DIGITAL DIVIDEND REVIEW

Derivation of Power Flux Density Spectrum Usage Rights

Transfinite Systems Ltd

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TRANSFINITE SYSTEMS

Document History

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1 Objective of Study

As part of the Digital Dividend Review (DDR) [1] Ofcom proposes that some of the spectrum in UHF band currently used for analogue TV services be made available for other applications.

The objective of this study was to derive area Power Flux Density (PFD) limits that can be used to define the Spectrum Usage Rights (SURs) for these services and at these frequencies.

This study considered five alternative usages of the released spectrum within UHF band, namely:

1) Digital Terrestrial Television (DTT)
2) Digital Video Broadcasting – Handheld (DVB-H)
3) IMT-2000 3G/WCDMA standard operating in Frequency Division Duplex (FDD) mode downlink (DL) i.e. Base Station (BS) transmit direction
4) IMT-2000 3G/WCDMA standard operating in FDD mode uplink (UL) i.e. User Equipment (UE) transmit direction
5) WiMax operating using Time Division Duplex (TDD)

Under Ofcom's DDR it is proposed that at least 112 MHz of spectrum be released, which would comprise 14 channels of 8 MHz. The mapping between channels and frequencies is identified in the figure below.

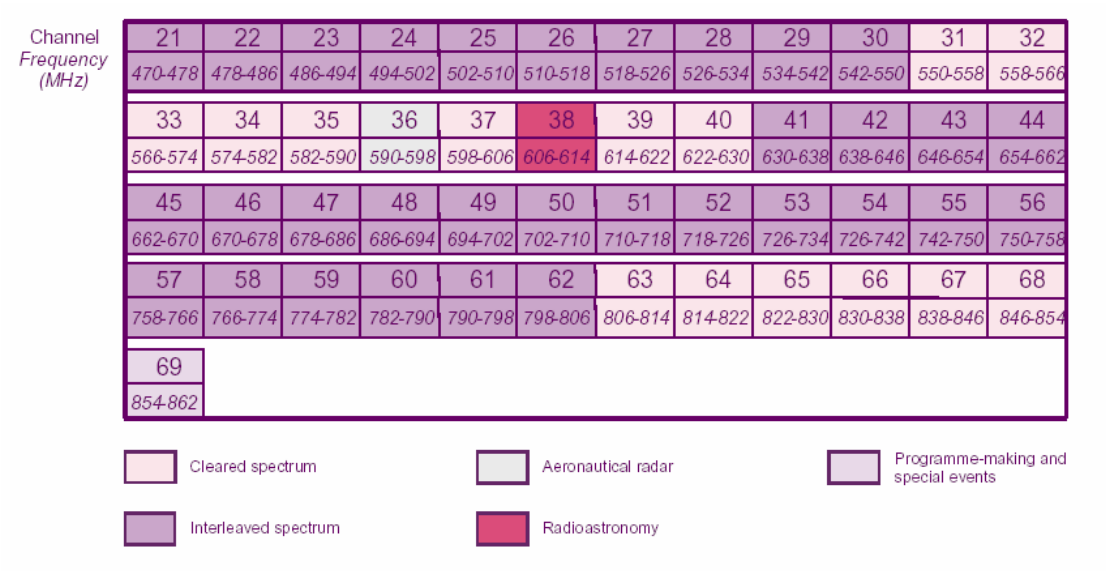


Figure 1: UHF Channels subject to DDR

While in principle any service could be permitted in any band, for the purposes of this study it was assumed that the lower channels would continue to be used for some form of broadcasting while the upper channels would be used for cellular type applications.

The following frequencies were therefore used in this study:

- DTT & DVB-H: C35 = 586 MHz
- IMT-2000 and WiMax: C65 = 826 MHz

2 Study Approach

The study approach followed similar processes to previous phases which generated area PFD SURs for the L-band auction 1452 – 1492 MHz [2] and S-band auction at 2 500 – 2 690 MHz. This involved:

1) Identification of key parameters: where feasible these were taken from industry standards or Ofcom published documents such as [3] and [4]
2) Analysis of assumptions and where necessary modification of parameters to ensure consistency with frequencies to be used for the study, using the the same propagation model as those studies for the coverage planning and power control algorithm
3) Creation of simulation files using Visualyse Professional Version 7 to model deployment of transmitters and derive associated area PFD levels, repeating five times to analyse degree of variation
4) Identification of the PFD level that would be met for 95% of locations for each of the scenarios

Note that a number of alternative sets of parameters could be used – for example, in different environments. The analysis was done assuming an urban environment as it was considered likely that it would have higher PFDs than a rural area.

3 Propagation Models

A key issue was the propagation model used to predict signal strengths. A number of propagation models were considered, including:

- ITU-R Rec. P.452 [5]
- ITU-R Rec. P.1411 [6]
- ITU-R Rec. P.1546 [7]
- ITU-R Rec. P.1812 [8]
- Hata / COST 231 [9]

Two of these propagation models, namely ITU-R Rec. P.452 and P.1812, were developed to use site specific information and terrain databases and were therefore considered inappropriate to generate area PFD masks that would be applied on a generic basis.

Hata / COST 231, while used by several other studies of DDR issues, was considered too generic, in that it defined a single median loss figure, without taking into account location variation.

The baseline propagation model used for the studies was therefore ITU-R Rec. P.1546. This is has been subject to peer review within the ITU-R Study Group 3 and has been accepted widely within the industry. It was the basis of the propagation model that is included in the Final Acts [10] of the Regional Radiocommunications Conference (RRC) held at Geneva in 2006 that planned transition of UHF bands to digital services in parts of Regions 1 and 3. It was also the propagation model used for previous studies for Ofcom, in particular to generate the area PFD masks proposed to be used at L-band.

Version 1546-2 of this model was configured for 50% of time and a location variability standard deviation of 5.5 dB used to derive the loss to a test point at height of 10m. To accurately model the variation in propagation loss it was necessary to convolve the various effects, as described in Annex 1. The model used included the standard extensions for paths under 1 km as described in document [11] which is similar to the sub 1 km model in P.1546-3. Pixels very close to a transmitter were excluded.

One limitation of Rec. P.1546 is it is designed to predict the loss between high height transmitters and receivers at a height of 10m. This is typically the case for broadcast systems which use a single high power high height antenna transmitting over a large area. It is less suited for low height transmitters such as mobiles: hence for low height to low height paths an alternative model was required.

The model used was ITU-R Rec. P.1411-3, which was configured as follows:

- Dual slope with initial slope n=2 for distances under 50m and n=4 afterwards
- Loss at break point at distance of 50m of 25 dB
- Additional log-normal variation of 8 dB

The parameters used were selected based upon Ofcom sponsored research into low-height to low-height propagation within urban area [12]. The output of this research has been used as an input to P.1411 (see document 3K/165-E: Proposed addition to Recommendation ITU-R P.1411-3, 10th April 2007).

The area PFD masks were to be derived at two heights, namely 10m and 1.5m. There was therefore a need to make an adjustment for height, namely:

- When using ITU-R Rec. P.1546, to determine area PFDs at 1.5m from area PFDs at 10m
- When using ITU-R Rec. P.1411, to determine area PFDs at 10m from area PFDs at 1.5m

The difference in signal strength at the two heights will depend upon a number of factors including the frequency used and the nature of clutter around the test point. If the clutter height is known then the difference can be derived using equations either in ITU-R Rec.P.1546 or in the Final Acts of the RRC.

In this case the objective was to derive generic PFDs in order to define SURs and hence specific details of the clutter were not available. Therefore it was considered it would be appropriate to use the general figures used in other studies, which were themselves taken from the Final Acts of the RRC.

The figure below shows this adjustment for the case of a transmitter at 500 MHz:

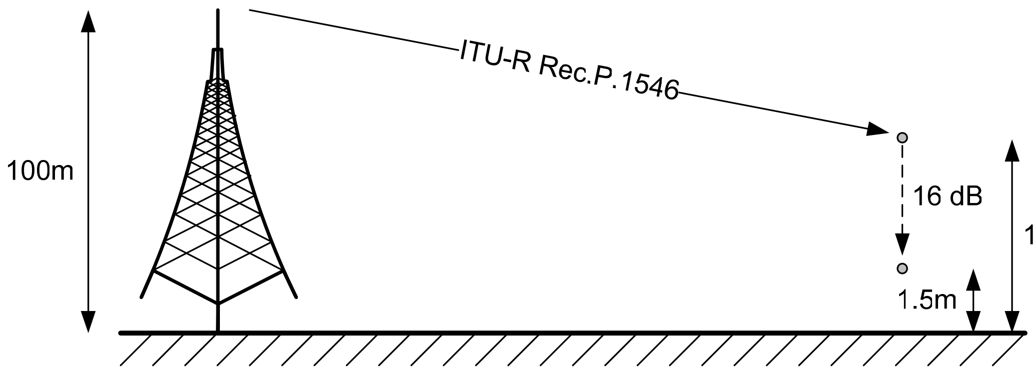


Figure 2: Height Loss Calculation

The height loss used varied according to the frequency involved. The values used were taken from the Final Acts of the RRC which were 16 dB at 500 MHz and 18 dB at 800 MHz.

For the WiMax case, which involved transmissions at two heights (base stations at 30m and mobiles at 1.5m), a combination of models was used as in the figure below.

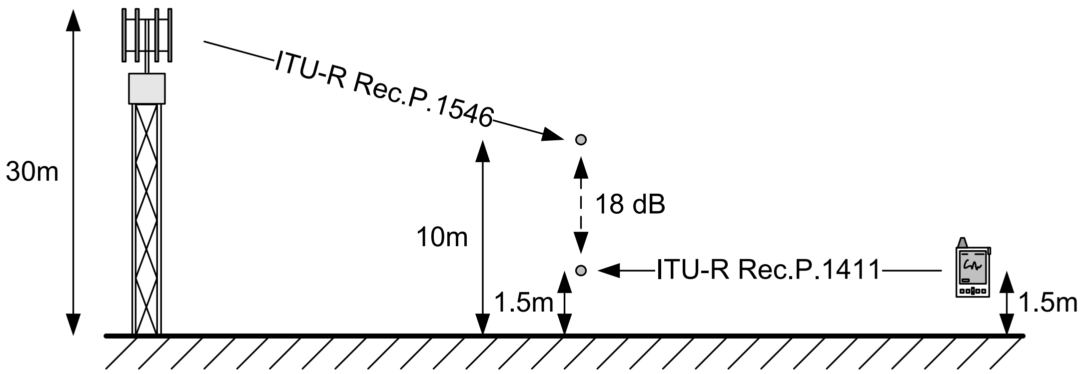


Figure 3: Combination of Propagation Models

Other heights would require different adjustment factors and hence result in different PFD levels.

