

RECOMMENDATION ITU-R M.1456*

**MINIMUM PERFORMANCE CHARACTERISTICS AND OPERATIONAL CONDITIONS
FOR HIGH ALTITUDE PLATFORM STATIONS PROVIDING IMT-2000
IN THE BANDS 1 885-1 980 MHz, 2 010-2 025 MHz AND 2 110-2 170 MHz
IN REGIONS 1 AND 3 AND 1 885-1 980 MHz
AND 2 110-2 160 MHz IN REGION 2****

(2000)

The ITU Radiocommunication Assembly,

considering

- a) that high altitude platform stations (HAPS)*** have the possibility of delivering IMT-2000 mobile and fixed wireless access using the proposed IMT-2000 terrestrial component radio transmission technologies and protocols;
- b) that each HAPS uses a phased array antenna to project hundreds of spot beams to provide telecommunication services to coverage areas that range in size from metropolitan to wider areas;
- c) that for non-HAPS terrestrial systems, such as tower-based systems, the illumination of areas outside the intended operational area is dependent on the characteristics of the tower-mounted antenna and the propagation attenuation. For HAPS, the dependence is more on the characteristics of the HAPS mounted antenna especially the side-lobe performance and pointing accuracy. As the coverage area of a HAPS increases the antenna performance becomes more demanding;
- d) that the characteristics of co-channel sharing and coordination between HAPS systems and other IMT-2000 systems are determined by the performance of the HAPS antennas, the IMT-2000 radio interface used by the HAPS and the HAPS coverage area;
- e) that the levels of out-of-band interference from HAPS into receiving mobile earth stations, fixed stations, space science stations and mobile stations operating in adjacent channels can be reduced by the HAPS use of filters or guardbands to limit out-of-band (OoB) emission levels;
- f) that the bands 1 885-1 980 MHz, 2 010-2 025 MHz and 2 110-2 170 MHz are allocated on a primary basis worldwide to the fixed service and the mobile service;

* This Recommendation should be brought to the attention of Radiocommunication Study Groups 4 and 9.

** The use of HAPS systems in these bands shall be optional for administrations. Each administration shall retain its individual authority over technical and regulatory matters pertaining to the sharing, coordination and implementation of HAPS systems in these bands.

*** HAPS is defined in RR No. S1.66A as "A station located on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth." A HAPS system consists of a HAPS, several ground stations, and numerous mobile and fixed subscriber stations. Each HAPS deploys a multibeam antenna capable of projecting numerous spot beams within its coverage area. The HAPS system mobile and fixed subscriber stations are identical to those used with traditional terrestrial IMT-2000 tower-based systems. Links between two HAPS and links between HAPS and HAPS system ground stations will not be in bands designated for IMT-2000 and will utilize non-IMT-2000 frequencies. Use of any proposed frequencies by HAPS for these links will need to be studied and coordinated.

The HAPS systems will be global in nature but national in service provision. Each HAPS will be positioned above commercial airspace at an altitude that is high enough to provide service to a large footprint but that is low enough to provide dense coverage. HAPS will offer a new means of providing IMT-2000 with minimal ground network infrastructure.

g) that the bands 1 980-2 010 MHz and 2 170-2 200 MHz are allocated on a primary basis worldwide to the MSS, that the band 2 160-2 170 MHz is allocated on a primary basis to the MSS in Region 2 and that the band 2 010-2 025 MHz is also allocated on a co-primary basis in Region 2 to the MSS (Earth-to-space);

h) that RR No. S5.388 states that “the bands 1 885-2 025 MHz and 2 110-2 200 MHz are intended for use, on a worldwide basis, by administrations wishing to implement International Mobile Telecommunications-2000 (IMT-2000). Such use does not preclude the use of these bands by other services to which they are allocated. The bands should be made available for IMT-2000 in accordance with Resolution **212 (Rev.WRC-97)**”;

j) that, however, administrations may use non-IMT-2000 systems in the mobile service in these bands,

recommends

1 that radio interfaces of HAPS providing IMT-2000 in the bands 1 885-1 980 MHz, 2 010-2 025 MHz and 2 110-2 170 MHz in Regions 1 and 3, and 1 885-1 980 MHz and 2 110-2 160 MHz in Region 2 should comply with Recommendation ITU-R M.1457;

