Field Measurements to Assist Ofcom to Verify the Approach to the Assessment of 3G Operator Rollout

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About Red-M

Red-M is a wireless professional services company that provides consultancy, audit, design, implementation, systems integration and management services. Through its services, Red-M provides insight into the benefits and challenges of current and future wireless technologies and creates mission critical wireless networks that are delivered to requirements, right, first time.

The company's capabilities span all wireless technologies including Cellular (2G, 3G & GSM-R) PMR, Wi-Fi and WiMAX, and its customers include 3, Airwave, BAA, British Land, Bullring, Network Rail, O2, Ofcom, and T-Mobile.

Red-M has successfully completed 1000s of radio projects including over 300 major wireless systems in a range of diverse and challenging locations, including corporate buildings (e.g. Canary Wharf), most of the major airports in the UK (Heathrow), large shopping centres (Meadowhall), key UK sporting venues (Millennium Stadium), train stations (Waterloo), and hospitals (Bristol).

Executive Summary

This document proposes a measurement methodology to assist Ofcom in a benchmarking exercise to assess the validity of their approach to the analysis of mobile network operators' 3G rollout obligations.

The measurement methodology shows how to determine the errors due to measurement, which are due both to basic accuracy of the scanning receivers proposed, and also due to the requirement to take a sufficient number of samples in a local area to enable the filtering out of the effects of 'fast fading' whilst keeping the integrity of the measured signal level. The analysis in this document has shown that it is possible to measure local mean signal strength to an accuracy of ±1.7dB.

This report also proposes how to plan a measurement campaign to help determine the accuracy of the models used during the benchmarking process. The approach is in essence to:

- Determine the areas where Ofcom and MNO models produce contradictory predictions of coverage at the defined level – the 'combined marginal' areas.
- Design a drive test passing close by population centroids, suitable for linear prediction methods.
- Perform a linear prediction process to predict the signal strength at the population centroids near the drive routes.
- For the areas that have been driven, calculate population coverage, using the 2001 census data.
- Calculate the 'hit rate' of the Ofcom implementation of P.1546-2 for the areas driven, by comparing the predicted signal strengths at the centroids with measurements.
- Use the hit-rate to estimate population coverage in the combined marginal areas that have not been driven.

The benefits of applying this methodology will be to give increased confidence to the assessment methodology based on the engineering analysis proposed by Ofcom. The incorporation of measurements into the process as described in this document will allow an assessment of the level of uncertainty in the engineering analysis to be made during the benchmarking process, and will also allow this level of uncertainty to be reduced. This benefit will be particularly significant during rollout obligation determination if the assessed population coverage of any of the operators is very close to the minimum prescribed by their licence conditions.

Table of Contents

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1. Introduction

The 3G licensees have an obligation to provide a telecommunications service to an 'area where at least 80% of the population live' by the 31st of December 2007. Ofcom reiterated in the 3G Rollout obligations statement published on the 27th of February 2007 that it expects all 3G licenses to meet the requirements for rollout as stated in their licences. This statement summarised the conclusions of the 2006 consultation in which Ofcom proposed three basic methods to assess compliance, being

- engineering analysis by Ofcom
- physical field strength measurement by Ofcom or an agent
- operator self-declaration (either based on prediction, measurement or a combination).

Ofcom intends to use a methodology based on engineering analysis backed up by measurements in the field to verify the results as necessary.

This report explains Red-M's proposed measurement methodology to support Ofcom's engineering analysis.

Red-M has been asked to split the measurement support task into two work packages

- WP1 – the production of the measurement methodology (this document)
- WP2 – undertaking measurements and processing results according to the methodology. If and when these measurements are taken, measurement reports would be produced.

In its recent statement, Ofcom has made it clear that they will assess coverage based on:

- data about base stations supplied by the licensees, mapped to 5 standard antenna types
- population data from the 2001 Census
- predictions arising from a standard planning tool (XG-Planner) using the ITU-P1546-2 model to predict 50% locations / 50% time signal strength outdoors at 1.5m from the ground using 100m resolution terrain data and assuming 10m clutter height
- a predicted CPICH level of -110dBm or greater

The statement, attached in *Appendix A: Ofcom 3G Rollout Obligations Statement*, also sets out a clear timetable for activity that will take place in the run up to the determination of coverage in early January 2008. The determination of coverage will be based on data supplied by the operators at the end of 2007. In the run up to this determination, a benchmarking exercise will take place. The benchmarking exercise will allow the methodology to be refined in a sample area, which is an area measuring 100km x 100km in the South-West of England. In order to support the benchmarking exercise, drive test measurements undertaken according to the methodology contained in this document may be required.

This report provides answers to four key questions:

- what the objectives of measurements are
- where the measurements should be taken
- in what form the results should be presented
- what should be done with the measurement results

Ofcom's timetable also anticipates that additional drive tests may be required in early 2008. These additional drive tests are out of the scope of this project. Red-M anticipates that the methodology presented in this report could also be applied to the 2008 drive tests, despite the fact that the objectives of these latter drive tests would be 'determination' rather than 'benchmarking'.

The different objectives of the 'benchmarking' drive tests and the 'determination' drive tests will affect the choice and number of locations measured, but the basic methodology for selecting drive test routes is a deliverable of this report. During 'determination' tests (as opposed to 'benchmarking'), Red-M considers that measurements will only be relevant for operators such as 'MNO C' in Figure 1, whose assessed coverage is a disputed/marginal fail within the uncertainty of Ofcom's engineering analysis.

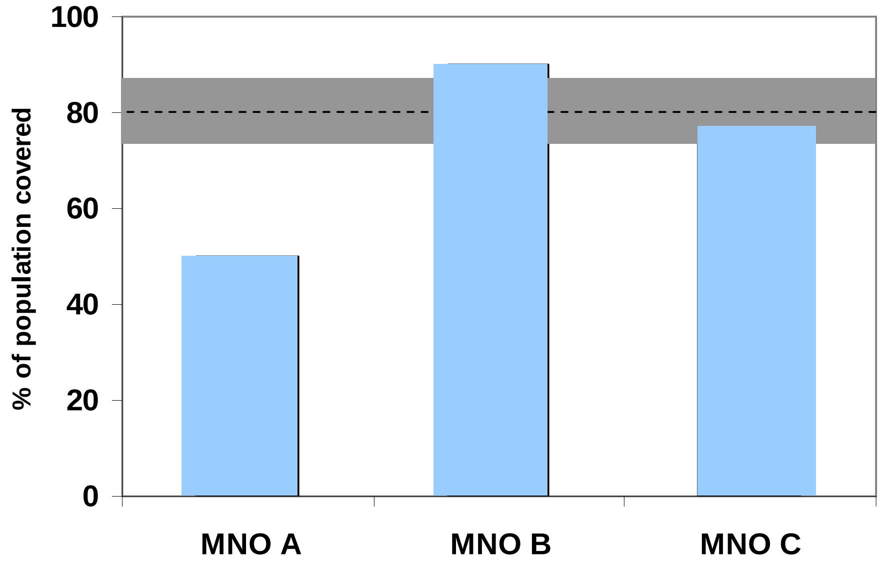

Figure 1 Three 3G operators: A- Fail, B – Pass, C – Result within uncertainty of engineering analysis

Red-M's proposed measurement methodology will allow the number and extent of drive-tests potentially required in January 2008 to be assessed as part of the benchmarking exercise.

2. Recommended approach

The ultimate objective of Ofcom is to determine whether operators have met their *population* coverage objective. This objective has a significant impact on the appropriate drive test methodology.

In essence, the ultimate objective is to achieve a binary decision pass/fail using a methodology accepted by stakeholders that treats each operator the same way. Some potential drive testing methodologies fail to address this objective efficiently as shown in Table 1.

Potential Objective	**Potential Test Methodology**	**Comment**	**Potential Value?**
Confirm Accuracy of Operator Site Data (site transmitting, orientation & downtilt correct etc)	Drive by Random Sample of Sites	Operator data assumed good and certainly not ‘weakest link’. Intensive measurements required for statistically significant result	No
Tune Propagation Model	Drive in representative sample of clutter types and assess correction mean/standard deviation	ITU P.1546 model not tuneable under terms of Ofcom’s published methodology. Intensive campaign required. If accuracy key requirement would probably use operator tuned models.	No
Assess Population Coverage in Selected Areas	Limited drive test in areas chosen from GIS with linear prediction based interpolation to 2001 census OA centroids	Gives population coverage % and confidence interval in measured areas only. Potentially need extensive drive tests.	Yes

Table 1 Potential Drive Test Methodologies

Since drive testing is a relatively costly activity, Red-M’s approach is to identify the minimum amount of drive testing commensurate with that overall objective. Population coverage is to be determined by Ofcom on the basis of coverage at the -110dBm CPICH level at the centroid of a 2001 census Output area (OA). Output areas vary greatly in size, depending on population density, but in urban and suburban areas they are generally smaller than a 3G cell.

With respect to Ofcom's objectives, four types of output areas could potentially be encountered for any one of the five operators, as shown in Figure 2.

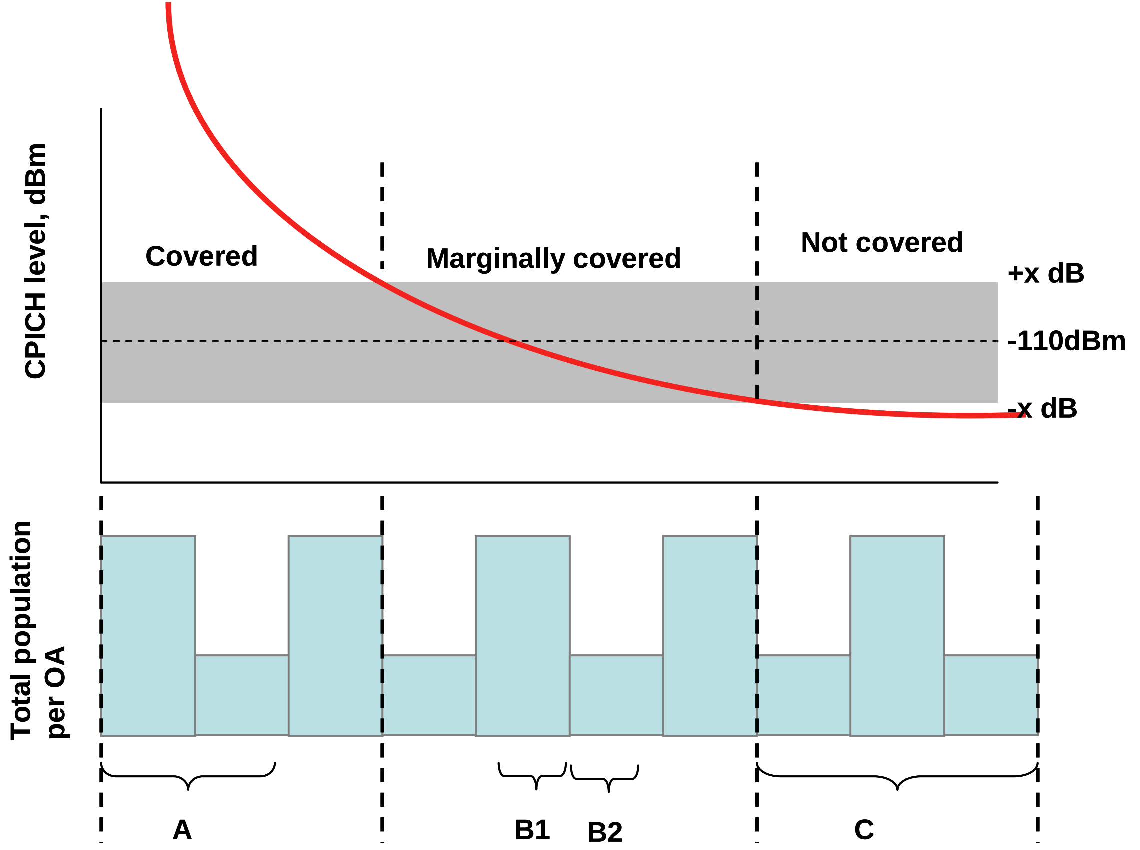

Figure 2 Types of output area coverage likely to be encountered. OA type 'B' is at the edge of cell coverage

The four types of output area are:

- A – area well in coverage – accuracy of Ofcom's engineering analysis does not affect %pop result
- B – coverage at or around -110dBm
    - B1 – high population density – accuracy of Ofcom's engineering analysis could have significant effect on population result
    - B2 – low population density – accuracy of Ofcom's engineering analysis not likely to have significant effect on population result
- C – well out of coverage – accuracy of Ofcom's engineering analysis does not affect %pop result

For areas of 'Type A' and 'Type C', assessing total population in coverage will simply consist of summing up the OA populations in areas determined by Ofcom's engineering analysis to be of 'Type A'. The added-value of measurements will be to estimate the confidence with which the model is accurately determining the coverage levels of the areas on the edge of coverage (i.e. areas of 'Type B'). Ideally, measurements should be focussed on obtaining an estimate of the statistical uncertainty of the engineering analysis predictions for the centroids of output area clusters of type B1. Areas of ‘Type B1’ are those with relatively high population density, where the output areas are geographically smaller, and a given length of drive test route will bypass a large number of OA centroids.

For benchmarking, all operators should be treated equally, and the coverage of all operators’ networks should be tested. Since B1 type output areas of each operator are unlikely to be exactly co-incident, additional measurements may be needed to meet the objective for all operators simultaneously. This measurement methodology will define how these areas would be chosen bearing in mind the objectives of the benchmarking exercise which are to validate Ofcom’s prediction methodology without recourse to a large measurement campaign.

2.1 Selecting the measurement areas

2.1.1 Measurement uncertainty

The boundaries of the marginal coverage area determined by measurement (i.e. the area for which the CPICH level is at -110 dBm) will be affected by the uncertainty introduced by the measurement system. One part of this uncertainty will remain constant throughout the measurements (antenna gain, feeder loss, any receiver offset) and should be eliminated by factoring in an offset into the measured data as part of the system calibration.