Once above the local clutter (buildings, trees etc) the adjustment factor and hence PFD level should not change significantly with height. So for example, in an area where the majority of buildings have a height of 10m, there should be only minor differences between the PFD at 10m and at 20m or 30m.

4 System Modelling

This section describes the analysis undertaken for each of the five scenarios.

4.1 DTT

4.1.1 Parameters

This section defines the DTT parameters to be used in the analysis assuming broadcasting to a fixed receiver at a height of 10m.

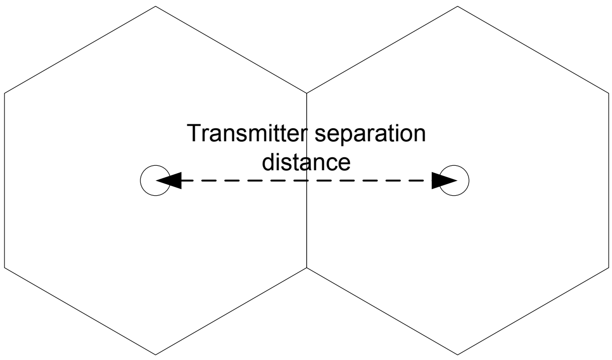
Field	Value	Comments
Frequency	586 MHz	Used in earlier studies [3]. Mid-range frequency within C31 – C37 assumed to be used for broadcasting applications
Bandwidth	8 MHz	Standard DTT channel bandwidth – see discussion below
Transmitter height	100 m	From [3]
EIRP	42.15 dBW	Equivalent to 10 kW ERP, from [3]
Transmitter separation distance	53.3 km	See discussion below
Attenuation to adjacent channel	70.5 dB	See discussion below

Table 1: Parameters for DTT SUR PFD Modelling

4.1.2 Analysis

The parameters were taken from document [1]. To ensure the parameters and models were consistent with the simulation tool used, the coverage plot was reproduced as in the figure below. From a cell radius of 30.8 km the transmitter separation distance of 53.3 km was derived.

The relationship between the cell radius and transmitter separation distance is shown in the figures below.



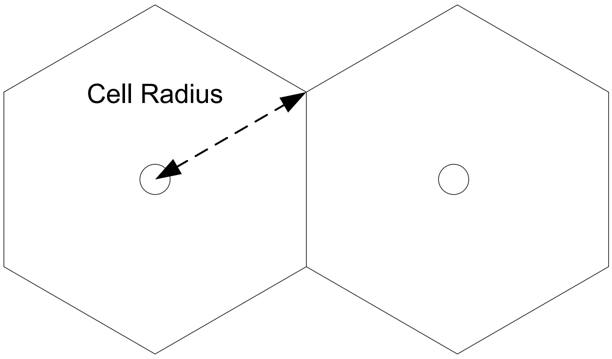


Figure 4: Transmitter Separation Distance and Cell Radius

The DTT analysis assumed use of ITU-R Rec. P.1546 as the propagation model with the standard adjustments for paths below 1 km as in document [11]

Figure 5: Prediction Coverage of DTT Network using Reference Parameters

The threshold C/N was seen to be reached at a cell radius of 30.8 km, and this value was used to derive the transmitter separation distance of 53.3 km. The prediction was based upon a channel bandwidth of 7.6 MHz to be consistent with document [3], though the PFD SURs were based upon a bandwidth of 8 MHz.

For a given EIRP, there would be a slight variation between the C/N at edge of cell between the lower and upper channel due to variations in propagation loss at the different frequencies. The range was between:

- Lower channel C31 at 554 MHz, edge of cell C/N = 23.4 dB
- Channel used C35 at 586 MHz, edge of cell C/N = 22.8 dB (target)
- Upper channel C37 at 602 MHz, edge of cell C/N = 22.5 dB

It was noted there was about 0.5 dB variation from the channel used to the two extrema. It was felt this variation was minor and hence the PFD mask derived at C35 could be applied across the range of channels from C31 to C37. In addition the actual variation in a measured system could be less due to compensating differences in peak gain at the various frequencies.

The link budget was similar to the Reference Planning Configuration (RPC) 1 in the RRC Final Acts [9], which suggested a C/N = 21 dB.

The spectrum mask was taken from the 8 MHz channel non-critical case from the RRC Final Acts as shown in the figure below.

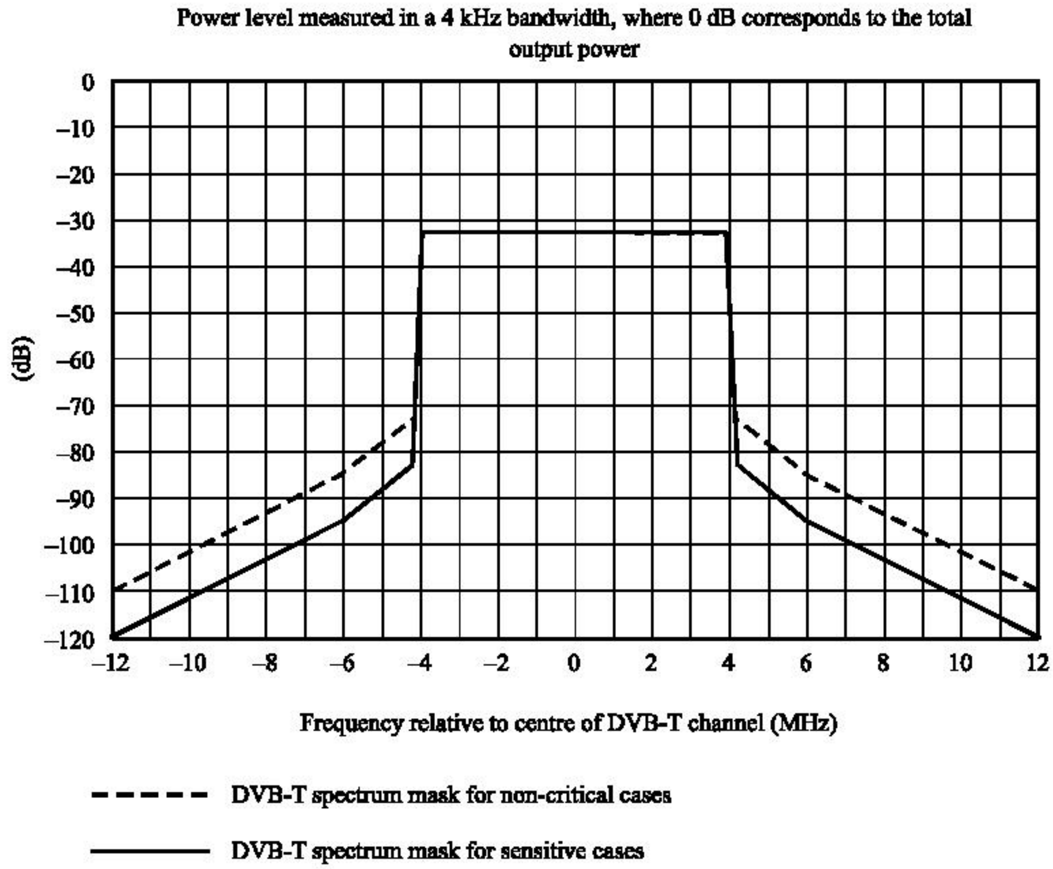


Figure 6: DVB-T Spectrum Mask from RRC-06

It was assumed that an 8 MHz channelisation would continue as in the figure below:

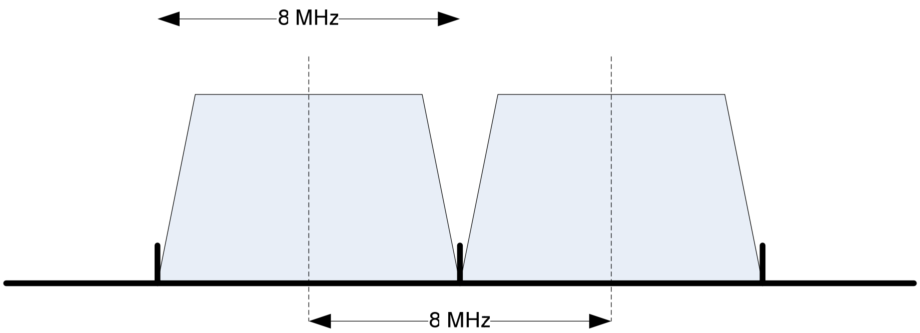


Figure 7: 8 MHz DTT Channel Plan

It was noted that the power at the centre of the adjacent 8 MHz channel will depend upon the mask, which will be:

Critical case: 70.5 dB below the in-band power

Non-critical case: 60.5 dB below the in-band power

The link budget to the test point at edge of coverage is given below.

Frequency (MHz)	586
Bandwidth (MHz)	7.6
Carrier	DVB-T
Transmit EIRP (dBW)	42.1
Path Loss (dB)	156.7
Location variation (dB)	9.0
ITU-R P.1546 Path Loss	147.7
Receive Gain (dBi)	12.8
Receive Feeder Loss (dB)	3.6
C (dBW)	-105.4
N (dBW)	-128.2
C/N (dB)	22.8

Table 2: DTT Link Budget

4.1.3 Simulation

A simulation file was generated as shown in the screen shot below with grids every 1° in latitude and longitude.

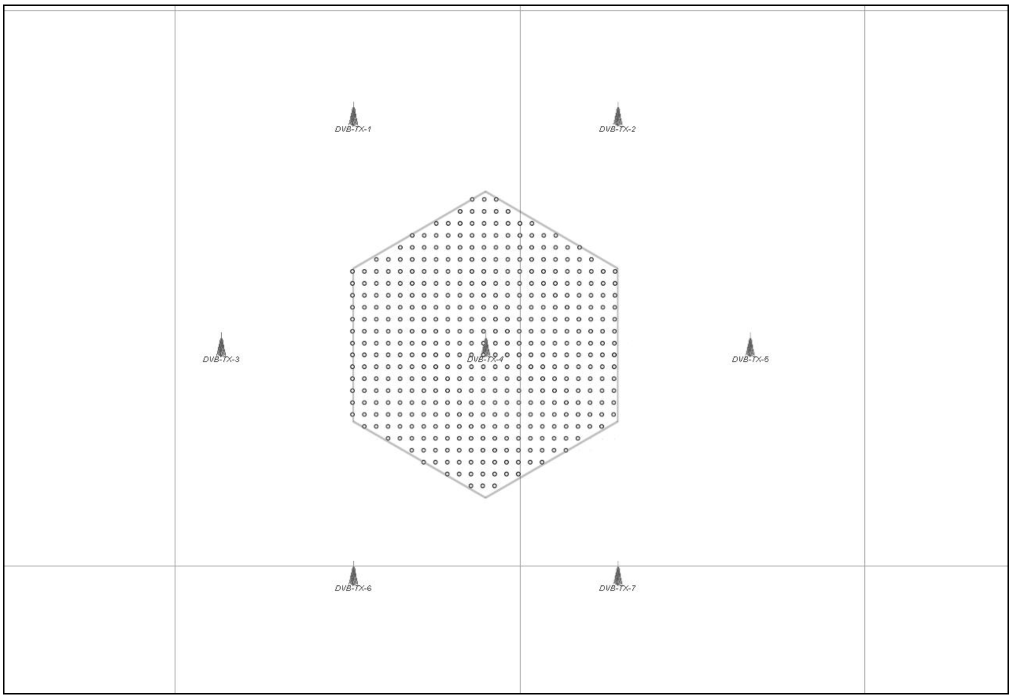


Figure 8: DTT Simulation File

The file was configured with seven transmitters arranged in a hexagonal cellular structure. The central cell was populated by 437 test points, and the aggregate PFD was determine at a height of 10m assuming the ITU-R Rec.P.1546-2 propagation model with location variability with standard deviation 5.5 dB.

