Spectrum Engineering Services

Smart Meter HAN 868MHz RF Coverage Campaign

Measurement Report

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Executive Summary

Ofcom carried out a series of measurements over a six week period during July and August 2015 at a number of different Multiple Dwelling Units (MDU) building types located in London, Bristol, Nottingham, Edinburgh and Perth.

As a result of carrying out measurements and analysis of the results, a radio coverage model has been derived for the implementation of 868MHz smart metering systems.

To maintain consistency with the previous testing campaign carried out by the company Red M, the same measurement methodology was used[1]. This comprised of a calibrated transmitted carrier wave (CW) signal source and signal fade measurements taken at a number of locations within each MDU building using a spectrum analyser and antenna, mounted on a purpose fabricated rotating arm tripod.

The transmitter and measurement locations at each site were chosen following direction by energy suppliers and Department of Energy and Climate Change (DECC) during each MDU site survey and selected from what was considered the typical link locations for a smart meter installation for that building type. 16 MDU buildings were visited with an average of 20 link measurements carried out at each site.

Measurement data and link location details for each MDU site are put together as separate survey documents and are included as appendices to the main report.

Using a calibrated transmitted carrier wave signal source, Tx/Rx Link measurements were carried out using a spectrum analyser. To capture multipath/ fast fading, the analyser Rx antenna was rotated around a circular radius approximately equal to 50cm as the signal was recorded by the analyser over a 10 second period. The received signal samples from each link were used to estimate the mean path loss and fade statistics for that link.

The main report uses the path loss prediction model derived from the Red M report to provide a path loss limit distance. This was achieved using the median values from the individual link measurements and applying a normalised standard distribution to develop a straight line graph model to assist in the prediction of MDU smart meter coverage.

In addition signal coverage range measurement was undertaken at the 5 larger MDU sites to determine the potential distance an 868MHz signal can travel in the environment around an MDU in order to assess the interference implications.

[1] Red M Report – Smart Meter RF Surveys; Doc ref: REDW_OPS_2012044 (https://www.gov.uk/government/publications/smart-meters-rf-survey)

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1 Introduction

Between 1st July and 13th August, 2015 Ofcom Spectrum Engineers, under a formal contract with the Department of Energy and Climate Change (DECC) and in support of the GB smart meter implementation programme, carried out a coverage measurement campaign in Multiple Dwelling Unit (MDU) properties to enable derivation of a HAN (Home Area Network) smart meter signal coverage model for MDUs.

A previous measurement campaign was completed covering one hundred and twenty separate properties, which primarily focused on houses (refer to the Red M report – Smart Meter RF Surveys[2]). This requirement was expanded to measure the radio signal path losses within low-rise and converted MDUs and provide an understanding of how radio signals, specifically those within the 868MHz radio spectrum, propagate within these building types.

Under the direction of DECC and its Stakeholders, measurements were carried out at 16 low-rise MDU sites located in London, Bristol, Nottingham, Edinburgh and Perth. These sites were chosen to provide a good spread of building types used in Great Britain for MDUs.

The approach taken for the MDU measurement campaign focused on attaining path loss measurements through the transmission of a calibrated carrier wave (CW) signal and recording the signal level with a spectrum analyser to at various locations within the MDU.

Two CW transmitters were used simultaneously, with one inside the building and the other outside to simulate both indoor and outdoor meter location scenarios.

The spectrum analyser (receiver) measurement locations and the two transmitter positions were identified following consultation with DECC and the Stakeholders.

The two CW frequencies were selected from the frequency range 869.400MHz – 869.650MHz forming part of the 868MHz sub band allocation for Short Range Device (SRD) applications. This sub-band allows non-specific use applications with a maximum radiated power of no greater than 500mW – Refer to the CEPT/ERC Rec 70-03, 869MHz band plan and Ofcom Interface Requirement document IR2030.

In addition, signal coverage measurements were carried out at the five larger MDU sites to determine the distance an 868MHz signal can propagate so to assess the implication for interference to other services in adjacent buildings as well as the potential frequency re-use. The CW transmitter was positioned at a high point within the MDU building with the Engineer walking around the site using a portable scanning receiver to continuously record Global Positioning System (GPS) data and signal strength.

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[2] Red-M Smart Meter RF Surveys, Document Ref.: REDW_OPS_2012044, Version 1.1, 08th June 2012

2 Measurement Methodology

Radio signals transmitted between a radio transmitter (Tx) and a remote receiver (Rx) experience two types of local propagation effects: A *slow fading* (shadowing) effect due to walls, large obstacles and apertures such as windows and doors; and *fast fading* effect, due to the constructive and destructive summation of signals following different radio paths between the transmitter and the receiver (multipath). Slow fading takes place over a large number of radio signal wavelengths where as fast fading takes place within distances of one or two wavelengths.

Measurements involved capturing the effect of fast fading, by using a portable spectrum analyser to measure the signal level at a number of locations positioned at various distances from two calibrated CW signal source transmitters. Using the measurement data from the analyser, the path loss was derived for each transmitter (Tx) - analyser (Rx) link.

The analyser antenna was mounted on a purpose made tripod (as shown in Figure 1) with a rotating arm to enable both horizontal and vertical circular movement of the antenna over a radius area of approximately 50cm. The wavelength of the 868MHz signal is ~34cm.

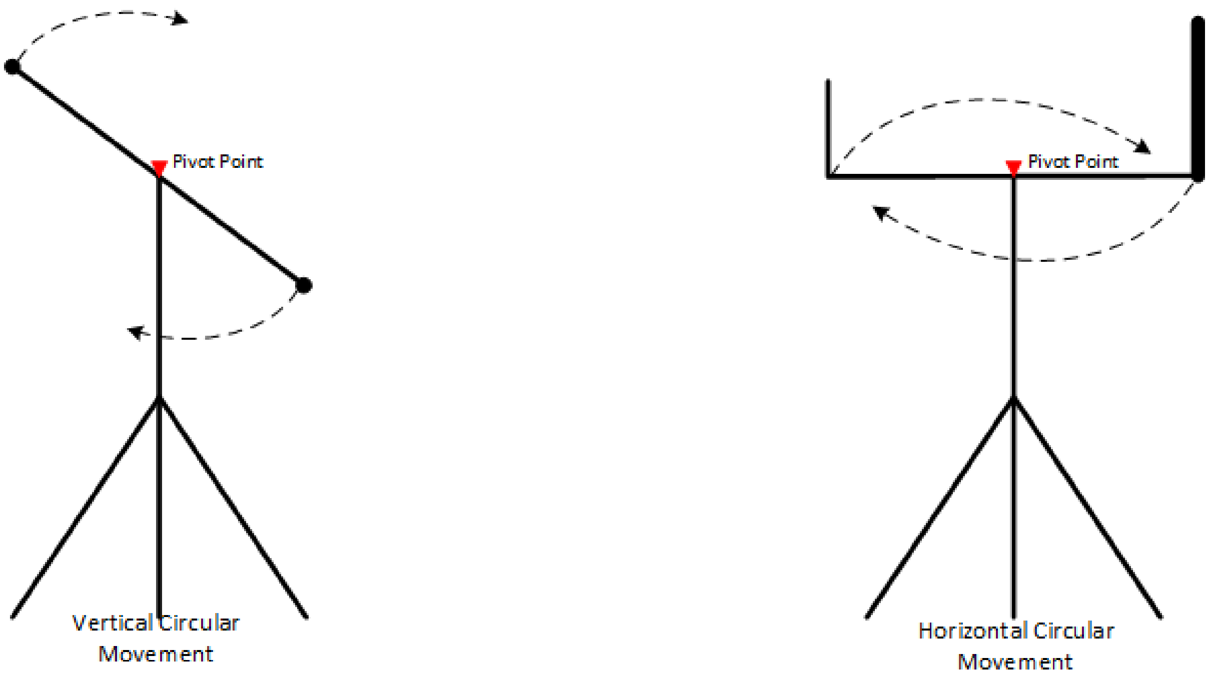

Figure 1 Antenna Rotation for Fast Fading

The purpose of rotating the analyser antenna was to capture the signal variability due to fast fading at the measurement location by recording a sufficient number of received signal samples. The movement of an antenna through a number of wavelengths around the measurement location is an acceptable method by which to simulate fast signal fading and derive an estimate of the mean path loss and fade statistics.

To capture the effects of slow fading, measurements were carried out over a large number of Tx/Rx links of similar types and distances at the 16 MDU buildings

As directed by DECC and the Stakeholders measurements were made with the analyser antenna rotated in both the horizontal and vertical planes to investigate the effects and differences between positioning the receive antenna in either orientation.

Following discussion with DECC and Stakeholders, it was agreed that electric and gas meters fitted within MDU buildings were likely to be mounted on or located close to building walls, typically in corridors, stairways or public areas. In order to simulate this, measurements were carried out with the analyser antenna positioned as close as possible to a wall but still to allowing rotation of the antenna.

The analyser antenna measurement tripod was adjusted to a height of 1.5m as this was considered within the proximity of the likely mounting height of a meter from the floor. This also enabled rotation of the tripod arm for horizontal measurements. Where building obstructions prevented complete rotation of the antenna, the tripod height was adjusted accordingly. Where there was antenna height variation it was not considered an issue or to impact upon measurement consistency as any variance in the analyser antenna height is compensated as a result of the antenna rotation and process of fade measurement.

The same omnidirectional antenna was used for both transmitters and analysers (receivers).

With the antenna mounted in a vertical position, the radiation pattern is such that a signal null is positioned directly above the top of antenna. In order to avoid signal loss to measurement locations positioned on floors directly above the transmitter, the transmitter antenna was positioned horizontally so that the antenna radiation pattern in this plane provided maximum signal propagation through the MDU.

Exact measurement locations were determined following site survey with DECC and Stakeholders. The CW transmitter was sited at ground or basement level as this was considered typical for meter locations, and with analyser (receiver) measurements carried-out at locations on each MDU floor or until the signal level become un-measureable.

Range coverage measurements were carried out at the 5 larger MDU properties using a 500mW CW signal source located at a high point within the MDU. Using a portable scanning receiver with GPS data logger, signal level measurements were recorded as the receiver was walked around the MDU site area. The transmitter antenna was positioned vertically to radiate the signal away from the MDU.

2.1 Measurement Method

To simulate typical inside and outside meter positions, two CW transmitter sources were used with one transmitter antenna located inside the MDU, (Tx1), and the other transmitter antenna, (Tx2) located outside typically next to an outside wall.

Both transmitters were operated at the same time on different frequencies to enable both inside and outside measurements to be completed during a single visit to each measurement location, and maximising the number of measurements taken at a MDU site.

To comply with the interface requirements for operation within the 868MHz band, the CW transmissions were limited to frequencies within the 869.400MHz – 869.650MHz[3] sub-band.

Prior to setting up the test equipment an initial frequency sweep of the sub-band was carried out to identify suitable clear frequencies for Tx1 and Tx2.

Both signal generators were set up and calibrated to radiate 100mW (20dBm) from their respective antennas using the spectrum analyser to measure the signal level at the feeder cables. Knowing the antenna gain, each generator output was adjusted to provide the correct radiated power.

Measurements were carried out with the spectrum analyser set to zero-span and with the signal level recorded over a period of ten seconds, as the analyser antenna was rotated to account for signal fading. Approximately 600 data samples were recorded over 10 second duration, to capture the signal level variance as a result of fast fading. This process was carried out for both horizontal and vertical antenna orientations and both transmitter frequencies. Each measurement was recorded to a unique data file. All the data files were processed to provide the result analysis detailed in this report.

Measurements were carried out at an average of twenty locations for each MDU site.

The signal coverage measurements were made by positioning a 500mW (27dBm) transmitted CW source at a high point location (where possible on the top floor of the MDU building) and with the transmit antenna mounted vertically. A portable scanning receiver with GPS was used to record signal level and position data as the receiver was walked around the MDU location and adjoining areas. The purpose of the test was to determine how far apart Tx/Rx combinations need to be separated to prevent interference between adjacent equipment. The signal level measurement trail from each walk is overlaid on the coverage maps included in Appendix B. The maps provide a pictorial view of the propagation coverage of the 868MHz signal around the external locality of the building.

2.2 Test Locations

Measurements were carried out at the following MDU sites:

London

1. Lillington Gardens
2. Norfolk House
3. Carey Mansion
4. Brunel Estate
5. Tothill House
6. Dufours Place

[3] CEPT/ERC Recommendation 70-03 Relating to the operation Short Range Devices in frequency band g3

Bristol

1. Henbury Court
2. Ashton Manor
3. Mawdeley House
4. Butterworth Court
5. BBond warehouse (commercial building)

Nottingham

1. William Bancroft Building
2. Michon Creative Design Studio (converted school building)

Edinburgh

1. Rossie Place

Perth

1. Loanhead farm
2. Marshall Place

A separate survey report has been compiled for each site providing building and measurement location detail and these can be found in Appendix A

2.3 Measurement Procedure

The measurement procedure taken was:

1. A frequency sweep of the 869MHz sub band (869.400MHz – 869.650MHz) to choose transmit frequencies for Tx1 and Tx2 and avoid interference to other radio services.
2. Signal-fade measurements in both the vertical and horizontal antenna orientations at the measurement locations as directed by DECC and Stakeholders.
3. Signal range measurements at the five larger sites using a mobile scanning receiver with GPS position logger.

2.4 Test Equipment Details

The following table lists the measurement equipment used during this measurement campaign.

Item	Make/Model	Serial / Asset Number	Calibration date/certificate No.
Signal Generator 1	R&S SMBV100B	256587 (0471)	1-6235742724-1 Cal date: 29-09-2015
Signal Generator 2	Anritsu MG3695A	032006	1-6716560165-1 Cal date: 07-05-2016
Power Amplifier	ENI 607I-01	162	1-6866215850-1 Cal date: 01-06-2016
Spectrum Analyser 1	R&S FSH8	115160/028	Calibrated and supplied by Rohde & Schwarz (R&S)
Spectrum Analyser 2	R&S ZVH8	1155159/EJ	1-6716560653-1 Cal date: 31-03-2016

Table 1 Test Equipment Details

Item	Make/Model	Serial Number	VSWR
Tx Antenna 1	Radio Structures ENF900	11911	1.43
Tx Antenna 2	Radio Structures ENF900	11883	1.51
Rx Antenna 1	Radio Structures ENF900	11910	1.42
Rx Antenna 2	Radio Structures ENF900	11882	1.62

Table 2 Antenna Details

2.5 Equipment Set-up

Before starting measurements at each location, a calibration process was carried out to confirm that the test equipment was performing as expected and to ensure continuity of the measurements:

With the spectrum analyser connected to the feeder cable of the transmitter, the signal generator output was adjusted to provide the required power needed to radiate 20dBm (100mW) from the antenna. This process was carried out for both transmit sources. Both transmitter antennas were fitted to tripods and orientated horizontally.