There remains a residual measurement uncertainty. The overall measurement variability will be a combination of the receiver accuracy s_{RX} and of the uncertainty in the estimation of the local mean s_{LM}. Since these two processes are independent of each other and both are characterised by normal sampling distributions[1], the overall measurement variability caused by both effects can be expressed as:

$$s_{MEAS} = \sqrt{s_{RX}^2 + s_{IM}^2}$$

Receiver accuracy s_{RX} is further characterised by two independent processes - RF measurement variability over time & RF level and variability associated with the quoted frequency/temperature range of the instrument.

Uncertainty in the estimation of the local mean s_{LM} arises from the fact that the estimate of the local mean is derived from a number of measurements on signals subject to a Rayleigh fading channel. A better

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[1] The sampling distribution is normal, even if the variable to be sampled is Rayleigh distributed.

estimate of the local mean is obtained when a larger number of samples are taken in the area where shadowing remains fairly constant[2].

Appendix B: Error Analysis assesses s_{RX} for the proposed measurement equipment, and calculates the sampling rate required to achieve a s_{LM} = ±1dB for a UMTS wideband signal[3]. s_{RX} and s_{LM} are both assessed for the 90% confidence interval. The total measurement variability at the 90% confidence level will therefore be:

$$s_{total} = \sqrt{s^2_{RX(time/lev)} + s^2_{RX(freq/temp)} + s^2_{IM}} = \sqrt{2^2 + 2^2 + 2^2} = 3.4 \text{ dB},$$

or ±1.7 dB.

2.1.2 Area Selection process

Steps for selecting areas:

i. Compare MNOi CPICH coverage (where i is MNO index and varies between 1 and 5) at -110dBm obtained by P.1546 (using site data and parameters provided by MNOi) and coverage provided by MNOi' own planning tool. Coverage difference between the two models will be obtained using the utility available in MapInfo's Vertical Mapper as advised by Ofcom. In an ideal situation, both coverage areas would be the same. It is recognised that P.1546 is not a tuned model and so there will be differences between the two sets of predictions.
ii. Superimpose the Census 2001 population geo-centres onto the area where coverage from all five MNO's models differ from that obtained by Ofcom as discussed.
iii. Select from above the areas where clusters of high populations are present.
iv. Design the routes to pass through most of the population centroids.

This approach assumes that P.1546 will provide a reasonably accurate description of the mean received CPICH level for all operators. Should the model be systematically out by a value that is much higher than the measurement uncertainty (e.g. if Ofcom assumes a CPICH level that is always lower or higher than what operators use, or if a particular clutter environment is not particularly well resolved by P.1546) then there is a potential risk that the models will disagree over a very wide area. If this is

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[2] Shadowing is caused by signal blocking due to geographic and man-made features that are positioned along the radio path between the transmitter and the receiver.
[3] Appendix B shows how the sampling rate required for a UMTS wideband signal can be related to the Lee Criterion for narrowband signals, but that when the received signal bandwidth is wider than the coherence bandwidth of the channel, a lower sampling rate can be tolerated.

the case, then step (iii) and (iv) above need to be more selective, so that a reduced measurement area is targeted.

2.2 The Benchmarking Process

For the benchmarking process, the situation illustrated by Figure 2 is made even more challenging by the fact that it is not just a single model (with its own uncertainty) that is used to determine which areas are in coverage and those that aren't, but two models: Ofcom's own P.1546 implementation (using operator's site parameters) and each operator's predicted coverage output from their own "tuned" model.

Since the two models (i.e. P.1546 and each of the operators own model) will be based on different physical assumptions, implementations and underlying terrain and clutter data, it is very likely that the two models will produce different coverage footprints for the -110dBm CPICH level contours.

The approach that we propose is to target the areas where the majority of MNO's predictions disagree with P.1546 at the -110dBm threshold (to within the uncertainty of the measurement). This way, the measurement process will optimise the use of the drive data by ensuring that a larger sample of data comes from areas where the models are in disagreement and thus will allow Red-M to determine the level of accuracy of the predictions.

In an ideal situation where the MNO and P.1546 predictions were exactly the same and predicted accurately the -110dBm contour, measurements would not be required but if, for hypothetical reasons they were required for verifying the predictions, one would simply need to drive as closely as possible to the -110dBm contour line on both sides to make sure that the predictions were always above on one side of the line and below on the other side.

Since there is an uncertainty in both MNO and P.1546 model, and that measurements will also carry a certain amount of uncertainty, the contour line becomes an area as illustrated in Figure 3.

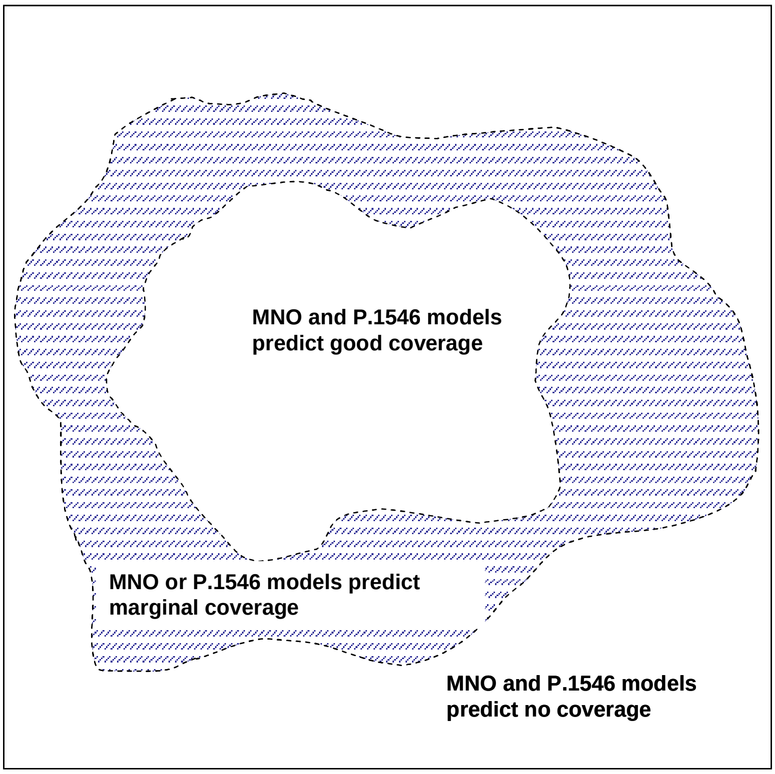

Figure 3 For the benchmarking process, the combined marginal coverage areas predicted by Ofcom's and the MNO's models will be investigated

The process by which we would define whether a population centroid is covered or not will be:

- Sum up all the population in the areas where both MNO and P.1546 predict no coverage and assume this subset of the population not to be covered. (Areas of 'Type C' from Figure 2)

- Sum up all the population where both models predict coverage and assume this sub-set of the population to be covered. (Areas of 'Type A' from Figure 2)

- In the "combined marginal" areas for which there are measurements, use the processed and interpolated measurements (see sections *2.4 Data Processing* and *2.5 Data interpolation*) to determine covered population. (Areas of 'Type B' from Figure 2). Add this to the population in areas of 'Type A'

- In the "combined marginal" areas for which there are no measurements, use a model 'hit rate analysis' to determine the likely population covered. The 'hit rate analysis' is an analysis that compares the model to measured values in the marginal area, and uses this to extrapolate in areas where no measurements have been taken. In doing this we assume that the statistical performance of the model is the same in areas where the hit-rate analysis has been performed and in areas where no measurements have been taken (in this case, both are in the marginal "type B" coverage area). The measurements will be compared to the model to predict the hit rate of the model. If this comparison is done at three threshold levels: -110 dBm, -111.7 dBm and -108.3 dBm, then the sensitivity of the results to measurement uncertainty can also be assessed.

The hit rate [see [4] for more detail] is a statistical means of providing a measure of the extent to which two processes agree (here the model prediction and the measurements). For the hit rate analysis, we will compare at each 100m pixel of the "combined marginal" area where measurements are available whether the model and the measurements are both above the selected threshold.

The output of the hit rate analysis will be a percentage value (at each threshold) that expresses the number of pixels where both P.1546 and measurements agree.

Table 2: Hit Rate Analysis

Model Prediction (P.1546)	Measurement Prediction	Hit?
covered	covered	Y
not covered	covered	N
covered	not covered	N
not covered	not covered	Y

The percentage value at -110 dBm will provide the median which will be used to weight the percentage of population in the "combined marginal" area that would be in coverage. The percentage values at -111.7 dBm and -108.3 dBm will provide the confidence interval for the measurement uncertainty.

Hit rates could be determined against the "nearest" measurement point (bearing in mind that the predictions are over a 100m resolution grid), against the mapped measurement data (see section 2.4.4), or against the interpolated measurement data (2.5).

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[4] A. S. Owadally, E. Montiel and S. R. Saunders, "A comparison of the accuracy of propagation models using hit rate analysis", IEEE Vehicular Technology Society Conference, Fall 2001.

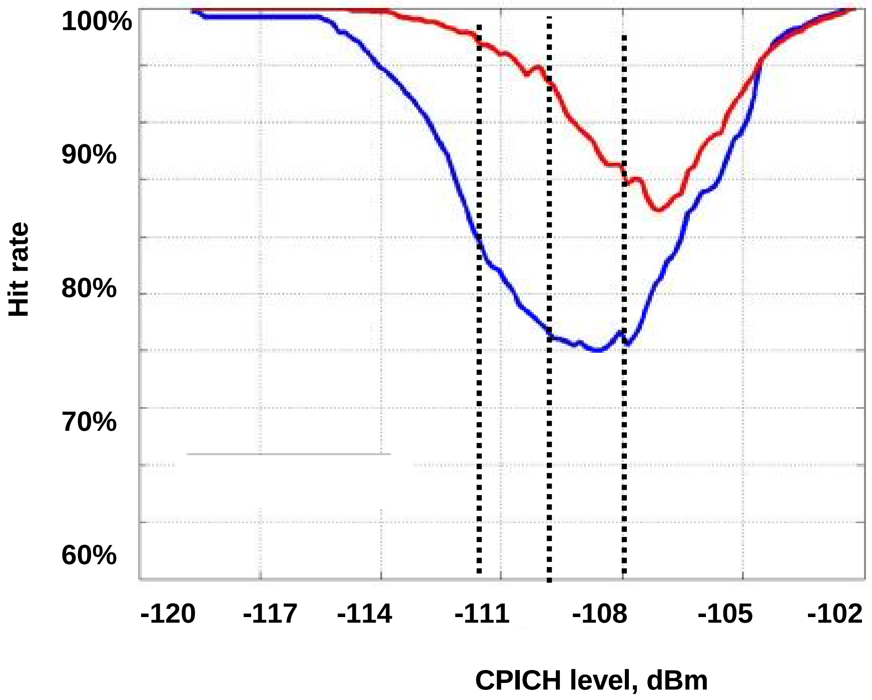

Figure 4 Example output from a hit rate analysis

Figure 4 shows an example of the output to be expected from a hit rate analysis. This summary curve does not distinguish between the 'model covered / measurement not-covered' and 'model not-covered / measurement covered' cases in Table 2, though in practice these are distinguished during the analysis. The red and blue curves will represent the analysis using the nearest measured data point and the interpolated data respectively for example. Examination of the collected data will be used to determine the best comparison data. At each of the three selected thresholds, each curve will yield a hit rate value that will be used to weight the total population in the "combined marginal" area.

The 'hit rate' analysis gives a quantitative assessment of the quality of the model as well as providing the mechanism by which the measurements are used to improve overall prediction accuracy. There is, however, a limit to the degree to which a poorly performing model can be improved in this manner. *If* the hit-rate analysis showed that the P.1546 model was performing poorly, then improved accuracy in the population coverage estimate would be achieved if a more accurate model were used for the underlying predictions. After measurements have been taken, it is a fairly simple operation to redo the hit-rate analysis using a different model when predictions from that model for the same geographical area are available. An example of an alternative model that could easily be compared to P.1546 using hit-rate analysis would be an extended COST231/HATA like model. Red-M would undertake a hit-rate analysis of a different model if Ofcom determined that this would be a useful exercise following assessment of the results of the P.1546 hit-rate.

2.3 Survey methodology

2.3.1 Drive route design

The drive route should be as extensively and as evenly distributed across the area of interest as can possibly be achieved under the timescales and other constraints of the data collection.

A route will be chosen that best attempts to drive across the area in a meshed pattern, passing through as many population centroids as possible. An example is shown in Figure 5.

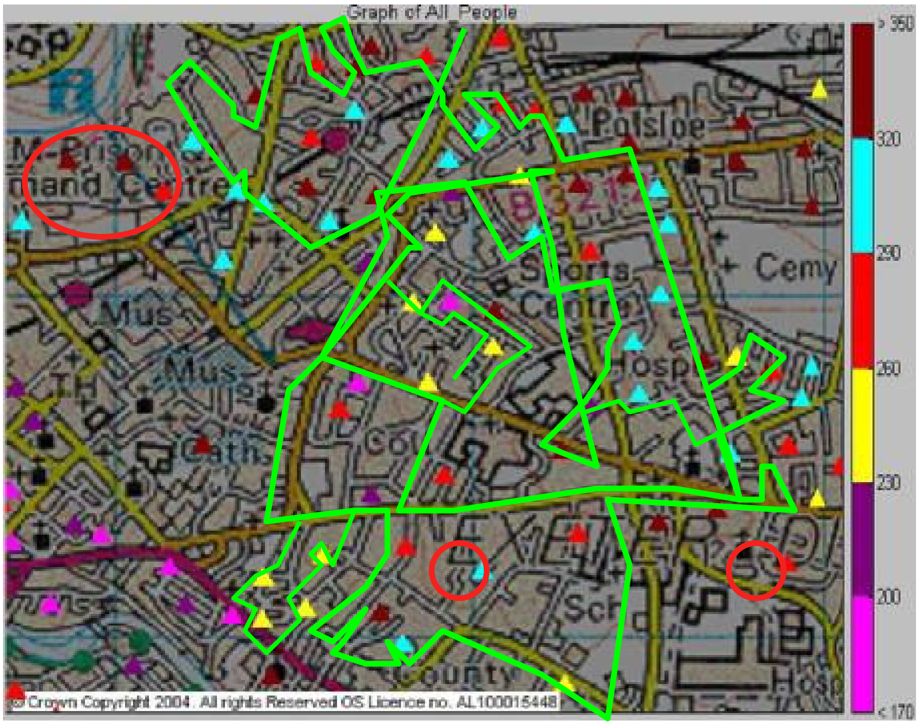

Figure 5: Illustration of a drive route design passing through most OA centroids with the highest populations. Some centroids (circled in reds) will not be driven by because of their remoteness or lack of nearby road. The centroids are colour-coded (scale on the right) according to population number.