The simulation was updated with 5 random seeds to derive 5 cumulative distribution functions (CDFs) as in the figure below.

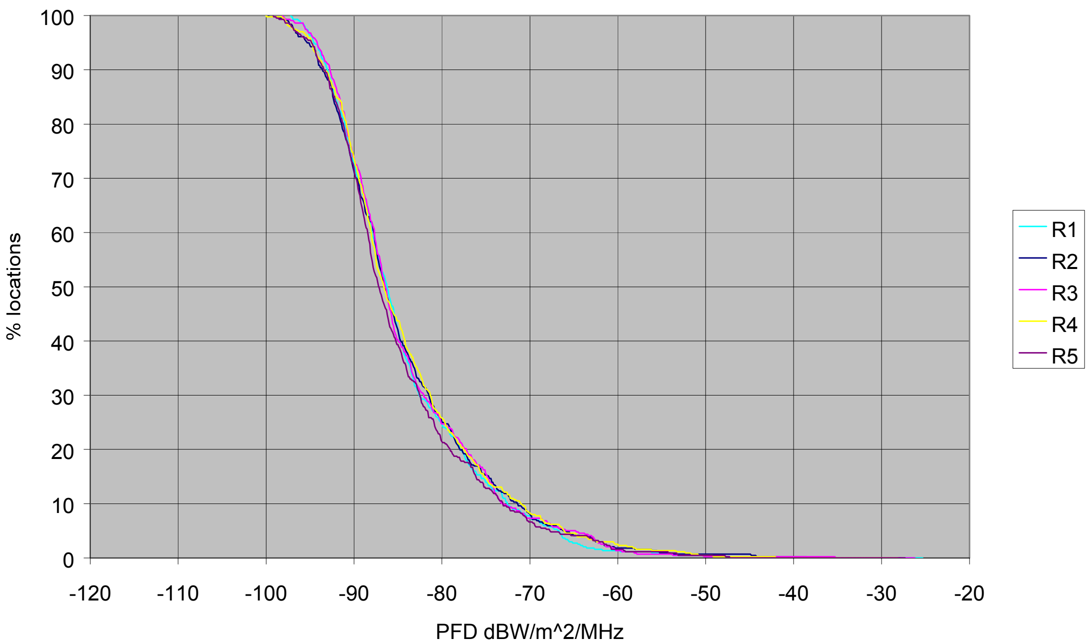


Figure 9: DTT In-band PFD at height = 10m

Using the envelope of the five curves, the highest PFD for 5% of locations identified as -64.7 dBW / m^2 / MHz.

4.1.4 Results

The table below shows the resulting area PFD levels exceeded at 5% of locations for both 10m and 1.5m heights and for both the in-band and adjacent band cases.

Height of test point	1.5 m	10 m
In-band PFD (dBW/m^2/MHz)	-80.7	-64.7
Adjacent band PFD (dBW/m^2/MHz)	-141.2	-125.2

Table 3: DTT PFD levels met for 95% of locations

4.2 DVB-H

4.2.1 Parameters

This section defines the DVB-H parameters used in the analysis assuming transmitting to a mobile indoor receiver at a height of 1.5m.

Field	Value	Comments
Frequency	586 MHz	Used in earlier studies [3]. Mid-range frequency within C31 – C37 assumed to be used for broadcasting applications
Bandwidth	8 MHz	Standard DVB channel bandwidth – see discussion below
Transmitter height	30 m	From [3]
EIRP	32.15 dBW	Equivalent to 1 kW ERP, from [3]
Transmitter separation distance	2.2 km	See discussion below
Attenuation to adjacent channel	60.5 dB	As derived above

Table 4: Parameters for DVB-H SUR PFD Modelling

4.2.2 Analysis

The parameters were taken from document [3]. To ensure the parameters and models were consistent with the simulation tool used, the coverage plot was reproduced as in the figure below with grid resolution 1 km for scale. From a cell radius of 1.25 km the transmitter's separation distance of 2.16 km was derived.

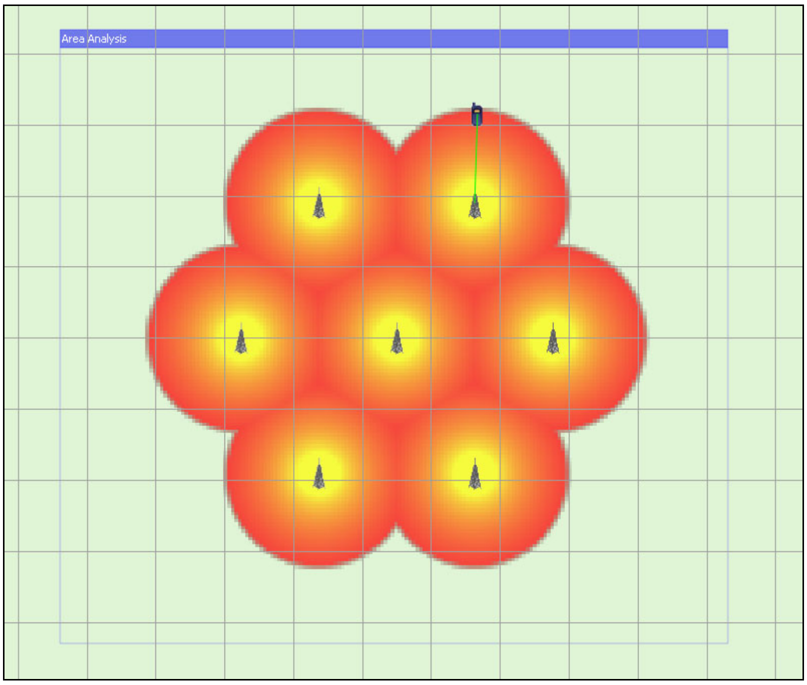


Figure 10: Prediction Coverage of DVB-H Network with Grid

An alternative way of getting a feel for the coverage is to overlay a map of South London, as in the figure below.

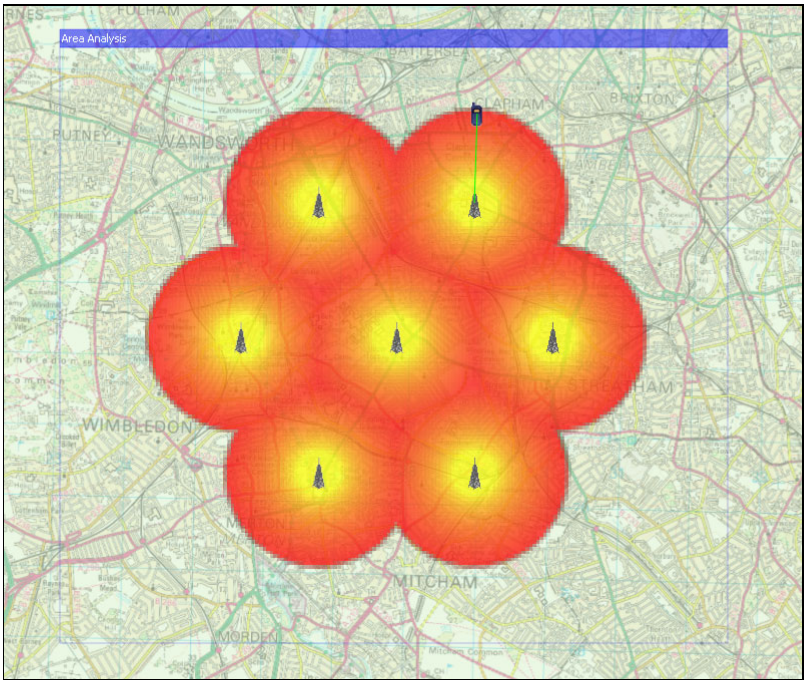


Figure 11: Prediction Coverage of DVB-H Network with Map

Note that no topographic or land use data was used – simply a map was overlaid to scale on the coverage.

The coverage predictions from reference [3] for DVB-H used Hata / COST231 (urban) to calculate the loss at a height at a height of 10m. From this point three adjustments were made:

- 16 dB of height gain from 10m to 1.5m (where appropriate)

- 5.5 dB sigma log-normal location variation to ensure cover 95% of locations within destination cell
- 11 dB mean plus 6 dB variation building penetration loss, again to the 95% coverage level

In total these three contributed an extra 40.3 dB of loss.

The spectrum mask was assumed to be the same as the DTT mask above.

The link budget to the test point at edge of coverage is given below.

Noise figure (dB)	6.0
Temp (K)	1154.5
Bandwidth (MHz)	7.6
Noise (dBW)	-129.2
C/N (dB)	11.0
Threshold C (dBW)	-118.2
Rx signal (dBW)	-118.1
Location variation (dB)	24.4
EIRP (dB)	32.2
Combined RX gain (dB)	-4.9
Path loss to height 1.5m (dB)	121.0
Height gain to height 10 m (dB)	16.0
Path loss to height 10 m (dB)	105.0
Coverage range (km)	1.25
Transmitter separation (km)	2.16

Table 5: DVB-H Reference Link Budget

4.2.3 Simulation

A simulation file was generated as shown in the screen shot below with grids every 1 km.

