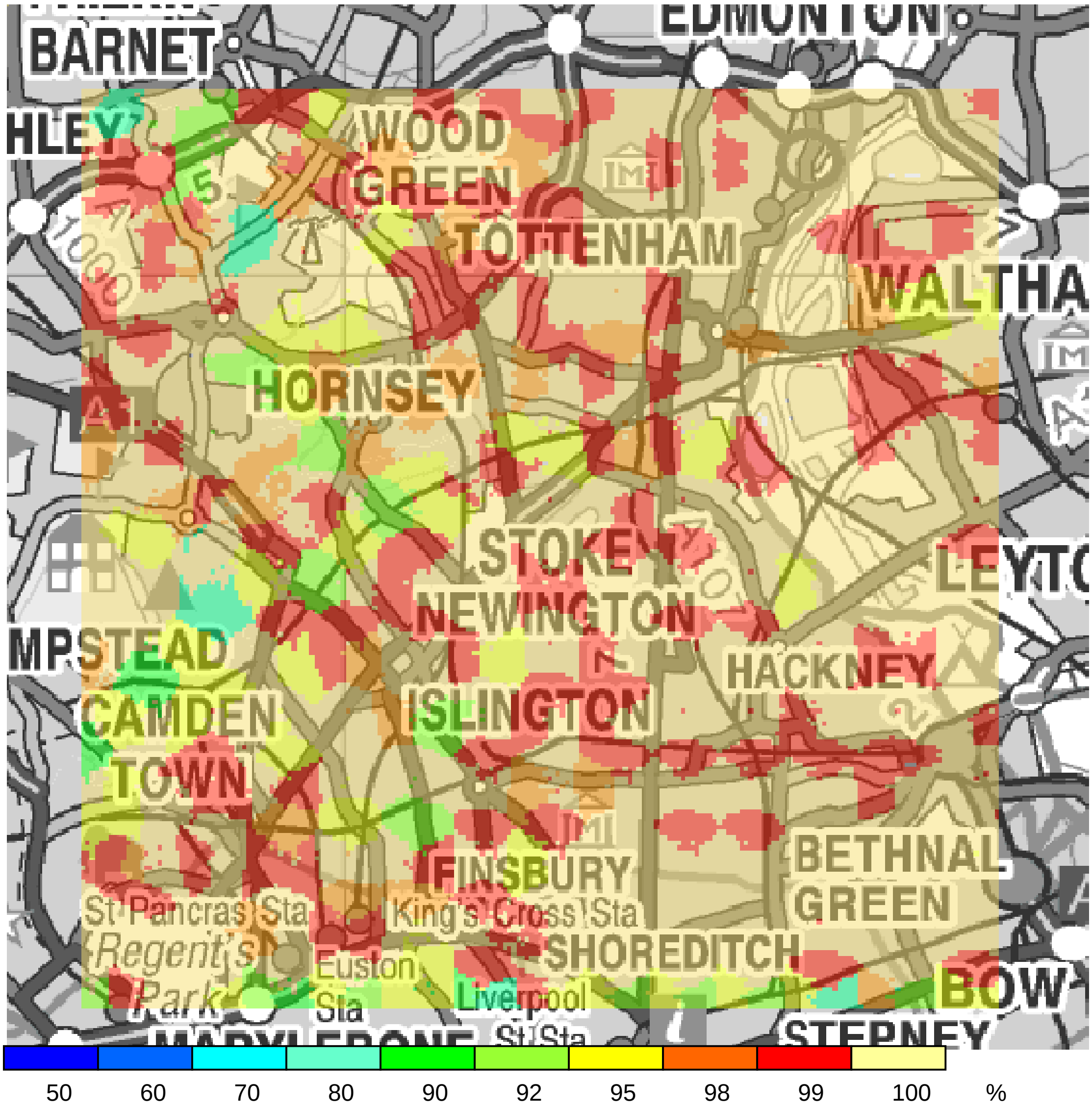

Figure 34: Grade of Service for London with 10MHz Spectrum Removed

This arrangement achieves 98% GoS in 89% of the focus zone.

Figure 35: Interference for London with 10MHz Spectrum Removed (Pink = Best Server Interference)

As expected, the regular arrangement easily achieves <0.5% of area interfered.