4G Coverage Obligation Notice of Compliance Verification Methodology

Statement

Publication Date: 24 November 2017

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Annex

1. Introduction

1.1 Section 5 of the Statement on the award of 800 MHz and 2.6 GHz spectrum states that a coverage obligation will be included in the licence that will authorise use of the frequencies 811 to 821 MHz paired with 852 to 862 MHz[1]. The associated licence condition is included in the relevant schedule to the template licence, included as an Annex to the Information Memorandum published by Ofcom at the same time as the Statement.[2]

1.2 The coverage obligation is specified as:

"6. Coverage Obligation

(a) The Licensee shall by no later than 31 December 2017 provide, and thereafter maintain, an electronic communications network that is capable of providing, with 90% confidence, a mobile telecommunications service with a sustained downlink speed of not less than 2 Mbps when that network is lightly loaded, to users:

(i) in an area within which at least:

a. 98% of the population of the United Kingdom lives, and

b. 95% of the population of each of England, Wales, Scotland and Northern Ireland lives; and

(ii) at indoor locations that meet the condition specified in paragraph 6(b)(ii) of this Schedule, which are within any residential premises within the area specified in paragraph 6(a)(i).

(b) For the purposes of paragraph 6(a)(ii) of this Schedule:

(i) the service must be provided using radio equipment which is not situated inside the relevant residential premises;

(ii) the condition referred to is that the radio signal propagation loss from the outside of the building to the location inside the building does not exceed:

a. 13.2dB for radio signals in the frequency ranges 791MHz – 821MHz and 832MHz – 862MHz;

b. 13.7dB for radio signals in the frequency ranges 880MHz – 915MHz and 925MHz – 960MHz;

c. 16.5dB for radio signals in the frequency ranges 1710MHz – 1785MHz and 1805MHz – 1880MHz;

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[1] See Section 5 of the Statement on the award of 800MHz and 2.6GHz spectrum http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/statement.pdf

[2] See Licence Schedule: licence for the 800 MHz band with coverage obligation http://stakeholders.ofcom.org.uk/binaries/consultations/award-800mhz/statement/IM2.pdf

d. 17.0dB for radio signals in the frequency ranges 1900MHz – 1980MHz and 2110MHz – 2170MHz;

e. 17.9dB for radio signals in the frequency range 2500MHz – 2690MHz;

f. Any other propagation loss notified to the Licensee by Ofcom in respect of radio signals in any other frequency band."

1.3 For the purposes of this notice, we interpret:

a '*network* [that] *is lightly loaded*' as having a single user demanding service within the serving cell, and the surrounding cells of the network are loaded to a light level (by which we mean the common channels only are transmitting at 22% of the maximum cell power).

1.4 Below, we summarize our approach to monitor and verify compliance with this obligation based on a service provided using current LTE or HSDPA technology, noting that the obligation holder may use any of its portfolio of licensed mobile spectrum in order to meet the obligation. However, it will also be open to the obligation holder to meet the obligation with alternative mobile broadband technologies if they wish to. Should this be requested then we confirm that we will provide a relevant compliance verification methodology for that technology. In order to ensure that it is consistent with this LTE or HSDPA based methodology we will ensure consistent principles are applied.

1.5 This October 2017 version of the compliance methodology updates the version previously published on 12 November 2012. Specifically, we have made the following amendments:

- Addition of parameters to allow 5 MHz LTE channels, and HSDPA technology to be used to meet the obligation. This has necessitated making some changes to text references specific to LTE and associated channels.
- Updated references for the population to be based on the 2011 census data and the specific version of the postcode data set as of 31st December 2016.
- An additional amendment to the implementation of model P.1812-2 to address an error that was corrected in later versions of P.1812 relating to terminal clutter heights. This is described in Table 2 and Annex A 1.24.
- Rectification of an incorrect reference in paragraph 2.15 which should refer to Table 3 and not Table 2.
- Rectification of an incorrect reference in paragraph 3.1 which should refer to Table 4 and not Table 3.

2. Summary of approach

2.1 In order to assess whether a terminal located at any specific reference indoor location can receive the minimum downlink speed, we consider that the following condition needs to be met:

- the signal to interference plus noise ratio (SINR) of the relevant data channel (i.e. the Downlink Shared Channel (DL-SCH) for LTE systems or the High Speed Downlink Shared Channel (HS-DSCH) for HSDPA systems) needs to be above a threshold required to sustain a downlink speed of not less than 2 Mbps. We set out below how that threshold is to be calculated.