Driving along Motorways and A-roads will be avoided where possible (except for access or transfer between areas) as these would generally be less populated than secondary roads.

In rural areas where the road network might be less dense than in a suburban or urban areas, the drive route should cover a large proportion of the routes available to drive, bearing in mind that only populated roads should be targeted.

The following output should be provided with each drive route:

- Summary of test details.

- Measured data containing the co-ordinates of the measured location and the signal strength of the dominant CPICH. Signal strength data represent the moving local mean over a 40 wavelength window, centred on the recorded coordinates (see *B.2.2 Estimation of the Local Measurement Mean* for more detail on the relationship between vehicle speed and local mean estimation).
- Map plot of coverage levels using a colour scheme showing the -110dBm level and the 90% confidence interval limits. A 1:50,000 scale map should preferably be included as background.

Detailed format of the data file is described in *Appendix C*.

2.3.2 Drive route density

Every attempt should be made to drive through or near population centroids, with the aim to drive a minimum of ~80% of the centroids in each selected location within the Benchmarking area (see *Appendix D: Benchmarking Area* for a description of the area).

Density (i.e. the number of roads that need to be driven within the same location) is not a major issue since the linear prediction method (see section *2.4 Data Processing*) is able to handle missing sections of roads provided data is collected in the vicinity. Priority will therefore be to evenly distribute the drive route rather than concentrate all the driving to a particular area.

There is a minimum density to be satisfied that depends on the concentration of OA's and on the population in those OA's. From the census 2001 data, we can conclude that population numbers are approximately the same between OA's but that the area of OA's will be in roughly inverse proportion to the population density. As a result, population centroids will be more closely distributed in highly populated areas and less so in rural areas.

The other factor that will have an influence on the choice and density of drive routes is the resolution at which the benchmarking is being conducted. According to Ofcom's benchmarking procedure, the model predictions will be generated over a grid of 100m resolution. As a result, if a given area has multiple roads that are separated by a distance smaller than the benchmarking resolution, only one of those will need to be driven by.

2.3.3 Mix of clutter

If the area targeted for measurements consists of two or more distinct types of clutter, non-evenly distributed across the total area (e.g. a suburban environment on one side and an open area on the other side), it is recommended to drive in all types of clutter accessible around the site in order to capture any variability in the coverage that might not have been resolved by the model.

This approach should primarily apply to target areas where significant portions of the area fall within two or more clutter categories. No particular attention will need to be taken in instances where there are small pockets of distinct clutter (e.g. Open parks in a predominantly suburban area) as these are likely to represent only a small proportion of the targeted population.

This will ensure that resources are used efficiently and that the local variability is captured by the process.

2.4 Data Processing

2.4.1 Distance averaging

Distance averaging of the measured data (with travelled distance) with a view to removing the fast fading component from the measurements is taken care of by the scanning receiver, aiming to achieve ±1 dB for 90% confidence as explained in *Appendix B Error Analysis*.

Averaging should be triggered by a pulse sent by the survey vehicle's odometer so that when the vehicle is stationary (e.g. at traffic lights) the receiver should not output a data point at that location.

2.4.2 Removing measurements from untypical locations

Every care should be taken to identify areas where the measured CPICH levels are not representative of the levels in the area. This generally happens in locations where there is a strong interference activity, or when the drive route is more (or less) exposed than the surrounding area, such as over or under bridges, in tunnels, flyovers or deep trenches. These instances will be rare and far apart but, more importantly, would not be representative of the CPICH levels at "street" level.

Every care should be made to avoid routes which would significantly bias the results. An example of such a route in the West Country would be narrow rural road surrounded by high earth banks with wall and hedgerow on the top. The signal strength on these routes is not representative of the signal in the area, and including a large number of measurements of this type could bias the model 'hit rate analysis'.

The prediction model used by Ofcom (P.1546) would not be capable of resolving these man-made features and would therefore result in underestimating (or overestimating) the levels at those locations, leading to a distorted representation of the CPICH levels at the pixel encompassing the feature.

We would therefore recommend filtering out all measurement points that were captured in these types of location.

This filtering is accomplished in practice in three ways
- Drive Route Design. The route is designed to avoid routes which appear on the map to be unsuitable. An example in this case would be the narrow rural road surrounded by high earth banks.
- Post Processing. The measured levels are plotted over an Ordnance Survey map, and large local variations in signal strength associated with tunnels and bridges can be identified visually. For interpolation purposes, these data points can be easily removed from the drive test data manually using a proprietary tool.
- Marking Up Routes. Where large sections of route are tainted, and where this was not anticipated during drive route design, or the drive route has to follow undesirable routes due to local road layout (e.g. road works, one-way restrictions), affected routes are marked manually on a map by the drive test team. Affected data points are removed from the drive test data before processing using the proprietary tool.

The amount of affected data that is removed is normally less than 5% of the total number of measured points.

2.4.3 Taking into account receiver limitations

Red-M intends to use two multi-channel scanning receivers in its system set-up. Each scanning receiver has a digital front-end capable of scanning up to 4 separate UMTS channels and decoding up to 20 CPICH codes on each RF channel. This means that up to 8 separate UMTS channels can be scanned simultaneously, allowing measurements to be performed on all five 3G operators in the UK.

This type of approach will also have the advantage of limiting discrepancies in system error (offset, feeder loss, antenna gain) between operators. Ideally, a single receiver would be used for the surveys, but that would require scanning with very high sampling rate in order to cover all 5 operators and satisfy the minimum sampling rate required to measure the local mean with adequate confidence.

One of the limitations of using a multi-channel scanning receiver, besides the “sharing” of the maximum sampling rate between the RF measured channels, is the desensitisation effect on the receiver caused by its large, but finite dynamic range. This effect is most prominently observed when one of the RF channels is much stronger than the other channels. Under these conditions, the receiver may not be able to detect the weaker signals with quoted accuracy.

The receivers Red-M intends to use have a 55dB desensitisation level, which means that none of the channels with a power 55dB below the strongest measured channel would be detected. For the purpose of the rollout validation, a CPICH threshold of -110dBm is set, which means that the methodology that is being discussed in this report is concentrated on marginal coverage areas where the signal level will be at or near -110dBm. As a result of the desensitisation effect, if the RF power on any of the scanned channels is above -110+55= –55dBm, none of the channels with a power at or near the threshold would be detected. The likelihood of being in such a situation is very small and would only generally happen close to one of the base stations in a line-of-sight to the transmit antennas.

As a precautionary step, Red-M will proceed with the filtering out of all measurement data points (regardless of the operator) where one of the RF channels is measured at or higher than -55dBm. This will result in the removal of an insignificant proportion of the data (if any) but will ensure that no distorted data is used in the analysis.

2.4.4 Mapping the data onto the Benchmarking grid

The exact locations at which drive data will be obtained will depend on the route but also on the speed of the vehicle, the sampling rate of the receiver and the size of the averaging window. As discussed elsewhere in this report [*Appendix B.2.2 Estimation of the Local Measurement Mean*], a sliding averaging window of 40 wavelengths (or ~6m) will be applied.

As a result, it is very likely that more than one data point will be obtained within any 100m grid pixel defined in the Benchmarking area as illustrated in Figure 6.

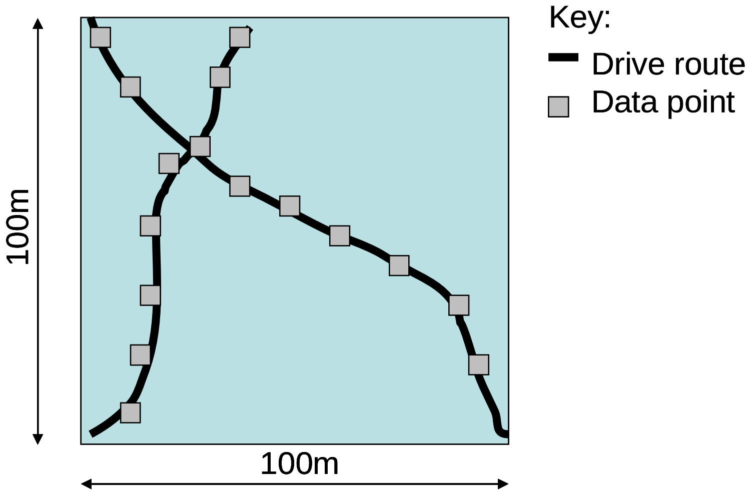

Figure 6 Each 100m pixel is likely to contain more than one measurement data point

Preliminary analysis of survey data showed that on average 10-12 data points will be measured in a 100m pixel, with peaks exceeding 50 data points in certain circumstances (e.g. very slow traffic).

Red-M recommends calculating, for each 100m pixel, the following variables:

- The mean CPICH level (per operator) in dBm value

- The number of samples obtained at the pixel
- The total number of people whose centroids falls within the 100m pixel
- The % of samples that fall below the threshold -110dBm
- % of samples that fall below the threshold -110-xdBm where x (dB) is the measurement uncertainty
- % of samples that fall below the threshold -110+xdBm

As measurements will generally be non-uniformly distributed over the full pixel area because of how road networks are designed, Red-M suggests that a pixel will be considered not to be in coverage at a given threshold provided 90% or more of the samples in any given pixel are measured below that threshold.

The percentage of samples (90%) was chosen to remain consistent with the percentage location variability at the cell edge[5] used by Ofcom when setting the fade margin of the path loss prediction model.

Format for a typical data file are presented in *Appendix C*.

2.5 Data interpolation

Red-M has developed mathematical techniques necessary to turn linear drive test data (for example, taken from roads), into area coverage predictions with associated statistical error estimates at required points (in this case potentially the centroids of the relevant 2001 census output areas within the measurement area). These general techniques are generally known as linear regression interpolation. In 2-dimensions, these techniques are suitable for radio propagation modelling over area surfaces. Red-M's use of these techniques have proved to be very valuable for extrapolating radio signal strength in areas that were not driven-by with good confidence, and these existing tools will be made available for use on this project. An example of this technique applied to sparse measurements is shown in Figure 7.

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[5] Section 3.17 of Ofcom's 3G Rollout Obligations Statement, 27 February 2007. For convenience, this document is contained in *Appendix A*.

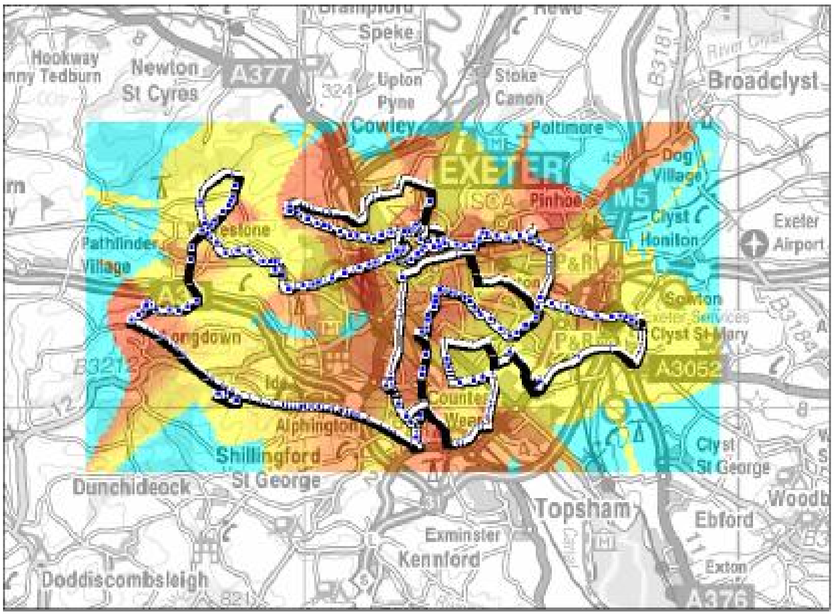

Figure 7 The CPICH level measured along the drive route could be interpolated over a raster grid encompassing the drive area

The key advantages of using this method in relation to the current project are that:

- it will be more cost-efficient to apply a linear regression technique to estimate the signal strength at a centroid than to measure the actual signal strength at each centroid (which may be inaccessible), giving rise to an efficient population coverage estimate in selected areas
- at the same time signal strengths at the points driven by will have low “prediction” uncertainty (the only uncertainty at these points will be the measurement inaccuracy) for comparison with Ofcom modelling predictions.

Figure 8 shows the interpolated and measured local mean signal strength along an arbitrary line drawn in the measurement area. The line intersects the drive route at a number of places. At these points measurement data provide the ‘correct’ value for the local mean, and the measured value (shown as blue squares), the interpolated value (red line) and 90% confidence interval estimates (green lines) are coincident.