The two receive antennas were mounted on their tripods and the arms rotated to position the antennas horizontally. With the analysers connected to the antennas, the tripods were positioned to 3m from the transmitter antennas. Both transmit and receive antennas were adjusted to be at the same height and alignment.

Allowing for the free space path loss, the magnitude of the received signal measured by each analyser was checked to be as expected. This enabled any discrepancies due to poor cable connections, incorrect settings to be rectified before starting the measurements.

The procedure for equipment setup and calibration method is detailed in the Ofcom test procedure document.[4]

2.5.1 Transmit Source

Two transmitter sources were employed:

- An R&S SMBV100B RF signal generator connected to an ENI power amplifier in order to provide the required power to the antennas for both the 100mW and 500mW tests.
- An Anritsu MG3695A was used for 100mW transmissions.
- Both signal sources were connected to Radio Structures ENF900 antennas and mounted horizontally on RF neutral nylon tripods.

An example of a transmit location is shown in .The locations for the transmit sources were chosen as directed by DECC and Stakeholders. The antenna height set to simulate the meter positions although this was ordinarily set to between 1m and 1.5m.

[4] OFCOM_SES(15)_011 – Smart Meter Measurement Setup

Figure 2 Typical Transmitter Location

2.5.2 Spectrum Analyser (Receiver)

Measurements were carried out using the R&S FSH8 and the R&S ZVH8 spectrum analysers. These were connected to Radio Structures EN900 antennas. To undertake the signal fade measurements, RF neutral nylon tripods were used allowing 360° rotation of the antenna in both vertical and horizontal planes. Measurements were carried out with the analyser antenna in both orientations as requested by DECC and Stakeholders to investigate the effects of receiving signals by mounting the receive antenna in either orientation.

See photographs, Figure 3 Spectrum Analyser Connected to the Horizontally Positioned Antenna and Figure 4 Spectrum Analyser Connected to the Vertically Positioned Antenna.

Figure 3 Spectrum Analyser Connected to the Horizontally Positioned Antenna

Figure 4 Spectrum Analyser Connected to the Vertically Positioned Antenna

3 Site Details

3.1 Building Plan and Test Locations

The building plan and test location details for each MDU site are detailed in the site repots included in Appendix A – Site Reports.

Ordnance Survey (OS) supplied plan drawings were used to provide the building foot-print detail and overlaid with a grid as a means to identify the indoor and outdoor transmitter and measurement locations. Because the OS map sheets covering the various locations were of differing scales, these were re-sized using map tools in order that a 4m grid could be overlaid as shown by the example in Figure 5. The transmitters and measurement locations were identified using the grid reference method as shown by the example provided in Table 3.

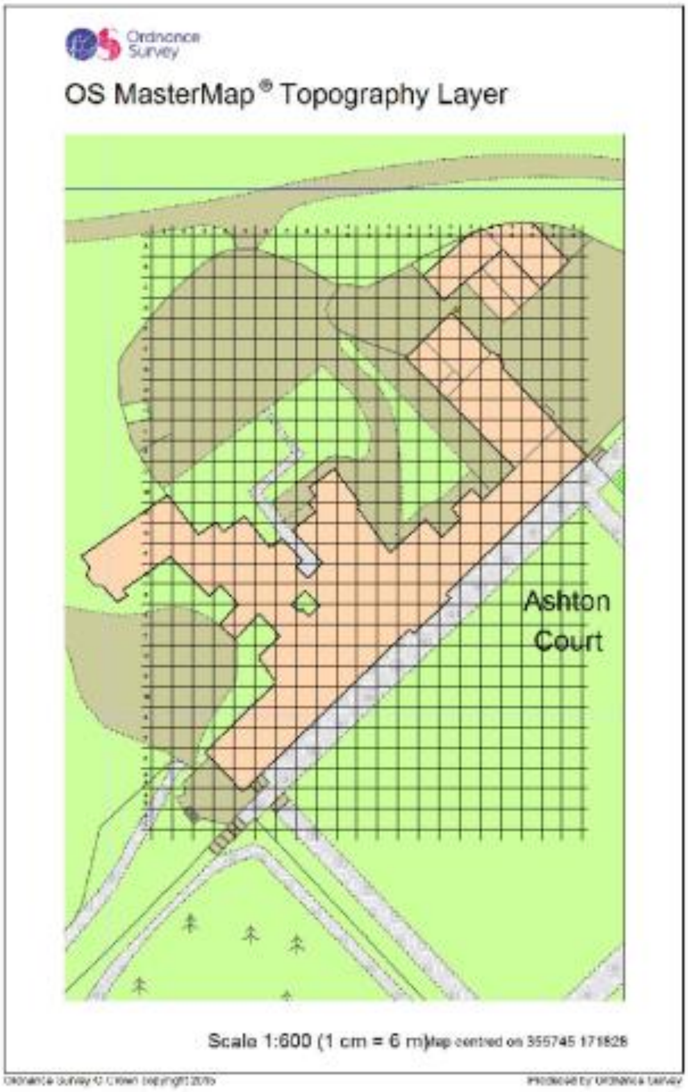

Figure 5 Building Plan Drawing with Grid Overlay

Team	Test	Floor	Inside/Outside	Grid Reference
-	Tx 1	Ground	Inside	O4
-	Tx 2	Ground	Inside	Q7
2	Rx 1	Ground	Inside	Q4
2	Rx 2	Ground	Inside	O5
2	Rx 3	Ground	Inside	O4
2	Rx 4	Ground	Outside	P6
2	Rx 5	Ground	Inside	R3
2	Rx 6	Ground	Inside	P6
1	Rx 7	Ground	Outside	V6
1	Rx 8	Ground	Outside	P1
1	Rx 9	Ground	Inside	T8
1	Rx 10	Ground	Inside	T10
1	Rx 11	Ground	Inside	P12
1	Rx 12	Ground	Inside	P13
1	Rx 13	Ground	Inside	N15

Table 3 Example Transmitter and Measurement Location Grid Reference

4 Transmitter Frequencies

4.1 Test Frequencies

A frequency scan of the spectrum was undertaken using a spectrum analyser to determine the frequencies for the two CW transmitters, Tx1 and Tx2. Complying with the CEPT/ERC Recommendation 70-03 and Ofcom Interface Requirement document 2030 for operating within the 868MHz band, frequency selection was limited to between 869.400MHz and 869.650MHz[5]. Unused channels were chosen to avoid interference to other services and limit any impact to the measurements. Figure 6 shows an example frequency scan taken at one of the MDU sites (The frequency scan for each MDU is include in its property report). In this example, the analyser span was set between 869.300MHz and 869.650MHz as the operator wished to confirm if there were any radio services operating just below 869.400MHz.

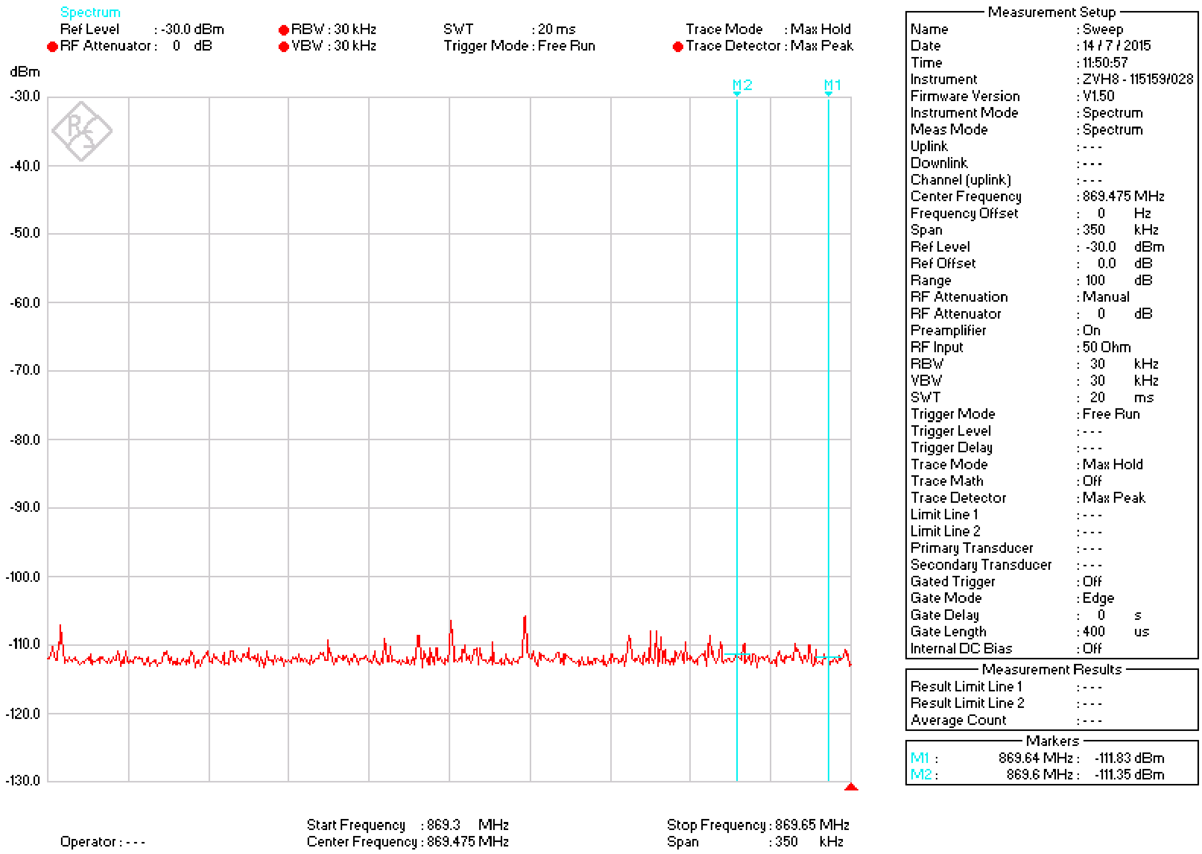

Figure 6 Frequency Scan of Band

[5] CEPT/ERC Recommendation 70-03 relating to the operation of Short Range Devices in frequency band g3

As an example, the following spot frequencies chosen were due to no other radio services being present and minimal RF noise.

Transmitter	Frequency
Tx 1	869.640 MHz
Tx 2	869.450 MHz

Table 4 Transmitter Frequencies

5 Measurement Method

5.1 Instrument Settings

The two signal generators were calibrated to transmit two 100mW (20dBm) CW signals (Tx1 and Tx2).

To confirm that the performance of the spectrum analyser was acceptable for the measurements being carried out the following assessment was made:

The spectrum analyser has a noise floor of ~-151dBm/Hz without the pre-amp enabled. With the analyser resolution bandwidth (RBW) set to 10 kHz brings the measurement noise floor to -111dBm.

$$(-151\text{dBm} + 10\log(10\text{x}10^3) = -111\text{dBm})$$

With a 20dBm transmitted signal and allowing an for an additional 4dB above the noise floor for signal detection provides a measurement dynamic range of 127dB.

If the radiated transmitter power of CW signals was reduced to 25mW (14dBm), this would still provide a dynamic range of 121dB.

It is therefore possible to measure signals with a path loss of 127dB which is deemed greater than the link budget allowance for typical smart metering equipment.

5.2 Fast Fading Measurements

Fast fading is as a result of the multipath propagation between a transmitted signal source and the receiver. When combined in a destructive way, this can lead to fades in the signal. The movement of both transmit and receive antenna over a few wavelengths to measure the local signal variability enables fast fading (multipath) to be resolved. Due to the practical limitations of rotating both antenna simultaneously and applying the same method as the previous measurement campaign, the receive antenna is moved over a few wavelengths with the transmit antenna left stationary.

To capture this effect, the analyser (receiver) antenna was mounted on a tripod with a rotating arm of 50cm radius. By rotating the antenna through a number of wavelengths, (the wavelength is approximately 34cm at 869MHz) and setting the spectrum analyser to measure sufficient signal samples enables the average signal strength at the measurement location to be estimated.

With the spectrum analyser set to zero-span, a sweep period of ten seconds was used to record the measured signal level as the analyser antenna was rotated through a number of 360° revolutions. This resulted in capturing approximately 600 data samples containing the peak and null signal fading levels. A typical measurement sweep shown by the analyser display is provided in Figure 7. The cyclic pattern of the sweep indicates that the antenna was rotated three times during this measurement.

