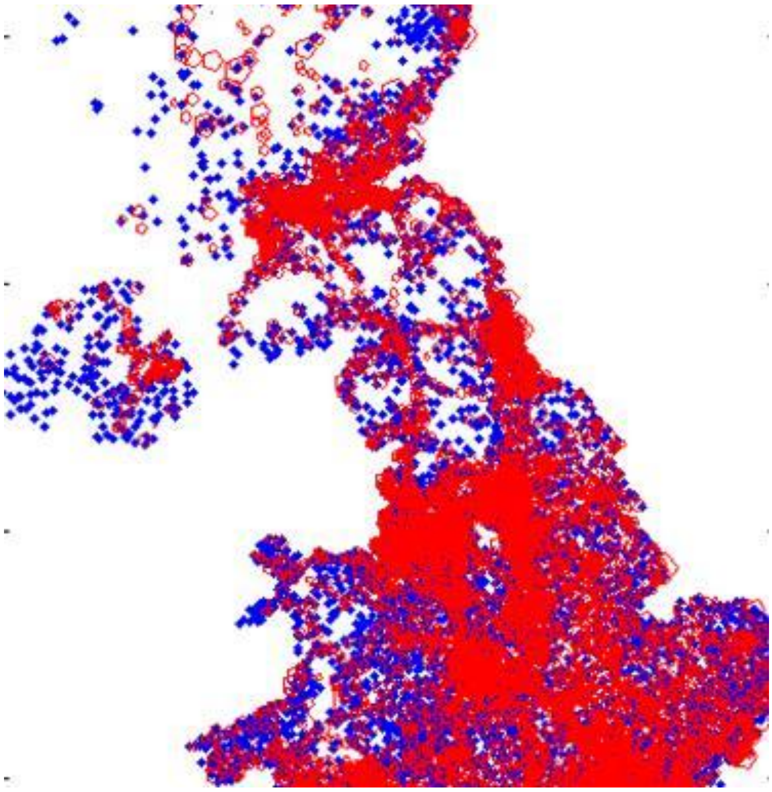
Methodologies used for the analysis of costs relating to a coverage obligation at 800MHz

For existing sites and using MIP sites



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Executive summary

This technical briefing note provides details on the methodologies implemented by Real Wireless in analysing the cost implications of meeting a coverage obligation at 800MHz making use of:

- Existing MNO (or national wholesaler) sites
- Potential new sites available through the mobile infrastructure project (MIP)

This work was carried out as part of our on-going technical support to Ofcom in the area of the combined award of the 800MHz and 2.6GHz bands.

Within this work we have estimated coverage levels achievable at 800MHz based on two approaches:

- A phase 1 method – based on applying an adjusted LTE 800MHz planning threshold (to allow for path loss and EIRP differences between frequency bands) to predicted received signal strength data for existing networks available from MNOs.
- A phase 2 method – based on existing site locations for MNOs, predicting LTE 800MHz site ranges around these and upgrading in order of the sites which deliver the lowest cost per premises first.

This document details these two methodologies and how we have used the results from phase 1 to calibrate the results from phase 2. It also briefly outlines our assumptions when determining site upgrade costs in our model.

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1. Introduction

1.1 Document Background

As part of on-going technical support to Ofcom during their spectrum clearance and auction programme (SCAP) related to the combined auction of 800Hz and 2.6GHz spectrum, Real Wireless was asked to analyse the implications of an 800MHz coverage obligation for existing Mobile Network Operators (MNOs). This document provides an overview of the models we implemented for this work.

It should be noted that within this document we use the term MNOs when referring to mobile operators whereas the term national wholesaler may be used in other documents published alongside our work. In the context of this document the terms MNO and national wholesaler are intended to be interchangeable.

1.2 Overview of coverage obligation modelling aims

The aims of the coverage obligation modelling work undertaken were to understand the potential coverage levels and related upgrade costs that could be achieved by existing MNOs for a 2Mbps LTE service at 800MHz based on:

- Upgrading their existing sites
- Potentially making use of new sites becoming available under the Mobile Infrastructure Project (MIP)

To achieve this coverage at 800MHz for existing MNOs has been investigated based on the following two methods:

- A "Phase 1" method – based on applying an adjusted LTE 800MHz planning threshold (to allow for path loss and EIRP differences between frequency bands) to existing 2G and 3G predicted received signal strength data provided by the MNOs. This is covered in section 2 of this report.
- A "Phase 2" method – based on using existing site locations for MNOs, predicting LTE 800MHz site ranges around these and upgrading in order of the sites which deliver the lowest cost per premises first. This is covered in section 3 of this report.

Prior to running the above two models we also needed to determine site upgrade costs to use in these models. Our assumptions related to upgrade costs are detailed in section 4.

2. Phase 1 – Estimating coverage at 800MHz based on predicted received signal strength data for existing networks

This section details the first of the two approaches used in our analysis of potential coverage that could be achieved by MNOs at 800MHz using their existing sites. This is based on applying an adjusted LTE 800MHz planning threshold (to allow for path loss and EIRP differences between frequency bands) to existing 2G and 3G predicted received signal strength data supplied by MNOs.

2.1 Overview of phase 1 method

For this method, received signal strength data provided by MNOs for GSM at 900MHz and 1800 MHz and UMTS at 2100 MHz has been used as the starting point for the LTE 800 MHz indoor coverage estimation. It is assumed that the existing site locations and infrastructure of each MNO will be reused to meet the coverage obligation at 800MHz.

To serve as a reference, unadjusted planning levels are obtained using the LTE 800MHz link budget for a target indoor 2Mbps downlink service as described in Appendix 1. We apply adjustment factors to the target LTE indoor planning level that would be required to meet the coverage obligation at 800MHz to allow for the fact that we are applying this threshold to received signal strength data for existing frequency bands rather than the 800MHz band. Having applied this adjusted threshold we then sum all premises with coverage for each MNO to arrive at the maximum coverage results for each MNO for the UK and each nation.