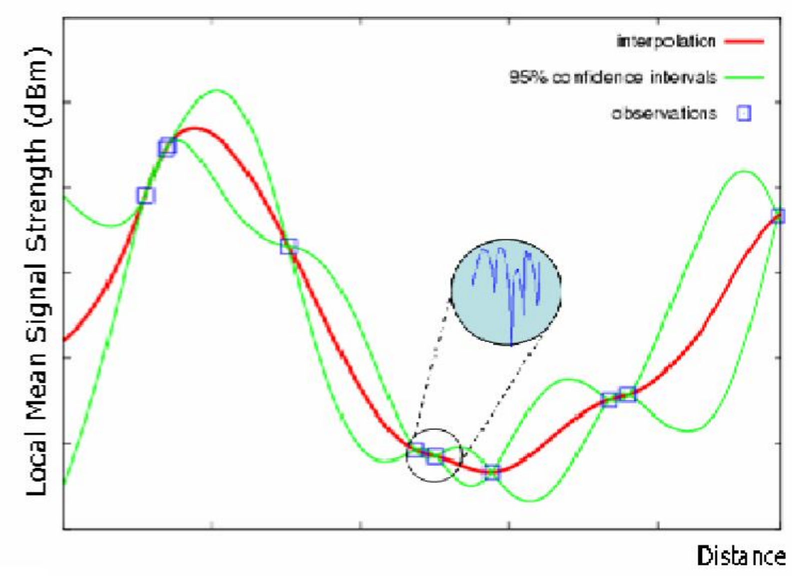

Figure 8 Illustration of interpolation error in 1-D

At the measured points, uncertainty in the measurement is related to:

- measurement error, such as calibration of antenna and receive chain, and the fundamental accuracy of the scanning receiver, and
- error in estimation of the local mean from measurements taken in a fading channel (illustrated as a rapidly varying local signal shown in the blue circle in Figure 8).

Between the points of observation, where the interpolation gives an estimation of the result, there is a greater uncertainty in the 'measured' value, and the red and green lines diverge. Because correlation decreases rapidly with distance with varying degrees depending on the local clutter, the uncertainty will generally be small close to measurement locations and large where no measurements were made. The challenge in designing the drive routes will therefore be to enable sufficient data locations to be surveyed to ensure the interpolation method yields accurate results while keeping the cost of surveying within allocated budgets.

Red-M's interpolation method uses a linear prediction algorithm that takes into account the correlation signature of the area whilst also generating a measure of the variance by which the interpolated value was obtained.

Fields required and corresponding formats for the interpolated data are described in Appendix C.

3. Selecting the measurement locations in the Benchmarking Area

This section shows an example of selection of areas to measure described in paragraph *2.2 The Benchmarking Process* and an example drive route design using the process described in paragraph *2.3.1 Drive route design*.

In order to make the example process as clear as possible, we have based the exercise in this section on imaginary data. For clarity, a small area of the overall benchmarking area shown in was analysed. Figure 9 shows the imaginary coverage data for this small area overlaid on the output areas from the 2001 census.

The area shown in Figure 9 has a good mixture of clutter, as it includes coastal areas, urban and suburban areas surrounding Brixham, Paignton and Torquay, the smaller town of Totnes and rural areas including the hinterland behind Torbay and the lower slopes of Dartmoor. In Figure 9, coverage areas (of 100m x 100m resolution) are shown in a scale of colours, with blue corresponding to the lowest signal strengths and red signifying the highest signal strengths. White areas are those predicted by the model data to have less than -110dBm signal strength.

The total area selected for the benchmark exercise is 100km x 100km, and contains 4065 ‘Output Areas’ (OA) in the 2001 census. The total population in the benchmarking area is 1,174,213, giving an average of 289 people per output area.

The evaluated area in Figure 9 consists of 510 output areas with area and population as shown in Table 3. As explained earlier in the report, the most densely populated areas within Figure 9 are those where the OA’s are the smallest in size.

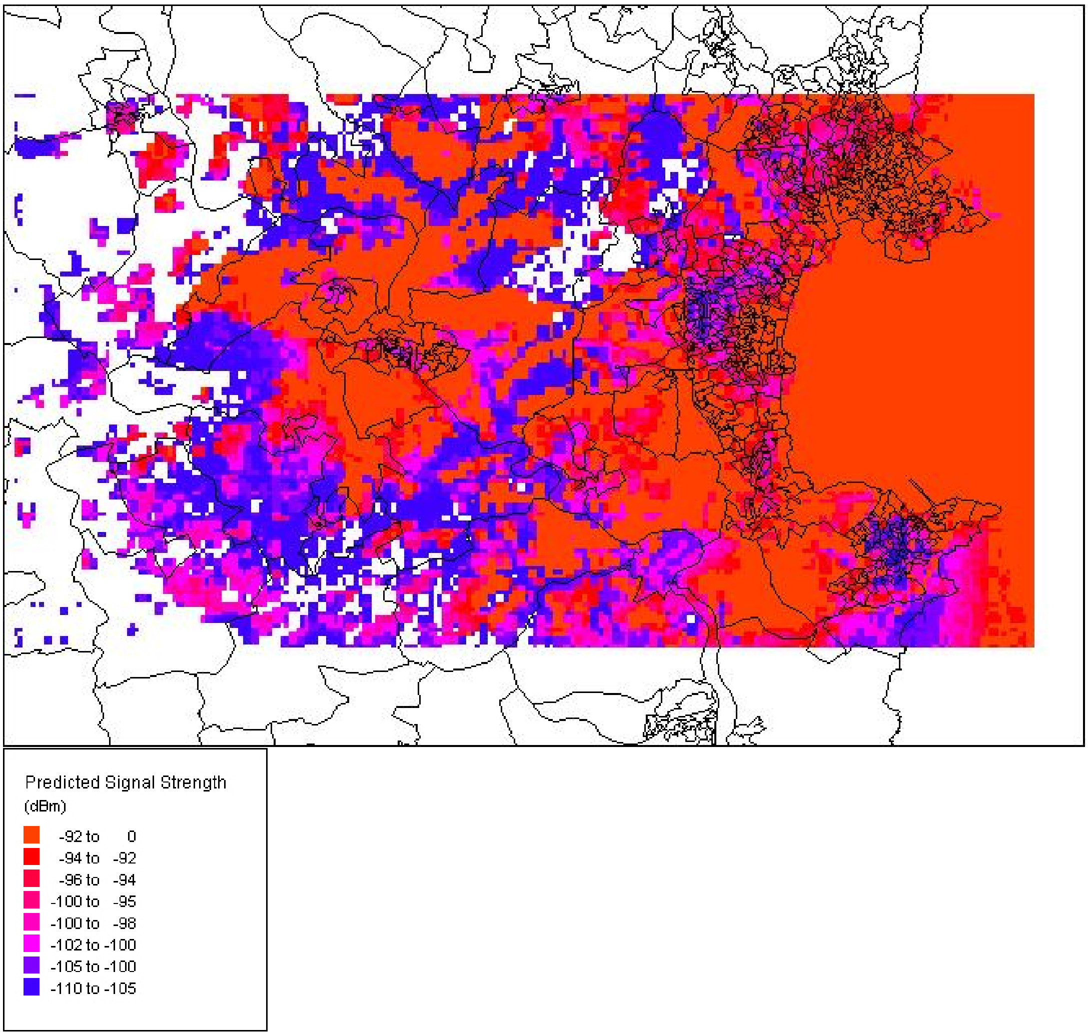

Figure 9 Subset of Benchmarking Area - Torbay, Totnes and Dartmoor (part)

Table 3 Subset of Benchmarking Area – Population and Area Statistics for 510 Output Areas

Field	**Sum**	**Average per OA**
Hectares	26,826.25	52.6
Total population	143,015	280

Figure 10 shows the same area as in Figure 9, but with signal strengths modified manually to represent a second model. The data in Figure 10 has been generated so that it is, on average, 10dB below that in Figure 9 at the -110Bm level, and a uniformly distributed random element of ±2dB has been included to attempt to represent the variability associated with different implementations of terrain and clutter loss.

We consider, for the purposes of this illustration, that the imaginary data in Figure 9 represents the data obtained from predictions with a tuned MNO model and Figure 10 represents the Ofcom implementation of ITU P.1546-2 applied to the same area.

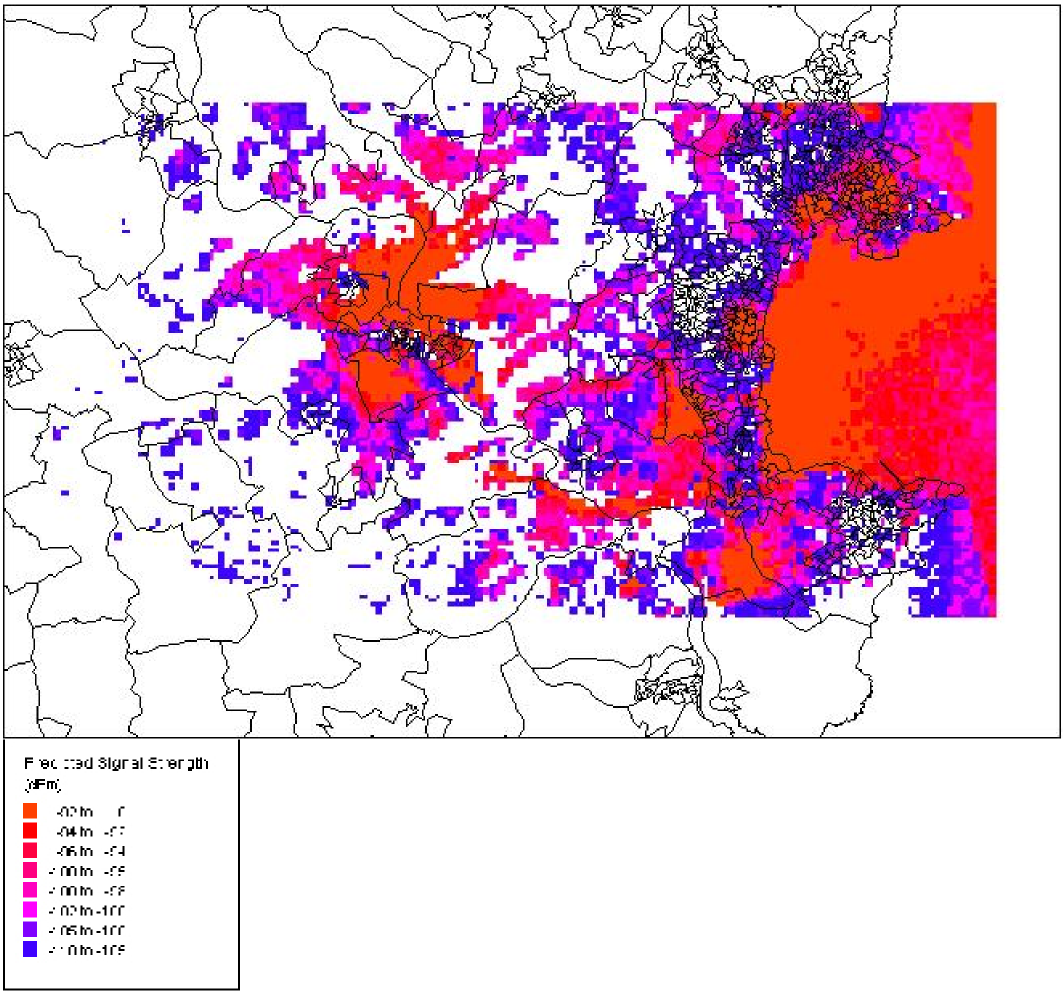

Figure 10 Subset of Benchmarking Area - Torbay, Totnes and Dartmoor (part) – second model

Having generated some imaginary data the area selection process outlined in paragraph 2.2 of this report can now be applied. Figure 11 shows the subset of the evaluated area where both 'MNO' and 'Ofcom' models predict no coverage.

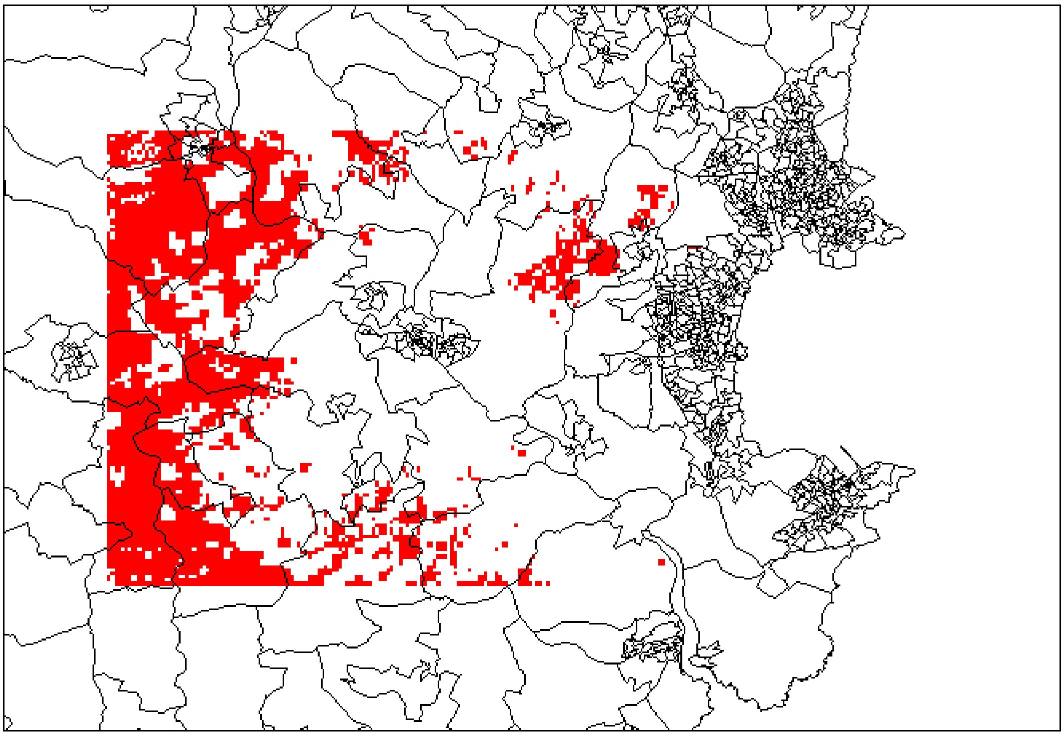

Figure 11 Subset of Benchmarking Area – Not Covered

Figure 12 shows the subset of the evaluated area where both ‘MNO’ and ‘Ofcom’ models predict coverage at a level above -110dBm.