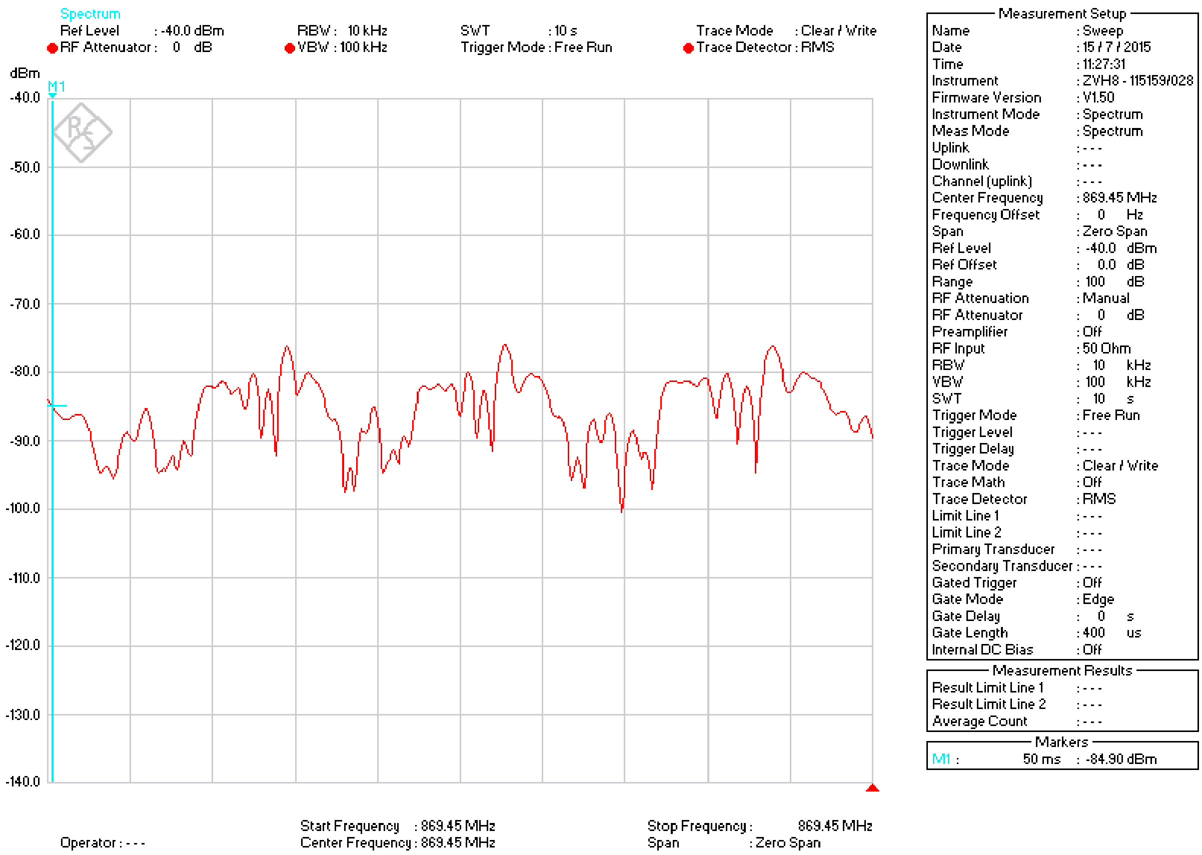

Figure 7 Spectrum analyser measurement sweep showing signal variation

At each receiver location four measurements were made namely; a vertical and horizontal antenna measurement for indoor transmitted signal (Tx1), and a vertical and horizontal antenna measurement for outdoor transmitted signal (Tx2). An example of a measurement is shown in Figure 7.

Figure 8 shows the signal fade measurement set up arrangement.

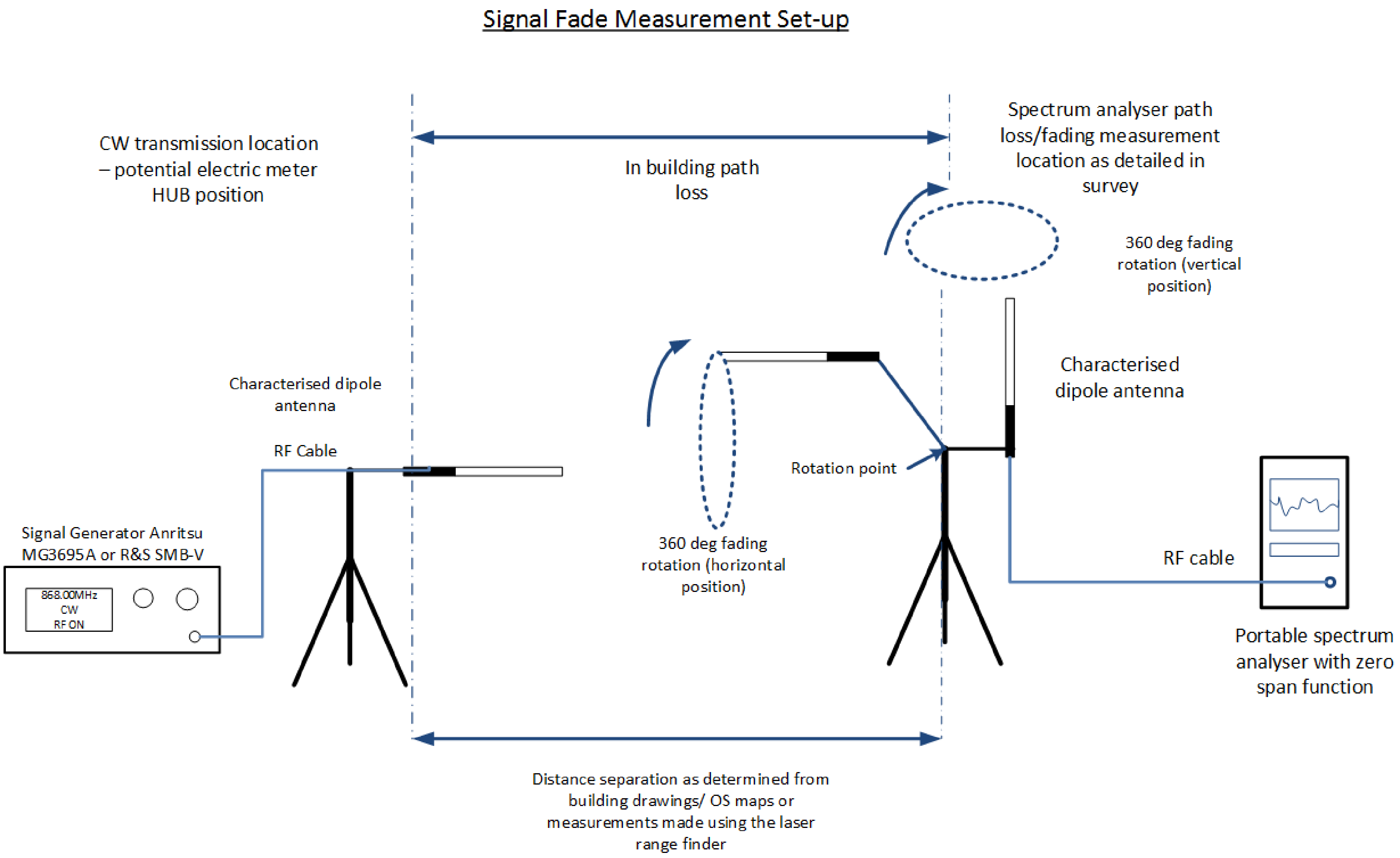

Figure 8 Signal Fade Measurement Set up

6 Measurement Result Analysis

The following sections identify the measurement data collected and the approach taken in the evaluation HAN coverage at 868MHz.

6.1 Building Path loss Model – Effects of Slow Fading

To maintain consistency with the previous DECC building measurement programme, the approach taken for the measurement data analysis and derivation of the path loss model is that followed in the Red-M Smart Meter RF Surveys report dated June 8, 2012. This uses an adaption of the COST-231[6] multiwall model but with the addition of a tuned slope to include the effects due to slow fading.

The model uses the median values (50th percentile of the distribution of the path loss signal levels) from the data of the measurements to develop a tuned path loss slope as follows.

Data is taken from the analyser measurements made with the transmitter and analyser (receive) antennas in the same polarisation, i.e. with both transmit and receive antenna mounted in the horizontal plane.

The data is plotted on a log (logarithmic base 10) scale of path loss against distance to produce a median (50th percentile) line through the data points. The line takes the form:

$$Pathloss = A * \ log(distance) + B$$

The 50th percentile slope line is shown on the chart in Figure 10 as the dotted blue line.

The 50th percentile slope line is used to calculate the path loss at every measurement point. The error between the model value and that measured at a given location is calculated using the following formula.

$$Model\ error = model\ value - \ measured\ value$$

By computing the standard deviation (SD), the error variability between the calculated and measured values can be ascertained. The probability density function (PDF), is derived by organising the path loss data into 3dB bins from lowest to the highest and with the resulting distribution normalised. Figure 9 shows the theoretical PDF plotted against the standard deviation of the measurement data. As the two distributions are similar, the data samples can be assumed normal such that the Normal or Gaussian distribution function estimator can be applied to produce the 90th percentile slope line for the data as added to the chart in figure 10. The 90th percentile path loss captures the variability of the measurement data, i.e. to account for the differing median field strengths for a given distance between the different MDUs as a result of slow fading effects.

[6] COST-231 Final Report, Digital Mobile Radio: COST 231 View on the evolution towards 3rd Generation Systems, European Commission/ COST Telecommunications, Brussels, 1998.

As a comparison, the chart in Figure 11 plots the 90th percentile slope line against free space loss to demonstrate the reduction distance for a given path loss as a result of signal propagation within MDU buildings.

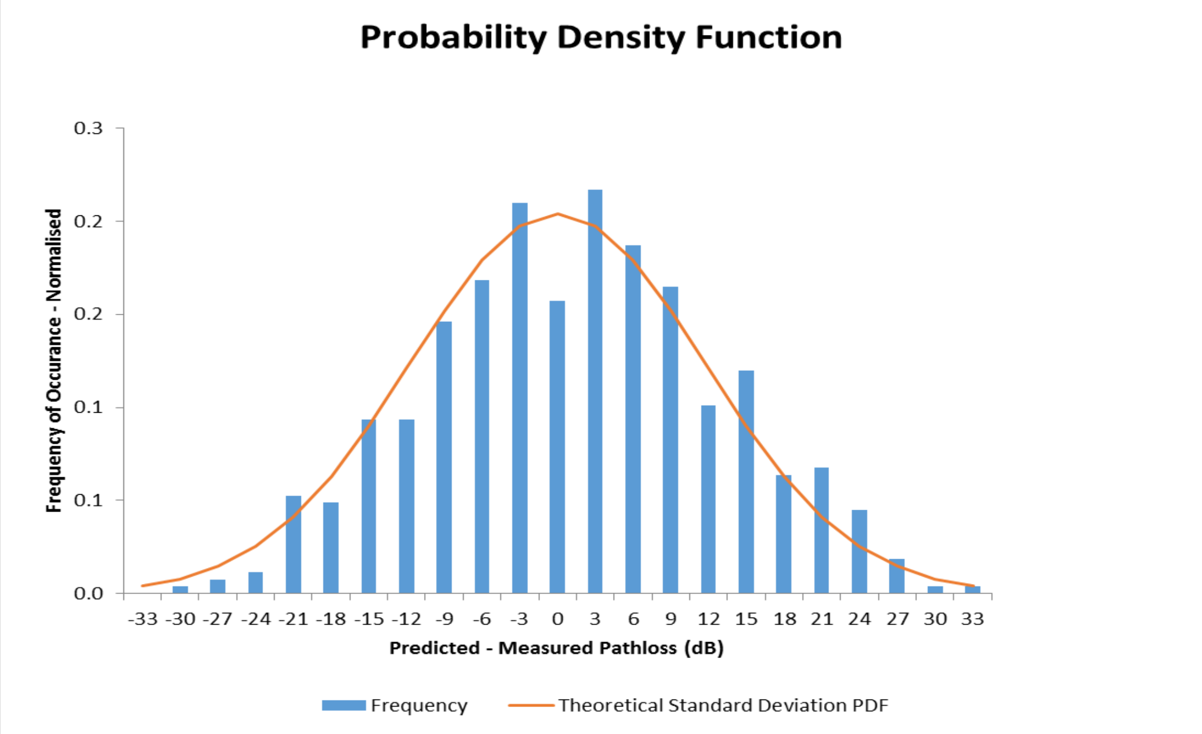

Figure 9 Probability Density Function Plotted Against Normalised Standard Deviation

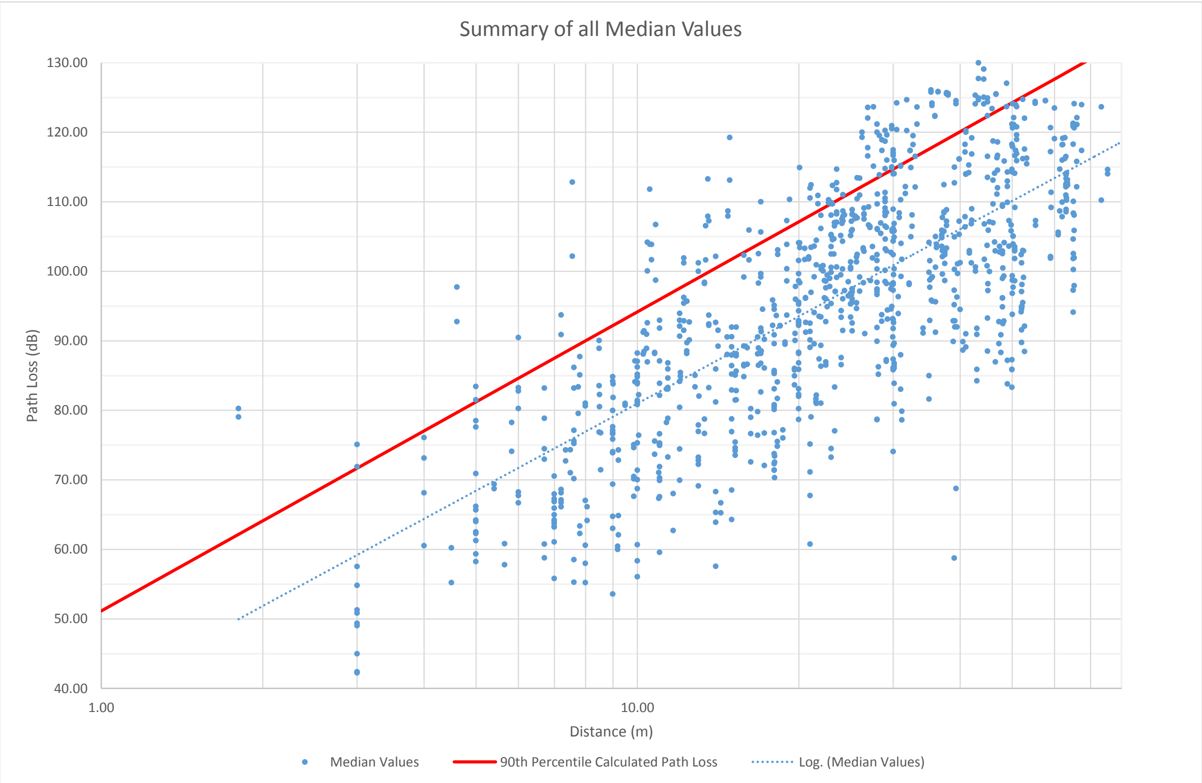

Figure 10 Building Path Loss Limit with 90th and 50th (Median) Percentile Slope Lines