2.2 Our approach is to calculate a SINR (DL-SCH or HS-DSCH) distribution for a hypothetical test terminal located at a reference indoor location at each population point taking into account signals from the 20 closest base sites operating in that band.

2.3 The SINR threshold used to verify compliance with the obligation will be dependent on the bandwidth and technology of the channel being assessed. The SINR threshold is derived from TR 36.942[3] as shown in Table 1, however a minimum SINR cut-off is assumed at -5dB and this is reflected in the threshold applied in the verification process.

Bandwidth (MHz)	Theoretical SINR Threshold	SINR Threshold applied in verification
HSDPA		
5	+0.2 dB	+0.2 dB
10	-3.6 dB	-3.6 dB
LTE		
5	-0.3 dB	-0.3 dB
10	-4.1 dB	-4.1 dB
15	-6.1 dB	-5.0 dB
20	-7.5 dB	-5.0 dB

Table 1: SINR Thresholds

[3] See Annex A Section A.1 of 3gpp TR 36.942 Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Frequency (RF) system scenarios", http://www.3gpp.org/ftp/Specs/html-info/36942.htm

Population distribution model

2.4 A population dataset based on residential delivery point data at a postcode unit level will be used. The current version of this is Geopoint Plus R68.

2.5 Population from the latest census data will be uniformly distributed across all residential delivery points within each census output area.

2.6 The most up to date full census dataset will be used in any assessment. For the first verification exercise this will be the 2011 dataset[4].

2.7 For subsequent compliance verification exercises, the version of source census and delivery point data for the population distribution that is current one calendar year prior to the date of the verification will be used.

Propagation model

2.8 A median path loss will be calculated using ITU-R Recommendation P.1812-2 "A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands"[5].

2.9 This recommendation predicts signal levels at the median of the multipath distribution exceeded for a given percentage of time, the assessment will use a time percentage of 50%.

2.10 Predictions are based on the terrain profile and clutter along the path.

2.11 A clutter end correction is applied at transmitter and receiver. This is based on a representative clutter height assigned to each clutter category. The representative clutter height depends not only on the typical physical height of clutter objects but also on the horizontal spacing of objects and the gaps between them.

2.12 We will use the default parameters for representative clutter heights as defined in ITU-R Recommendation P.1812-2 with table headings as corrected in P.1812-3. These are given in Table 2.

[4] The 2011 data set has now been published by the Office of National Statistics.
[5] http://www.itu.int/rec/R-REC-P.1812-2-201202-I/en

Clutter Type	Representative Clutter Height (m)	
	Use in profile equation[6] For i=2 to n-1	Use in Terminal clutter losses[7] and add to profile equation for i=1 and n
Water/Sea	0	10
Open/Rural	0	10
Suburban	10	10
Urban/Trees/Forest	15	15
Dense Urban	20	20

Table 2: Default Information for clutter-loss modelling in ITU-R Recommendation P.1812

2.13 Location variation can be considered to be approximately a lognormal distribution with zero mean. The location variation specified in ITU-R Recommendation P.1812-2 will be implemented using a standard deviation σ_L within the Monte Carlo process that will be used to create the SINR distribution:

$$\sigma_L = K + 1.3\log(f) \qquad \text{dB}$$

with a value of K = 5.1 dB for Urban and Suburban clutter and K = 4.4 dB for all other clutter types listed in Table 2. Frequency, f, is in GHz.

Terrain database

2.14 Ordnance Survey "Land-form Panorama®" 50 m resolution digital terrain map data shall be used.

Clutter database

2.15 The 50 metre resolution clutter dataset produced by Infoterra shall be used.

2.16 This dataset identifies 10 different clutter categories. For location variation these are mapped to the required urban, suburban and open clutter designations as outlined in Table 3.