More specifically, the following steps are performed:

1. Calculate the LTE planning level threshold in dBm required to sustain a 2Mbps throughput indoors at 800 MHz using the link budget parameters and target building penetration loss assumptions provided in Appendix 1.
2. Calculate the adjustment factor required to be applied to this planning level based on:
    a. The difference in maximum permitted EIRP between frequency bands
    b. The difference in path loss between frequency bands
3. Apply the adjusted LTE indoor planning level threshold in dBm to the received signal strength data for each MNO and calculate the total percentage of premises covered in the UK and each nation for each MNO.

2.2 Assumptions and inputs to phase 1 analysis

The following inputs have been used to generate the phase 1 results:

- Predicted received signal strength data for existing networks at a resolution of 200m x200m and a 90% confidence level provided across the MNOs as follows:
    - GSM 900 MHz data
    - GSM 1800 MHz data
    - UMTS 2100 MHz data
- Link budget parameters detailed in Appendix 1. These were used to calculate the unadjusted LTE 800 MHz indoor planning level at 2Mbps using a 10MHz bandwidth and EIRP of 64 dBm/10 MHz.

The unadjusted LTE 800 MHz indoor planning level is used as a starting point to calculate the "adjusted" planning level thresholds that need to be applied to the received signal strength data provided by MNOs for existing networks to estimate the LTE 800 MHz indoor coverage that could potentially be achieved.

Two factors are applied to the unadjusted LTE 800 MHz indoor coverage planning levels to calculate the "adjusted" LTE 800 MHz planning level thresholds:

- A difference in path loss due to the frequency change to 800MHz – As the predicted received signal strength data from MNOs for existing networks is for frequency bands above 800MHz we would expect that these signal levels would have been higher if predicted for an 800MHz network due to a lower path loss. This difference in path loss due to the frequency change to 800 MHz is obtained by comparing the 1km intercept path losses for the relevant frequency bands based on the Seamcat V2 implementation of the Extended Hata model [1]. These are shown for different clutter type assumptions in Table 2-1.
- A difference in maximum permitted EIRP between frequency bands – Where there is a difference between the maximum permitted EIRP level at 800MHz, assuming a 10MHz bandwidth LTE system will be used at 800MHz, and the maximum permitted EIRP for GSM and UMTS networks on existing frequency bands we assume that MNOs would increase or decrease their EIRP levels at 800MHz in line with this. Therefore we allow for this EIRP difference in the "adjusted" planning level.

Frequency, MHz	Urban	Suburban	Rural
942	1.8 dB	1.4 dB	1.1 dB
1842	11.2 dB	8.9 dB	7.2 dB
2140	12.7 dB	10.1 dB	8.2 dB

Table 2-1: Path loss correction factors to translate predicted received signal strength data for existing networks at different frequencies to 800MHz

The phase 1 coverage analysis was carried out for two BPL assumptions: MinVar and MaxVar, which respectively, relate to lower and higher loss assumptions for the building penetration loss.

The BPL values used for the MinVar and MaxVar assumptions are shown in Table 2-2.

MinVar BPL	MaxVar BPL
Mean =8.4 dB, Std. dev. = 5.4dB	Mean =10.5 dB, Std. dev. = 6.8dB

Table 2-2: Building penetration loss values for MinVar and MaxVar assumptions

By way of example of the calculation of the adjusted planning thresholds applied in the phase 1 method, Table 2-3 shows steps in calculating the adjusted LTE indoor planning threshold to be applied to existing received signal level predictions for the case of using

MinVar BPL assumptions and a difference in path loss correction based on the extended Hata model for suburban areas.

	GSM 900 MHz	GSM 1800 MHz	UMTS 2100 MHz
Difference in path loss due to frequency change to 800MHz /dB (assuming suburban clutter type)	1.4	8.9	10.1
Difference in maximum licensed EIRP between current band and 800MHz /dB	2	2	2
Adjustment required to convert existing predicted received signal strength data to 800MHz /dB	3.4	10.9	12.1
Unadjusted LTE indoor 800MHz planning threshold to apply to 800MHz outdoor signals/ dBm (using MinVar BPL assumptions)	-71.2	-71.2	-71.2
Adjusted LTE indoor 800MHz planning threshold to apply to existing predicted received signal strength data for MinVar BPL assumptions/ dBm	**-74.6**	**-82.1**	**-83.3**
Adjusted LTE indoor 800MHz planning threshold to apply to existing predicted received signal strength data for MaxVar BPL assumptions / dBm	**-71.9**	**-79.4**	**-80.6**

Table 2-3: Calculation of adjusted LTE 800 MHz indoor coverage planning thresholds to be applied to existing received signal strength data for different frequency bands to estimate LTE 800MHz coverage from these

2.3 Limitations of the phase 1 method

The aim of this phase 1 method is to give an approximation of the level of LTE 2Mbps indoor coverage that MNOs might achieve at 800MHz based on predicted received signal strength data for existing networks. We acknowledge that this method (as with the phase 2 method) does not replace a full network simulation based on site locations and modelling of the local environment surrounding each site.

In particular we anticipate that this approach will provide coverage estimates that:

- Assume that EIRP levels in LTE 800MHz will be set commensurate to EIRP levels in existing networks which may be a pessimistic assumption due to improved interference cancellation techniques in LTE.
- Assume that only the sites that we have received predicted received signal strength data for will be upgraded to 800MHz LTE. In the case of some MNOs

this means that this method assumes that only their GSM sites will be upgraded when in practice 3G sites will also be available for upgrade.

- Makes use of a difference in path loss adjustment to the LTE planning level to allow for the difference in frequency that is based on an empirical model which is an approximation to but not a replacement for real measurements.

3. Phase 2 – Estimating coverage at 800MHz and upgrade costs based on site locations

This section details the second of the two approaches used in our analysis of potential coverage that could be achieved by existing MNOs at 800MHz. This is based on using existing site locations for MNOs, predicting LTE 800MHz site ranges around these and following a site upgrade route that follows the lowest cost per premises first.