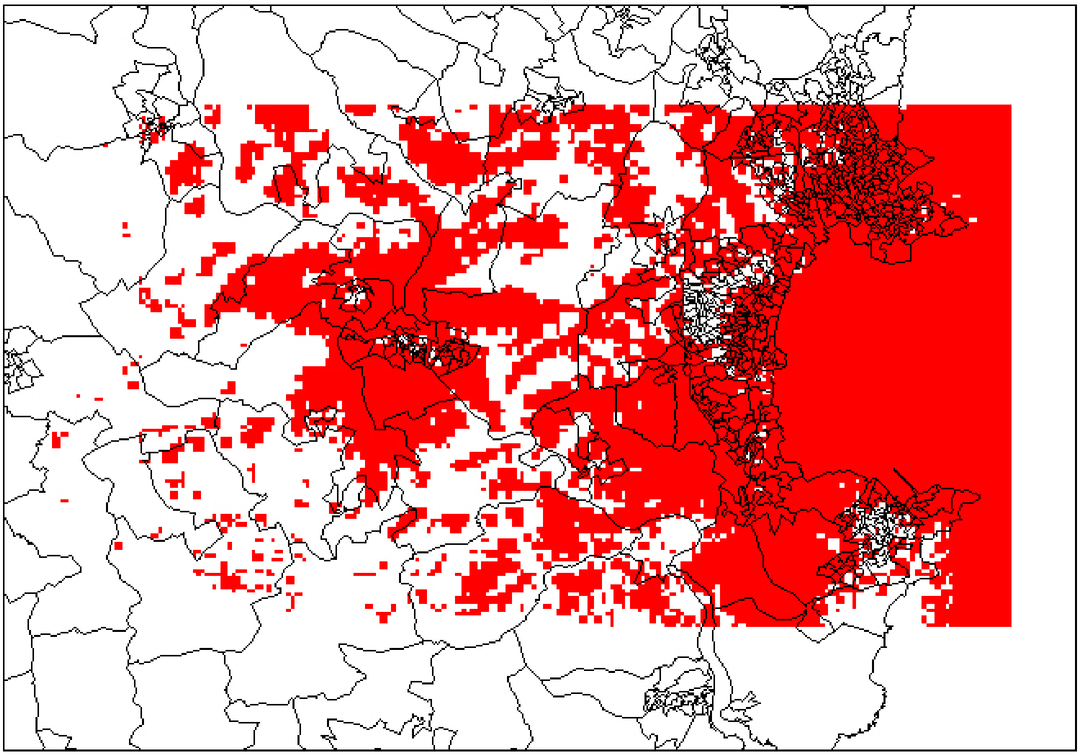

Figure 12 Subset of Benchmarking Area – Covered

Figure 13 shows the subset of the evaluated area where there is disagreement between the models as to the extent of coverage at the

-110dBm threshold. In this report, this area is called the 'Combined Marginal' area.

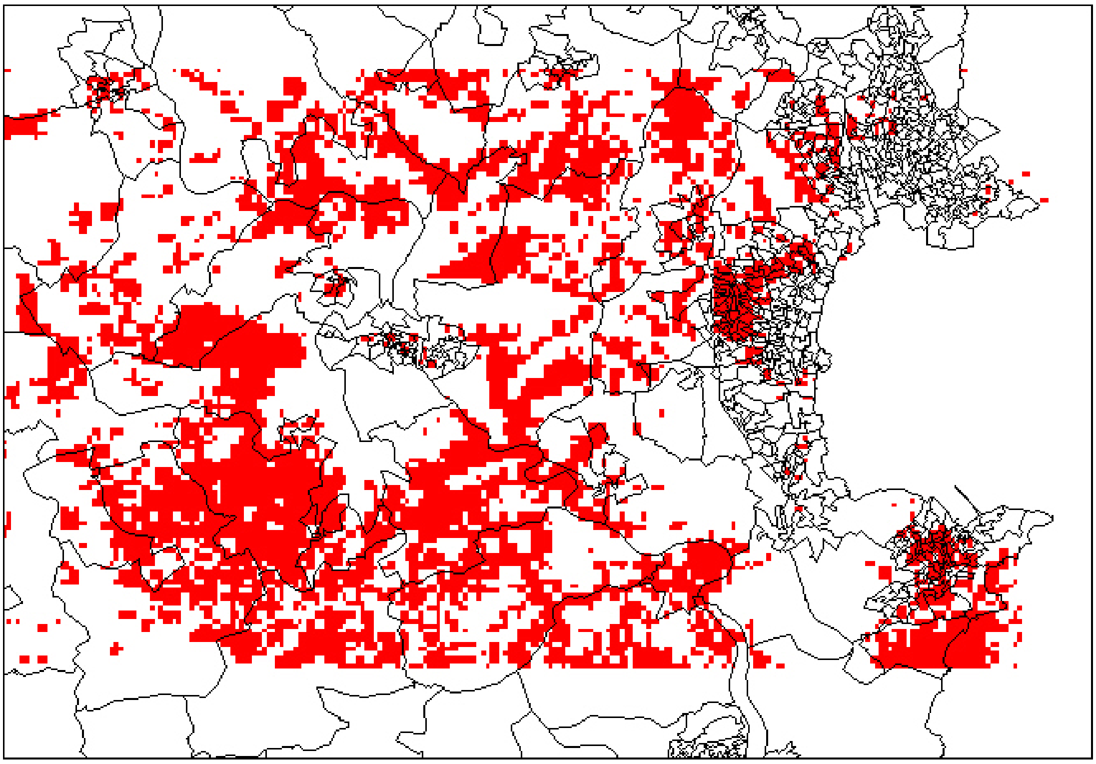

Figure 13 Subset of Benchmarking Area – 'Combined Marginal' Area

The extent of the 'not-covered', 'covered' and 'combined marginal' areas shown in Figure 11, Figure 12 and Figure 13 respectively are summarised in Table 4 where we have categorised the areas depending on the classification of coverage at the population weighted centroid of the output area.

Table 4 Summary of Covered, Not Covered and Combined Marginal Areas

OA Centroid	# of Centroids	Average Signal Strength at Centroid (MNO Prediction) (dBm)	Average Signal Strength at Centroid (Ofcom Prediction) (dBm)	Total Area (Hectares)	Total Population	Average population per OA
Not Covered (Figure 11)	9	-117	-128	4,410	2,755	306
Covered – (Figure 12)	380	-90	-101	14,008	106,153	277
Combined Marginal (Figure 13)	121	-102	-113	11,113	35,056	290

The key areas to be considered for a measurement campaign are those 'combined marginal' areas shown in Figure 13, because these are the areas where there is disagreement between the predictions as to the extent of coverage at the -110dBm threshold.

Table 5 Subset of Benchmarking Area – Population in 'combined marginal areas'

Field	**# of OAs**	**Pop. Sum**	**Pop. Average per OA**
Population in an OA with at least one 100m x 100m square in 'combined marginal areas' (*Figure 14 – left*)	257	74,071	288
Population in an OA with the population weighted centroid in a 100m square which is a 'combined marginal area' (*Figure 14 – right*)	121	35,056	290
Population in an OA cluster (inside the two green circles in *Figure 14 – right*) where the population weighted centroid is in a 'combined marginal area'	95	27,558	290

Table 5 shows population and area statistics for those areas coloured red in Figure 13. Although roughly 50% (257) of the output areas under evaluation have some 'combined marginal' areas within them, only the subset of 121 output areas listed in Table 4 have their population weighted centroid in a 'combined marginal area'. Graphically, this can be understood by reference to Figure 14. In *Figure 14 – left* all 257 output areas are coloured yellow, whereas in *Figure 14 – right*, only the subset of 121 output areas are coloured yellow.

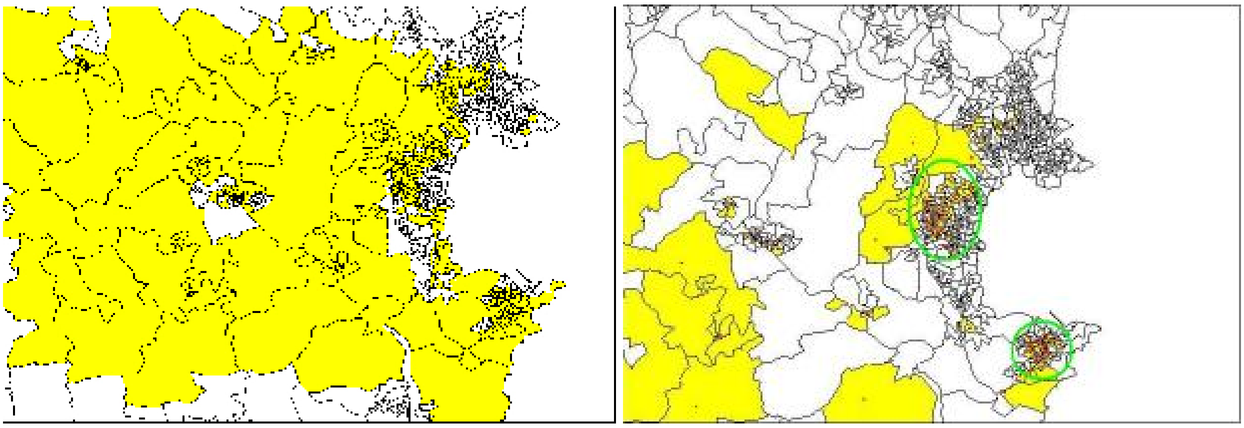

Figure 14 Subset of Benchmarking Area – 'Combined Marginal' Output Areas

The areas shown yellow in *Figure 14 – right*, are those areas which have the largest effect on the benchmarking population coverage result. Closer inspection shows that in this case, the population weighted centroids (the red dots in the figure) cluster in two areas (shown in green circles): around Paignton and Brixham, with a smaller cluster in Torquay. The outlying rural areas to the southwest of Totnes (yellow shading around a single red dot) may cover a larger surface, but contain so few people that it is not cost-effective to survey them.

If just the main clusters of output areas from *Figure 14 – right* in Paignton and Brixham are selected, then 95/121≈80% of the 'combined marginal' population weighted centroids of the area under evaluation would be driven. Since output areas are all of similar population, this would also cover approximately 80% (27,558/35,056) of the population in these 'combined marginal' areas, as shown in Table 5.

Figure 15 shows the Paignton cluster of 'combined marginal' OA centroids at larger scale, and superimposed on the OS 1:50,000 map. The population centroids are shown as red squares. A drive route following the guidelines given in section *2.3 Survey methodology*, has been superimposed on the map. This drive route is shown by the green lines.

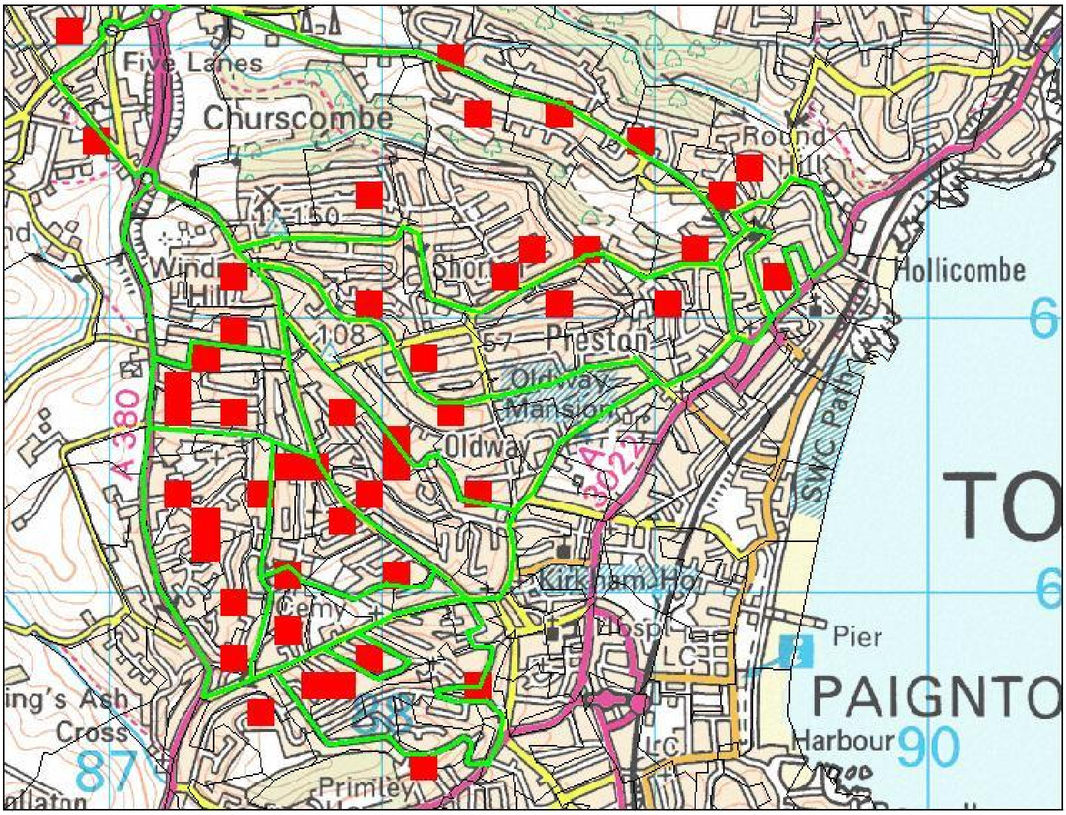

Figure 15 Drive Route Design

This section has shown how to follow the procedure to select measurement locations and design a route based on a comparison of imaginary predictions for a fictitious operator. To enable the process to be followed easily and re-created using real data from all the real operators the sample MapInfo data and queries are included in this report as a .zip file in Appendix F.

To determine the actual drive test regions for benchmarking, the process described above will be repeated for each operator, and over the whole benchmarking area. The extent of clustering of OA centroids in combined marginal areas and the extent to which the clusters from each operator are co-incident remains to be determined.