2 that for the purpose of protecting stations operated by neighbouring administrations from co-channel interference, administrations using HAPS as base stations to provide IMT-2000 should use antennas that comply with the following antenna pattern:

$$G(\psi) = G_m - 3 (\psi/\psi_b)^2 \quad \text{dBi} \quad \text{for} \quad 0^\circ \leq \psi \leq \psi_1 \quad (1)$$

$$G(\psi) = G_m + L_N \quad \text{dBi} \quad \text{for} \quad \psi_1 < \psi \leq \psi_2 \quad (2)$$

$$G(\psi) = X - 60 \log (\psi) \quad \text{dBi} \quad \text{for} \quad \psi_2 < \psi \leq \psi_3 \quad (3)$$

$$G(\psi) = L_F \quad \text{dBi} \quad \text{for} \quad \psi_3 < \psi \leq 90^\circ \quad (4)$$

where:

$G(\psi)$: gain at the angle ψ from the main beam direction (dBi)

G_m : maximum gain in the main lobe (dBi)

ψ_b : one-half the 3 dB beamwidth in the plane of interest (3 dB below G_m) (degrees)

L_N : near-in-side-lobe level (dB) relative to the peak gain required by the system design, and has a maximum value of -25 dB

L_F = $G_m - 73$ dBi, far side-lobe level (dBi)

$$\psi_1 = \psi_b \sqrt{-L_N/3} \quad \text{degrees} \quad (5)$$

$$\psi_2 = 3.745 \psi_b \quad \text{degrees} \quad (6)$$

$$X = G_m + L_N + 60 \log (\psi_2) \quad \text{dB} \quad (7)$$

$$\psi_3 = 10^{\frac{X - L_F}{60}} \quad \text{degrees} \quad (8)$$

The 3 dB beamwidth ($2\psi_b$) is again estimated by:

$$\psi_b = \sqrt{\frac{7\,442}{10^{0.1G_m}}} \quad (9)$$

where G_m is the peak aperture gain (dBi);

3 that a HAPS operating as a base station to provide IMT-2000 should not exceed a co-channel pfd level of $-121.5 \text{ dB(W/(m}^2 \cdot 1 \text{ MHz))}$ on the Earth's surface outside an administration's boundaries unless agreed otherwise with the affected neighbouring administration*. The methodology provided in Annex 1 can be used by potentially affected administrations to evaluate whether the use of a HAPS as a base station to provide IMT-2000 is acceptable for their use of the band;

4 that a HAPS operating as a base station to provide IMT-2000, in order to protect mobile earth stations (MES) from interference, should not exceed an OoB pfd level of $-165 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$ on the Earth's surface in the bands 2 160-2 200 MHz in Region 2 and 2 170-2 200 MHz in Regions 1 and 3. Annex 2 provides the basis for this pfd level;

5 that a HAPS operating as a base station to provide IMT-2000, in order to protect fixed stations from interference, should not exceed an OoB pfd level on the Earth's surface in the band 2 025-2 110 MHz of:

5.1 $-165 \text{ dB(W/(m}^2 \cdot 1 \text{ MHz))}$ for angles of arrival, θ , less than 5° above the horizontal plane;

5.2 $-165 + 1.75 (\theta - 5) \text{ dB(W/(m}^2 \cdot 1 \text{ MHz))}$ for angles of arrival between 5° and 25° above the horizontal plane; and

5.3 $-130 \text{ dB(W/(m}^2 \cdot 1 \text{ MHz))}$ for angles of arrival between 25° and 90° above the horizontal plane.

Annex 2 provides the basis for this pfd level;

6 that a HAPS operating as a base station to provide IMT-2000 in accordance with the performance characteristics provided in Annex 1 will not interfere with space stations in the space science service operating in the band 2 025-2 110 MHz (see Annex 3);

7 that performance enhancement techniques, such as the use of high performance transmit filtering, and a reduction of the number of spot beams, the number of users, and the power of the HAPS should be used by HAPS where necessary to avoid interference into stations operating in the fixed service, including point-to-multipoint (P-MP) systems, the mobile service, and the MSS in frequency bands adjacent to those used by HAPS.