3.1 Overview of phase 2 method

To assess the cumulative LTE 800 MHz indoor coverage and hence to arrive at the cumulative costs at different coverage levels, our phase 2 method examines existing site locations and models estimated coverage at 800MHz around each of these. Within this method we use information such as existing site locations and site types to estimate the maximum coverage ranges for different site locations to arrive at cumulative coverage estimates.

To ensure that the site ranges calculated in this approach are realistic, we perform the additional step of calibrating site ranges against the predicted received signal strength data provided by MNOs' in phase 1. We have also validated our results against our previous study on the LTE 800 MHz coverage obligation for Ofcom [2].

Based on the calibration step, terrain correction factors (TCF) for different geotypes are introduced to the model which, as detailed in section 3.3.3 later, are in line with those used by Holma and Toskala in [3].

As in the case of the phase 1 method, the phase 2 coverage analysis is carried out for two BPL assumptions: MinVar and MaxVar relating to lower and higher loss assumptions for the building penetration loss.

In summary within phase 2, to determine the cumulative LTE 800MHz indoor coverage versus upgrade cost for each MNO based on their existing site locations we:

- Calculate the maximum acceptable path loss (MAPL) of sites in each clutter type to achieve the 2Mbps indoor cell edge planning target
- Adjust the MAPL for these site ranges using a terrain correction factor so that the LTE 800MHz indoor coverage achieved from the site locations data with their reported EIRP levels is consistent with the LTE 800MHz indoor coverage level estimated from the predicted received signal strength data in phase 1 (ensuring that where phase 1 results are based on GSM only sites that GSM site locations are used in the calibration process)
- Determine the number of premises served by each site if upgraded to 4G at 800MHz and assuming a maximum licensed EIRP was used (which is considered optimistic)
- Select the most cost efficient site to upgrade i.e. the one with the highest number of premises served per pound spent on the upgrade (where costs are calculated on a present value basis, see section 4 for details)
- Repeat the above step for the remaining sites and remaining number of premises to be served until all sites have been upgraded, sites no longer add coverage or all of the premises have been covered

- Plot the cumulative coverage versus cumulative cost for each MNO or MNO combination of interest[1]

3.2 Inputs and assumptions to phase 2 method

The following information has been used to generate the phase 2 modelling results:

- Sites locations, antenna height, sectors per site and EIRP where available from the MNOs
- The LTE 800 MHz link budget used in Phase 1 (and detailed in appendix 1) is used to calculate the unadjusted MAPL for each site
- Premises locations in the UK are used to calculate cumulative coverage
- The phase 1 results based on predicted received signal strength data from each MNO are used for the site range calibration stage.

3.3 Phase 2 method in more detail

3.3.1 Estimating coverage for a single MNO from existing sites

The phase 2 method has been implemented using a simulation model that uses the available information for each site location to determine upgrade costs and site ranges as appropriate to each site. This allows for a more detailed analysis of coverage than in phase 1 to be carried out such as reporting cumulative coverage vs. cost in each nation rather than just the total expected coverage and cost level. In this context, the phase 1 method data and results serve as a reference point that can be used to calibrate and verify phase 2 results. Ideally, the coverage obtained from the phase1 method and the phase 2 method should produce the same maximum coverage point as illustrated in Figure 1 for each MNO. However, the difference in methodology and source data will lead to a somewhat different result, so the model parameters in phase 2 are tuned to align with the coverage levels predicted in phase 1.

[1] The coverage results for a combination of MNOs are aimed at representing larger potential site portfolios that might be achieved due to sharing arrangements between MNOs.

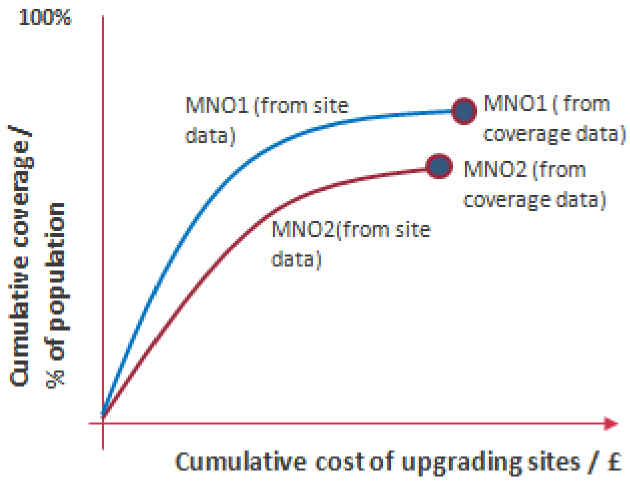

Figure 1: Illustration of overall approach of phase 1 and 2 methods and the link between them for obtaining coverage and cost results

Model description

An algorithmic flow diagram of the model is shown in Figure 2 and is run for calculating the cumulative coverage and cost results for each MNO. We have used the following assumptions in the model:

- No capacity constraints are applied on existing sites
- Premises falling within the coverage area of multiple sites are covered by the first upgraded site

The flow diagram shown in Figure 2 shows the steps followed as follows:

- First the location information of all the UK premises is loaded.
- Then the location, antenna height and site type information for all the sites of the MNO being examined are loaded into the model.
- Link budget parameters for a LTE 800 MHz 2Mbps indoor service and EIRP in proportion to each site's existing EIRP are used to calculate the MAPL for each site of the MNO for an ideal scenario within a flat area and circular coverage.
- The coverage with this approach for the sites represented by the received signal strength data used in phase 1 (i.e. GSM sites only are considered if only GSM received signal strength levels were provided by the MNO for phase 1) is compared to that calculated from the phase 1 method to obtain terrain correction factors for three clutter types (urban, suburban and rural) that will be added to the MAPL values of each site as per the clutter type of its location.
- The adjusted MAPL level for each site is next calculated using the clutter type information of its location, the appropriate terrain correction factor and the maximum licensed EIRP of 64dBm. This is then used to calculate the maximum range of each site for the LTE indoor coverage requirements (for MinVar and MaxVar BPL assumptions).