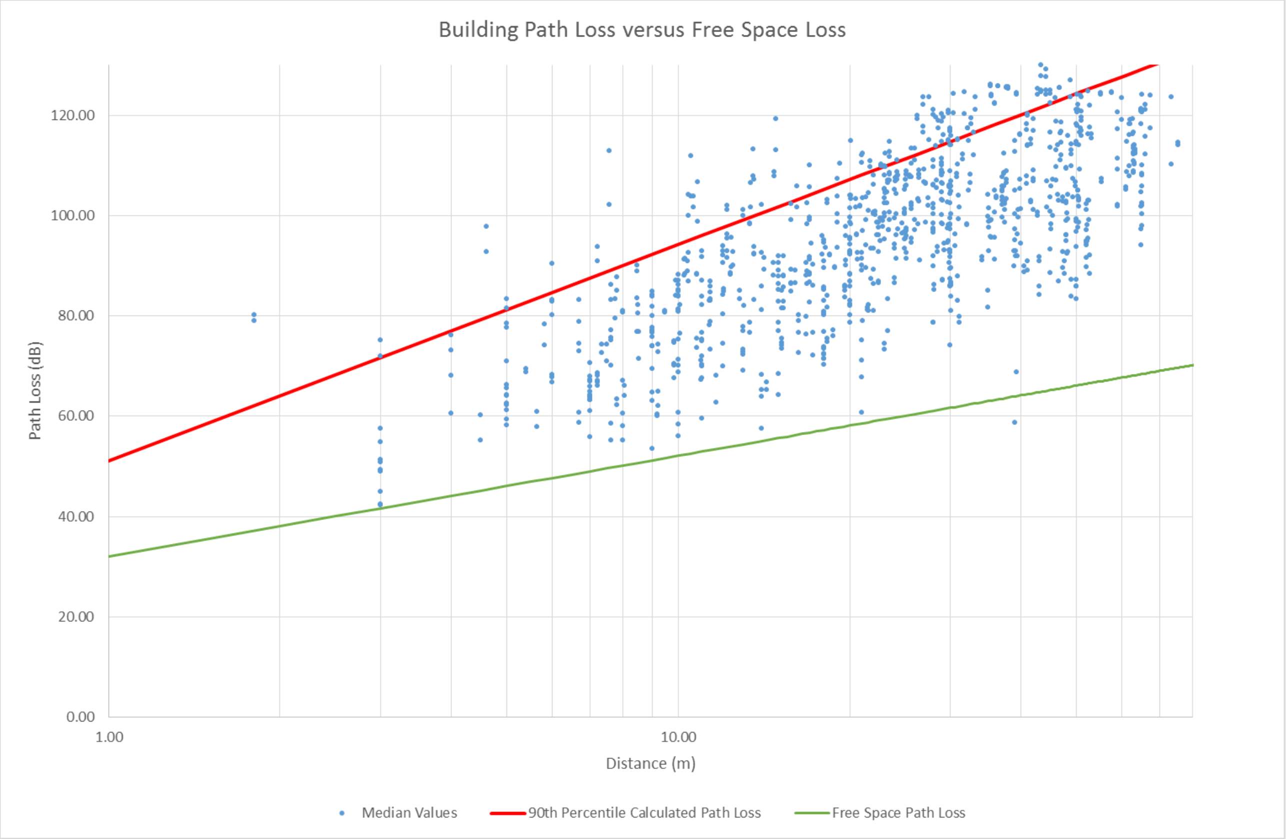

Figure 11 90th Percentile Path Loss and Free Space Loss Slope Lines

6.2 Fading Analysis – Effects of Fast Fading

As a result of carrying out fast fade measurements, four data files were created at each receiver measurement location, i.e. as a result of rotating the analyser receive antenna in the horizontal and vertical plane for Tx1 and Tx2 measurements. The data was processed to produce a median signal value for each data file, generated from the mid-point of the signal difference from peak to null through rotation of the analyser antenna.

The median or 50th percentile is a probabilistic measure giving the 50% reliability that the signal received at the measurement location will be the same as the median signal value.

The results of plotting path loss versus distance for the median measurement values for the example buildings: Lillington Gardens, Carey Mansions and William Bancroft are shown in the graphs of Figure 12, Figure 13 and Figure 14.

Two best fit lines are produced. One as a result of plotting the median signal values from the antennas of the same orientation measurements and a second from plotting the median signal values of the mixed antenna orientation measurements.

Although it is observed that there can be a significant difference between the antennas of the same orientation (vertical: vertical/ horizontal: horizontal) compared to the mixed orientation (vertical: horizontal) at a particular distance, close proximity of the two lines suggest that the random effects of fading (multipath, shadowing) have an influence on the propagation of a signal within a MDU building such that there is a close correlation between the signal medians from both sets of measurements.

Taking each data point within each measurement set, and comparing it to the median value for that data set provides a series of difference values which can be plotted to provide a distribution curve for the fast fade margin. The curve follows that of a Rayleigh distribution agreeing with technical literature that describes the use of this statistical curve for modelling the effects of fast fade when calculating the link budget for a radio network[7].

It is possible to combine all fade margin values for all data sets to provide a summary distribution. The summary distribution curve resulting from the median values of all the MDUs can be found in Figure 15. To provide a level of certainty for edge coverage within a system, a probability of 90%[8] is used to determine the level of fade margin allowance. The fade margin for 90% of all values was taken from the chart, at the 10% level on the 'Y' axis. The 90% value for the summary is 8.6dB and this is the fade margin that would be required as part of the link budget.

Table 5 lists the fade margins from the 100mW measurements for each MDU.

To confirm that the path loss between a transmitter and receiver is not dependent upon the magnitude of the transmitted signal, some additional measurements were carried out with

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[7] Kirkman N C, etal. (2006). *Mobile Radio Network Design in the VHF and UHF Bands*: *A Practical Approach*. London: Wiley.

[8] Jakes, W (1994). Microwave Mobile Communications. London: Wiley.

the transmitter power set to 25mW and 500mW. These tests were carried out at a number of the larger MDU sites.

Using the median values from measurements made at 25mW, 100mW and 500mW, three fade margin distribution curves are produced as shown in Figure 16. The minimal difference between the three fade margin curves, demonstrates that the path loss between a transmitter and receiver is not dependent upon the magnitude of the transmitted signal. It should be noted that the majority of measurements were made with 100mW transmissions.

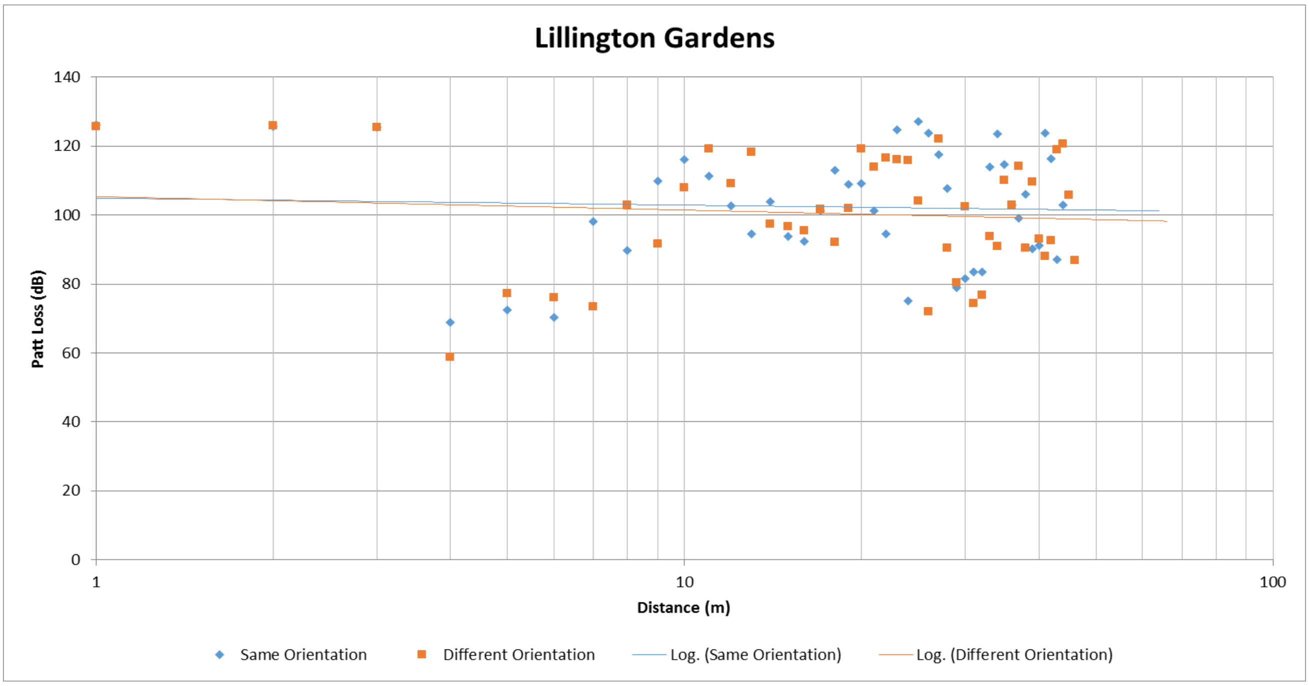


Figure 12 Lillington Gardens Median Horizontal and Vertical Values (same orientation is horizontal to horizontal)

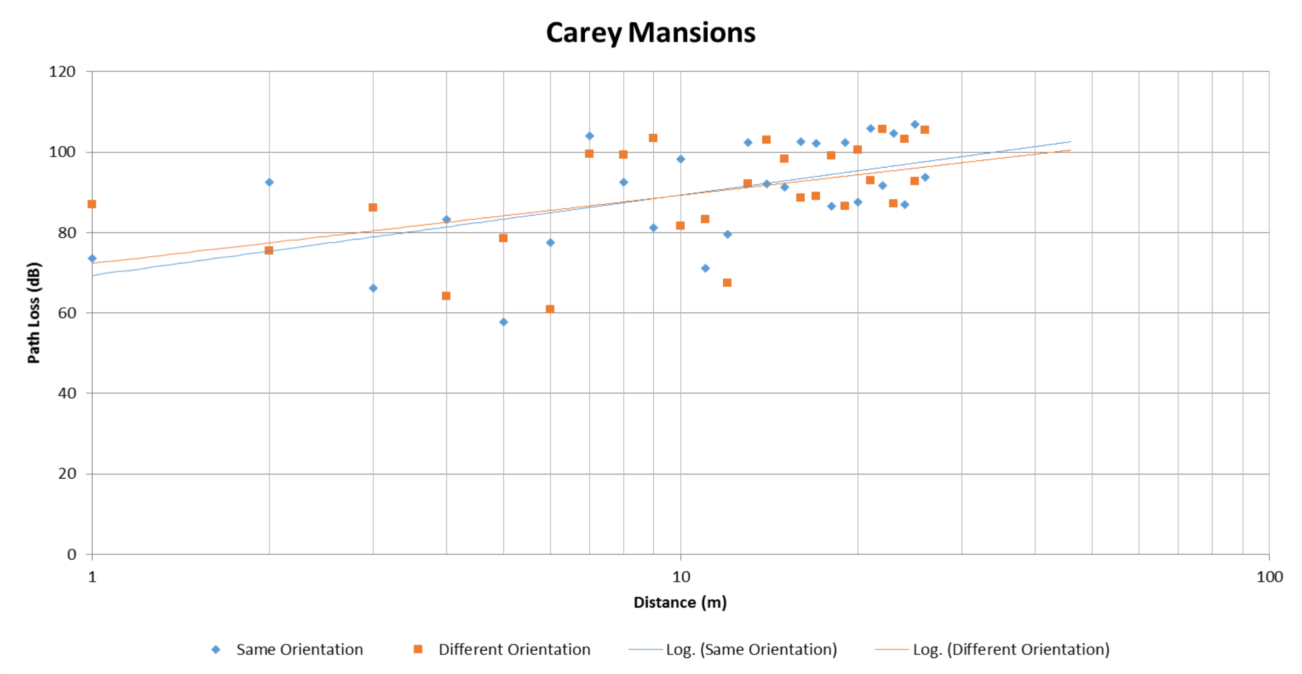


Figure 13 Carey Mansions Median Horizontal and Vertical Values (same orientation is horizontal to horizontal)

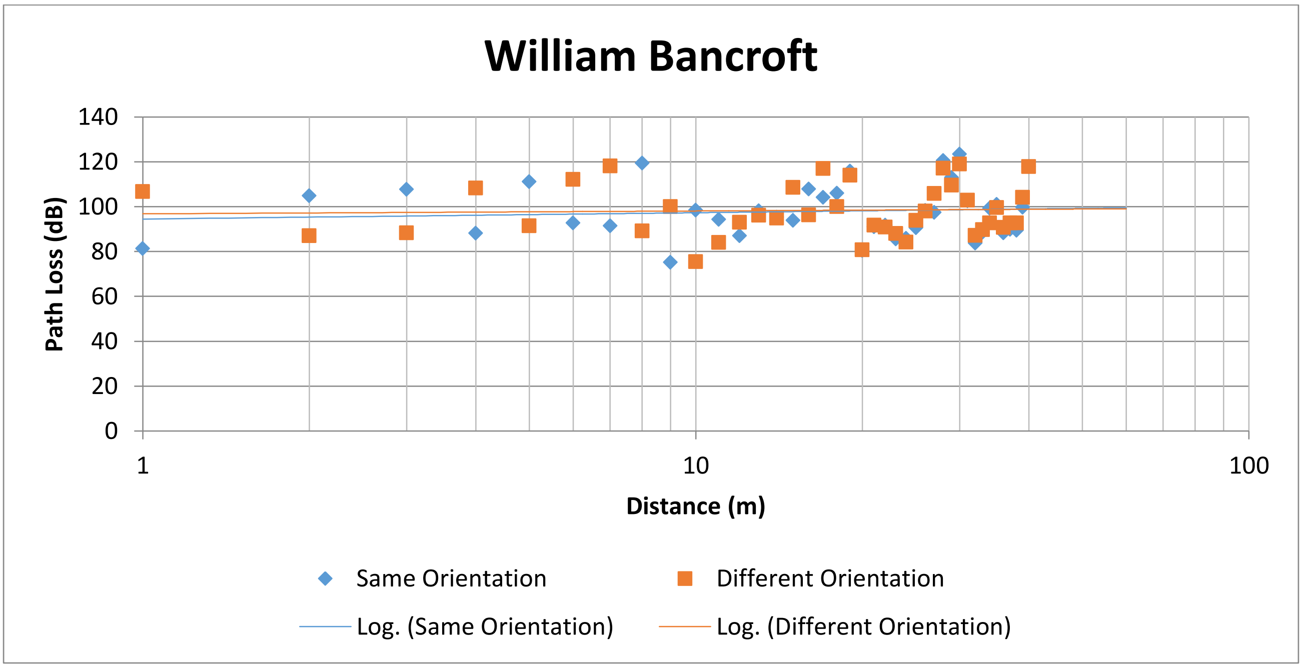


Figure 14 William Bancroft Buildings Median Horizontal and Vertical Values (same orientation is horizontal to horizontal)