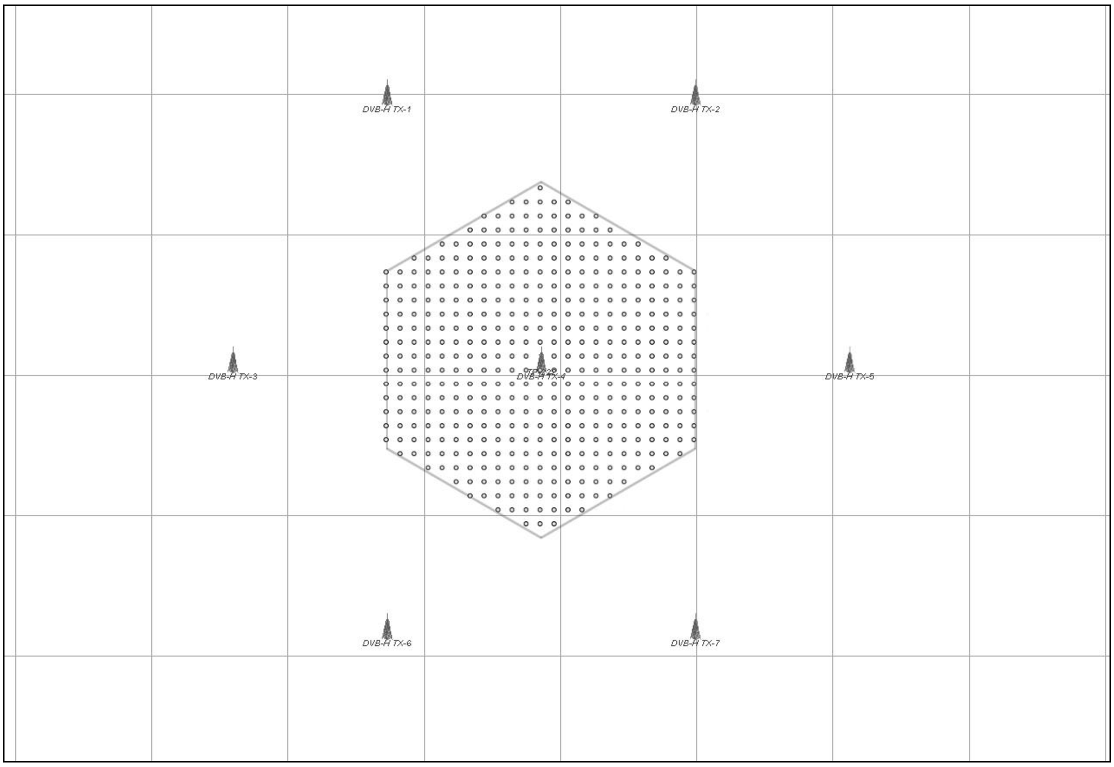


Figure 12: DVB-H Simulation File

The file was configured with seven transmitters arranged in a hexagonal cellular structure. The central cell was populated by 430 test points, and the aggregate PFD was determine at a height of 10m assuming the ITU-R Rec.P.1546-2 propagation model with location variability with standard deviation 5.5 dB.

The simulation was updated with 5 random seeds to derive 5 cumulative distribution functions (CDFs) as in the figure below.

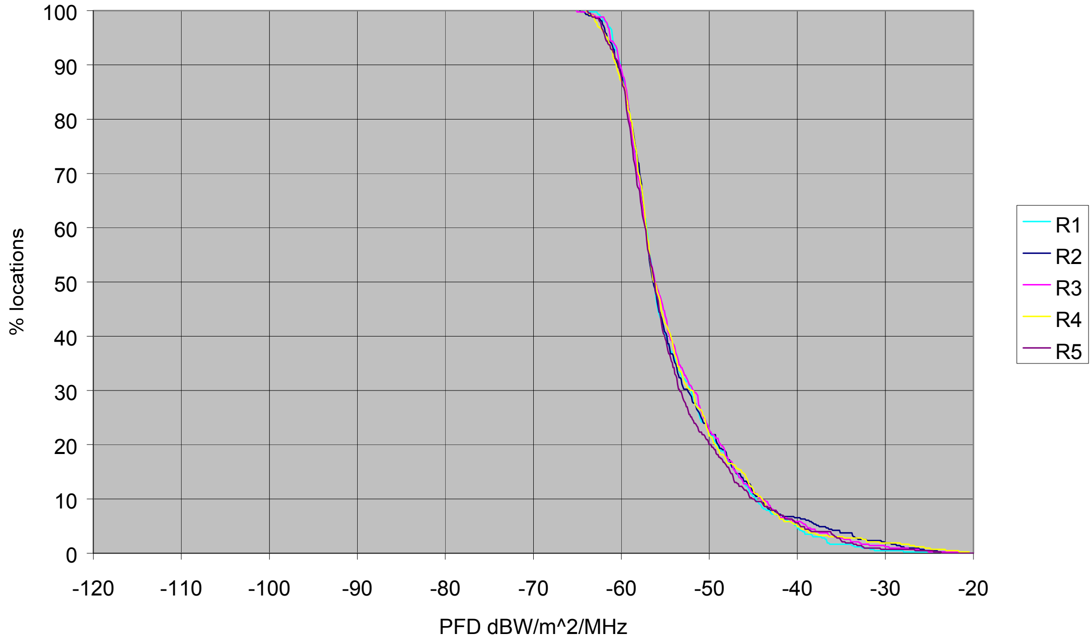


Figure 13: DVB-H In-band PFD at Height = 10 m

Using the envelope of the five curves, the highest PFD for 5% of locations identified as -37.6 dBW / m^2 / MHz.

4.2.4 Results

The table below shows the resulting area PFD levels exceeded at 5% of locations for both 10m and 1.5m heights and for both the in-band and adjacent band cases.

Height of test point	1.5 m	10 m
In-band PFD (dBW/m^2/MHz)	-53.6	-37.6
Adjacent band PFD (dBW/m^2/MHz)	-114.1	-98.1

Table 6: DVB-H PFD levels met for 95% of locations

4.3 IMT FDD DL

4.3.1 Parameters

This section defines the IMT BS TX parameters used in the analysis. These proved less straight forward to define than the other systems types. Some differences were noted between the parameters used in different documents:

- The target cell area probabilities in the SEAMCAT analysis in Appendix B of document [4] where not the same as in the IMT-2000 link budgets in Appendix C of the same document
- The BS peak gain was given as 15 dBi in document [4] but in ERC Report 45 [13] a typical value for urban area pedestrian voice was 5 dBi

- The number of users per cell was similarly different – document [4] gave an "arbitrary" figure of 37 users per cell against 65 in [13]
- Furthermore the link budgets in [4] gave the EIRP per BS per UE as being 43 dBm and did not indicate the total BS EIRP taking into account all users and signalling channels unlike [13] which gave indicative aggregate values

It was noted that document [13] considered the 2.5 GHz band while document [4] considered the UHF band under consideration for this study. Therefore the approach taken was to baseline the link budgets on Appendix C of document [4] and making various assumptions about power control and voice activation to generate the aggregate BS transmit power.

Following the analysis given in the following section, the following parameters were selected:

Field	Value	Comments
Frequency	826 MHz	Channel 65
Bandwidth	3.84 MHz within 5 MHz	Standard channel bandwidth for WCDMA networks
Transmitter height	30 m	From [4] for urban environment, also in [13] for macro vehicular environments
Total EIRP all users	22.7 dBW	Corresponding to a transmit power of 37.7 dBm and BS gain of 15 dBi
Transmitter separation distance	1.86 km	See discussion below
Power attenuation at frequency offset of 5 MHz	46.2 dB	From 3GPP TS 25.104 [14]

Table 7: Parameters for IMT FDD BS TX SUR PFD Modelling

4.3.2 Analysis

Note that document [4] gave the EIRP of the base station as 43 dBm with associated link budget in annex. This however was based upon a single voice user – it is likely the cell would be loaded with additional users.

Using the 37 users / cell figure also in [4] the total EIRP was calculated as being 52.7 dBm = 22.7 dBW less 3 dB for voice activation and 3 dB for power control. Note that this was significantly higher than the EIRP in document [13].

A range of antennas could be used at each base station with differing gain patterns in horizontal or vertical planes, and degrees of downtilts. A single antenna with equal gain (i.e. equal EIRP in all directions) in all directions was used as the simulation antenna at the base station as this represents the envelope of all potential physical antennas.

The shortest distance between cell centre and cell edge was assumed given as 0.94 km at a frequency of 810 MHz in reference [4] from which a transmitter separation distance of 1.88 km was derived. To ensure the parameters and models were consistent with the simulation tool used, the coverage plot was reproduced as in the figure below with grid resolution 1 km for scale.

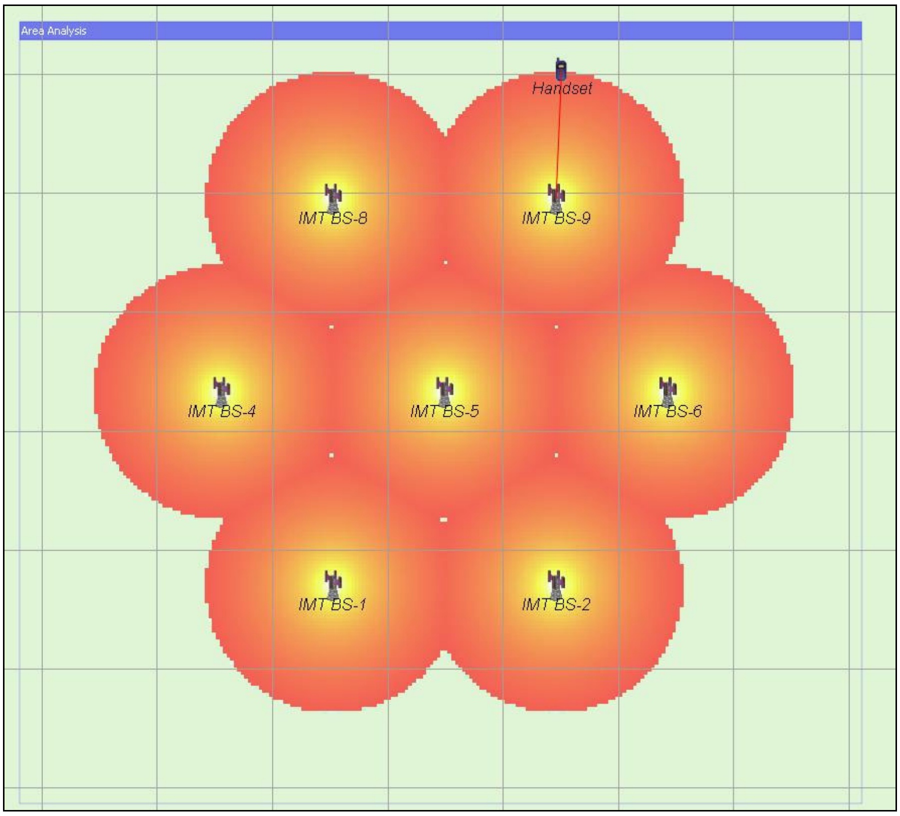


Figure 14: Prediction Coverage of IMT-2000 Network with Grid

The link budget was then scaled to the required central frequency of 826 MHz and the shortest distance between cell centre and cell edge reduced from 0.94 km to 0.93 km, i.e. transmitter separation distance of 1.86 km.