It is also possible that the 100m pixel by 100m pixel data used in this example will not be available for all operators. Although this pixel-by-pixel data is the most desirable, other forms of data can also be processed. A MapInfo 'Vertical-Mapper' file containing only the coverage contour at -110dBm contains much less information than the pixel-by-pixel predictions, but still allows the 'combined marginal' area to be determined with similar accuracy. It is possible that some operators may only be able to produce bit-map images of coverage at the -110dBm contour level. This type of information is the least desirable type of input since it is hardest to process automatically, but bit-maps can still be geo-referenced and combined using the colour of the covered area, and hence used to aid the manual selection of combined marginal areas. If manual selection like this is necessary, the process will only be able to identify combined marginal area clusters, which would then be used for further processing. The process will not be able to accurately identify individual population weighted centroids, and the application of the hit-rate analysis will therefore be negatively impacted.

4. Conclusion

This document has proposed a measurement methodology to assist Ofcom in a benchmarking exercise to assess the validity of their approach to the analysis of 3G rollout obligations.

The measurement methodology has shown how to determine the errors due to measurement, which are due both to basic accuracy of the scanning receivers proposed, and also due to the requirement to take a large number of samples in a local area to remove the effects of 'fast fading', whilst maintaining the integrity of the measured signal. The analysis in this document has shown that it is possible to measure local mean signal strength to an accuracy of ±1.7dB.

The document has also proposed how to plan a measurement campaign to help determine the accuracy of the models used during the benchmarking process. The approach is in essence to:

1. Determine the areas where Ofcom and MNO models produce contradictory predictions of coverage at the defined level – the 'combined marginal' areas.
2. Target clusters of these areas with high population density.
3. Design a drive test passing close by population centroids, suitable for linear prediction methods.
4. Collect and report on drive test measurements.
5. Perform a linear prediction process to predict the signal strength at the population centroids close to the drive route but that have not been driven by.
6. Report on linear prediction results.
7. For the areas that have been driven, calculate population coverage, using the 2001 census data.
8. Report on population coverage.
9. Calculate the 'hit rate' of the Ofcom implementation of P.1546-2 for the areas driven, by comparing the predicted signal strengths at the centroids to predictions.
10. Report on model 'hit rate'
11. Use the hit-rate to estimate population coverage in the combined marginal areas that have not been driven as part of the benchmarking exercise.
12. Report on application of 'hit rate' analysis to predicted results.
13. Perform an error analysis of the process.

The benefits of applying this methodology will be to give increased confidence to the assessment methodology based on engineering analysis proposed by Ofcom. The incorporation of measurements into the process as described in this document will allow an assessment of the level of uncertainty in the engineering analysis to be made during the benchmarking process, and will also allow this level of uncertainty to be reduced. This benefit will be particularly significant if the assessed population coverage of any of the operators is very close to minimum prescribed by their licence conditions.

In case the measurement activities during benchmarking are insufficient to allow all parties to agree on the results of the actual coverage determination in early 2008, a further set of measurements using this methodology would enable additional accuracy to be incorporated into the overall process.

Appendix A Ofcom 3G Rollout Obligations Statement

This statement is included as an Adobe Acrobat document. Please click on the link to open the document.

Ofcom 3G Rollout
Obligations Statemen

Appendix B Error Analysis

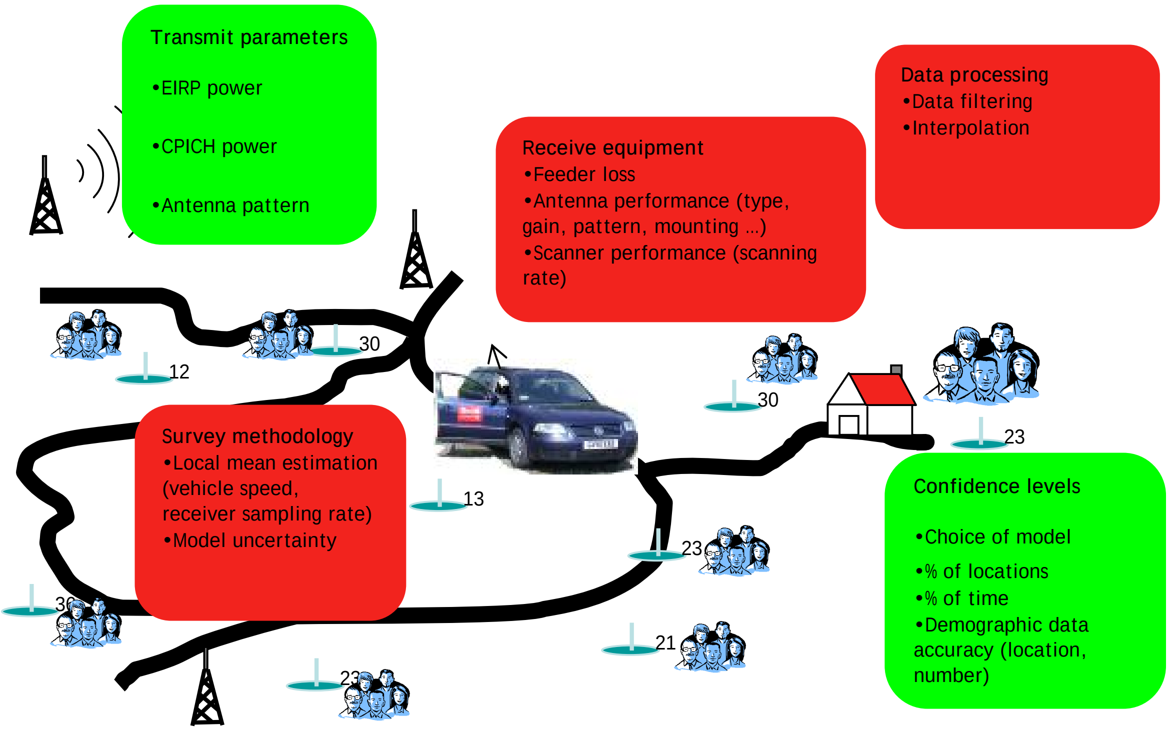

Figure 16 Sources of error

Figure 16 illustrates the different sources of error associated with the process of identifying the number of people that are in coverage. The boxes highlighted in green were handled by Ofcom and discussed in their "3G Rollout Obligations" document recently issued.

In this section, we will focus on the errors originating from:

- Receiver equipment: scanning receiver accuracy and offset, feeder loss, antenna gain
- Data processing including data filtering
- Survey methodology and the impact of the vehicle speed and scanner performance on the estimation of the local mean

These errors fall into two categories: systematic errors which will be eliminated at the post-processing stage, and measurement error which will be built into the procedure for determining the percentage of population covered.

B.1 Systematic errors

A systematic error will be introduced into the measurements by the fact that the signal will be subjected to a gain at the receiver antenna, and a loss through cable and connectors. The receiver might also have a fixed offset.

The sum of these errors should however remain constant at a given frequency, received level and ambient temperature. Red-M will therefore apply a correction factor to the measured levels in order to remove this error.

The error will be quantified prior to the commencement of the surveys using a signal injection test into the full chain (from the RX antenna input to the receiver) to determine the total loss of the system including any receiver offset.

In this test, a signal of known power will be injected at all test frequencies and the reading on the receiver will be recorded. The power will be varied between the lower and upper limits of the receiver in steps of 5dB.

B.2 Measurement variability

B.2.1 Receiver Accuracy

The manufacturer of the receiver Red-M intends to use for the measurements quotes an absolute accuracy of ±1 dB in Basic RF Input Power Range, with an additional ±1 dB over the RF Frequency Range and operating temperature range. From these specifications, we conclude that the 90% confidence interval limits will be approximately 2 dB for Basic RF Input and 2 dB for the other effects.

We can conclude that since the receiver will be used to scan over a set of frequencies from more than one operator and that RF input levels will be expected to cover the full dynamic range of the receiver that the overall receiver uncertainty at the 90% confidence interval limits will be $\sqrt{1^2+1^2} = \pm 1.4dB$ for the receiver only.

Further variability will be introduced by the sampling rate applied during the surveys as discussed in the next section.

B.2.2 Estimation of the Local Measurement Mean

Fading signals in mobile radio systems are made-up of three main components: a mean component which is primarily linked to how far the receiver is from the transmitting base-station, a slow fading component (also known as log-normal fading) which is caused by the physical characteristics of the local propagation environment (size of buildings, vegetation, orientation of the streets, geographic features along the path...) and a fast fading component (also known as Rayleigh fading), which is caused by the constructive and destructive inference of multiple signal paths from objects in the environment close to the receiver.

When trying to re-create the mean of the signal power from measurements (i.e. removing the “unpredictable” fast fading component), sufficient samples are required. The number of samples recorded will have a direct impact on the uncertainty of the mean.

A number of different methods of determining this local mean exist. The most common one is generally termed the Lee Criterion [[6]], although other criteria are also available (e.g. the Parsons Criterion [[7]]). These criteria generally specify that a number of samples, N, are required to be averaged over a particular distance, d. The exact values of N and d depend on various parameters and the acceptable uncertainty in the results. The net result however is that a scanning receiver with a fixed time based sample rate will imply a particular maximum drive speed.

The length of the local mean, d, is critical, if it is set too short, then some of the fast fading will still be present, however if it set too long, then some of the longer period, slow fading will be averaged out, and some of the detail of the system coverage which the test is aimed at revealing is lost.

Lee's calculations to estimate the minimum required number of samples were developed with narrowband[8] signals in mind. There is a fundamental difference between narrowband and wideband signal because, different portions of the wideband signals will to experience fast fades at different locations. In the case of a narrowband signal the signal in its entirety will either be in a fast fade or not. We will first describe the narrowband case.

Lee Uncertainty in estimation of the local mean	**Number of samples required per average**
1 dB	36
1.5 dB	16
2 dB	9

Table 6 Number of samples required for a selection of uncertainties as calculated by Lee for a narrowband signal

Lee calculates that the averaging distance must be between 20λ and 40λ. This relates to the typical distances over which the 'log normal' shadowing remains fairly constant outdoors (i.e. typical widths of buildings and other features). Lee's calculations were derived for a narrowband signal and the results, for uncertainties of 1, 1.5 and 2dB are reported in Table 6.

By using Lee criterion with a Lee uncertainty of 1dB in estimation of the local mean, we estimate that the probability of our measured local mean being less than 1dB from the true mean is 90%. When using receivers that have a

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[6] Lee, W.C.Y. "Estimate of local average power of a mobile radio signal", IEEE Trans., VT-34, No.1, pp. 22-27 (1985)

[7] Parsons, J.D. "The Mobile Radio Propagation Channel", Wiley,2nd Edition

[8] 'Narrowband' in this context is where the signal bandwidth is narrower than the coherence bandwidth of the channel. 'Wideband' in this context is where the signal bandwidth is wider than the coherence bandwidth of the channel.

constant sample rate in time, the number of samples (36) required per average leads directly to a maximum vehicle speed.

Lee calculates the 90% confidence interval of the estimated value of local mean being within ±σ dB of the true value as:

$$\frac{6}{\sqrt{N}} < s \text{ dB}$$

σ is termed the uncertainty in the estimation of the local mean. The value for σ that is suggested by Lee is 1dB, which implies that N = 36.

Although Lee suggests the use of a ±1dB uncertainty with a requirement for 36 samples every 40λ of driven distance, decreasing the number of samples (e.g. where vehicle speed cannot be kept low such as on motorways/dual-carriageways) is still possible at the expense of the signal uncertainty.

An extension to Lee's work carried out in 2006 [9] shows that for a wideband signal, fewer samples would be required to achieve the same level of uncertainty. These findings stem from the fact that a wideband signal such as in UMTS can be regarded as a combination of multiple independent Rayleigh fading components. When these are combined coherently, as in the case of the scanning receiver, the resulting power distribution approaches a normal distribution. In other words, as the bandwidth of the signal exceeds the coherence bandwidth of the signal, parts of the signal will be in a fading phase while other parts won't when averaging over a number of samples.

As a result, the number of samples required to achieve the same level of uncertainty is reduced. Figure 17 shows the difference in the required number of samples between a narrowband and a UMTS WCDMA signal for a given vehicle speed.

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[9] **Kurt, T., Y. Le Helloco and B. Breton, Wideband local mean estimation, Electronics Letters, Feb 2006, Vol. 42, No. 3.**

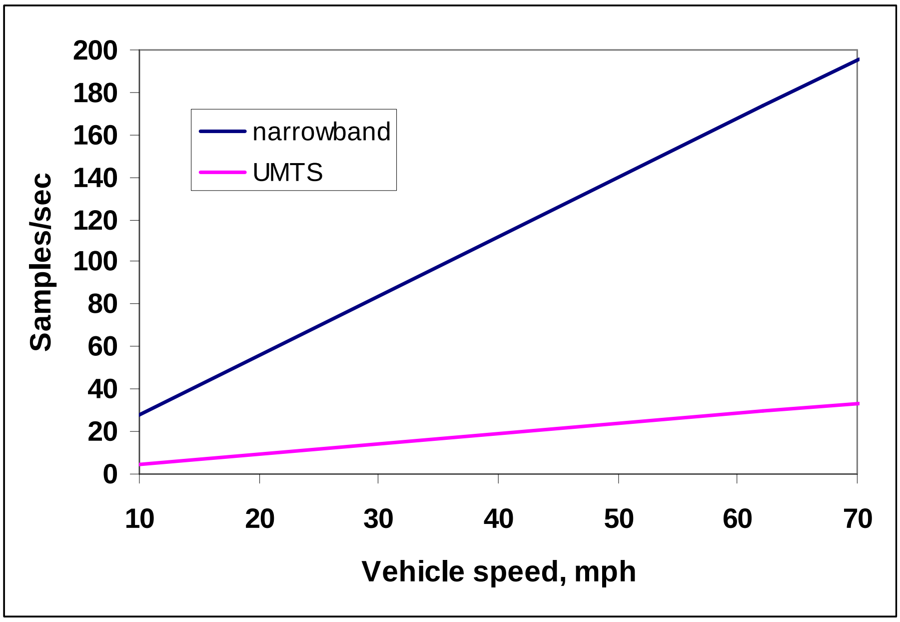


Figure 17 Required sampling rates as a function of vehicle speed for narrowband and UMTS signals

The graph in Figure 17 shows that ~6 times fewer samples per second are required for a wideband signal than for a narrowband one. The minimum required number of samples/s for typical vehicle speeds in the UK to achieve a ±1 dB accuracy estimate of the local mean the 90% confidence level are given in Table 7.