- Using the UK premises location data, site location data and the site ranges, covered premises and serving sites in the UK in a matrix form is obtained for post processing and further analysis.
- Sites are upgraded for the MNO being examined starting with the site that covers the highest number of premises per £ spent at each iteration and so on until the model finds that all sites have been upgraded, coverage is not being extended or all of the population has been covered.

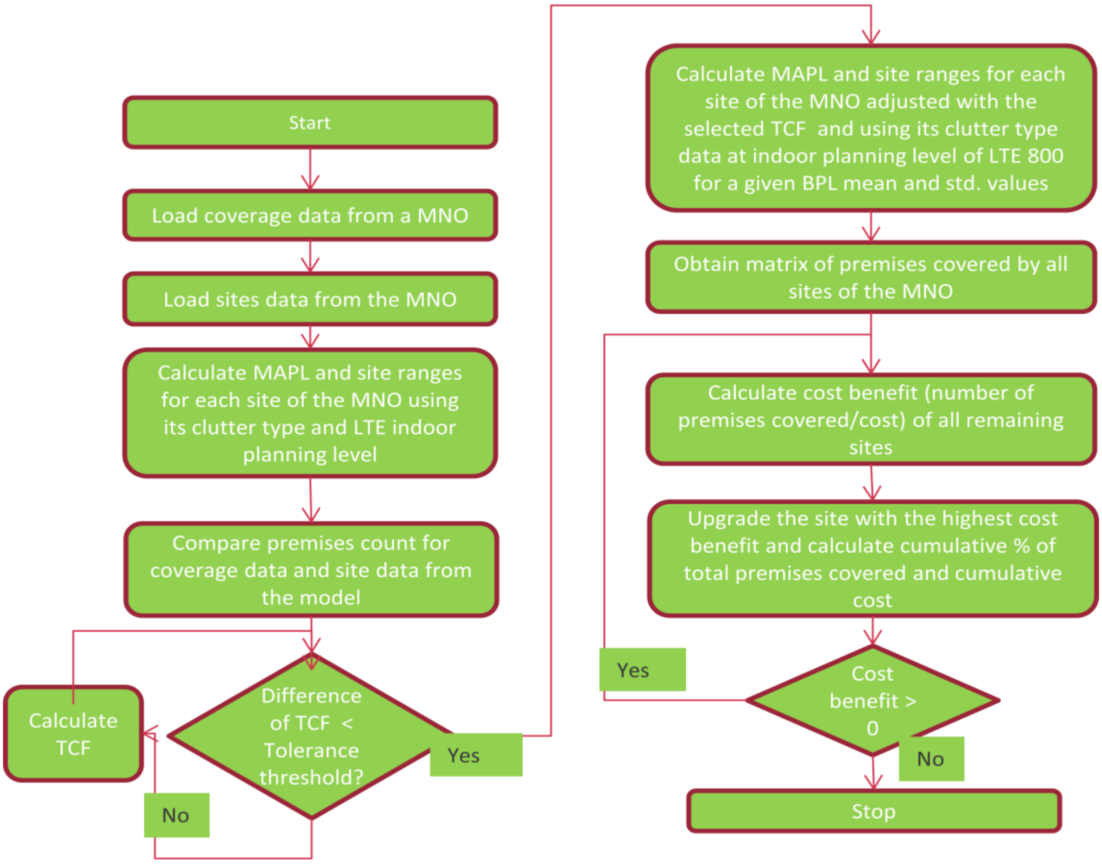

Figure 2: Flow diagram of the model used in phase 2 method

Verifying the calculated site ranges

When calculating site ranges from the target MAPL the following propagation models [1] are used:

- SE21-Hata model for urban and suburban clutter types
- Open area of Extended Hata model for rural clutter types

Since these propagation models do not explicitly account for terrain we have included a terrain correction factor (TCF) based on calibrating site ranges against the predicted received signal strength data received from MNOs for existing networks used in phase 1. More details on the TCF calculation are provided in section 3.3.3.

As an example of the site ranges this leads to the mean terrain corrected site ranges targeting indoor coverage with the MinVar BPL assumptions are shown in Table 3-1.

Site base	Mean of urban site ranges, km	Mean of suburban site ranges, km	Mean of rural site ranges, km
Site portfolio 1	1.34	1.73	3.24
Site portfolio 2	1.34	1.80	3.46

Table 3-1: Example site ranges from phase 2 model

Note that calculated site ranges depend upon many factors such as MAPL, clutter type, transmit and receive antenna heights. To ensure that the site ranges calculated are reasonable, as a further check, these values have been compared and validated against the previous LTE 800 MHz coverage obligation study produced by Real Wireless for Ofcom [2].

3.3.2 Estimating coverage for a combination of MNO sites or using MIP sites

This task estimates the improvement in the LTE 800 MHz coverage that could be achieved by an existing site portfolio if MIP sites or another MNO's sites were also added to this portfolio of sites. The link budget parameters used to calculate the site ranges are the same as those used for the case of using a MNO's existing sites as described in section 3.3.1. Additionally, the following assumptions are used in this task.

- The starting point for this task is that MIP sites or other MNO sites are adding to is the result of the LTE 800MHz indoor coverage achieved by upgrading all existing sites for given MNO's existing sites or portfolio of existing sites as per the method in section 3.3.1.
- Terrain correction factors (TCFs) and site ranges as used in section 3.3.1 are assumed for MIP sites or other MNO sites in this task i.e. site ranges using a TCF which is an average of the MNO1 and MNO2 calibrated TCFs.
- No capacity constraints are assumed on existing or MIP sites.
- MIP site upgrade costs include only the costs to upgrade the site for one operator (although MIP sites are multi operator sites) and assume that MIP sites can be treated as GSM sites but with 3G support for the purposes of determining backhaul costs.
- We assume all MIP sites will use the maximum licensed EIRP and are sectored macrocell sites.
- The MIP site list to provide coverage to 60,000 premises produced by Real Wireless under our support work to Ofcom in the area of addressing mobile Not-spots has been used as the list of MIP sites input to this task as the exact sites that will be built for MIP are unknown at this stage.