The final link budget per user is given in the table below:

Carrier type	voice
Frequency (MHz)	826
EIRP / user (dBm)	43.00
Thermal noise density (dBm/Hz)	-173.93
UE Noise figure (dB)	6.00
UE noise density (dBm/Hz)	-167.93
Chip rate	3,840,000.00
UE RX noise power (dBm)	-102.09
DL Interference margin (dB)	3.01
UE RX noise + interference (dBm)	-99.08
DL data rate (bps)	12,200.00
UE processing gain (dB)	24.98
UE required Eb/No (dB)	7.00
UE Sensitivity (dBm)	-117.06
Soft handover gain (dB)	2.00
UE antenna gain (dB)	0.00
UE body loss (dB)	10.00
UE required signal power (dBm)	-109.06
Maximum path loss (dB)	152.06
Edge coverage requirement (%)	90.00
Sigma factor	1.28
SD fading (dB)	7.00
SD building penetration (dB)	8.00
Mean building penetration (dB)	12.00
Total sigma (dB)	13.61
Total loss indoor operation (dB)	25.61
Maximum Hata Loss (dB)	126.45
Cell radius (km)	1.07
Transmitter separation distance (km)	1.86

Table 8: IMT-2000 DL Link Budget

The attenuation of power density compared to in-band was calculated as in the table below using Table 6.5 of [14].

In-band power (dBm)	37.7
In-band power density (dBm/MHz)	31.9
Power density at frequency offset (dBm/MHz)	-14.3
Attenuation at frequency offset wrt in-band (dB)	46.2

Table 9: IMT-2000 BS Attenuation at 5 MHz Frequency Offset

4.3.3 Simulation

A simulation file was generated as shown in the screen shot below with grids every 1 km.

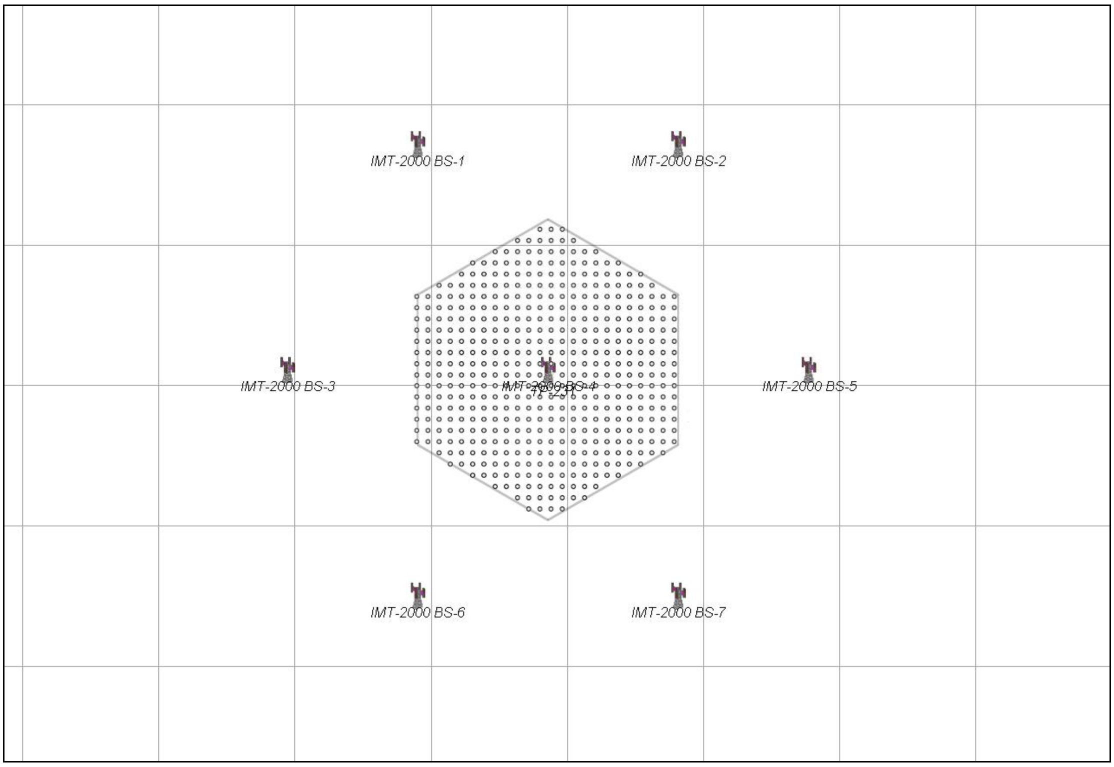


Figure 15: IMT-2000 DL Simulation File

The file was configured with seven base stations arranged in a hexagonal cellular structure. The central cell was populated by 479 test points, and the aggregate PFD was determined at a height of 10 m

The simulation was updated with 5 random seeds to derive 5 cumulative distribution functions (CDFs) as in the figure below.

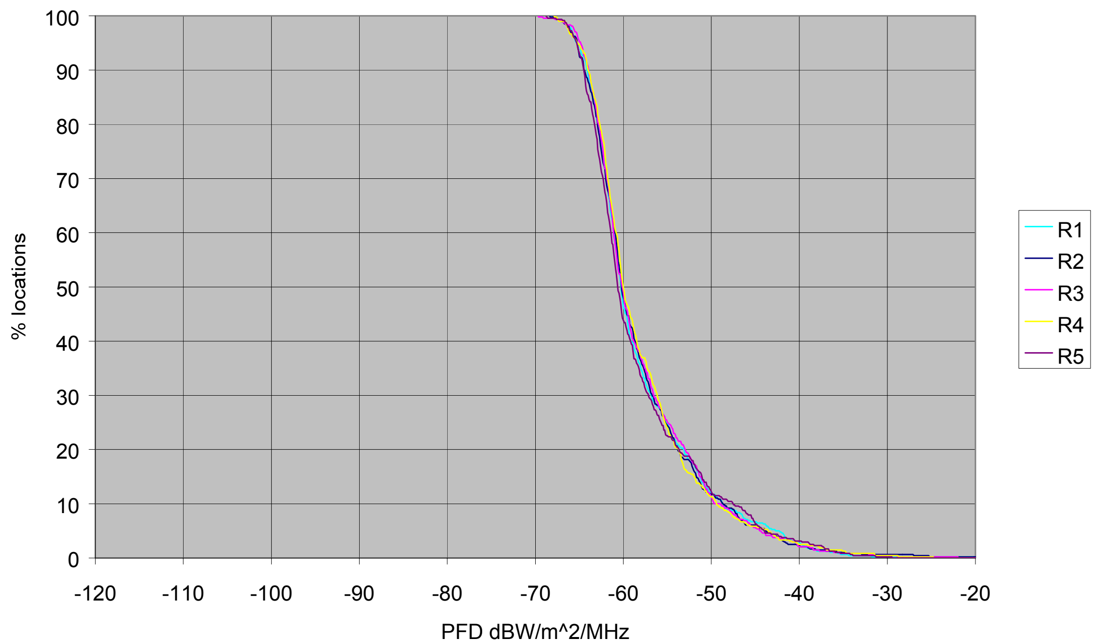


Figure 16: IMT-2000 In-band PFD at height = 10 m

Using the envelope of the five curves, the highest PFD for 5% of locations identified as -42.2 dBW / m^2 / MHz.

4.3.4 Results

The table below shows the resulting area PFD levels exceeded at 5% of locations for both 10m and 1.5m heights and for both the in-band and adjacent band cases.

Height of test point	1.5 m	10 m
In-band PFD (dBW/m^2/MHz)	-60.2	-42.2
Adjacent band PFD (dBW/m^2/MHz)	-106.4	-88.4

Table 10: IMT-2000 DL PFD levels met for 95% of locations

4.4 IMT FDD UL

4.4.1 Parameters

This section defines the IMT UE TX parameters used in the analysis.

Frequency	826 MHz	Channel 65
Bandwidth	3.84 MHz within 5 MHz	Standard channel bandwidth for WCDMA networks
Cell Radius	0.93 km	As before
Number of UE / cell	37	From [4]
Transmitter height	1.5 m	From [4]
Maximum EIRP	-19 dBW	From EIRP of 11 dBm in [4]
Power control range	45 dB	From [3] – the difference between minimum and maximum power that could be transmitted by the UE to achieve the required received signal level
Transmitter separation distance	1.86 km	See discussion below
Power attenuation at frequency offset of 5 MHz	30.7 dB	From 3GPP TS 25.101 [15]

Table 11: Parameters for IMT FDD UE TX SUR PFD Modelling

4.4.2 Analysis

The link budget is similar with balanced 152 dB UL/DL path loss, and hence the cell radius and coverage graphic is the same as the previous section.

It was assumed that the link employed uplink power control: for the parameters given the target wanted signal level at the base station was -122.1 dBm = -152.1 dBW.

The link budget is then:

Carrier type	voice
Frequency (MHz)	826
EIRP (dBm)	11.00
Thermal noise density (dBm/Hz)	-173.93
BS Noise figure (dB)	3.00
BS noise density (dBm/Hz)	-170.93
Chip rate	3,840,000.00
BS RX noise power (dBm)	-105.09
UL Interference margin (dB)	3.01
BS RX noise + interference (dBm)	-102.08
UL data rate (bps)	12,200.00
BS processing gain (dB)	24.98
BS required Eb/No (dB)	5.00
BS Sensitivity (dBm)	-122.06
Soft handover gain (dB)	1.00
Mast head amplifier gain (dB)	2.00
Antenna Diversity gain (dB)	3.00
BS antenna gain (dB)	15.00
BS feed loss (dB)	1.95
BS required signal power (dBm)	-141.11
Maximum path loss (dB)	152.11
Edge coverage requirement (%)	90.00
Sigma factor	1.28
SD fading (dB)	7.00
SD building penetration (dB)	8.00
Mean building penetration (dB)	12.00
Total sigma (dB)	13.61
Total loss indoor operation (dB)	25.61
Maximum Hata Loss (dB)	126.50
Cell radius (km)	1.07
Transmitter separation distance (km)	1.86

Table 12: IMT-2000 UL Link Budget

The power attenuation at a frequency offset of 5 MHz was calculated from table 6.10 of document [15] as follows:

In-band power (dBm)	17.9
In-band power density (dBm/MHz)	12.1
Relative requirements (dBc)	-36.5
Power density at offset (dBm/MHz)	-18.6
Attenuation offset wrt in-band (dB)	30.7

Table 13: IMT-2000 UE Attenuation at 5 MHz Frequency Offset

4.4.3 Simulation

A simulation file was generated as shown in the screen shot below with grids every 1 km.