Vehicle speed [mph]	**Minimum required number of samples/sec**
30	15
40	20
60	29
70	34

Table 7 Minimum required number of samples/sec for the local mean estimation to ±1 dB of a UMTS signal at typical vehicle speeds.

The scanning receiver that Red-M intends to use for the performance of the WP2 drive surveys can achieve a maximum of 16 samples/sec/RF channel (see datasheet in *Appendix E: Measurement System* for more detail). This rate meets the minimum requirements at the lowest speed illustrated in Table 7. As a result, we can safely claim that, provided the vehicle is driven at a speed of about 30mph, the measurement uncertainty associated with the determination of the local CPICH mean will be ±1 dB or better (i.e. the 90% confidence interval is 2dB). Since the benchmarking process has identified the most populated areas as being the target survey areas, speed limits in these areas will be at either 30 or 40mph in any case.

Appendix C Data Formats

This section provides detail of the format for the various data sets required for the benchmarking. The actual data given in these format examples is imaginary.

C.1 Filtered survey data

The filtered data from each drive survey will be provided in the following format:

- Each data file will consist of 3 columns: Eastings, Northings, CPICH level
- Data provided in comma separated values (CSV) format
- The (Eastings,Northings) co-ordinates will be provided in OSGB36 map projection
- The signal strength of the dominant CPICH will be provided in units of dBm. Signal strength data should represent the moving local mean over a 40 wavelength window, centred on the recorded coordinates.
- Signal data should be normalised to represent a 0dBi receive antenna gain with 0 dB receive feeder loss (see *B.2.2 Estimation of the Local Measurement Mean* for more detail on the relationship between vehicle speed and local mean estimation).
- One set of data will be provided per drive route and per operator

Table 8 shows an example output for an operator. There will be one such file for each operator.

Eastings	Northings	CPICHLev_MNO1
291729	93430	-77.4
291735	93433	-82.5
291741	93436	-78.6
291748	93438	-74.6
291755	93442	-68.2
291762	93445	-75.6
291772	93450	-74.5
291791	93459	-78.6
…	…	…

Table 8 Example output from the drive survey

C.2 Survey data mapped onto the benchmarking grid

Following analysis, the survey data will be mapped onto the 100m resolution benchmarking grid. As a result of this analysis, the measurements will be expressed in a different way to the “Filtered data” discussed in the previous section. The analysed data should be provided in two different formats: a plain text format (csv) for ease of transfer and a grid format ready for import into MapInfo. The content of the files for each of these two formats is explained below.

C.2.1 In csv format

For the plain text format, the files should contain the following data:

- There will be a single CSV file per operator for the entire benchmarking area
- Each file will consist of 8 columns:
  - Eastings and Northings of the pixel position
  - Total population in the pixel
  - Total number of measurements in the pixel
  - Mean CPICH level at the pixel
  - % of measured samples at a CPICH level less than -110dBm
  - % of measured samples at a CPICH level less than -111.7dBm
  - % of measured samples at a CPICH level less than -108.3dBm

Typical output from this process should resemble the illustration shown in Table 8 (commas between the fields have not been shown for clarity, mean CPICH level column not shown).

Eastings	Northings	TOTAL POPULATION	TOTAL SAMPLES	% OF SAMPLES <- 110dBm	% SAMPLES <-110+xdBm	% SAMPLES < 110+xdBm
526600	134600	0	39	74.4	100	0
526700	134600	0	27	44.4	100	3.7
526600	134700	0	13	38.5	100	0
526700	134700	0	15	26.7	100	0
526600	134800	0	5	20	100	0
526600	134900	0	8	12.5	100	0
526500	135000	0	5	20	100	0
526600	135000	0	7	0	85.7	0
526400	135100	0	1	100	100	0
…	…					

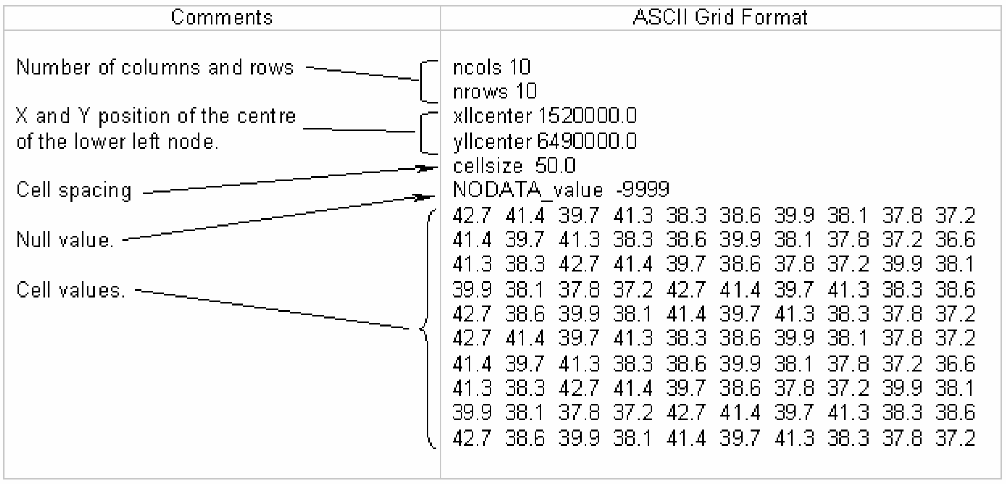
Table 9 Example output from mapping the survey data onto the benchmarking grid.

C.2.2 In grid format

The above data will also be provided in a grid format ready for import into MapInfo's Vertical Mapper tool. The grid import format selected is the one defined in Vertical Mapper as *ASCII Grid* (see Vertical Mapper's User Guide, version 3.0, 2005, pp73). This format is reproduced in Figure 18 from the user guide.

The files will be provided in text format and will consist of:

- One ASCII Grid file per operator and per field.
- Fields include: total population, number of measured samples, Mean measured CPICH level, % samples measured at less than -110dBm, % of samples measured at less than -117dBm and % samples measured at less than -108.3dBm.
- Areas not measured at will have their value set to the standard NO_DATA_VALUE user by MapInfo (generally -9999).



Comments	ASCII Grid Format
Number of columns and rows	ncols 10 nrows 10
X and Y position of the centre of the lower left node.	xllcenter 1520000.0 yllcenter 6490000.0
Cell spacing	cellsize 50.0
Null value.	NODATA_value -9999
Cell values.	42.7 41.4 39.7 41.3 38.3 38.6 39.9 38.1 37.8 37.2 41.4 39.7 41.3 38.3 38.6 39.9 38.1 37.8 37.2 36.6 41.3 38.3 42.7 41.4 39.7 38.6 37.8 37.2 39.9 38.1 39.9 38.1 37.8 37.2 42.7 41.4 39.7 41.3 38.3 38.6 42.7 38.6 39.9 38.1 41.4 39.7 41.3 38.3 37.8 37.2 42.7 41.4 39.7 41.3 38.3 38.6 39.9 38.1 37.8 37.2 41.4 39.7 41.3 38.3 38.6 39.9 38.1 37.8 37.2 36.6 41.3 38.3 42.7 41.4 39.7 38.6 37.8 37.2 39.9 38.1 39.9 38.1 37.8 37.2 42.7 41.4 39.7 41.3 38.3 38.6 42.7 38.6 39.9 38.1 41.4 39.7 41.3 38.3 37.8 37.2

Figure 4.1 Example of a grid file illustrating the construction of an ASCII grid file.

Figure 18 Extract from Vertical Mapper v3.0 User Guide (p73) with detail of the ASCII grid format.

C.3 Interpolated data

Interpolated data should be provided in the same formats as the grid-mapped data described above, i.e. in CSV and in ASCII grid formats. The interpolation is done at the same grid resolution and definition as the prediction grid.

The required fields are described below.

C.3.1 In csv format

The attributes of the CSV file are:

- There will be one CSV file covering the entire benchmarking area and containing the interpolated values for all 5 operators
- The CSV file will consist of 12 fields:
  - § Eastings, Northings of the pixel position
  - § The interpolated CPICH level for MNO1 at the pixel
  - § The uncertainty of the interpolated CPICH level at the pixel represented by the variance of the interpolation process for MNO1
  - § Same as the above two fields for MNO2, MNO3, MNO4 and MNO5 (i.e. 4 x 2 fields)

An example CSV file is shown in Figure 19. In this file, all 12 fields described above are shown. Note that in this example, MNO2 (columns 5 and 6) has no data and interpolated values are therefore represented by the NO_DATA_VALUE.

Eastings	Northings	CPICH_OP1	CPICHvar_OP1	CPICH_OP2	CPICHvar_OP2	CPICH_OP3	CPICHvar_OP3	CPICH_OP4	CPICHvar_OP4	CPICH_OP5	CPICHvar_OP5
524600	136400	-89.5	5.6	-999	-999	-91.3	4.0	-98.8	3.9	-83.0	2.1
524600	136500	-90.4	5.5	-999	-999	-92.2	4.2	-99.9	4.0	-83.7	2.9
524600	136600	-88	5.5	-999	-999	-89.9	3.5	-97.3	4.3	-81.5	2.5
524600	136700	-86.2	5.5	-999	-999	-87.6	3.6	-96.2	3.7	-79.5	2.4
524600	136800	-85.7	5.4	-999	-999	-86.8	4.0	-95.7	4.1	-78.7	2.0
524600	136900	-87.9	5.4	-999	-999	-89.7	3.5	-97.6	3.6	-81.2	2.4
524600	137000	-88.6	5.5	-999	-999	-90.2	4.3	-97.8	3.9	-81.7	2.9
524600	137100	-86.9	5.5	-999	-999	-88.0	4.1	-96.6	4.1	-79.9	2.9
524600	137200	-88.9	5.6	-999	-999	-90.4	4.3	-98.6	4.4	-81.9	2.4

Figure 19 Example CVS file containing the fields from the interpolated results (commas have been omitted for clarity).

C.3.2 In grid format

The same grid format presented in Figure 18 should be used to enable loading of the interpolated data onto MapInfo’s Vertical Mapper tool. Contrary to the CSV format file described in the previous section, one ASCII Grid file will be required per field and per operator, making a total of 10 files covering the entire benchmarking area each.

Each file will relate to a single operator and there will be one file per each of the following fields:

- The interpolated value of the CPICH level at the pixel
- The uncertainty (in dB) of the interpolated value at each pixel

Appendix D Benchmarking area

A detailed description of the extent and location of the Benchmarking Area was provided by Ofcom[10]. In this appendix, we provide the key features of this area.

- Ofcom selected an area 100km x 100km in the south west of England (Figure 20) to apply the methodology developed in this report.

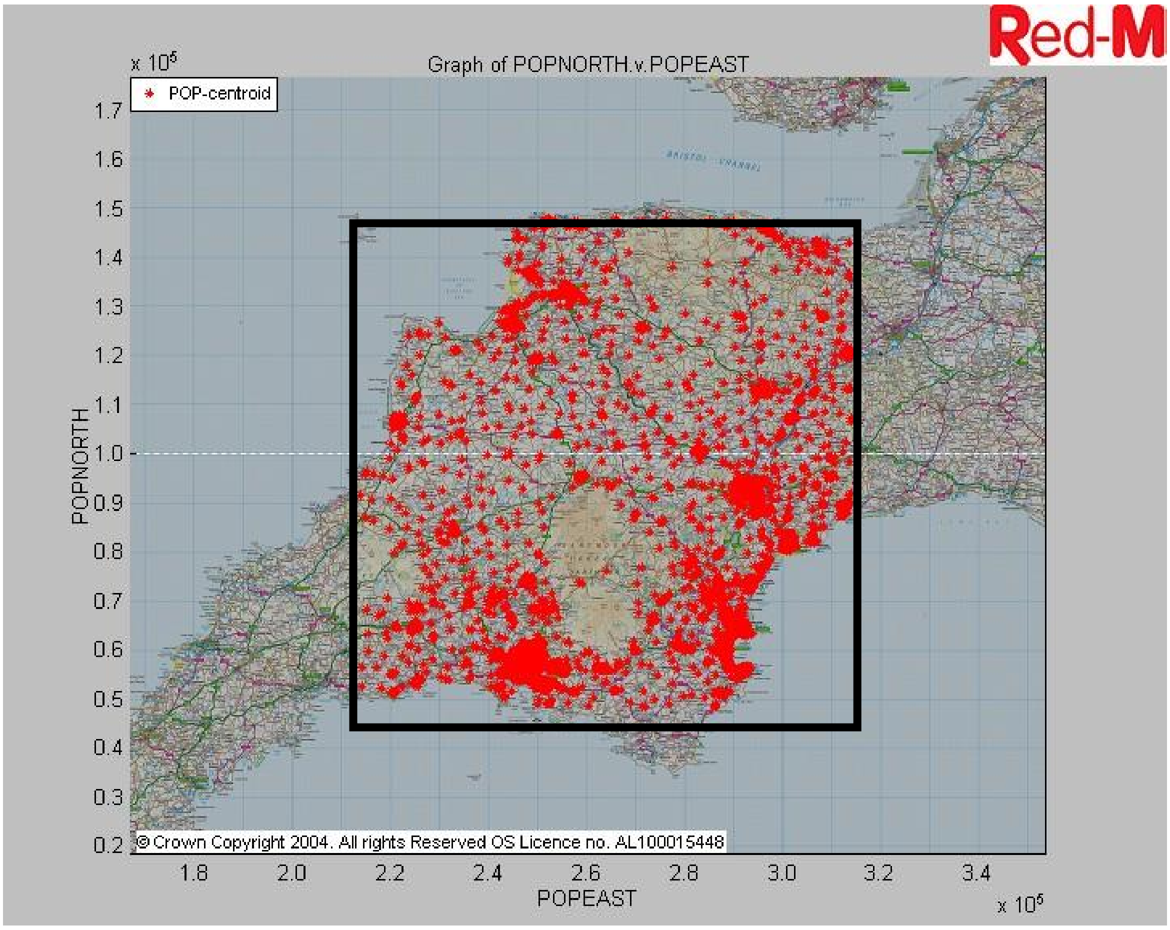


Figure 20 Extent of Benchmarking Area showing the population centroids from the Census 2001 data

- For the purpose of the model predictions, the area is extended 20km out of the one shown in Figure 20 (i.e. 120km x 120km) in order to include any coverage provided by sites located outside the Benchmarking area.