3.3.3 Calibration of terrain correction factors and site ranges in phase 2

The phase 1 coverage results using adjusted LTE indoor coverage planning thresholds for each operator are obtained based on predicted received signal levels generated by MNOs and as such represent realistic existing coverage and implicitly contain the factors such as terrain and local radio propagation conditions around each site. The phase 2 method, uses the phase 1 maximum UK coverage result as a reference to tune its results against and to obtain a terrain correction factor to account for the terrain and local propagation environment around sites. A different factor is applied for each of the three clutter types of urban, suburban and rural by multiplying the TCF with a different weight for each clutter type to update the MAPL values for the site range calculations.

Using this approach, we obtained the following TCF for a selection of MNOs given in Table 3-2.

Calibration approach	Terrain correction factor
Matching phase 1 result from MNO1 predicted received signal strength data with phase 2 coverage based on MNO1 site locations for the relevant existing frequency band	-12 dB
Matching phase 1 result from MNO2 predicted received signal strength data with phase 2 coverage based on MNO2 site locations for the relevant existing frequency band	-13.3 dB
Matching phase 1 result from MNO3 predicted received signal strength data with phase 2 coverage based on MNO3 site locations for the relevant existing frequency band	-5.3 dB
Final terrain correction factor used for the model for all MNOs is based on the mean of TCF in dB of MNO1 and MNO2	-12.6 dB

Table 3-2: TCFs obtained by calibrating against phase 1 result for different MNOs

Ideally a TCF would be generated for each MNO based on matching the phase 1 and phase 2 results from their site locations and predicted received signal strength data. However, this gives different site ranges across MNOs which is not sensible as physically there is no reason why a site range for a site at the same frequency, height and EIRP would differ between MNOs. Therefore the same TCF should be applied to the site ranges across MNOs. The differences seen in Table 3-2 may arise from differences in the calibration of the propagation models used by the different MNOs and differences in the underlying technology assumptions.

A TCF of -12.6 dB, which is the mean of the TCFs calibrated against the MNO1 and MNO2 phase 1 coverage results, was decided to be used for all MNOs for generating phase 2 results. This was because:

- We have found that the LTE 800MHz indoor coverage results based on MNO1 or MNO2 predicted received signal strength data align better (than the equivalent results based on data from other MNOs) with the coverage results based on a more detailed propagation model which allows for local terrain found in [2].
- We have compared the mean site ranges obtained with the TCFs from MNO1 and MNO2 predicted received signal strength data against the site ranges for the Welsh study region in our previous 800MHz coverage obligation study [2] and found that these are closer to the mean suburban and rural site ranges found in

our previous study than those calibrated with the TCFs from the data from other MNOs It should be noted that in the case of urban site ranges the sample size of urban sites from the previous study was too small to get a reliable mean site range.

- We are aware of issues (such as inaccurate EIRP levels) with some of the site location data from some of the MNOs but these issues did not apply to the site portfolios of MNO1 and MNO2.
- The MNO1 and MNO2 TCFs aligned well with each other and the TCFs used by Holma and Toskala [3] when calculating site ranges.

Weighting of the TCF across the clutter type

To ensure that we apply the TCF fairly across different site locations of the UK, we have used a weighting factor to be applied to the TCF for a site that takes into account the clutter type of the location of the site. The resulting TCFs applied to sites located at different clutter types using the final weighting factors of [0% 30% 100%] for [urban suburban rural] sites are given in Table 3-3 as follows:

Urban, dB	Suburban, dB	Rural, dB
0	3.8	12.6

Table 3-3: Weighting factor applied to TCF across different clutter types of sites

This weighting selection is based on rural site ranges being the longest and so likely to be impacted the most by terrain. These weightings are also similar to the correction factor weightings, and subsequent TCFs, between environments used in [3].

3.3.4 Determining cost per added premises per site

This addition to the phase 2 model was requested to further analyse the results of the modelling detailed in section 3.3.1 to understand how the costs per premises added increases with increased number of upgraded sites or the increased UK coverage.

The following steps were added to the phase 2 model used to obtain results in this area:

1. Load the results containing premises added per upgraded sites and cost of each upgraded site.
2. Using the loaded results, calculate cost per added premises for each upgraded site in the UK by dividing the cost of each site by the number of premises it serves.
3. Categorise each of the premises in the UK and each site that serves those premises based on its location into each of the 4 nations: England, Scotland, Wales and Northern Ireland.
4. Also categorise the costs associated with each site in to each of the 4 nations.
5. Output the cost per premises added of each site against coverage levels achieved in the UK and for each nation.

3.3.5 Determining the sensitivity of estimated coverage to changes in MAPL

This extension of phase 2 was concerned with understanding the sensitivity of estimated coverage at 800MHz to changes in the target MAPL (which might be due to different BPL assumptions for example).

The steps below were used along with rerunning the model described in the section 3.3.1 for this task:

1. Set the increase in the MAPL to 6 dB as a starting point.
2. Load the UK premises and the target MNO's sites location data.
3. Using the site parameters such as EIRP, antenna heights, clutter type etc. calculate the MAPL for these assumptions and allowing for the TCF used in the original phase 2 model.
4. Update the MAPL by accounting for the MAPL increase and calculate site ranges for the updated MAPL values for all sites.
5. Run the coverage analysis routine using the site ranges using the updated MAPL.
6. Check if the maximum coverage for the MNOs is less than 98%.
7. If the maximum coverage achieved is higher than 98% then revise the increase of MAPL from 6 dB to 5 dB, 4 dB and so on.
8. Continue 1 to 7 until the maximum coverage for the MNOs is more than 98%.
9. Record the increase in MAPL and the final MAPL that gives maximum coverage for the MNOs just above 98%.
10. Run the cumulative coverage vs. cost model as in section 3.3.1 using the final MAPL to obtain the cumulative coverage vs. cost results.