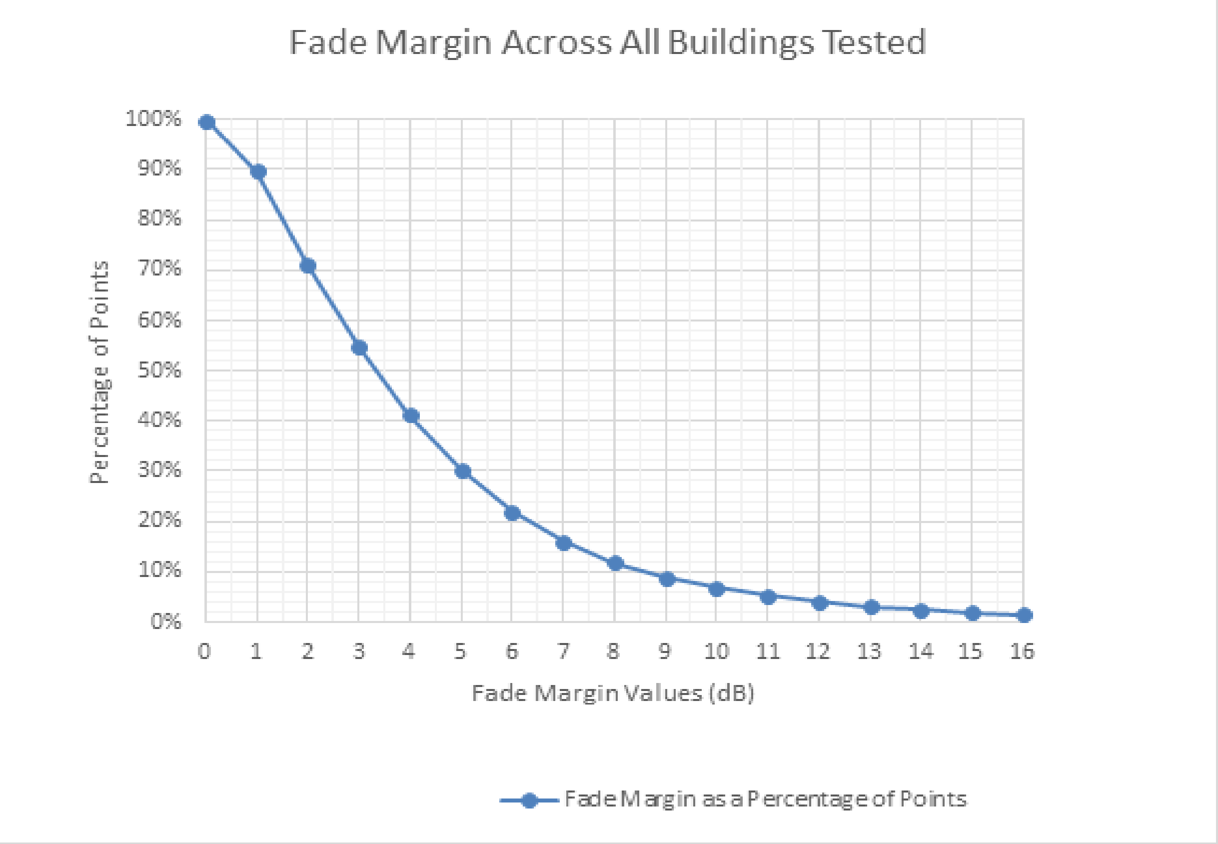


Figure 15 Average Fade Margin for All Buildings Tested

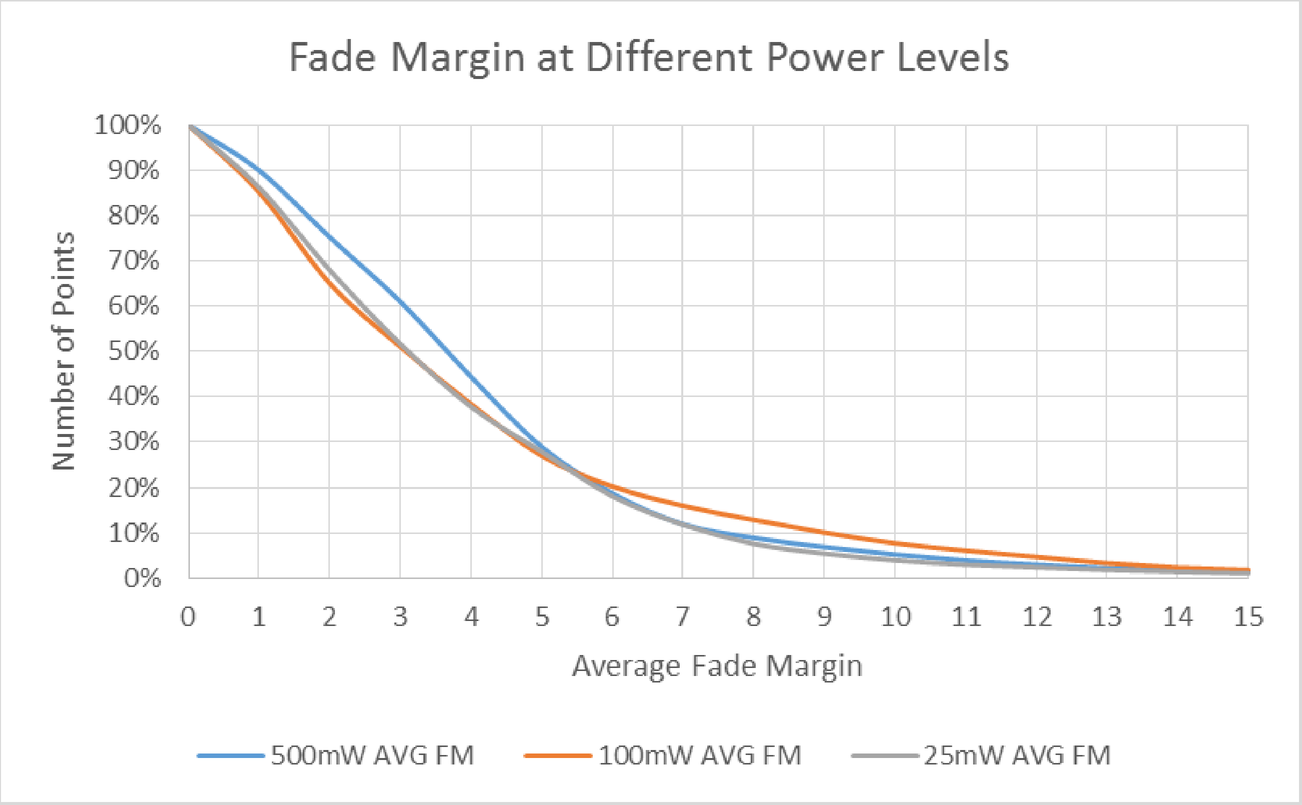


Figure 16 Fade Margin for 500mW, 100mW and 25mW Power Levels

MDU site	Fast Fading Margin Value (dB)
Ashton Manor	8.6
Lillington Grdns	9.0
Carey Mansions	9.0
Norfolk House	8.7
Brunel Estate	8.4
Henbury Court	9.0
Butterworth Court	9.0
Michon Ceative	9.0
William Bancroft	9.0
BBond Warehouse	8.0
Rossie Place	8.7
Loanhead farm	7.5
Marshall Place	9.0
Tothill House	8.0
Dufour Place	9.0
Mawdeley House	8.7

Table 5 Median Fade Margin for Each Site from 100mW Measurements

The above table lists the individual 90% fade margin values for each MDU. The values are comparable with the 8.2 dB, fade margin figure provided in the text book by Kirkman N C, etal. (2006). *Mobile Radio Network Design in the VHF and UHF Bands*: *A Practical Approach*. London: Wiley. Therefore, the resulting value of 8.6dB for the fade margin from Figure 15 is considered an appropriate value for fade allowance within the link budget and compares well with the 9dB worse case fast fade margin allowance in the Red M RF survey report.

6.3 Building Path Loss Limit

A coverage reliability of 90% has been used to determine the maximum distance for a given transmitter power.

Based Upon the following design assumptions:

- An 8.6dB fast fading margin
- 6dB antenna loss – Consistent with value used in the Red M Report
- 1.4dB for additional loss allowance for cables, connectors etc.

A total allowance of 16dB has been applied to the link budget for the above losses.

The following table shows the distances expected against path loss for different transmitted powers.

Power (mW)	Power (dBm)	Path Loss (dB)	Distance (m)
25	14	104	16.67
100	20	110	23.05
500	27	117	33.64

Table 6 Building Path Loss and Distance Values for Increasing Transmitter Powers

The path loss values in Table 6 are based on a link budget that is an average across three chip manufacture implementations.

6.4 Result Summary

The result of carrying out link measurements at 16 MDU properties has enabled a path loss model to be developed comprising of slow fading and fast fading components through processing the measurement data sets from each measurement at all the MDUs.

As a result of plotting the median signal values from all the measurement locations on a path loss versus distance log-scale chart, a 50th percentile path loss slope line can be produced through the points. As the distribution of the median values follows a Normalised Gaussian probability density function (PDF), the slope line can be tuned to encompass the 90th percentile of values to reflect the difference between measurement values as a result of slow fade effects from the construction, layout and building materials used at different MDUs. The target has been to provide 90% system reliability at coverage edge. Using this approach the slope line can be tailored to encompass a greater or lesser percentage of measurement values reflecting the necessity of a particular HAN solution to reliably cover a particular proportion of MDUs.

The fast fade margin value used in the path loss link budget is as a result of the Rayleigh distribution of measurement values from the median. An 8.6dB fade margin has been applied as this is the figure taken from the 90% distribution. However, this value can be increased or decreased within the link budget dependent upon a HAN system coverage reliability and fade margin certainty.

7 Signal Range Measurements

The following measurements were carried out to determine the distance an 868MHz signal can travel in the environment around a MDU, which can be used to assess equipment interference implications, range tests were performed at the five larger 5 MDU sites.

This was undertaken with the R&S SMBV100B signal generator and power amplifier to provide a 500mW (27dBm) CW radiated transmission positioned in a high point location. A CRFS RF-Eye, ruggedized spectrum analyser with GPS location logger housed in a ruck sack was used to record the received signal. This was walked around the locality of the MDU site while recording the signal level. Both transmitter and Analyser used vertically orientated Radio Structures ENF900 antennas.

The following five locations (and their environments) were chosen for the measurements:

Ashton Court - rural

Brunel Estate - urban

Butterworth Court - urban

Lillington Gardens - urban

Mawdeley House - urban

The measured signal and pedestrian routes are included in Appendix B – Signal Coverage Walk measurement plots for reference.

The resulting path loss slope line as shown in Figure 17 is produced from the measurement data. The measurements from Ashton Court are scattered below the trend followed by the other locations. This is as a result of Ashton Court being located in an open country park (rural environment) where propagation of the transmitted signal is not as influenced by the proximity of other buildings unlike the other MDU sites.

Two path loss slopes are produced; one with and one without the inclusion of Ashton Court. Excluding Ashton Court alters the slope gradient such that the path loss for a given distance is increased.

It is considered that were MDU buildings are located in an urban environment such as in towns, city suburbs the path loss slope, excluding Ashton Court, would provide a more accurate model.

The resulting distance for the three transmitted power values for urban only locations is provided in Table 7. (Urban only – this excludes Ashton Court which is a large manor house in open country side)

Power (mW)	Power (dBm)	Path Loss (dB)	Distance (m) Urban (to the nearest 10m)
25	14	104	70
100	20	110	90
500	27	117	130

Table 7 Possible Distances for Given Transmit Powers in the Urban Environment

Figure 17 Path Loss Slope: CRFS Measurement

8 Conclusion

Undertaking a campaign of fade loss and coverage measurements at 16 MDU buildings has enabled the creation of a MDU path loss slope model by adapting COST-231 multiwall model, and taking the approach applied by Red M from the initial RF smart meter survey.

Using the method of recording receiver signal variance by rotation of the receive antenna at a number of measurement locations within a MDU building has enabled the effect of signal fade within this multipath environment to be analysed, with the measurements confirming agreement with the statistical model approach described in a number radio propagation modelling text books

A statistical method was applied to analyse the difference to the received signal from each measurement location and plot this on a Rayleigh distribution curve to derive a figure to account for the effects of fast fading. Using the 90% figure from the curve provided a fade margin value of 8.6dB which is then applied to the path loss link budget.

A path loss model has been developed by plotting the points of all the median measurement values on a logarithmic (log base 10) scale of path loss versus distance chart to produce a straight line slope. As a result of producing the probability density function from the error difference (standard deviation) between the measurement points and the median slope line (50^{th} percentile), it is shown that this follows a normal Gaussian distribution. Using this, the slope line can be tailored to fit a given distribution percentile to account for the loss due to the effects of slow fading (shadowing etc.).