- The resolution at which the predictions are carried out is 100m.

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[10] 3G Rollout Benchmark Procedure (draft), 30 March 2007, Ofcom

Appendix E Measurement System

The in-car measurement configuration is shown diagrammatically in Figure 21. There are two UMTS antennae mounted on the roof of the vehicle, one for each scanning receiver. A GPS antenna is also mounted on the roof, and connected via the patch-panel to a Trimble 455 unit with dead-reckoning capability. Measurements are downloaded from the scanning receivers to data-logging PCs running TEMS investigation software.

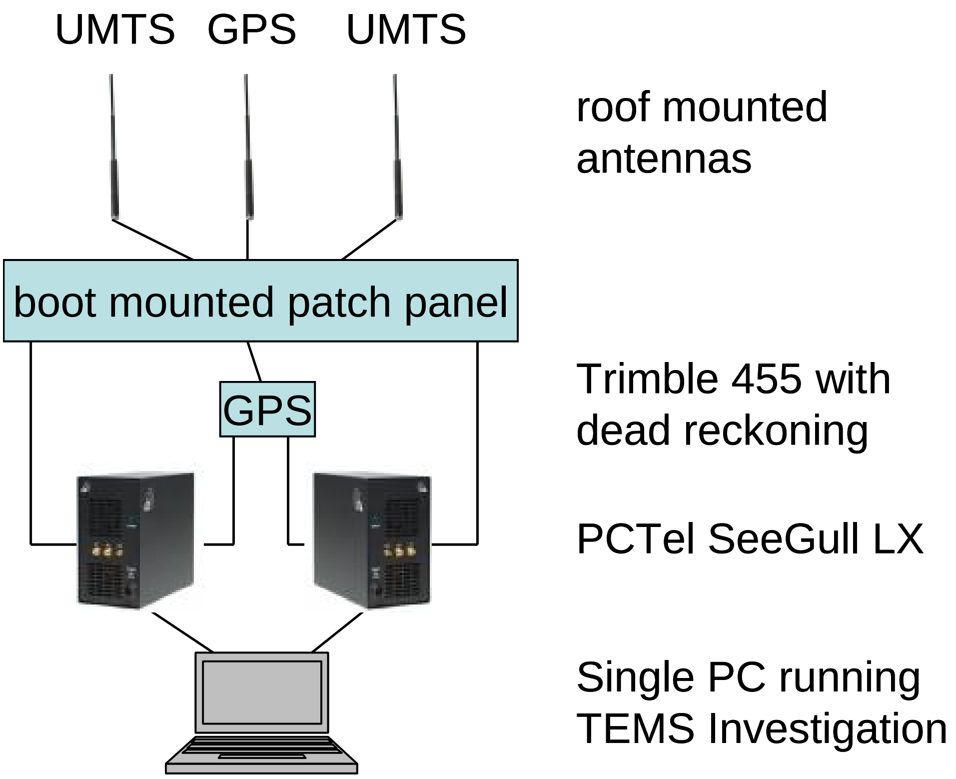
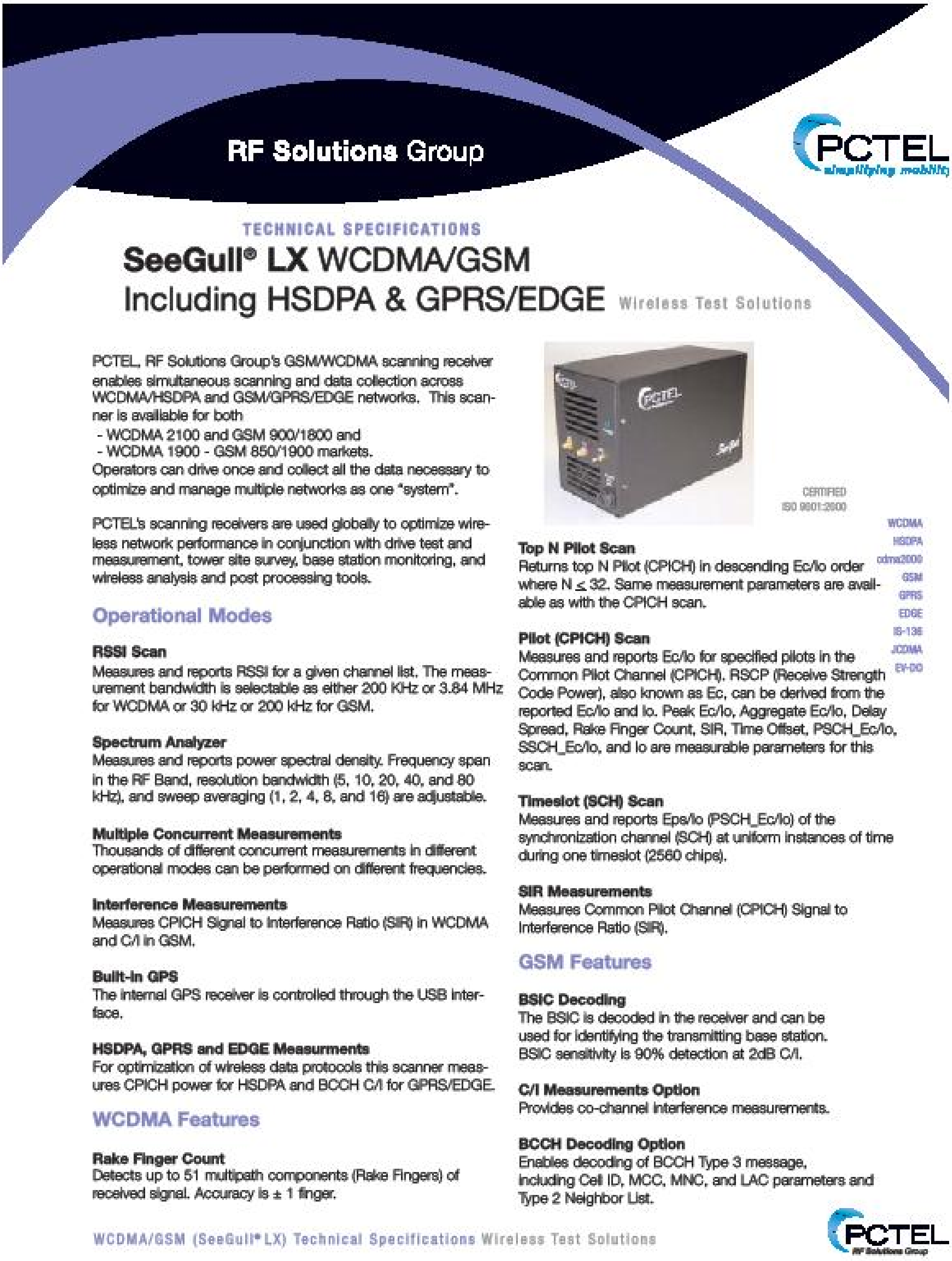


Figure 21: Measurement Configuration

The key features and specifications of the scanning receiver are shown in Figure 22 and Figure 23 respectively.



RF Solutions Group

PCTEL simplifying mobility

TECHNICAL SPECIFICATIONS

SeeGull® LX WCDMA/GSM Including HSDPA & GPRS/EDGE

Wireless Test Solutions

PCTEL, RF Solutions Group's GSM/WCDMA scanning receiver enables simultaneous scanning and data collection across WCDMA/HSDPA and GSM/GPRS/EDGE networks. This scanner is available for both

- WCDMA 2100 and GSM 900/1800 and
- WCDMA 1900 - GSM 850/1900 markets.

Operators can drive once and collect all the data necessary to optimize and manage multiple networks as one "system".

PCTEL's scanning receivers are used globally to optimize wireless network performance in conjunction with drive test and measurement, tower site survey, base station monitoring, and wireless analysis and post processing tools.

Operational Modes

RSSI Scan
Measures and reports RSSI for a given channel list. The measurement bandwidth is selectable as either 200 KHz or 3.84 MHz for WCDMA or 30 kHz or 200 kHz for GSM.

Spectrum Analyzer
Measures and reports power spectral density. Frequency span in the RF Band, resolution bandwidth (5, 10, 20, 40, and 80 kHz), and sweep averaging (1, 2, 4, 8, and 16) are adjustable.

Multiple Concurrent Measurements
Thousands of different concurrent measurements in different operational modes can be performed on different frequencies.

Interference Measurements
Measures CPICH Signal to Interference Ratio (SIR) in WCDMA and C/I in GSM.

Built-In GPS
The internal GPS receiver is controlled through the USB interface.

HSDPA, GPRS and EDGE Measurments
For optimization of wireless data protocols this scanner measures CPICH power for HSDPA and BCCH C/I for GPRS/EDGE.

WCDMA Features

Rake Finger Count
Detects up to 51 multipath components (Rake Fingers) of received signal. Accuracy is ± 1 finger.

CERTIFIED
ISO 9001:2000

WCDMA
HSDPA
cdma2000
GSM
GPRS
EDGE
IS-136
JCDMA
EV-DO

Top N Pilot Scan
Returns top N Pilot (CPICH) in descending Ec/Io order where $N \leq 32$. Same measurement parameters are available as with the CPICH scan.

Pilot (CPICH) Scan
Measures and reports Ec/Io for specified pilots in the Common Pilot Channel (CPICH). RSCP (Receive Strength Code Power), also known as Ec, can be derived from the reported Ec/Io and Io. Peak Ec/Io, Aggregate Ec/Io, Delay Spread, Rake Finger Count, SIR, Time Offset, PSCH_Ec/Io, SSCH_Ec/Io, and Io are measurable parameters for this scan.

Timeslot (SCH) Scan
Measures and reports Eps/Io (PSCH_Ec/Io) of the synchronization channel (SCH) at uniform instances of time during one timeslot (2560 chips).

SIR Measurements
Measures Common Pilot Channel (CPICH) Signal to Interference Ratio (SIR).

GSM Features

BSIC Decoding
The BSIC is decoded in the receiver and can be used for identifying the transmitting base station. BSIC sensitivity is 90% detection at 2dB C/I.

C/I Measurements Option
Provides co-channel interference measurements.

BCCH Decoding Option
Enables decoding of BCCH Type 3 message, including Cell ID, MCC, MNC, and LAC parameters and Type 2 Neighbor List.

WCDMA/GSM (SeeGull® LX) Technical Specifications Wireless Test Solutions

PCTEL RF Solutions Group

Figure 22: Scanning Receiver Key Features (from manufacturer datasheet)

SeeGull® LX WCDMA/GSM including HSDPA & GPRS/EDGE

Specifications

Overview

RSSI Bandwidth
30/200 kHz (CW/Wide) -GSM
200/3840 kHz (CW/Wide) - WCDMA

Spectrum Analysis Dynamic Range
> 90 dB

RSSI Measurement Rate
150/500 Ch/Sec (CW/Wide) -GSM
500/250 Ch/Sec (CW/Wide) -WCDMA

Absolute Accuracy
± 1.0 dB in Basic RF Input Power Range

Relative Accuracy
± 1.0 dB for Ec/Io ≥ -17 dB
± 1.0 dB for 17 dB ≥ SIR ≥ -17 dB

BSIC False Detection - GSM
< 0.1%

CPICH False Detections - WCDMA
< 0.1%

Minimum Detectable WCDMA Signal
-21.5 dB relative, -116 dBm absolute

CPICH Measurement Time
60 ms (minimum)

Input Frequency Tolerance
2 ppm

BSIC Detection Sensitivity - GSM
90% detection at 2dB C/I

Hardware

RF Frequency Ranges (Forward Channels)

WCDMA 1900	1930 MHz to 1990 MHz
WCDMA 2100	2110 MHz to 2170 MHz
GSM 850	869 MHz to 894 MHz
GSM 900	925 MHz to 959 MHz
GSM 1800	1805 MHz to 1880 MHz
GSM 1900	1930 MHz to 1990 MHz

Frequency Accuracy
± 0.05 ppm GPS Locked
± 0.1 ppm GPS Unlocked (room temperature)

Conducted Local Oscillator
-75 dBm Maximum

Intermodulation Spurious Response Attenuation
Frequency separation of 800 kHz greater than 55 dB for signals input up to -43 dBm

Co-Located Transmitter Susceptibility
Receiver performance maintained for signals up to -25 dBm to the RF input within the reverse frequency band of the technology

Internally Generated Spurious Response
-115 dBm Maximum

Protection Against Spurious Response Interference
88 dB Minimum

Desensitization
55 dB Adjacent and 65 dB Alternate Channel

RF Input Power Range
-15 dBm Maximum (operating in-band)
-5 dBm Maximum (operation out-of-band)

Physical

Input Power
+8 to +16 VDC (Negative Ground)
2.5 A Max @ 12 VDC

Communications Interface
USB

Size
8.5" L x 4.00" W x 5.58" H
215.9mm L x 101.6mm W x 141.7mm H

Weight
6.0 lbs / 2.7 Kilograms

Temperature Range

Operating:	0°C to +50°C
Storage:	-40°C to +85°C

Connectors

(2) RF Input (Scanner)	SMA Female (50 Ohm)
(1) RF Input (GPS)	SMB Male (50 Ohm)
(1) Data and Power	Custom USB/Power Cable

Certification CE

PCTEL
RF Solutions Group

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www.pctel.com

10MRK1-06
Rev. H
January 2006
Specifications Subject to Change Without Notice.

Figure 23: Scanning Receiver Specifications (from manufacturer datasheet)

Appendix F MapInfo Area Selection Files

The MapInfo data and queries used for the example area selection process in *Secti0n 3 - Selecting the measurement locations in the Benchmarking Area* are included in this section as a .zip file. Opening the workspace file (.WOR) from within MapInfo should open all linked tables and display the thematic graph for the combined marginal areas.

Selecting
Measurement Locatio