Table 3-4 shows how the maximum UK coverage for two example existing site portfolios changes with a 3.5dB increase in MAPL which is of particular interest as this would bring coverage for these site portfolios close the a 98% coverage obligation level.

	Site portfolio 1	Site Portfolio 2
Maximum indoor coverage in the UK, % with 3.5dB increase in MAPL above MinVar case	98.27	98.10
Maximum indoor coverage in the UK, % for original MinVar case for MAPL	96.78	96.96

Table 3-4: MAPL increase vs. maximum indoor coverage achieved for increase of MAPL = 3.5 dB

As an example, the 3.5dB change in MAPL which might ensure that a coverage level of 98% could be reached by existing MNOs could be built into a revised coverage obligation in a number of ways:

- A 3.5dB decrease in the mean BPL specified (or a combination of BPL mean and standard deviation)
- A 6% reduction in cell area coverage confidence from 90% (in the original case without added MAPL) to 84%

3.4 Limitations in the phase 2 method

While the phase 2 method is an improvement over the phase 1 method as it gives further detail on the upgrade order and corresponding cumulative potential 800MHz coverage and upgrade costs of a site portfolio rather than estimating solely the maximum achievable coverage based on upgrading all existing sites as in the phase 1 method. However we acknowledge that this method still only gives an approximation of potential coverage that might be achieved by different site portfolios at 800MHz and includes the following limitations:

- A circular coverage area is assumed around existing sites when in practice this will be shaped by the local terrain.
- A maximum permitted EIRP is assumed for each site whereas in practice this is likely to be backed off to manage interference between sites.
- While a TCF is included to allow for terrain this is an average correction and doesn't replace a full propagation model which allows for local terrain as used in our previous 800MHz coverage obligation study for Ofcom [2].

4. Site upgrade cost assumptions used

This section discusses the top level assumptions that we have used in determining the site upgrade costs within our coverage models and examples of how these translate in to upgrade costs for example site types.

4.1 Assumptions on site upgrade costs

It was decided that the exact 4G upgrade costs per site will depend on the features of that site such as:

- Whether a site is already multi-standard (and likely to have a base-station that would only need a software upgrade to support LTE)
- Whether a site already has a multi-band antenna to support 800MHz (due to some forward thinking by MNOs expecting spectrum at 800MHz to be released)
- Whether a site is rural, urban or suburban (which in particular impacts the backhaul cost)
- Whether the site could potentially use a microwave backhaul

Table 4-1 shows the final assumptions agreed to be applied to upgrade costs for existing 4G sites based on their types and locations.

Site Feature	Site feature from database used	Notes
Multi-standard basestation at the site	Transmission type	We assume that only sites listed as supporting both GSM and UMTS will potentially have a multi standard basestation. Of these, it is assumed that 60% of all sites supporting both GSM and UMTS will have multi standard basestations and hence be able to support 4G via a software upgrade.
Existing support for 800MHz	None	Assume the worst case that no operators have installed antennas to support 800MHz yet. This aligns with feedback from the MIP Intellect workshops where operators showed a lack of interest in equipping MIP sites for 800MHz.
Location type Rural, urban or suburban	Clutter type	The site location type is determined from the clutter type of the pixel from the clutter database that the site falls into.

Microwave backhaul	Clutter type	We assume that urban areas where high rooftop sites are available will have more potential for LOS microwave backhaul. Whether a site supports a microwave backhaul is randomly distributed based on the site location type as follows: • Rural 20% of sites to support microwave links • Suburban 40% of sites to support microwave links • Urban 50% of sites to support microwave links

Table 4-1: Cost applied in the Phase 2 model to sites based on the sites information

With regards to the costs of multi-standard base-station sites, to be more realistic 60% of all the sites that supported both GSM and UMTS were considered to have multi-standard basestations installed and attract lower upgrade costs as a result of this. Also, it has been assumed that existing sites do not have antennas installed to support 800 MHz which based on our industry knowledge we feel represents current network deployments. We take in to account the clutter type of the location of existing sites when considering the cost associated with that site and in particular the backhaul cost associated with that site. Also realising that in there will be a mix of fixed and microwave backhaul options depending on the remoteness of sites, different proportions of sites in different clutter types were assigned microwave backhaul types as shown in the table above and as agreed with Ofcom.

4.2 Use of present value (PV) costs

After discussion with Ofcom it was agreed that the phase 2 method should capture the following two PV upgrade costs of each site:

- PV based on cost of capital
- PV based on social discounting

When upgrading sites in the cumulative cost model the order of upgrading sites is selected based on the cost of capital PV upgrade cost (but the social discount PV cost is also reported).

The PV calculations were carried out based on the following assumptions:

- A 20 year present value calculation
- No residual value assumed
- Civil works cost not repeated during the 20 year period
- Capex is assumed to be at the beginning of the year
- Opex is assumed to be incurred midyear
- Social discount rate of 3.5%
- Cost of capital rate of 6.2%
- Equipment life of 10 years
- 0% assumed for real price trends for civil works, all equipment and on-going costs

These assumptions and the PV calculation methodology were specified by Ofcom.

4.3 Example of site upgrade costs assumed

As an example of the upgrade costs used within the phase 2 model, Table 4-2 gives example PV 4G upgrade costs for sectored sites with fixed line backhaul. A significant factor in the cost of these sites is the backhaul provider's construction cost involved in upgrading the fixed line connection to the site. In the case of rural GSM only sites with low capacity existing backhaul this cost could be between £20k and £150k depending on factors such as the remoteness of the site.