[6] Equation 1c in P.1812-2: http://www.itu.int/rec/R-REC-P.1812-2-201202-I/en

[7] Section 4.7 in P.1812-2 applicable to Equation 64b for water/sea/open and rural categories and Equation 64a for the other categories and profile equation 1c

Category	Description	Clutter Designation
1	Dense Urban	Urban
2	Urban	Urban
3	Industry	Suburban
4	Suburban	Suburban
5	Village	Suburban
6	Parks/Recreation	Open
7	Open	Open
8	Open in Urban	Open
9	Forest	Open
10	Water	Open

Table 3: Infoterra clutter code mapping

3. Key parameters to be used in the SINR calculation

3.1 Table 4 contains the key parameters to be used in the SINR calculation; these are given for 800, 900, 1800, 2100 and 2600 MHz. Should assessment be required for any other frequency band, suitable parameters will be set by Ofcom upon request from the licensee with the obligation.

Parameter	HSDPA	LTE				
	900 MHz	800 MHz	900 MHz	1800 MHz	2100 MHz	2600 MHz
UE Noise figure	10 dB	10 dB	10 dB	10dB	9 dB	9 dB
UE Antenna gain	0 dB	0 dB	0 dB	0 dB	0 dB	0 dB
HS-DSCH Power or D-SCH Power	78%	78%	78%	78%	78%	78%
Common channels	22%	22%	22%	22%	22%	22%
Body/orientation loss	2.5 dB	2.5 dB	2.5 dB	2.5 dB	2.5 dB	2.5 dB
Reference indoor location loss	13.7dB	13.2 dB	13.7dB	16.5 dB	17.0 dB	17.9 dB

Table 4: Key parameters for HSDPA and LTE

3.2 Theoretical radiation patterns taken from 3GPP TR36.814 tuned to the supplied antenna beamwidths will be applied in the SINR calculation.

Azimuth pattern: $$A_H(\varphi) = -min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right]$$

Elevation pattern: $$A_V(\theta) = -min\left[12\left(\frac{\theta-\theta_{tilt}}{\theta_{3dB}}\right)^2, SLA_v\right]$$

The values of φ_{3dB}, θ_{3dB} and θ_{tilt} are supplied inputs, A_m = 25 dB and SLA_v = 20 dB

4. Overview of the calculation method

4.1 The calculation would proceed along the following lines, illustrated in Figure 1, commencing with the 4G network layers:

4.2 The operator supplies data for each site in its network. This data should include all of the following:

- unique site reference
- easting (OSGB36 format with 1 metre resolution);
- northing (OSGB36 format with 1 metre resolution);
- height above ground level (metres);
- channel bandwidth (MHz);
- technology (HSDPA or LTE);
- number of sectors;
- for each sector;
  - frequency carrier(s)
  - boresight direction (degrees east of north);
  - boresight gain (dBi);
  - horizontal 3 dB beamwidth (degrees);
  - vertical 3 dB beamwidth (degrees);
  - combined mechanical and electrical downtilt (degrees);
  - EIRP (dBm);

4.3 For each population data point:

4.3.1 the nearest 20 base stations transmitting on that carrier to the population data point are identified;

4.3.2 for each sector of the nearest base stations identified in the previous step, the median downlink power that would be received by a terminal 1.5 metres above ground level at the population data point location is calculated;

4.3.3 a theoretical antenna radiation pattern tuned to the beamwidths provided in the input data is applied to each sector;

4.3.4 the base station sector providing the highest received power at each iteration of the subsequent calculation is designated as the serving sector;

4.3.5 non-serving sectors are assumed to be transmitting at 22% of their maximum power (i.e. they are lightly loaded). The serving sector is assumed to be transmitting at its maximum power in the case of LTE and at 78% of its maximum power in the case of HSDPA due to the different modulation scheme. Additionally, in the case of HSDPA 8.8% of the maximum serving sector power is included as interference based on a 60% correlation coefficient;

4.3.6 a SINR of DL-SCH (or HS-DSCH for HSDPA carriers) distribution is created using a Monte Carlo process calculated by assuming 0.5 location variability cross-correlation between the serving and non-serving sites;

4.3.7 if 90% of the resultant SINR distribution is calculated to be greater than or equal to the SINR threshold in Table 1, then the population data point is deemed to be served;

4.3.8 if the first carrier does not serve the population data point it is noted and assessed against the next and subsequent carriers (until all provided carriers are exhausted or the coverage criteria is met). If one of them meets the criteria in the steps above the population data point is deemed to be served;

4.3.9 the population associated with the served population data point is added to the 'cumulative total population served' and the 'cumulative population served' of its associated nation. Once the value of 'cumulative population served' is greater than or equal to 98% population of the UK and greater than or equal to 95% population of each nation, the licence condition will be deemed to have been met and the verification process is stopped.