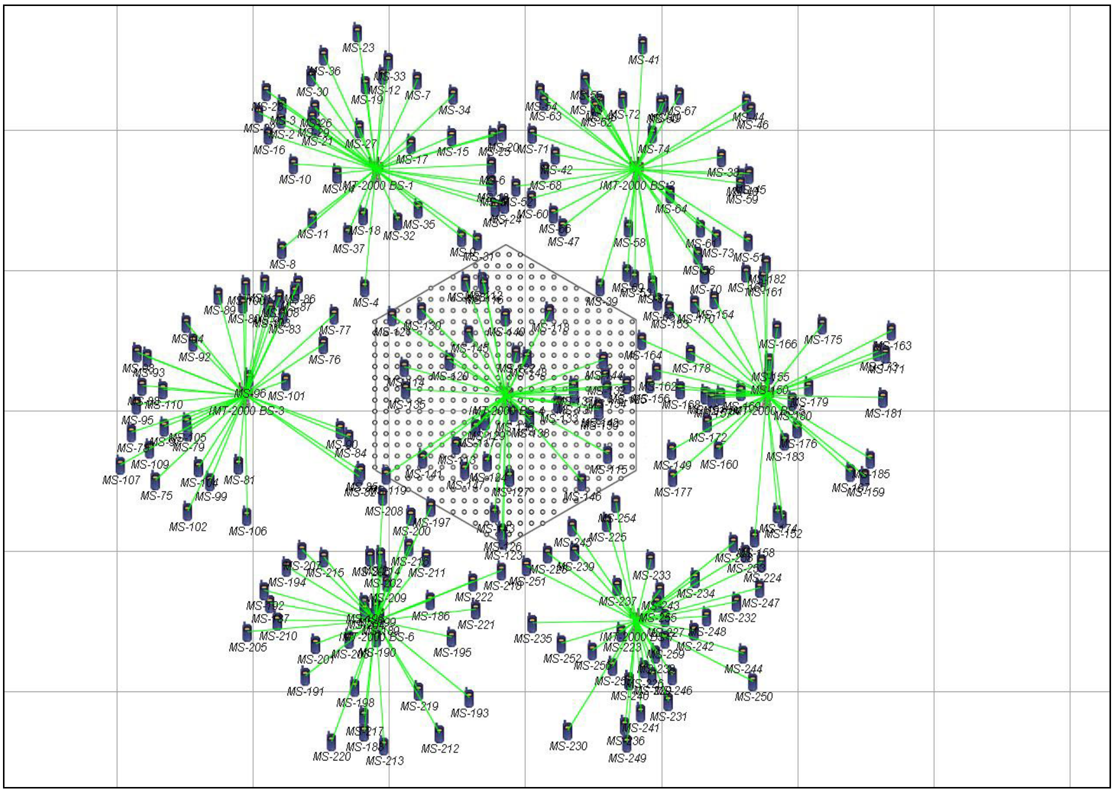


Figure 17: IMT-2000 UL Simulation File

The file was configured with seven base stations arranged in a hexagonal cellular structure each containing 37 UEs deployed at random within the cell. The central cell was populated by 479 test points, and the aggregate PFD was determined at a height of 1.5 m

The simulation was updated with 5 random seeds to derive 5 cumulative distribution functions (CDFs) as in the figure below.

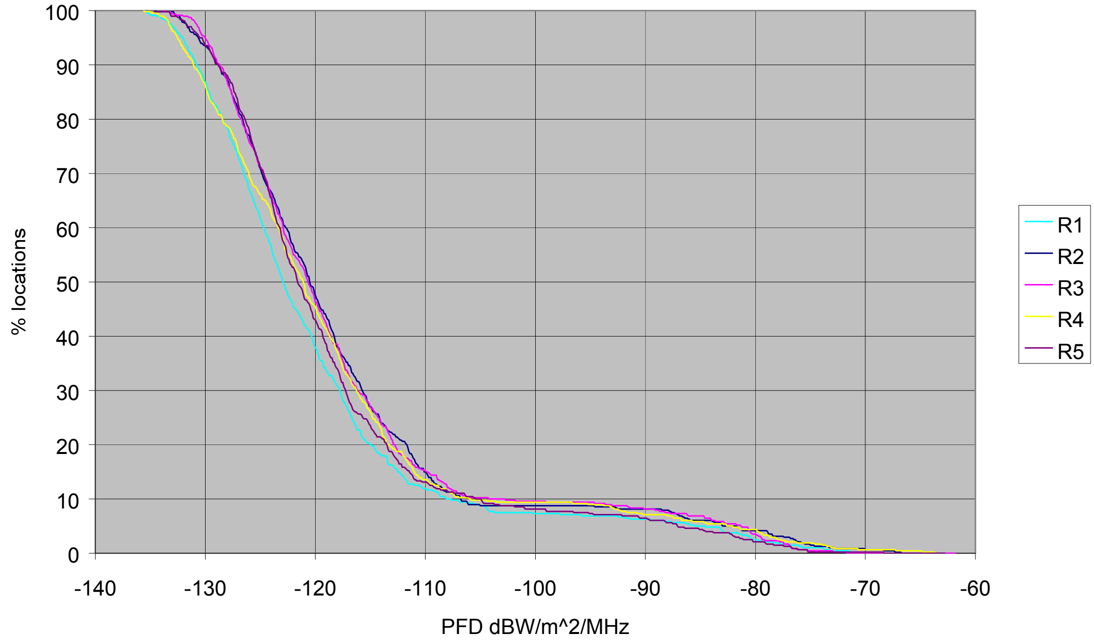


Figure 18: IMT-2000 UL In-band PFD at height = 1.5 m

Using the envelope of the five curves, the highest PFD for 5% of locations identified as -81.2 dBW / m^2 / MHz.

4.4.4 Results

The table below shows the resulting area PFD levels exceeded at 5% of locations for both 10m and 1.5m heights and for both the in-band and adjacent band cases.

Height of test point	1.5 m	10 m
In-band PFD (dBW/m^2/MHz)	-81.2	-63.2
Adjacent band PFD (dBW/m^2/MHz)	-111.9	-93.9

Table 14: IMT-2000 UL PFD levels met for 95% of locations

4.5 WiMax

This section defines the WiMax parameters used in the analysis. There are two sub-sections, one for BS TX and one for UE TX.

It was noted that most original source documents reference (e.g. [16]) gave link budgets for other frequency bands, typically 2.5 GHz. These had to be scaled to UHF band and this necessarily involved making various assumptions.

In addition the bandwidth in the WiMax documents was 10 MHz rather than 5 MHz assumed here: a 3 dB adjustment was therefore made to the EIRP. This corresponds to use of 420 sub-carriers rather than the full 840.

It was assumed that the 5 MHz WiMax carrier was located at the centre of a 5 MHz channel as in the figure below.

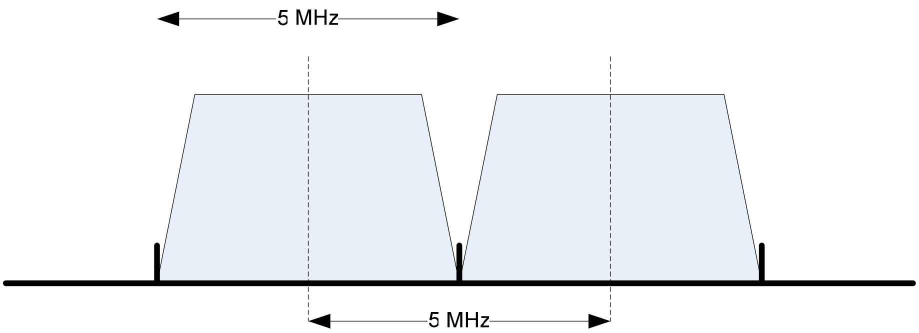


Figure 19: 5 MHz WiMax Carriers within 5 MHz Channel Plan

It was noted that the objective of the PFD SURs was to provide a technology neutral format for licensing. Thus it would be appropriate for the TDD mask to facilitate a number of technologies, including WiMax but also IMT-2000 in TDD mode. It was further noted that in document 8F/1079 Rev 1 [19] it was suggested that the WiMax spectrum mask would be "similar to other IMT-2000 RTTs".

Hence the IMT-2000 spectrum mask as given in 3GPP documents [17] and [18] were used to define the adjacent band PFD for TDD scenarios.

The area PFD SUR was calculated by performing a power summation of the contributions from the uplink and downlink.

4.5.1 WiMax BS TX

4.5.1.1 Parameters

This section defines the WiMax BS TX parameters used in the analysis.

Field	Value	Comments
Frequency	826 MHz	Channel 65
Bandwidth	5 MHz	Standard channel bandwidth – see discussion previously
Transmitter height	30 m	From [16]
EIRP	24.3 dBW	From [16], subtracting 3 dB as using 5 MHz channels rather than 10 MHz
Transmitter separation distance	2.08 km	See discussion below
Power attenuation at frequency offset of 5 MHz	45.4 dB	From 3GPP TS 25.105 [17]

Table 15: Parameters for WiMax BS TX SUR PFD Modelling

4.5.1.2 Analysis

The primary source of parameters was document [16] with a cross-check against those in document [2]. As for the IMT-2000 BS TX scenario above, a single isotropic antenna was used to represent all potential physical antennas at the base station.

The link budget was reconstructed for the frequency under consideration as follows:

Frequency (MHz)	826
EIRP (dBm)	54.3
Sub-carriers	420.0
Total sub-carriers	420.0
EIRP/sub-carrier (dBW)	-1.9
Path loss (dB)	128.2
Location variation (dB)	19.6
RX gain (dB)	2.0
RX signal (dBW)	-147.7
Bandwidth / sub-carrier (Hz)	10940.0
Noise figure (dB)	7.0
N in bandwidth (dBW)	-156.6
SNR Required (dB)	8.9
Cell radius (km)	1.2
Transmitter separation distance (km)	2.08

Table 16: WiMax DL Link Budget

The spectrum mask was assumed to be consistent with that of the TDD mode of IMT-2000. Hence the attenuation of power at a frequency offset of 5 MHz was calculated using table 6.5 of [17] as follows:

In-band power (dBm):	37.0
In-band power density (dBm/MHz):	30.4
Power density at 5 MHz offset (dBm/MHz):	-15.0
Attenuation compared to in-band:	45.4

Table 17: WiMax DL Calculation of Attenuation at 5 MHz Frequency Offset

4.5.2 WiMax UE TX

4.5.2.1 Parameters

This section defines the WiMax UE TX parameters used in the analysis.

Field	Value	Comments
Frequency	826 MHz	Channel 65
Bandwidth	5 MHz	Standard channel bandwidth – see discussion previously
Number of UE / cell	15	From [2] that gave 5 UE per sector and 3 sectors / cell. The cell size is as given for the WiMax BS TX case
Transmitter height	1.5 m	From [2]
Maximum EIRP	-12.1 dBW	See discussion below
Power control range	45 dB	From [2]
Power attenuation at frequency offset of 5 MHz	30.7 dB	From 3GPP TS 25.102 [18]

Table 18: Parameters for WiMax UE TX SUR PFD Modelling

4.5.2.2 Analysis

The parameters were taken from documents [2] and [16].