	Urban	Urban	Suburban	Suburban	Rural	Rural
	Single standard BS	Multi standard BS	Single standard BS	Multi standard BS	Single standard BS	Multi standard BS
	Fixed line	Fixed line	Fixed line	Fixed line	Fixed line	Fixed line
	Cost	Cost	Cost	Cost	Cost	Cost
Civil works (excluding BT construction costs)	£27,950	£18,000	£29,400	£19,450	£52,050	£42,100
Equipment costs (excluding BT construction costs)	£22,300	£12,800	£22,300	£12,800	£21,700	£12,200
OPEX	£21,450	£13,700	£21,450	£13,700	£21,450	£11,200
Total PV of costs (excluding BT construction cost) - using social discount rate	£376,204	£237,962	£377,654	£239,412	£399,279	£224,889
Total PV of costs (excluding BT construction cost) - using cost of capital	£311,946	£197,153	£313,396	£198,603	£335,117	£191,248
BT construction costs	£0	£0	£10,000	£10,000	If GSM 20,000 + Rand * (150,000-20,000) If 3G support £10,000	£10,000
Total PV of costs - using social discount rate	£376,204	£237,962	£387,654	£249,412		£234,889
Total PV of costs - using cost of capital	£311,946	£197,153	£323,396	£208,603		£201,248

Table 4-2: Example cost outputs from the cost modelling for use in Phase 2 model

4.4 Assumptions on MIP site upgrade costs

In the case of upgrading MIP sites the 4G upgrade costs are slightly different than for existing MNO sites. We make the assumptions shown in Table 4-3 when determining 4G upgrade "build" costs for MIP sites.

	Notes
Key assumption	All MIP sites will have been acquired and designed to support the 4G upgrade requirements and the site agreement between the MIP site owner and MNOs allow for the additional 4G frequencies to be deployed without any additional negotiation or cost – the key impact of these assumptions are:
Planning & site negotiation	There will be no requirement to obtain planning or site owner consent for the upgrade works – there will be a requirement to engage with the site owner to both plan and manage the upgrade works as this will be a shared site and the hardware on the tower is assumed to be under the control of the site owner.
Upgrade work	The physical components that will need to be upgraded to support 800MHz on a MIP site will be the antenna, the combiner and the base station software. The transmission link installed for the MIP site is assumed to be capable of being upgraded without incurring additional Capex costs and all costs associated with the increased backhaul capacity are Opex only.

Table 4-3: Build assumptions for MIP sites

We also make the following assumptions for upgrade costs as in Table 4-4 related to site features when determining 4G upgrade costs for MIP sites.

Site Feature	Notes
Multi-standard basestation at the site	We assume that all MIP sites will have multi standard basestations. This is based on all MIP sites being new installations and so will have the latest basestations installed which in the case of Huawei and NSN at least would support an upgrade to 4G via software. MNOs may decide to reuse an old basestation from a busier site that they are upgrading to 4G on a MIP site but we assume that they would not do this on sites that they require to meet the coverage obligation at 800MHz.
Existing support for 800MHz	We assume the worst case that MIP sites won't initially have installed antennas to support 800MHz and would need existing antennas and combiners to be replaced to support 800, 900 and 1800MHz.
Location type Rural, urban or	The site location type for each MIP site will be determined from the clutter type of the pixel from the clutter database that the

suburban	site falls into. It is likely most MIP sites will be rural but we don't automatically assume this.
Microwave backhaul	We assume that there will be the same opportunity to use microwave backhaul on MIP sites as for existing sites in line with the following assumptions: We assume that urban areas where high rooftop sites are available will have more potential for LOS microwave backhaul. Whether a site supports a microwave backhaul is randomly distributed based on the site location type as follows: • Rural 20% of sites to support microwave links • Suburban 40% of sites to support microwave links • Urban 50% of sites to support microwave links

Table 4-4: Site features assumptions related to MIP site upgrade costs

5. Appendix 1: Link budget parameters and assumptions

The Table 5-1 shows the list of parameters and assumptions used in the link budget used to calculate the unadjusted LTE 800 MHz indoor coverage planning level.

			LTE 800 (2 Mbps) Min Var BPL		LTE 800 (2 Mbps) Max Var BPL		Comments
Parameters	**symbol**	**Units**	**DL**	**UL**	**DL**	**UL**	
Frequency band		MHz	800	800	800	800	
Receiver type			UE	Macro	UE	Macro	
Number of antennas	AntCnt		2	2	2	2	Technology specification
Bandwidth	BW	MHz	10	10	10	10	10 MHz typical bandwidth expected for initial LTE roll out
Maximum licensed EIRP DL		dBm	64.0	N/A	64.0	N/A	64 dBm in 10 MHz bandwidth [4]
Subcarrier Spacing, Receiver filter BW	subBW	kHz	15	15	15	15	Technology specification
Utilised EIRP/10MHz (over all antennas)	EIRP10	dBm	63.3		63.3		64 dBm adjusted based on the loading level (typically 85%) to give 63.3dBm [5] NB: This is the total EIRP for the system
Utilised EIRP (over all antennas)	EIRP	dBm		23.0		23.0	Assumption for UL from [4]
Tx antenna gain	TxGain	dBi	15.4	-1.1	15.4	-1.1	Assumption from [4].