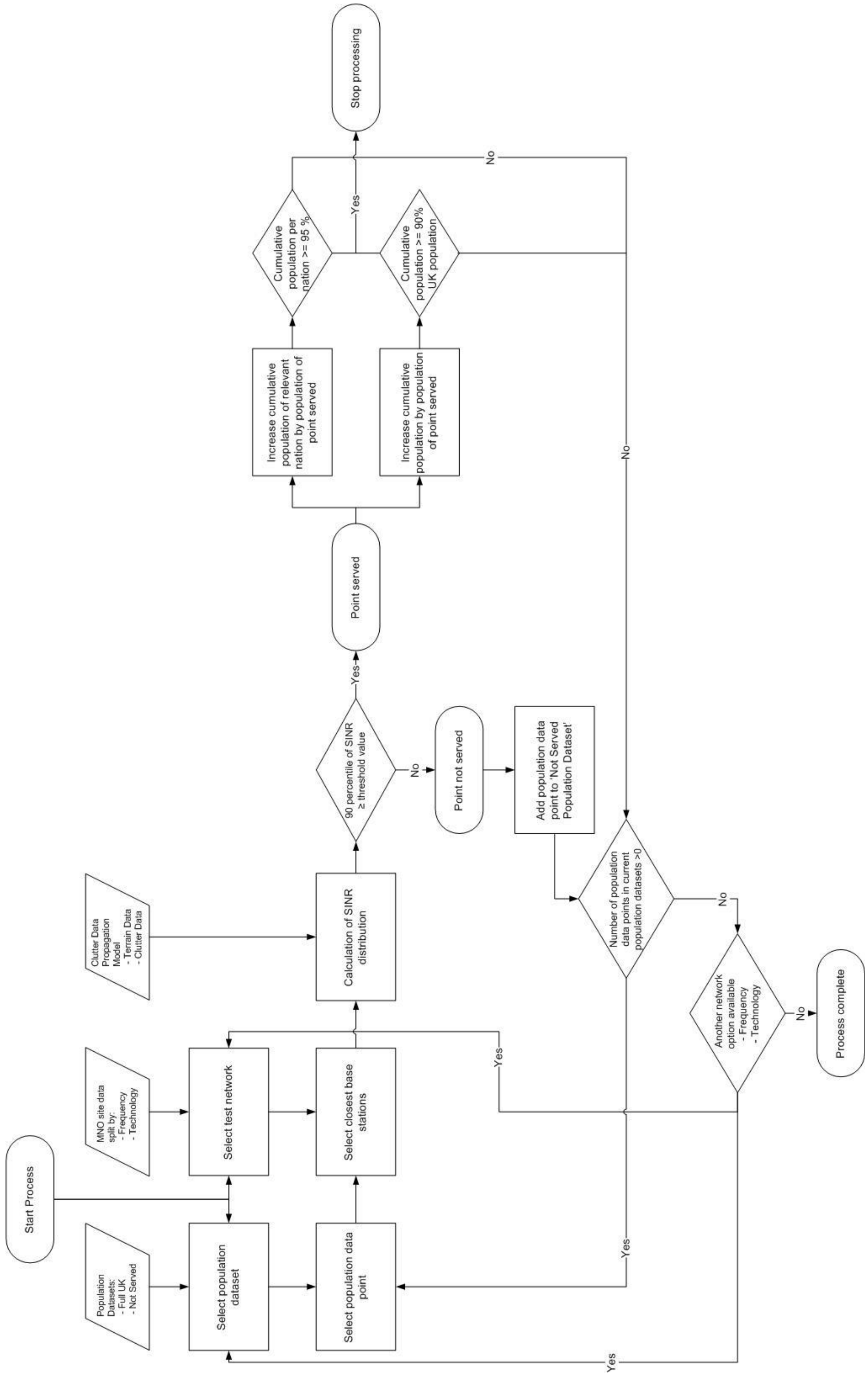

Figure 1. Process Overview

A1. Clarifications regarding the use of ITU-R Recommendation P.1812-2

Overview of ITU-R Recommendation P1812-2

A1.1. ITU-R Recommendation P.1812-2 calculates transmission loss by combining three sub-models: these account for diffraction, troposcatter and ducting/layer reflection.