Note that using 5 MHz channel implies 420 sub-carriers rather than 840. With 5 mobiles per sector that implies 420 / 5 = 84 sub-carriers allocated for each uplink. Given that document [16] used an EIRP = 22 dBm with 216 sub-carriers, the EIRP for 84 sub-carriers was derived as 17.9 dBm = -12.1 dBW.

It was assumed that the link employed uplink power control: for the parameters given the target wanted signal level at the base station was -109.9 dBm = -139.9 dBW.

The propagation model was assumed to be reciprocal – i.e. the same parameters were used as per the downlink.

The link budget is then:

EIRP (dBm)	17.9
Sub-carriers	84.0
Total sub-carriers	420.0
EIRP/sub-carrier (dBW)	-31.3
Path loss (dB)	103.4
Location (dB)	42.3
RX gain (dB)	18.0
RX signal (dB)	-159.1
Bandwidth / sub-carrier (Hz)	10,940.0
N in bandwidth (dBW)	-159.6
C/N (dB)	0.5
Interference margin (dB)	3.0
Target C/N (dB)	-2.5

Table 19: WiMax UL Link Budget

The attenuation of the signal at a frequency offset of 5 MHz was calculated using Table 6.5 of [18] as follows:

Frequency offset (MHz)	5
In-band power (dBm)	17.9
In-band power density (dBm/MHz)	12.1
Relative requirements (dBc)	-36.5
Power density at offset (dBm/MHz)	-18.6
Attenuation offset wrt in-band (dB)	30.7

Table 20: WiMax UL Attenuation at 5 MHz Frequency Offset

4.5.3 Simulation

A simulation file was generated as shown in the screen shot below with grids every 1 km.

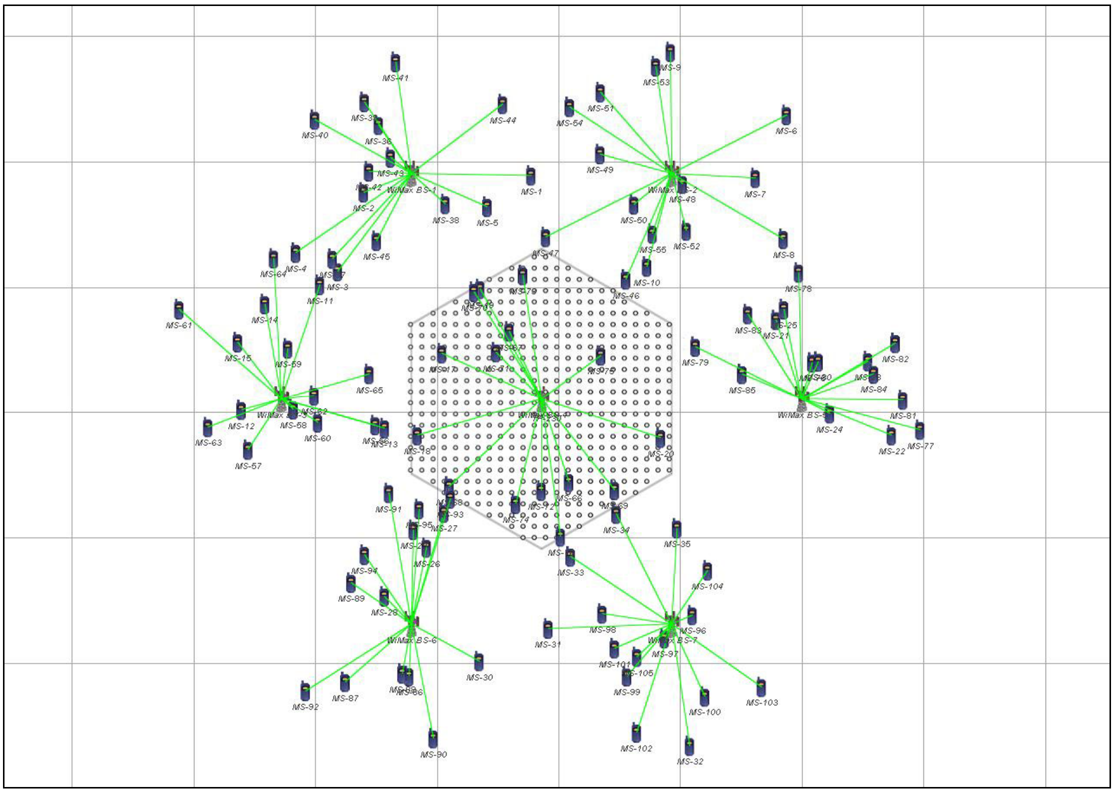


Figure 20: WiMax Simulation File

The file was configured with seven base stations arranged in a hexagonal cellular structure each providing a service to 15 mobiles co-frequency in TDD mode. The central cell was populated by 475 test points, and the aggregate PFD was determined at a height of 1.5m assuming the propagation models:

- BS TX: ITU-R Rec.P.1546-2 propagation model with location variability with standard deviation 5.5 dB and 18 dB height loss to 1.5m
- MS TX: ITU-R Rec.P.1411 with location variability 8 dB

The simulation was updated with 5 random seeds to derive 5 cumulative distribution functions (CDFs) as in the figure below.

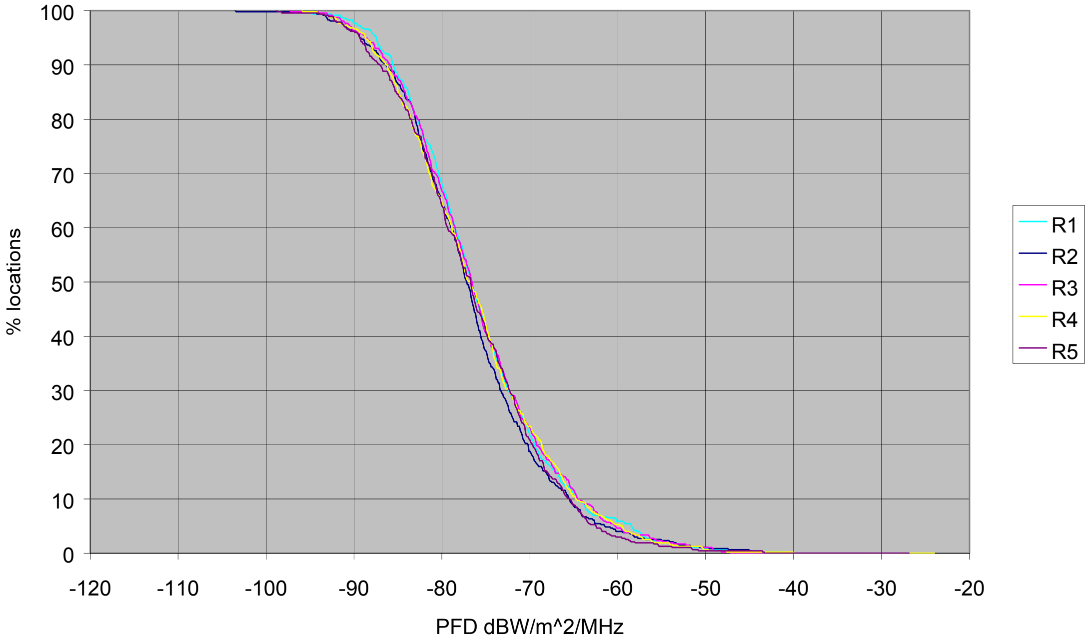


Figure 21: WiMax In-band PFD at height = 1.5 m

Using the envelope of the five curves, the highest PFD for 5% of locations identified as -58.5 dBW / m^2 / MHz.

4.5.4 Results

The table below shows the resulting area PFD levels exceeded at 5% of locations for both 10m and 1.5m heights and for both the in-band and adjacent band cases.

Height of test point	1.5 m	10 m
In-band PFD (dBW/m^2/MHz)	-58.5	-40.5
Adjacent band PFD (dBW/m^2/MHz)	-101.6	-83.6

Table 21: WiMax PFD levels met for 95% of locations

5 DDR PFD SURs

The table below gives the PFD levels to be met for 95% of locations derived for the systems considered as part of the study of DDR SURs:

PFD SURs dBW/m^2/MHz	**In-band**		**Adjacent Band**	
	1.5m	*10m*	*1.5m*	*10m*
DTT	-80.7	-64.7	-151.2	-135.2
DVB-H	-53.6	-37.6	-124.1	-108.1
WiMax	-58.5	-40.5	-101.6	-83.6
IMT-2000 DL	-60.2	-42.2	-106.4	-88.4
IMT-2000 UL	-81.2	-63.2	-111.9	-93.9

Table 22: DDR PFD SURs

Annex 1: Impact of Propagation Variation

The objective of the modelling was to predict the PFD levels that would be measured across the reference area. To be accurate the simulations should therefore model the various effects that can cause variations in signal strength.

For broadcasting networks the transmit power is set at a constant level and so the variation in PFD can be assumed to be due to differences in the propagation of radio waves across the test area. This section gives more information about the main propagation model used in the analysis, namely ITU-R Rec. P.1546.

The core model in ITU-R Rec. P.1546 predicts the median field strength i.e. the most likely value that would be measured at a certain distance from the transmitter. This decreases in distance as in the figure below.

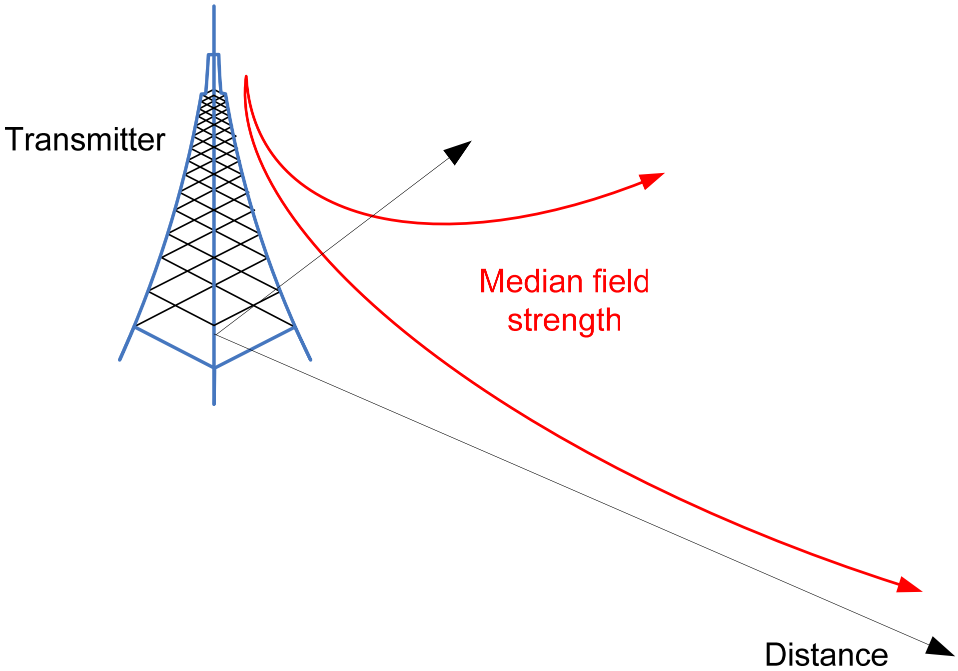


Figure 22: Variation in Field Strength due to Distance

In practice the field strength would not decrease smoothly with distance and there is likely to be differences between the field strength at two measurement points even if they are the same distance from the transmitter.