To be consistent with the Red-M fading approach, the slope line for the 90^{th} percentile was used for the MDU model. Based upon the scattering of the measurement points this is considered to provide a good model for the determining the propagation distance for an 868MHz HAN signal within a MDU for a given path loss.

Applying this model, the propagation distance as a result of the link budget for a given transmitter power and receiver specification can be sought. Although the propagation distance for three transmitter powers was determined, the model can be applied for any transmit power and link budget by directly reading the values from the path loss slope line.

The model has also been applied to the five range coverage tests, and the 90^{th} percentile slope line is used to provide the coverage distance for the three transmitter powers as shown in Table 7.

As a comparison, the 90^{th} percentile line with and without the inclusion of Ashton court is used to demonstrate the variance of the model by using data from the urban and rural measurement environments.

Using this model as a basis signal coverage rings could be created and overlaid on a map to determine the interference potential to other 868MHz services in adjacent buildings from the candidate MDU as well as a tool for frequency planning and co-channel re-use.

9 Smart Metering Home Area Network Coverage Analysis

As a result of the measurement work carried out by Ofcom and Red M, and the derivation of a smart meter HAN radio coverage model for homes and MDUs, the following chapter describes the methodology used by DECC[9] to determine the number of GB premises that could be provided by a Smart Metering Home Area Network (HAN) based on:

- 868MHz (at power levels of 25mW, 100mW, 250mW, 300mW, 400mW and 500mw); and
- Alternative HAN solutions (also referred to as Alt HAN, solutions used to extend the HAN operating range of standard metering equipment).

Propagation distances (Section 6.3) were used to filter building data provided by Ordnance Survey (OS). The OS data set includes dimensions of every premise in GB as well as other data as described within Table 8.

Data Item	Description
Country	The country that the premise is located within.
Postcode Sector	The postcode sector that the premise is located within.
Postcode Density Percentile Band	The premise density of the postcode that the premise is located within, as a percentile based on the national distribution.
Multiple Occupancy Band	The number of premises within the building that contains the premise.
Building Classification	The classification of the building that contains the premise.
Length 2D Band	The longest 2D length along the footprint of the building that contains the premise.
Circularity Band	The circularity (a ratio between area and perimeter) of the building that contains the premise. The exact formula is 4 * PI * area / (perimeter * perimeter), which should produce a value of 1 for a perfect circle.
Building Height Band	The mean height (where available) of the building that contains the premise.
Rural Building with Outbuildings	Rural Building with Outbuildings: A single-occupancy building with three or more 60m2 outbuildings within 40m of the premise, located within a postcode in the 0-5% (least dense) Postcode Density Percentile Band.

[9]The content of this chapter has been produced by DECC with data supplied by Ordnance Survey and Ofcom.

Building Type	The type of the building that contains the premise. Residential buildings are classed as terraced, detached. Semi-detached or flats. Commercial buildings are classed as commercial. Where a confident class is not possible, unknown is used.
Building Count	The number of buildings that possess the same combination of the above characteristics.
Premise Count Residential	The number of residential premises that possess the same combination of the above characteristics.
Premise Count Commercial	The number of commercial premises that possess the same combination of the above characteristics.

Table 8 OS Data Items

Figure 18 below provides an example of the OS data set.

	A	B	C	D	E	F	G	H	I	J	K	L
1	COUNTRY	POSTCODE_DENSITY_PERCENTILE_BAND	MULTIPLE_OCCUPANCY_BAND	BUILDING_CLASSIFICATION	LENGTH_2D_BAND	CIRCULARITY_BAND	BUILDING_HEIGHT_BAND	RBWOB	BUILDING_TYPE	BUILDING_COUNT	PREMISE_COUNT_R	PREMISE_COUNT_C
2	WALES	20-50%	1	R	5-10m	0.7-0.8	NA	FALSE	SEMI-DETAC	44316	44,316	0
3	WALES	50-80%	1	R	5-10m	0.7-0.8	NA	FALSE	SEMI-DETAC	31861	31,861	0
4	WALES	20-50%	1	R	5-10m	0.7-0.8	3-6m	FALSE	SEMI-DETAC	31096	31,096	0
5	WALES	50-80%	1	R	10-20m	0.4-0.6	NA	FALSE	TERRACED	27901	27,901	0
6	WALES	50-80%	1	R	5-10m	0.7-0.8	3-6m	FALSE	SEMI-DETAC	26903	26,903	0
7	WALES	50-80%	1	R	5-10m	0.7-0.8	NA	FALSE	TERRACED	23280	23,280	0

Figure 18 Sample of OS Data Set

Classification of premises

The OS data set (Crown copyright and database rights 2015 OS 100049123.) identified that there are 26.4m premises in GB. The English, Scottish and Welsh housing survey data identified that there are 22.6m households in England, 2.4m households in Scotland and 1.3m households in Wales. Therefore, there is congruence between the data sets.

843,914 premises in the OS data set were re-classified according to the following rules:

- 435,696 premises with an ‘unknown’ building type were allocated a housing type based upon, the multiple occupancy of the premises. 337,236 were given the allocation of ‘flats’ and 98,460 were given the allocation of ‘house’.
- 387,892 houses (detached, semi-detached and terraced houses) were reallocated as flats (where houses were found to have a multiple occupancy greater than one)
- 20,326 flats were reallocated as houses (where flats were found to have the occupancy of one)

After these adjustments the data set, for analysis purposes, comprised of 6.0m flats and 20.4m houses.

HAN Coverage in houses

As shown in Figure 18, the maximum length of all premises provided in the OS data set is banded i.e. 5-10m, 10.0-12.5m. Given this, within the HAN coverage analysis there are three scenarios. These include the minimum, the maximum and the average length scenario which map onto the lower end of the band, the upper end of the band and the mid-point of the band, respectively.

To ascertain which HAN solution could serve each size of house, it has been assumed that for a house to be served by a specific HAN solution i.e. 25mW 868MHz, 100mW 868MHz etc. the hypotenuse of the house footprint in plan-view must be less than the propagation distance for that specific HAN solution. This is because the worst case scenario is that the electricity and gas meters are at opposite ends of the premises. Both meters are however likely to be on the ground floor, it is also expected that the IHD will likely be located on the ground floor.

Based on this method, each house in the OS data set has been allocated a HAN solution that could serve it. This was undertaken for the minimum, maximum and average scenarios.

If a house was identified as having out buildings then it was classified as Alternative HAN. A worked example is shown in Figure 19. This shows that for two different types of houses that have a maximum length of 10.0m and 15.0m, under all scenarios both houses could be served by the 25mW 868MHz HAN solution.

The path loss measurements used to calculate the propagation distances are based on the RedM measurements (~550) and comprise a mixture of indoor to indoor, indoor to outdoor and outdoor to outdoor links. The majority of links in this data set was indoor to outdoor (~350), which are more challenging than the other links. As such the propagation distance calculated and resulting HAN coverage is conservative.

ID	COUNTRY	POSTCODE_DENSITY_PERCENTILE_BAND	MULTIPLE_OCCUPANCY_BAND	BUILDING_CLASSIFICATION	CIRCULARITY_BAND	LENGTH_2D_BAND	LENGTH_2D_BAND_MIN	LENGTH_2D_BAND_MAX	LENGTH_2D_BAND_AVERAGE	BUILDING_HEIGHT_BAND	RBWOB	BUILDING_TYPE	REALLOCATED_BUILDING_TYPE	REALLOCATION_MATCHING	BUILDING_COUNT	PREMISE_COUNT_R	PREMISE_COUNT_C	POWER_DISTANCE_MIN	POWER_DISTANCE_MAX	POWER_DISTANCE_AVERAGE
116	ENGLAND	80-90%	1	R	0.7-0.8	5-10m	5	10	7.5	NA	FALSE	TERRACED	HOUSE	MATCH	36474	36,474	0	LP25	LP25	LP25
117	ENGLAND	20-50%	1	R	0.6-0.7	12.5-15.0	12.5	15	13.75	3-6m	FALSE	SEMI-DETACHED	HOUSE	MATCH	36147	36,147	0	LP25	LP25	LP25

Figure 19 Worked example of HAN coverage allocation in houses

Propagation results for houses

Using the above method which allocates a HAN solution to all houses, it is estimated that under the average scenario, (when not considering meter location information), 99% of houses could be served by the 25mW 868MHz, HAN solution.

HAN Solution	Minimum Length Scenario		Maximum Length Scenario		Average Length Scenario	
	Premises	**Percent**	**Premises**	**Percent**	**Premises**	**Percent**
25mW 868MHz	20308940	99%	20281186	99%	20308940	99%
100mW 868MHz	10737	0%	34180	0%	6426	0%
250mW 868MHz	0	0%	0	0%	4311	0%
300mW 868MHz	0	0%	0	0%	0	0%
400mW 868MHz	796	0%	4311	0%	0	0%
500mW 868MHz	0	0%	0	0%	0	0%
Alternative HAN	117783	1%	118579	1%	118579	1%
Error	0	0%	0	0%	0	0%
TOTAL	20438256	100%	20438256	100%	20438256	100%
CUMULATIVE COVERAGE						
25mW 868MHz	99%		99%		99%	
100mW 868MHz	99%		99%		99%	
250mW 868MHz	99%		99%		99%	
500mW 868MHz	99%		99%		99%	
Alternative HAN	100%		100%		100%	

Table 9 HAN solution coverage in houses (without meter locations)

HAN Coverage in flats

As with the data on houses, the maximum length of all buildings containing flats provided in the OS data set was banded i.e. 5-10m, 10.0-12.5m. Additionally, building height data was required in the analysis of flats and this data is also banded i.e. 6.0-9.0m. Therefore the minimum, maximum and average HAN coverage scenarios from the analysis of flats relate to analysis based upon the minimum length band with minimum height band, the maximum length band with maximum height band and the average length band with the average height band, respectively.

Within the flats data set, there were a number of entries with missing building heights. Where building height data was missing a proxy building height was allocated based upon the average of building heights in a data set which had the same building length and multiple occupancy characteristics.

To ascertain which HAN solution could serve each flat a slightly different methodology was adopted compared to the one used for houses. This is because for flats, the worst case scenario is that meters are located on different floors to the flat. Therefore, the hypotenuse of the entire building in elevation (hypotenuse between the maximum length of the building in plan and the building height) must be less than the propagation distance for a specific HAN solution, for it to be assumed to work. Based on this method, each building containing flats in the OS data set was allocated a HAN solution that could serve it. This was undertaken for the minimum, maximum and average scenarios.

Once a HAN solution was allocated to each building, individual HAN solutions were allocated to the individual premises within the building. This is because on lower floors that are nearer the assumed worst case meter location, low power 25mW 868MHz may be sufficient, but different solutions such as high power 868MHz or Alt HAN may be needed to serve upper floors. To allocate different HAN solutions to individual premises, the total number of premises within the building was split out proportionally based upon the propagation distances for each HAN solution. Premises were split out using a square law on the assumption that the number of flats that could be served increases along the propagation distance as a square. For example, if a building is allocated as requiring a high power 100mW 868MHz HAN solution, then allocation of flats to each HAN solution could be estimated using the following formulae:

- Number of low power 25mW premises = [P1^2 / H^2] * (total number of flats in building)
- Number of high power 100mW premises = [1-(P1^2 / H^2)] * (total number of flats in building)

If a building is allocated as requiring an Alternative HAN solution, then allocation of flats to each HAN solution could be estimated using the following formulae:

- Number of low power 25mW premises = [P1^2 / H^2] * (total number of flats in building)
- Number of high power 100mW premises = [(P2^2 / H^2) – (P1^2 / H^2)] * (total number of flats in building)
- Number of high power 250mW premises = [(P3^2 / H^2) – (P2^2 / H^2)] * (total number of flats in building)
- Number of high power 300mW premises = [(P4^2 / H^2) – (P3^2 / H^2)] * (total number of flats in building)
- Number of high power 400mW premises [(P5^2 / H^2) – (P4^2 / H^2)] * (total number of flats in building)
- Number of high power 500mW premises [(P6^2 / H^2) – (P5^2 / H^2)] * (total number of flats in building)
- Number of Alternative HAN premises = [1-(P6^2 / H^2)] * (total number of flats in building)

Where P1 is the propagation distance for low power 25mW 868MHz, P2 is the propagation distance for high power 100mW 868MHz, P3 is the propagation distance for high power 250mW 868MHz, P4 is the propagation distance for high power 300mW 868MHz, P5 is the propagation distance for high power 400mW 868MHz, P6 is the propagation distance for high power 500mW 868MHz and H is the hypotenuse distance of the building in elevation as shown in Figure 20.