ANNEX 1

Co-channel interference from HAPS operating as an IMT-2000 base station

1 Power received as a function of the distance from nadir

For frequency division duplex (FDD) mode, only HAPS systems employing terrestrial IMT-2000 CDMA and TDMA radio interfaces will be considered. Among the IMT-2000 FDD radio interfaces, only two, namely IMT-2000 CDMA direct spread and multi-carrier will be considered since the remaining technologies are closely related to one or the other. For IMT-2000 TDMA formats, only IMT-2000 TDMA single-carrier will be considered. The time division duplex (TDD) will not be considered because the time delay between the HAPS and the surface of the Earth makes TDD unsuitable for use by HAPS.

* This value may not be appropriate for the protection of some stations operating in these bands in the fixed and mobile services.

Since IMT-2000 CDMA direct spread and IMT-2000 CDMA multi-carrier may require different carrier spacing, it would be appropriate to use pfd to compare the transmission characteristics of HAPS-based IMT-2000 CDMA direct spread implementation and HAPS-based IMT-2000 CDMA multi-carrier implementation. The maximum pfd for a fully loaded IMT-2000 CDMA direct spread system is $-98.2 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$, whereas a fully loaded HAPS IMT-2000 CDMA multi-carrier has a pfd of $-101.1 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$.

For HAPS using IMT-2000 TDMA single-carrier format, the maximum pfd for a fully loaded HAPS TDMA system is $-96.8 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$. This is slightly higher (by 1.4 dB) than the corresponding figure for the IMT-2000 CDMA direct spread format.

The maximum pfd is computed based on a fully loaded HAPS IMT-2000 system with 700 beams.

The calculations are based on the assumption that the HAPS is deployed at an altitude of 22 km.

1.1 HAPS using IMT-2000 TDMA

The total received spectral power at nadir can be computed from the pfd of $-96.8 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$ and the effective antenna aperture of $-27.5 \text{ dB(m}^2)$ for the 0 dBi handset antenna. This gives $-124.3 \text{ dB(W/4 kHz)}$ for the received spectral power density, which is 38.7 dB above the thermal noise level: $-135.5 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$ based on the thermal power in an isotropic receiving antenna, -204 dB(W/Hz) at 299 K, and a 5 dB noise factor, and an aperture of an isotropic antenna at 2 GHz of $-27.5 \text{ dB(m}^2)$. Since the permissible interference level, I , is 10 dB below thermal noise level, the received spectral power density is 48.7 dB above the permissible level. Compare this level with the level of the aggregated far side-lobe interference which is 43.1 dB below the received power and one sees that the far side-lobe contribution is still 5.6 dB above the permissible level. Hence the far side lobe should be significant in the determination of the coordination distance. In fact, the far side-lobe contribution strongly affects the size of the coordination distance since once the aggregated far side-lobe level is reached, the only way that it will decrease is through the increase in free space path loss. The slow decrease of the far side-lobe interference level as a function of the distance from nadir causes the coordination distance to become large.

The isoflux coverage arrangement produces an essentially flat pfd up to the edge of the main coverage zone, and then the pfd falls rapidly owing to both the roll-off of the antenna radiation profile away from the main lobe and the increasing free space path loss. This can be seen in Fig. 1, where the pfd profiles as functions of the distance from nadir are plotted for coverage radius of 8, 19, 27, 43, 62, 78, 108, 131 and 158 km, respectively. The maximum pfd is essentially independent of the coverage radius. To provide a 700-beam coverage of a main radius of only 8 km, a 12.5 m phased array antenna is needed in order to achieve a maximum antenna gain of 45.7 dBi.