For example in one direction there could be a large building between the transmitter and the measurement point which would reduce the field strength, while in another direction the measurement point could be at the end of a street that points at the transmitter so that reflections off the buildings increase the received signal.

Hence in practice the actual field strength is likely to vary significantly from the smooth curves above, and be more realistically shown as in the figure below.

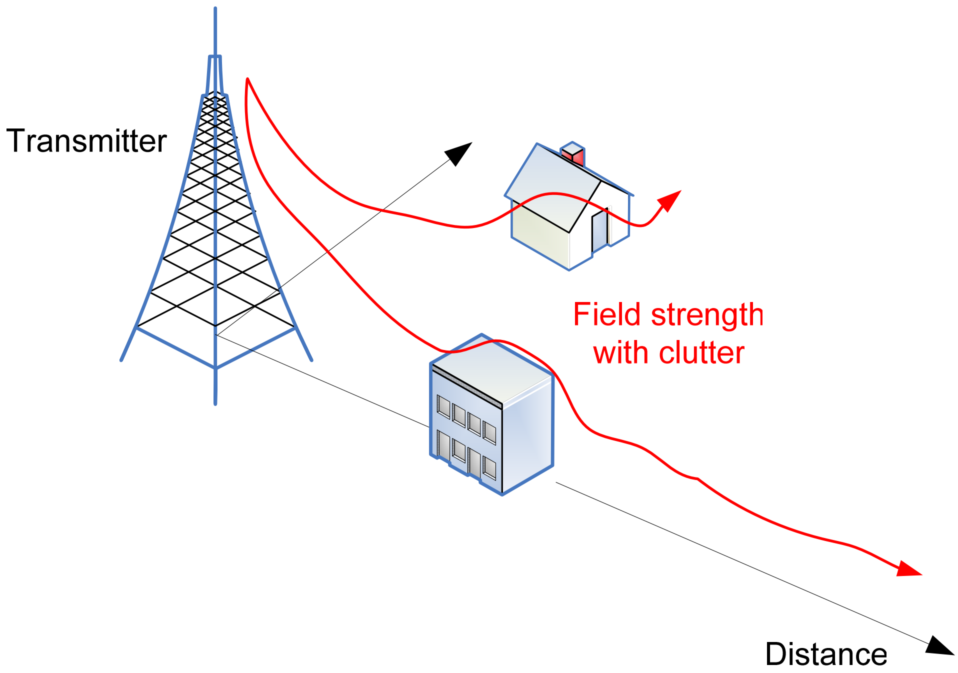


Figure 23: Variation in Field Strength due to Clutter and Distance

In ITU-R Rec. P.1546 this effect is modelled using a location variation term with log-normal distribution and standard deviation that can vary by environment. The median loss and the location variation are shown graphically in the figure below.

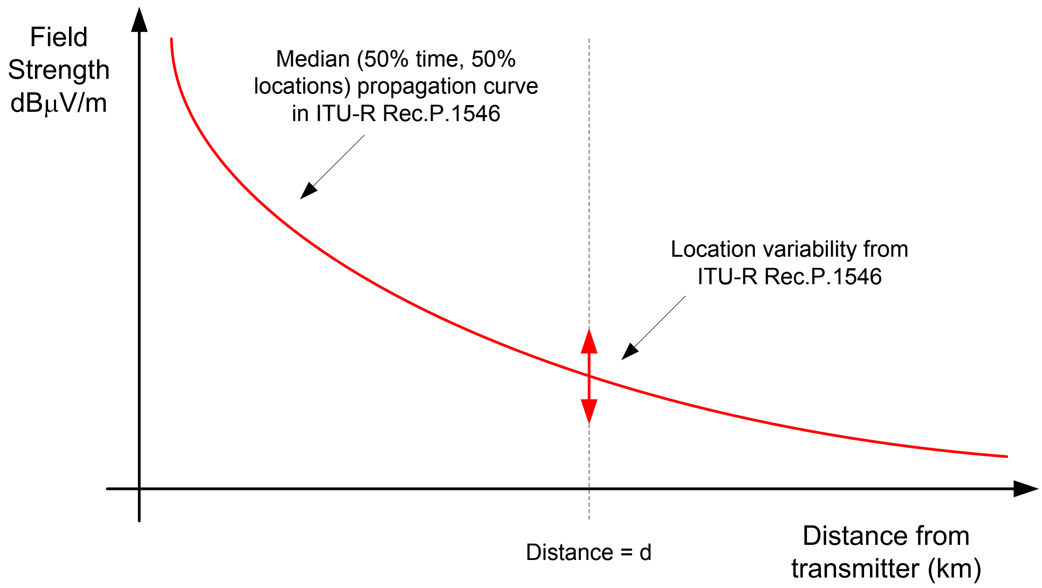


Figure 24: Rec.P.1546 Median Loss and Location Variability

The signal strength measured at a certain distance from the transmitter would depend upon the characteristics of the environment around the measurement point (i.e. clutter etc): some values would be below the median and some above.

The location variability is included in planning procedures to determine the required transmit power. So to ensure 95% of locations can receive the required service at distance=d a factor of 1.64 times the standard deviation must be added to the target median field strength. The standard deviation for outdoor scenarios – which would be applicable to the expected approach to measurement – is 5.5 dB.

To model measurement across a service area it was therefore necessary to include both types of variation (by distance and by location at a specified distance) using a mathematical method called convolution.

This analysis was done to create a cumulative distribution function (CDF) of probability of PFD against probability measuring the value across the service area, as in the figure below.

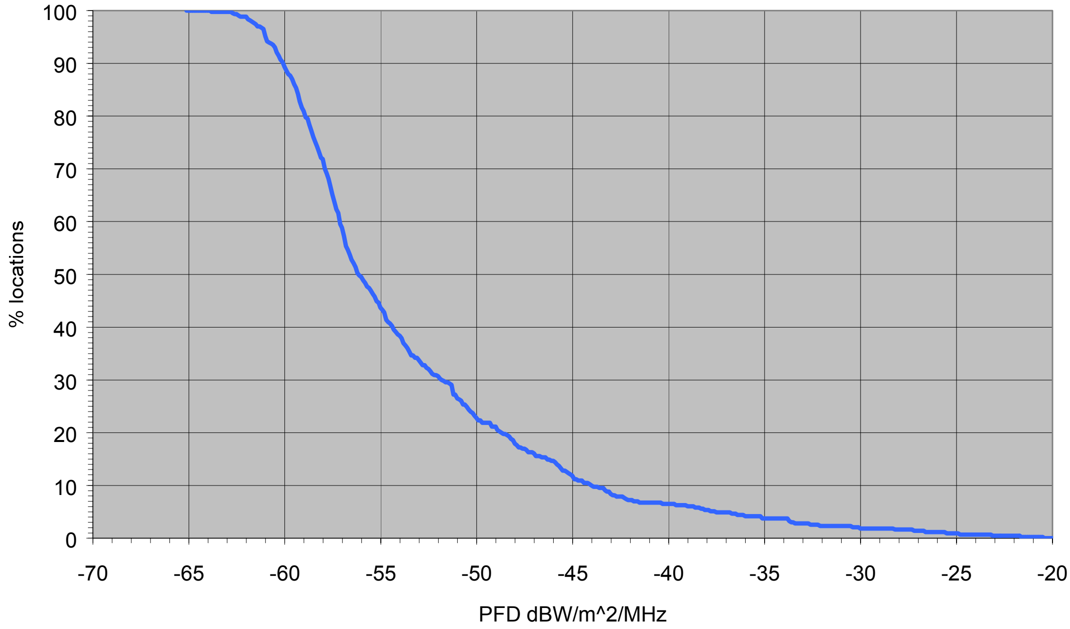


Figure 25: Example CDF of Variation of PFD

From this curve the PFD that would be exceeded at 5 % of locations could be identified.

Annex 2: References

1.	Digital Dividend Review: A statement on our approach to awarding the digital dividend, Ofcom, 13th December 2007
2.	Award of available spectrum: 1452 – 1492 MHz, Statement, Ofcom, 7th December 2007
3.	Digital Dividend: Interference Analysis of Mobile WiMax, DTT, and DVB-H Systems, Final Report for Ofcom, Aegis Systems, 20th November 2007
4.	Digital Dividend – Mobile Voice and Data (IMT), Study by Mason Communications Ltd, October 2007: in particular: • Appendix B: Adjacent Channel Interference between IMT and Other candidate uses of UHF cleared Spectrum • Appendix C: UMTS Link Budgets
5.	ITU-R Recommendation P.452: Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz
6.	ITU-R Recommendation P.1411: Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz
7.	ITU-R Recommendation P.1546: Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz
8.	ITU-R Recommendation P.1812: A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands
9.	Final Acts of the Regional Communication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3 in the frequency bands 174 – 230 MHz and 470 – 862 MHz (RRC-06)
10.	Wireless Communications, Theodore S. Rappaport, Prentice-Hall, 1996
11.	Ofcom's preferred implementation of Recommendation P.1546
12.	Predicting path loss between terminals of low height, Phase 2, Final Report, Red-M Services, April 2007
13.	ERC Report 45: Sharing and Adjacent Band Compatibility between UMTS/IMT-2000 in the band 2500 – 2 690 MHz and other services
14.	3GPP TS 25.104: Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD)
15.	3GPP TS 25.101: Universal Mobile Telecommunications System (UMTS); User Equipment (UE) radio transmission and reception (FDD)
16.	Mobile WiMax – Part 1: A Technical Overview and Performance Evaluation, WiMax Forum, August 2006
17.	3GPP TS 25.105: Universal Mobile Telecommunications System (UMTS); UTRA (BS) TDD: Radio transmission and reception
18.	3GPP TS 25.102: Universal Mobile Telecommunications System (UMTS); User Equipment (UE) TDD: Radio transmission and reception
19.	8F/1079 Rev 1: Additional Technical Details supporting IP-OFDMA as an IMT-2000 Terrestrial Radio Interface, WiMax Forum, January 2007