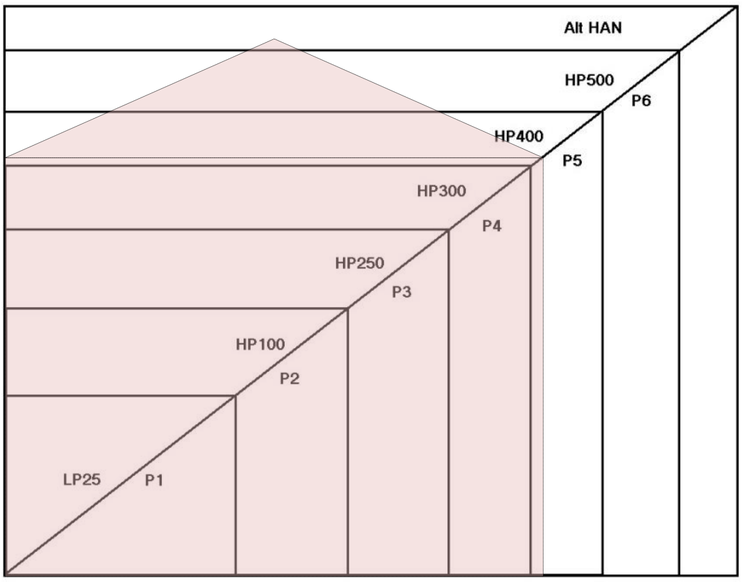


Figure 20 Diagram showing hypotenuse and propagation distances used to estimate HAN solutions in flats (not to scale)

A worked example of this method for a building allocated as Alternative HAN is shown in Figure 21.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
COUNTRY	POSTCODE_DENSITY_PERCENTILE_BAND	MULTIPLE_OCCUPANCY_BAND	BUILDING_CLASSIFICATION	LENGTH_2D_BAND	LENGTH_2D_BAND_MIN	LENGTH_2D_BAND_MAX	LENGTH_2D_BAND_AVERAGE	CIRCULARITY_BAND	BUILDING_HEIGHT_BAND	BUILDING_HEIGHT_BAND_MIN	BUILDING_HEIGHT_BAND_MAX	PROXY_HEIGHT_BAND_MIN	PROXY_HEIGHT_BAND_MAX	BUILDING_HEIGHT_WITH_PROXY_BAND_MIN	BUILDING_HEIGHT_WITH_PROXY_BAND_MAX	BUILDING_HEIGHT_WITH_PROXY_BAND_AVERAGE	MIN_HYP_DISTANCE	MAX_HYP_DISTANCE	AVERAGE_HYP_DISTANCE
ENGLAND	>95%	37-49	R	50-75m	50	75	62.5	0.0-0.4	6-9m	6	9	12.1	15.1	6	9	8	50.36	75.54	62.95

U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
MIN_HYP_AREA_VOLUME	MAX_HYP__AREA_VOLUME	AVERAGE_HYP_AREA_VOLUME	RBWOB	BUILDING_TYPE	REALLOCATED_BUILDING_TYPE	REALLOCATION_MATCHING	BUILDING_COUNT	PREMISE_COUNT_R	PREMISE_COUNT_C	POWER_DISTANCE_MIN	POWER_DISTANCE_MAX	POWER_DISTANCE_AVERAGE	LP25_MIN_PREMISES	HP100_MIN_PREMISES	HP250_MIN_PREMISES	HP300_MIN_PREMISES	HP400_MIN_PREMISES	HP500_MIN_PREMISES	Alt HAN_MIN_PREMISES
2536.00	5706.00	3962.50	FALSE	FLATS	FLATS	MATCH	293	12,247	0	Alt HAN	Alt HAN	Alt HAN	1343	1224	623	691	758	826	6783

Figure 21 Worked example of HAN coverage allocation in flats

The path loss measurements used to calculate the propagation distances are based on the Ofcom measurements (~400) and comprise a mixture of indoor to indoor, indoor to outdoor and outdoor to outdoor links

Propagation results for flats

Using the above method which allocates a HAN solution to all flats, it is estimated that under the average scenario (when not considering meter location information), 66% of flats could be served by the 25mW 868MHz, HAN solution.

HAN Solution	Minimum Length Scenario		Maximum Length Scenario		Average Length Scenario	
	Premises	Percent	Premises	Percent	Premises	Percent
25mW 868MHz	4276517	71%	3660382	61%	3982631	66%
100mW 868MHz	741228	12%	1013540	17%	860556	14%
250mW 868MHz	177556	3%	214133	4%	183955	3%
300mW 868MHz	147844	2%	149297	2%	141528	2%
400mW 868MHz	126641	2%	115353	2%	115748	2%
500mW 868MHz	83213	1%	92063	2%	102757	2%
Alternative HAN	428075	7%	736305	12%	593899	10%
Error	9538	0%	9538	0%	9538	0%
TOTAL	5990612	100%	5990612	100%	5990612	100%
CUMULATIVE COVERAGE						
25mW 868MHz	72%		61%		67%	
100mW 868MHz	84%		78%		81%	
250mW 868MHz	87%		82%		84%	
500mW 868MHz	93%		88%		90%	
Alternative HAN	100%		100%		100%	

Table 10 HAN solution coverage in flats (without meter locations)

Meter Locations

Electricity and gas meters can be located inside or outside the premises. It is assumed that:

- where both meters are located within the premises (houses and flats) the 2.4GHz HAN solution can be utilised
- where both meters are in close proximity to a flat, i.e. on the landing in a block of flats, that the low power 25mW 868MHz solution can be utilised

Where this is not the case, the type of HAN solution available depends on the size of the premises and which HAN solution is sufficient to propagate the length of that house or to reach that flat (Table 9 and Table 10).

Data provided by Siemens, EDF and Scottish Power on meter locations in flats and by SSE on meter locations in houses has led to the following assumptions detailed in Table 11.

Flats	2.4 GHz HAN Solution	53.6%
	Low power 868 MHz HAN Solution	4.8%
	HAN solution – dependent on size of premises	41.6%
Houses	2.4 GHz HAN Solution	35.8%
	Low power 868 MHz HAN Solution	0.0%
	HAN solution – dependent on size of premises	64.2%

Table 11 Meter locations assumptions in flats and houses

It has therefore been assumed, that regardless of propagation distance that 58.4% (3,498,432) of all flats could be served by either the 2.4GHz or 868MHz HAN solution and that 35.8% (7,315,556) of all houses could be served by the 2.4GHz HAN solution. It has been assumed that the allocation of the remaining flats (41.6%) and houses (64.2%) are split evenly across the different HAN solutions identified in the previous analysis based on propagation distance (Table 9 and Table 10).

To elaborate, it has been identified, based on propagation distance alone, that 3,982,631 (66%) flats could be served by the 25mW 868MHz HAN solution (see Table 10), given it is already assumed that 58.4% of all flats could be served by the 25mW 868MHz HAN solution or the 2.4GHz HAN solution as a result of meter location, to find those flats served by the 25mW 868MHz HAN solution as a result of propagation distance, this figure of 3,982,631 (66%) is multiplied by 41.6%. This gives an additional number of premises that could be served by the 25mW 868MHz HAN solution of 1,656,831. This value is added to the 3,498,432 (58.4%) that are assumed to be served by the 25mW 868MHz HAN solution or 2.4GHz HAN solution. The total number of flats that could be served by the 25mW 868MHz HAN solution or the 2.4GHz HAN solution is therefore 5,155,263.

Using the same method, 860,556 (14%) flats could be served by the 100mW 868MHz HAN solution (see Table 10), this figure is also multiplied by 41.6% to give a final number of premises that could be served by the 100mW 868MHz HAN solution of 358,003. This is repeated for each type of HAN solution. The same method is used to allocate a HAN solution to houses.

Propagation results for all premises

Using the above method which allocates a HAN solution to houses and flats, based on both propagation distances and meter locations, it is estimated that under the average scenario 96.5% of all houses and flats could be served by the 25mW 868MHz HAN solution.

HAN Solution	Minimum Length Scenario		Maximum Length Scenario		Average Length Scenario	
	Premises	**Percent**	**Premises**	**Percent**	**Premises**	**Percent**
2.4GHz (local meters)	10528336	39.8%	10528336	39.8%	10528336	39.8%
25mW 868MHz (local meters)	285653	1.1%	285653	1.1%	285653	1.1%
25mW 868MHz	14818762	56.1%	14544621	55.0%	14696501	55.6%
100mW 868MHz	315255	1.2%	443593	1.7%	362129	1.4%
250mW 868MHz	73866	0.3%	89083	0.3%	79296	0.3%
300mW 868MHz	61505	0.2%	62110	0.2%	58878	0.2%
400mW 868MHz	53196	0.2%	50757	0.2%	48153	0.2%
500mW 868MHz	34618	0.1%	38300	0.1%	42748	0.2%
Alternative HAN	253710	1.0%	382449	1.4%	323206	1.2%
Error	3968	0.0%	3968	0.0%	3968	0.0%
TOTAL	26428868	100%	26428868	100%	26428868	100%
CUMULATIVE COVERAGE						
25mW 868MHz	97.0%		96.0%		96.5%	
100mW 868MHz	98.2%		97.6%		97.9%	
250mW 868MHz	98.5%		98.0%		98.2%	
500mW 868MHz	99.0%		98.5%		98.8%	
Alternative HAN	100.0%		100.0%		100.0%	

Table 12 HAN solution coverage in all premises with meter locations considered

Breakdown of building types indicating where 868MHz is less likely to work

The tables below provide a breakdown by the number of buildings and number of premises where 868MHz is less likely to work. Please note that the numbers do not take meter location data into account. The analysis has been kindly provided by Energy UK.

Count of Buildings	Maximum 2D horizontal dimension						
	<10m	10-17.5m	17.5-30m	30-40m	40-75m	>75m	Grand Total
Commercial/Industrial Buildings	**282,876**	**255,566**	**213,810**	**82,196**	**81,910**	**29,396**	**945,754**
Comml >144 premises	1	4	14	8	38	85	150
Comml 65-143 prems	2	9	27	25	207	185	455
Comml 17-64 prems	38	182	459	336	935	781	2,731
Comml 3-16 prems	1,197	6,899	11,020	5,448	8,936	5,164	38,664
Comml 2 prems	3,731	17,236	18,439	6,863	8,382	3,406	58,057
Comml 1 prems	277,907	231,236	183,851	69,516	63,412	19,775	845,697
Flats	**469,256**	**681,980**	**240,533**	**30,555**	**26,976**	**3,586**	**1,452,886**
HR Flats	1,714	8,223	10,252	2,715	3,601	517	27,022
Sprawling LR Flats			212,953	26,332	22,349	2,849	264,483
Compact LR Flats	11,489	96,484					107,973
3/4-Block Flats	57,860	144,268					202,128
2-Block Flats	390,740	378,815					769,555
House>Flats	7,453	54,190	17,328	1,508	1,026	220	81,725
Houses	**10,801,092**	**8,800,961**	**792,690**	**31,008**	**11,889**	**1,171**	**20,438,811**
DETATCHED	1,600,733	3,548,191	542,668	26,780	10,574	979	5,729,925
SEMI-DETACHED	5,231,915	2,377,329	113,720	1,759	368	14	7,725,105
TERRACED	3,918,816	2,821,113	123,524	1,093	158	6	6,864,710
Flats>House	2,829	9,193	3,719	454	182	18	16,395
Other>House	46,799	45,135	9,059	922	607	154	102,676
Residential & Commercial Combined Buildings (eg flat above shop/pub/restaurant etc)	**12,952**	**60,187**	**27,981**	**2,947**	**1,682**	**482**	**106,231**
Compact R+C (30m & LR)	12,921	60,069	27,873				100,863
High or Sprawling R+C (HR or >30m)	31	118	108	2,947	1,682	482	5,368
Total	**11,566,176**	**9,798,694**	**1,275,014**	**146,706**	**122,457**	**34,635**	**22,943,682**

Table 13 Breakdown by number of buildings where 868MHz is least likely to work (Shading indicates buildings where 868MHz is more likely to work) **[© Crown copyright and database rights 2015 OS 100049123]**

Count of Residential Premises	Maximum 2D horizontal dimension						
	<10m	10-17.5m	17.5-30m	30-40m	>75m	40-75m	Grand Total
Commercial/Industrial Buildings	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Comml >144 premises	-	-	-	-	-	-	-
Comml 65-143 prems	-	-	-	-	-	-	-
Comml 17-64 prems	-	-	-	-	-	-	-
Comml 3-16 prems	-	-	-	-	-	-	-
Comml 2 prems	-	-	-	-	-	-	-
Comml 1 prems	-	-	-	-	-	-	-
Flats	**1,083,683**	**2,129,927**	**1,511,118**	**389,151**	**124,096**	**651,668**	**5,889,643**
HR Flats	17,193	80,672	200,429	80,913	25,250	151,792	556,249
Sprawling LR Flats			1,241,383	297,962	93,299	484,254	2,116,898
Compact LR Flats	94,841	659,379					754,220
3/4-Block Flats	177,029	470,060					647,089
2-Block Flats	772,229	743,721					1,515,950
House>Flats	22,391	176,095	69,306	10,276	5,547	15,622	299,237
Houses	**10,801,095**	**8,800,973**	**792,692**	**31,008**	**1,172**	**11,889**	**20,438,829**
DETATCHED	1,600,733	3,548,197	542,670	26,780	980	10,574	5,729,934
SEMI-DETACHED	5,231,917	2,377,330	113,720	1,759	14	368	7,725,108
TERRACED	3,918,817	2,821,118	123,524	1,093	6	158	6,864,716
Flats>House	2,829	9,193	3,719	454	18	182	16,395
Other>House	46,799	45,135	9,059	922	154	607	102,676
Residential & Commercial Combined Buildings (eg flat above shop/pub/restaurant etc)	**12,179**	**57,031**	**26,435**	**2,749**	**439**	**1,563**	**100,396**
Compact R+C (30m & LR)	12,151	56,915	26,327				95,393
High or Sprawling R+C (HR or >30m)	28	116	108	2,749	439	1,563	5,003
Total	**11,896,957**	**10,987,931**	**2,330,245**	**422,908**	**125,707**	**665,120**	**26,428,868**

Table 14 Breakdown of residential premises where 868MHz is least likely to work (dark green shading indicates groups of buildings where 868MHz is least likely to work; light green shading indicates next most likely sites where 868MHz is least likely to work - particularly 3rd/ 4th floor flats) **[© Crown copyright and database rights 2015 OS 100049123]**

Count of Commercial Premises	Maximum 2D horizontal dimension						
	<10m	10-17.5m	17.5-30m	30-40m	>75m	40-75m	Grand Total
Commercial/Industrial Buildings	**290,473**	**294,147**	**268,318**	**111,144**	**67,639**	**140,035**	**1,171,756**
Comml >144 premises	169	683	616	464	1,702	800	4,434
Comml 65-143 prems	158	309	730	823	4,435	5,404	11,859
Comml 17-64 prems	607	2,917	6,303	5,254	12,864	16,716	44,661
Comml 3-16 prems	4,606	26,465	42,710	22,536	22,922	38,619	157,858
Comml 2 prems	7,026	32,537	34,108	12,551	5,938	15,083	107,243
Comml 1 prems	277,907	231,236	183,851	69,516	19,778	63,413	845,701
Flats	**4,730**	**39,240**	**36,507**	**8,919**	**3,780**	**9,730**	**102,906**
HR Flats	139	3,263	3,217	1,278	979	2,361	11,237
Sprawling LR Flats			27,494	6,561	2,634	6,674	43,363
Compact LR Flats	1,008	11,489					12,497
3/4-Block Flats	2,399	16,283					18,682
2-Block Flats	-	-					-
House>Flats	1,184	8,205	5,796	1,080	167	695	17,127
Houses	**-**	**-**	**-**	**-**	**-**	**-**	**-**
DETATCHED	-	-	-	-	-	-	-
SEMI-DETACHED	-	-	-	-	-	-	-
TERRACED	-	-	-	-	-	-	-
Flats>House	-	-	-	-	-	-	-
Other>House	-	-	-	-	-	-	-
Residential & Commercial Combined Buildings (eg flat above shop/pub/restaurant etc)	**12,604**	**59,751**	**30,220**	**3,754**	**1,655**	**3,109**	**111,093**
Compact R+C (30m & LR)	12,448	59,226	28,982				100,656
High or Sprawling R+C (HR or >30m)	156	525	1,238	3,754	1,655	3,109	10,437
Total	**307,807**	**393,138**	**335,045**	**123,817**	**73,074**	**152,874**	**1,385,755**

Table 15 Breakdown of commercial premises where 868MHz may not work (dark green shading indicates sites where 868MHz is least likely to work; light green shading indicates next most likely building groups where 868MHz may not work). Alternatives to 868MHz HAN installation in commercial premises only applies to those business consumers that are within the scope of the smart metering rollout and where a standard HAN will not operate.