Transmit Cable, Combiner and Connector Losses	TxCCCL	dB	0.0	0.0	0.0	0.0	Assumption from [4]
Max power (over all antennas)		dBm	47.9	24.1	47.9	24.1	=EIRP-TxGain+TxCCCL
No of occupied Subcarriers	subCnt	subcarriers	600	12	600	12	Technology specification
No of occupied Resource Blocks	RBcnt	RBs	50		50		Technology specification
EIRP in channel	EIRPch	dBm/15 kHz/ant (DL)	32.5	12.2	32.5	12.2	=EIRP - 10*LOG10(subCnt) - 10*LOG10(AntCnt) (DL), EIRP - 10*LOG10(subCnt) (UL)
Receiver Antenna Gain	RxGain	dB	-1.1	15.4	-1.1	15.4	Assumption from [4].
Body Loss (relative to free space)	RxCCCL	dB	5.0	5.0	5.0	5.0	Assumption Data-Smartphone, 5 dB (UE) for data and 3 dB (UE) for voice [4].
Noise figure	BL	dB	10.0	5.0	10.0	5.0	Assumption from [4]
Thermal Noise Density	NF	dBm/Hz	-174	-174	-174	-174	Constant
Thermal Noise	thNsDns	dBm	-132	-132	-132	-132	=thNsDns+10*LOG(subBW*1000)

Background RSSI	thNs	dBm	-122	-127	-122	-127	=thNs+NF
Interference Degradation Margin	RSSI	dB	3.0	1.0	3.0	1.0	Assumptions based on industry practice, [3] and [6]
Coverage obligation	IM	Mbps	2.0		2.0		Project input, 2 Mbps
Network loading	covObl	%	85%		85%		Assumption, The loading is defined here as the percentage of available resources (frequency and time) used to deliver download service to users as in [4]
Frequency selective scheduling gain	Loading	%	0%		0%		Assumption, Single user active on the network
Overhead	schGain	%	20%		20%		Assumption from [4]
Number of RB's available for data	OHpc	RBs	34		34		=floor(RBcnt*Loading*(1-OHpc))
Required throughput per data RB	RBcntData	Mbps	0.06		0.06		=covObl/RBcntData
Required spectral efficiency in data RB	reqThPerDatRB	bps/Hz	0.33		0.33		=reqThPerDatRB*1000/(subBW*12) / (1+schGain)
Required SNR	reqSE	dB	-5.00	-5.00	-5.00	-5.00	Assumption from MaxVar case in [5]. Note: For a single cell edge user at 2Mbps this minimum SNR cut-off is the limiting factor on

							coverage rather than the SNR required to achieve 2Mbps.
Sensitivity	reqSNR	dBm	-127.2	-132.2	-127.2	-132.2	=RSSI+reqSNR
Cell-edge coverage-confidence	RxSens	%	0.78	0.78	0.78	0.78	Assumption, Corresponds to approx. 90% cell-area coverage-confidence [7]
Confidence factor			0.77	0.77	0.77	0.77	Inverse of the normal cumulative distribution (mean: 0)
Location variability (outdoor)	cf	dB	8.3	8.3	8.3	8.3	Assumption, non-urban geotype from [4]
Buliding penetration loss (BPL)	Lv_sd	dB	8.4	8.4	10.5	10.5	Mean values used for MinVar and MaxVar BPL assumptions specified by Ofcom
BPL SD	BPL_mn	dB	5.4	5.4	6.8	6.8	Standard deviation values used for MinVar and Max BPL assumptions specified by Ofcom
Fade margin (indoor)	BPL_sd	dB	16.05	16.0	18.79	18.8	=sqrt(Lv_sd^2+ BPL_sd ^2)*cf + BPL_mn
Fade margin (outdoor)	FM_in	dB	6.4	6.4	6.4	6.4	=sqrt(Lv_sd^2+ 0^2)*cf + 0
Maximum path loss (indoor)	FM_out	dB	134.52	137.7	131.78	135.0	=EIRPch + (RxGain-RxCCCL-BL) - RxSens - FMin – IM
Maximum path loss (outdoor)		dB	144.2	147.4	144.2	147.4	=EIRPch + (RxGain-RxCCCL-BL) -

							RxSens - FMout –IM
Planning level (indoor)		dBm	-71.2	-114.7	-68.5	-112.0	=EIRP-MAPL_in

Table 5-1 : Link budget assumptions and parameters

List of Acronyms

2G	Second generation systems e.g. GSM, IS-95
3G	Third generation mobile systems, e.g. UMTS
4G	Fourth generation mobile systems e.g. LTE, WiMax
CAPEX	Capital expenditures
CPE	Customer premises equipment
dBm	Decibels of measured power relative to a milliwatt
EIRP	Equivalent isotropic radiated power
GSM	Global system for mobile communication
MAPL	Maximum allowable path loss
MIP	Mobile infrastructure project
MNO	Mobile network operator
LOS	Line of sight
LTE	Long term evolution of mobile systems
OPEX	Operating expenses
PV	Present value
TCF	Terrain correction factor
UMTS	Universal mobile terrestrial system

Glossary of terms

Backhaul: Backhauls are the systems that link remote cellular basestations with the central network. Depending upon the wireless technology used the required backhaul capacity to transfer data between networks vary. For example, there are copper lines, fiber optic and microwave backhaul options available for the cellular industry.

Building penetration loss: Attenuation of radio signals transmitted from basestation or mobile handsets when dense medium such as building walls are encountered. In calculating the received signal level for a given transmitted signal power, BPL has to be taken into account which ranges from a few dB to tens of dB.

Capex: Capex or Capital expenditure is an expenditure that is incurred when a business spends money to buy fixed assets or add values to the existing assets. For examples mobile operators' spending on infrastructure and radio equipment for new sites or buying additional equipment for technology upgrades to 4G would be considered Capex.

Clutter type: Clutter type is a classification of geographical areas with varied densities of building or other obstructions in terms of coverage of radio signals. Generally there are three clutter types specified in the literature: urban, suburban and rural. By classifying each area in to these three clutter types, radio planning engineers can calculate the maximum coverage range of a transmitter.

Hata model: This is an empirical radio frequency propagation model which is used to estimate the path loss behaviour in different geographic areas. The Hata model along with the clutter type of a geographical area can be used to estimate the maximum coverage range of a transmitter at a simplified level at least. In practice local terrain conditions will shape a site's coverage area.

Opex: Opex or operating expenditure is an on-going cost for maintaining business day to day activities. This, for example, can be costs associated with power supply to sites, network and site maintenance.

Terrain correction factor: Some radio propagation models such as the Hata model are not designed to take into account local terrain information when predicting the coverage. To allow for this terrain correction factors can be introduced (as in our model) so that the predicted coverage ranges of transmitters are closer to those obtained from real measurements.

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