We consider that the most important of these for the path lengths of interest in assessing the coverage and self interference in a cellular network is the diffraction model. This will always dominate for line-of-sight paths and for the "mildly" diffractive paths that we would encounter in this application.

The ducting model is used to represent signal enhancements caused by anomalous propagation. This mode of propagation only occurs for small time percentages and the ducting model never dominates in median conditions. So for the 50% time, ducting can be ignored (although our implementation still includes this sub-model).

Troposcatter can dominate even for 50% time, it acts as a floor to the diffraction loss calculation, when the diffractive loss becomes very high (e.g. for paths in mountainous terrain) the troposcatter field may become dominant. A troposcatter signal will be incoherent and of little use to provide a service, but it may still contribute to interference.

Model Parameters

A1.2. For the purposes of assessing compliance with the coverage obligation contained in one of the licences for use of the 800MHz spectrum, we have assumed that radiated transmissions are vertically polarised.

A1.3. The path centre latitude, φ (degrees), is only used for the calculation of the parameter β_0 needed by the ducting model. The dependence of transmission loss on this parameter is weak, and given the path lengths of interest in this application, it is appropriate to set φ to the latitude of the population data point and use this value for the wanted and all interference paths. This avoids calculating the path centre from the transmitter and receiver coordinates.

A1.4. The value of φ calculated as above will also be adequate to use in the calculation of ΔN and N_0 described below in paragraphs A1.5 and A1.6.

A1.5. The parameter ΔN, describes the average radio-refractive index gradient in the 1km above the Earth's surface. It is used by the diffraction sub-model to calculate k-factor.

ITU-R Recommendation P.1812-2 provides a global map for ΔN in its Figure 1 of Appendix 1 with the ΔN = 45 profile running through the UK, this map is based on paper maps produced in the 1960s by Bean. During the preparation of ITU-R Recommendation P.2001 work was undertaken to create digital maps, based on a larger more current dataset, these maps are referenced in Section 3.5 of ITU-R Recommendation P.1812-2.

In our implementation, we are using the following simple interpolation formula which gives results consistent with the digital maps.

$$\Delta N = 42.5 - 0.25(\varphi - 50) \qquad \text{N-units/km}$$

A1.6. The parameter N_0, the sea-level surface refractivity, is used in the troposcatter sub-model.

Recommendation P.1812-2 provides a global map for N_0 in its Figure 2 of Appendix 1. This shows the UK between about 324 and 329, this map is base on paper maps produced in the 1960s by Bean. During the preparation of ITU-R Recommendation P.2001 work was undertaken to create digital maps, based on a larger more current dataset, these maps are also referenced in Section 3.5 of ITU-R Recommendation P.1812-2.

In our implementation, we are using the following simple interpolation formula which gives results consistent with the digital maps.

$$N_0 = 328 - (\varphi - 50) \quad \text{N-units}$$

Terrain and clutter profile extraction and analysis

A1.7. A terrain profile for the radio path is required for the application of the propagation prediction method in ITU-R Recommendation P.1812-2. Much of the processing is an analysis of the profile.

A1.8. Terrain height values should be obtained by bilinear interpolation, using the methodology in ITU-R Recommendation P.1144-6, from the 4 nearest grid points.

A1.9. Clutter categories (which are discrete integers) should be taken from the nearest grid point and not interpolated.

A1.10. The x-y coordinates of the terrain profile points should ideally be based on great circle calculations. But given that the terrain and clutter databases are based on the OSGB grid whose coordinates assume a flat surface and that the path lengths of interest, it will be adequate to use simple straight line geometry.

A1.11. The terrain profile point spacing does not need to be finer than the resolution of the database, 50m in this application. A suitable target spacing is 50m.

A1.12. The profile points should be equally spaced from each other and from each end of the path. Given a target profile spacing of Δd_t (m) the number of profile points required, n, is first calculated as $n = 1 + \text{ceil}(d/\Delta d_t)$, where d is the path length (m), and the ceil(x) function returns the nearest integer that is greater than or equal to x. If $n \geq 3$, the actual grid spacing to be used is given by $\Delta d = d/(n-1)$. This will result in an equally spaced profile with a point spacing that is slightly less than 50m. If $n < 3$ n should be forced to $n = 3$, and Δd set to d/2. In this case Δd will be less than 50m, and perhaps quite small.