The following notes apply:

- High Rise Flats: - Defined as more than 5 stories (identified as being >15m)
- Sprawling Low Rise Flats: - 5 stories or fewer & greater than 16.67m horizontal dimension (matching the maximum 25mW 868MHz propagation distance)
- Compact Low Rise Flats: - 5 stories or fewer & less than or equal to 16.67m horizontal dimension (matching the maximum 25mW 868MHz propagation distance)
- 3/4-Block Flats & 2-Block Flats - same dimension limits as Compact Low Rise Flats - but with fewer premises
- Residential & Commercial Combined Buildings - where a building has a single residential premises and a small number of Commercial premises built on the same common foundation
- Compact R+C' are a subset of the Residential & Commercial Combined buildings - with dimensions that suggest a 'flat above a shop'
- Flats>House & Other>House: where buildings labelled as 'flats' or 'unknown' comprise a single Residential Premise

10 Appendix A – Site Reports

10.1 - Ashton Court A_1

10.2 - BBond warehouse A_2

10.3 - Brunel Estate A_3

10.4 - Butterworth Court A_4

10.5 - Carey mansions A-5

10.6 - Dufours Place A_6

10.7 - Penbury Court A_7

10.8 - Lillington Gardens A_8

10.9 - Loanhead Farm A_9

10.10 - Marshall Place A_10

10.11 - Mawdeley House A_11

10.12 - Michon Creative A_12

10.13 - Norfolk House A_13

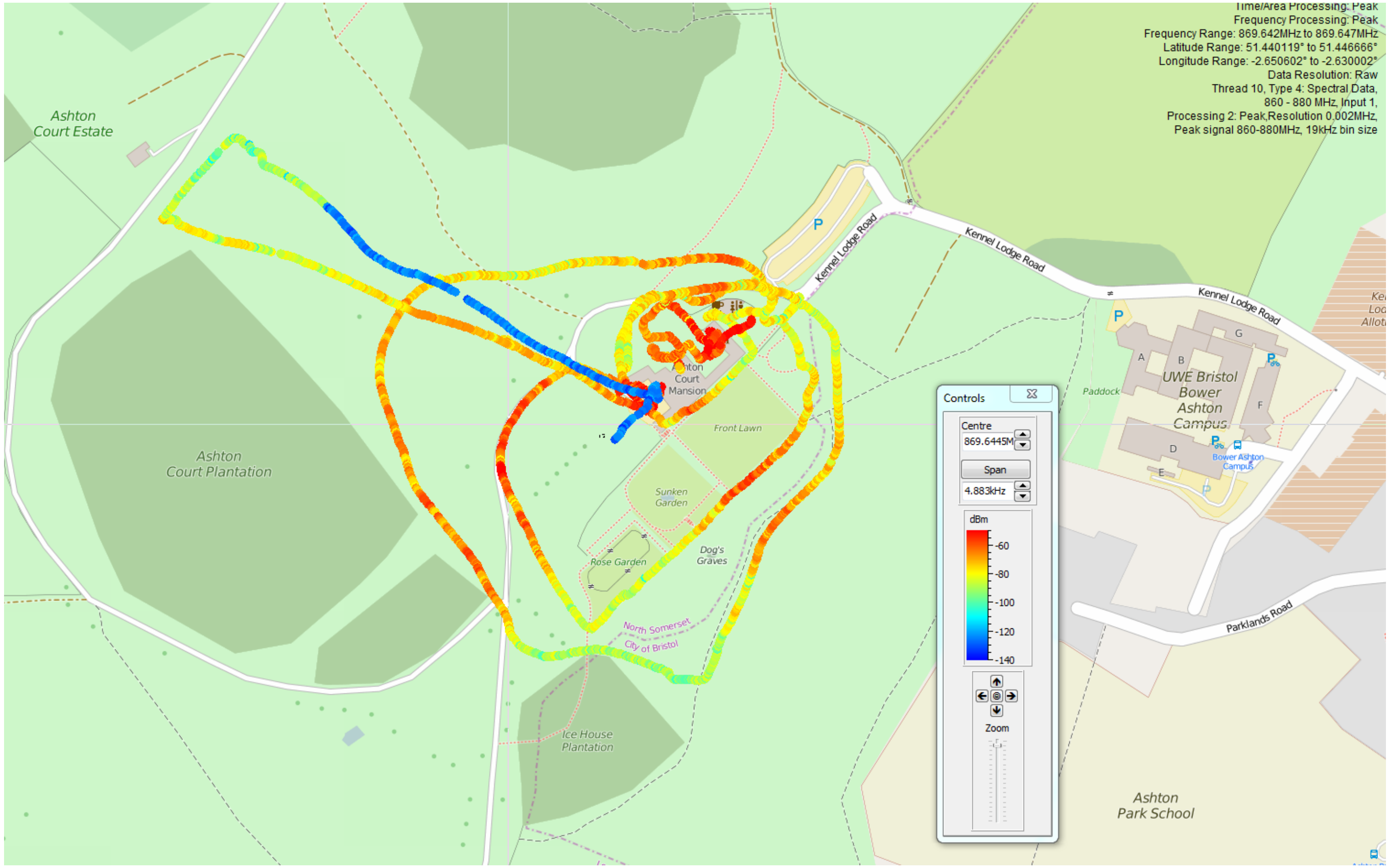
10.14 - Rossie Place A_14

10.15 - Tothill House A_15

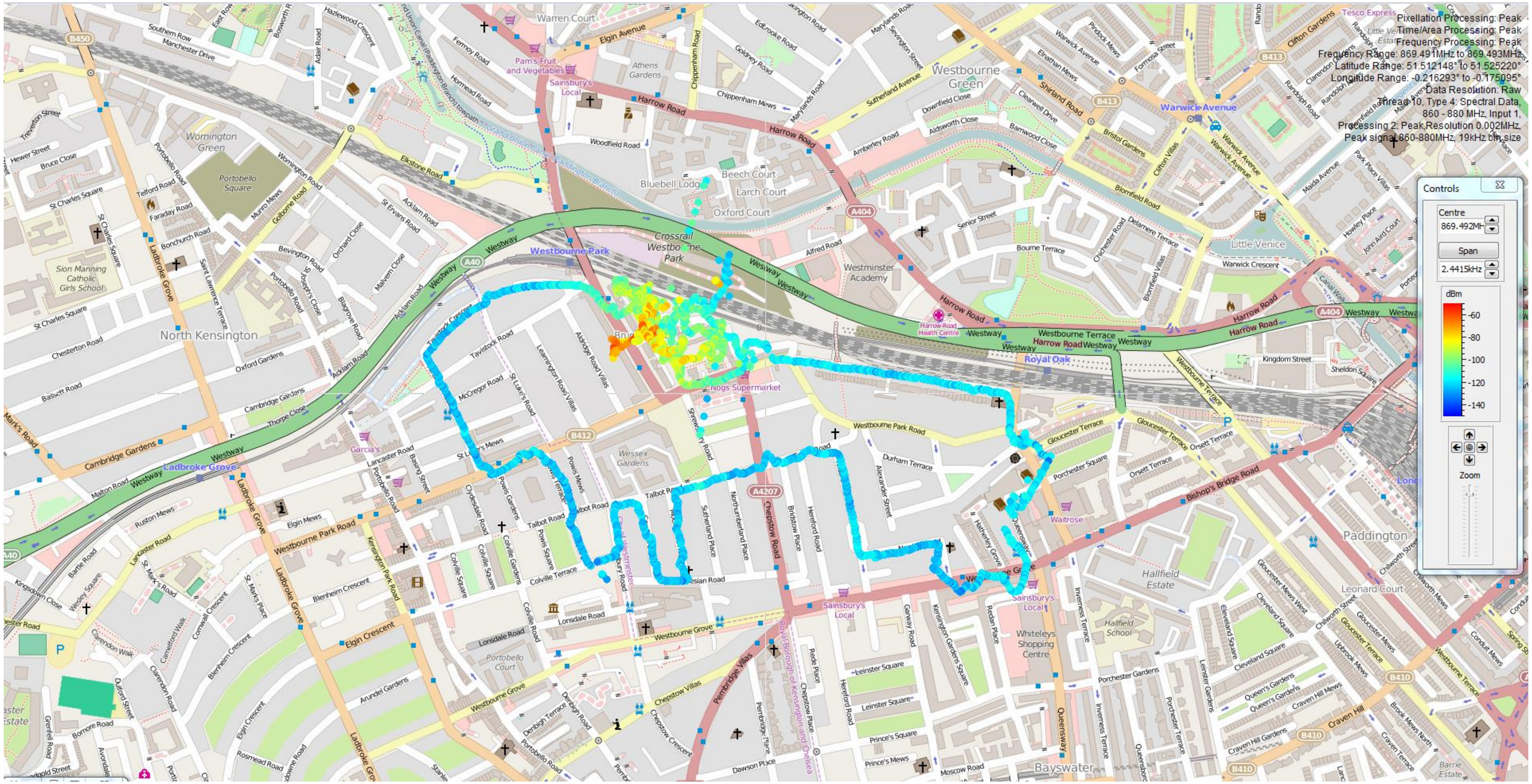
10.16 William Bancroft A_16

11 Appendix B – Signal Coverage Walk measurement plots

11.1 - Ashton Court

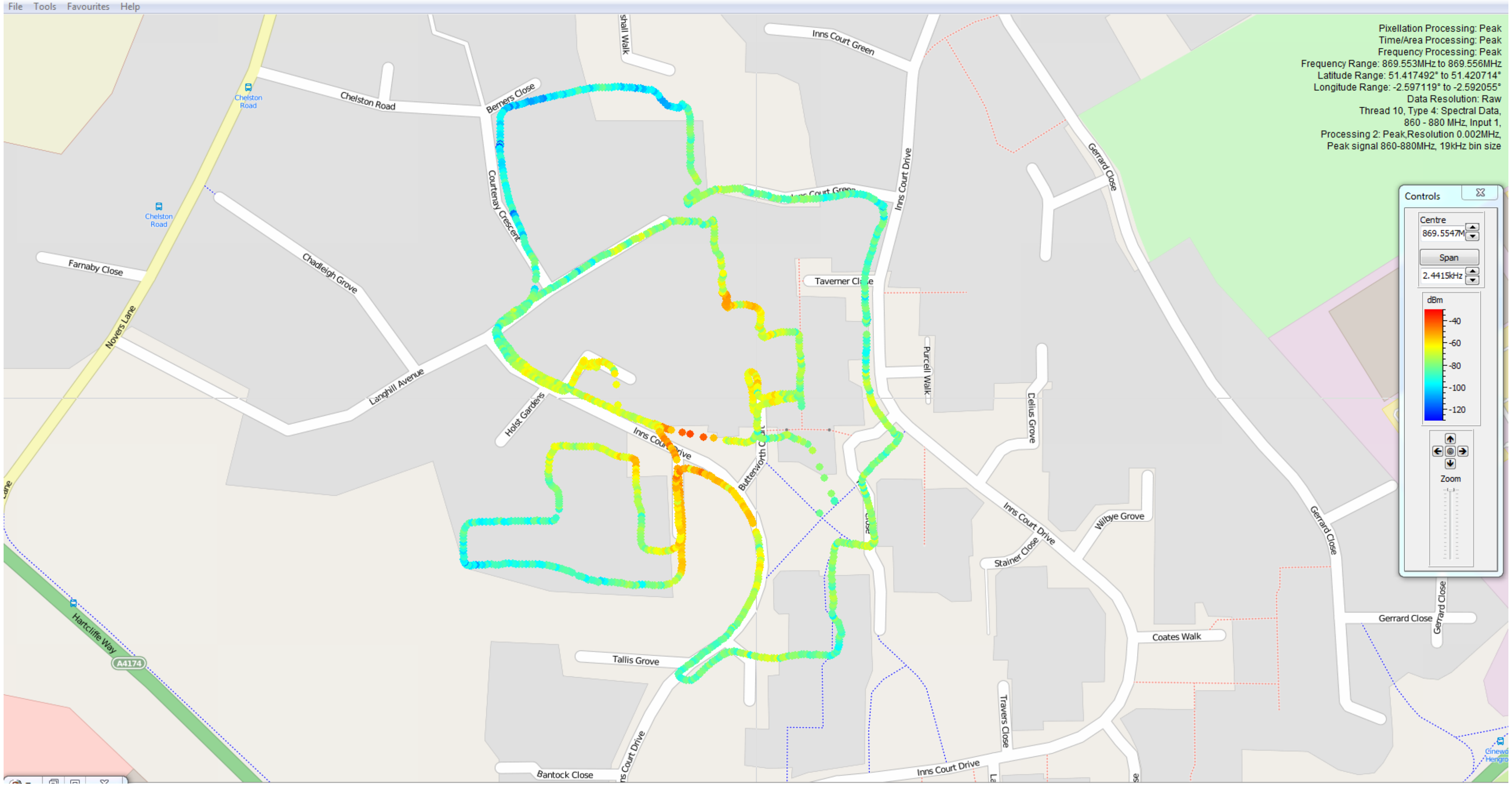


11.2 - Brunel Estate



11.3– Lillington Gardens

11.4 - Butterworth Court



11.5– Mawdeley House