A1.13. Note that a path length of d = 0 (i.e. the base station and population data point are co-located) is not allowed in the propagation model. In this case d = max (h_{tx}-h_{rx},2), where h_{tx} is the antenna height of the base station and h_{rx} is the antenna height of the population data point.

List of Corrections to ITU-R Recommendation P.1812-2

A1.14. There are a number of ambiguities and typographical errors in ITU-R Recommendation P.1812-2 which have already been acknowledged by ITU-R Study Group 3 Working Party 3K, who are responsible for the upkeep and development of ITU-R Recommendation P.1812. These are listed in Annex 1 of Document 3K/29 (http://www.itu.int/md/dologin_md.asp?lang=en&id=R12-WP3K-C-0029!N01!MSW-E). Most of these are trivial and in our view unlikely to cause confusion. The most substantive error is that the text specifies the use of the uncluttered path profile, rather than the profile which includes ground clutter, in the diffraction calculation. This is a drafting error (ITU-R Recommendation P.1812-1 clearly indicated that the cluttered profile should be used) and there is in our view no doubt what is intended. The corrections given below should be taken into account when implementing ITU-R Recommendation P.1812-2.

A1.15. Section 3.2

Two paragraphs before Table 2, last word in the paragraph replace “equation (54b)” with “equation (64b)”.

A1.16. Section 3.7

Insert new paragraph at end of the section. “A general effective Earth radius is defined, where $a_p = a_e$ for 50% of time, and $a_p = a_\beta$ for β_0% of time.”

A1.17. Section 4.3.1

In the penultimate sentence of the first paragraph replace "a_e" with a_p" in two places.

Add a new last sentence to the first paragraph "Values to be used for a_p are given in §4.3.5."

In equations (13), (15) and (17), replace “h_i” with “g_i”.

In equation (19), replace “d_b” with “d_{bp}” in two places.

A1.18. Section 4.3.2

In the line before equation (23) replace “h” with “h_{se}”.

In equation (23) replace “d_2” with “d_{se2}”, and “d_1” with “d_{se1}”.

In the line after equation (25) replace “$h > h_{req}$” with “$h_{se} > h_{req}$”.

A1.19. Section 4.3.4

In equation (37a) replace “h'_{ts}” with “h'_{tc}” and “h_{ts}” with “h_{tc}”.

In equation (37b) replace “h'_{rs}” with “h'_{rc}” and “h_{rs}” with “h_{rc}”.

In equation (38a) replace "h'_{ts}" with "h'_{tc}".

In equation (38b) replace "h'_{rs}" with "h'_{rc}".

A1.20. Section 4.3.5

In line 1 of paragraph 1, replace "a_e" with "$a_p = a_e$".

In line 2 of paragraph 4, replace "a_β" with "$a_p = a_\beta$".

In the sentence before equation (40a) replace "$\beta_0\% < p \leq 50\%$" with "$50\% > p > \beta_0\%$"

A1.21. Appendix 2, Section 5.1.6.1

Replace "h_{ted}" with "h_{std}" and "h_{red}" with "h_{srd}"

A1.22. Appendix 2, Section 5.1.6.2

In "where:" for "h_a" below equation (86b) replace "h_0" with "h_1"

A1.23. Appendix 2, Section 5.1.6.3

In equations (90a), (90b), (90c) and (90d) replace "h_{obi}" with "H_i".

In equation (90d) replace "h_{ts}" by "h_{tc}" and "h_{rs}" with "h_{rc}"

A1.24. Amend the column headers of Table 2 to read "Add to profile equation (1c) *for i= 2 to n-1*" and "Terminal clutter losses § 4.7 *and add to profile equation (1c) for i = 1 and n*". so that Table 2 becomes:

Clutter Type	Representative Clutter Height (m)		Terminal clutter loss model
	Add to profile equation (1c) For i=2 to n-1	Terminal clutter losses § 4.7 and add to profile equation (1c) for i=1 and n	
Water/Sea	0	10	Equation (64b)
Open/Rural	0	10	Equation (64b)
Suburban	10	10	Equation (64a)
Urban/Trees/Forest	15	15	Equation (64a)
Dense Urban	20	20	Equation (64a)