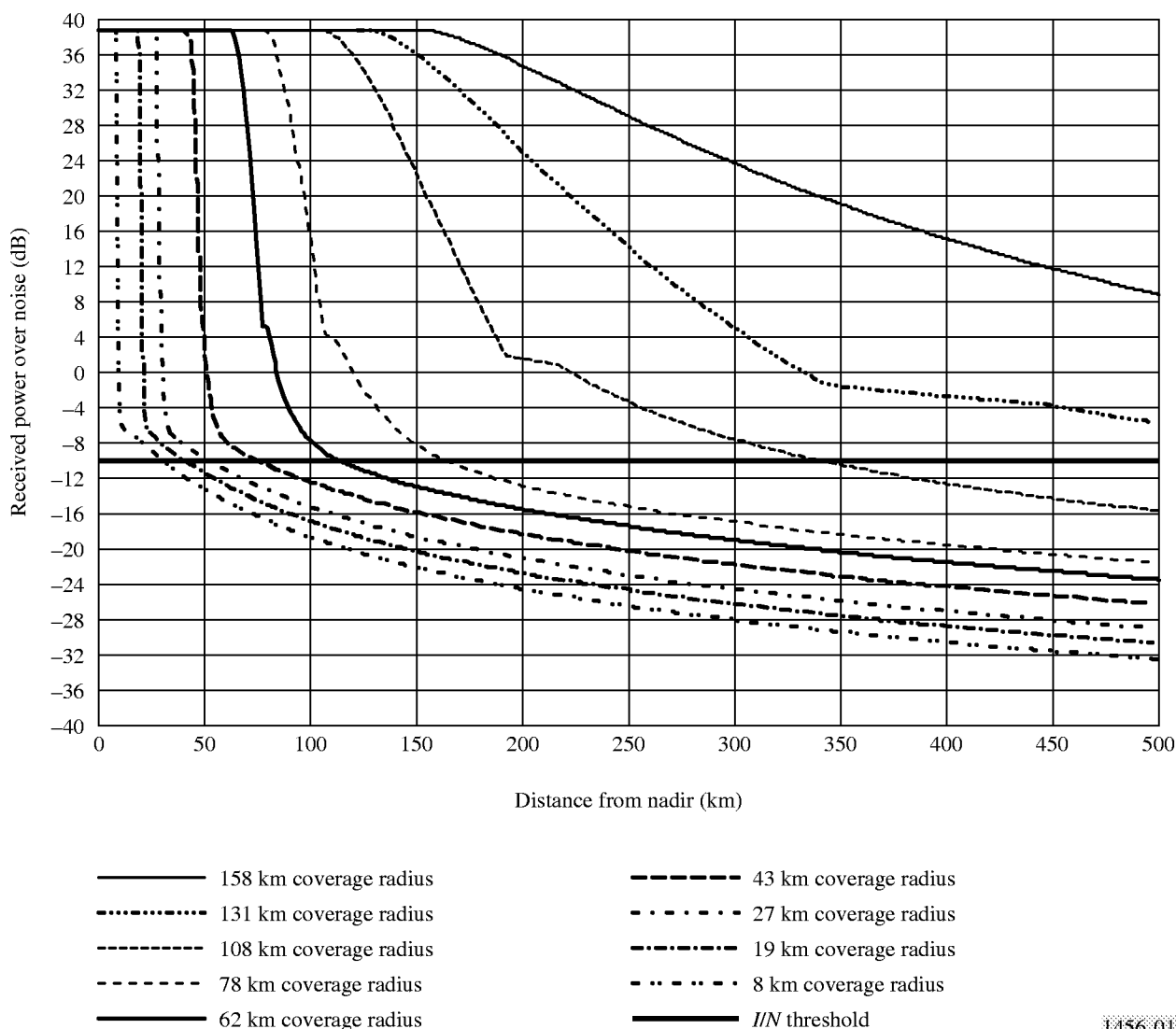
A HAPS using IMT-2000 TDMA single-carrier can provide wide-area coverage from a single HAPS. However, the possibility of interference between such wide-area coverage and the co-channel operation of an existing or planned tower-based IMT-2000 TDMA system within the same geographical area should be considered.

Figure 4 shows the distance between the coordination boundary and the nadir of HAPS as a function of HAPS coverage radius.

1.2 HAPS using IMT-2000 CDMA

The total received spectral power at nadir can be computed from the pfd of $-98.2 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$ and the effective antenna aperture of $-27.5 \text{ dB(m}^2)$ for the 0 dBi handset antenna. This gives $-125.7 \text{ dB(W/4 kHz)}$ for the received spectral power density, which is 37.3 dB above the thermal noise level. If the permissible interference level, I , is 10 dB below thermal noise level, then the received spectral power density is 47.3 dB above the permissible level. Compare this level with the level of the aggregated far side-lobe interference which is 44.5 dB below the received power, one sees that the far side-lobe contribution is still 2.8 dB above the permissible level. Hence the far side lobe should be significant in the determination of the coordination distance. In fact, the far side-lobe contribution strongly affects the size of the coordination distance since once the aggregated far side-lobe level is reached, the only way that it will decrease is through the increase in free space path loss.

FIGURE 1
Received power over the thermal noise level versus distance from nadir
(HAPS using IMT-2000 TDMA)



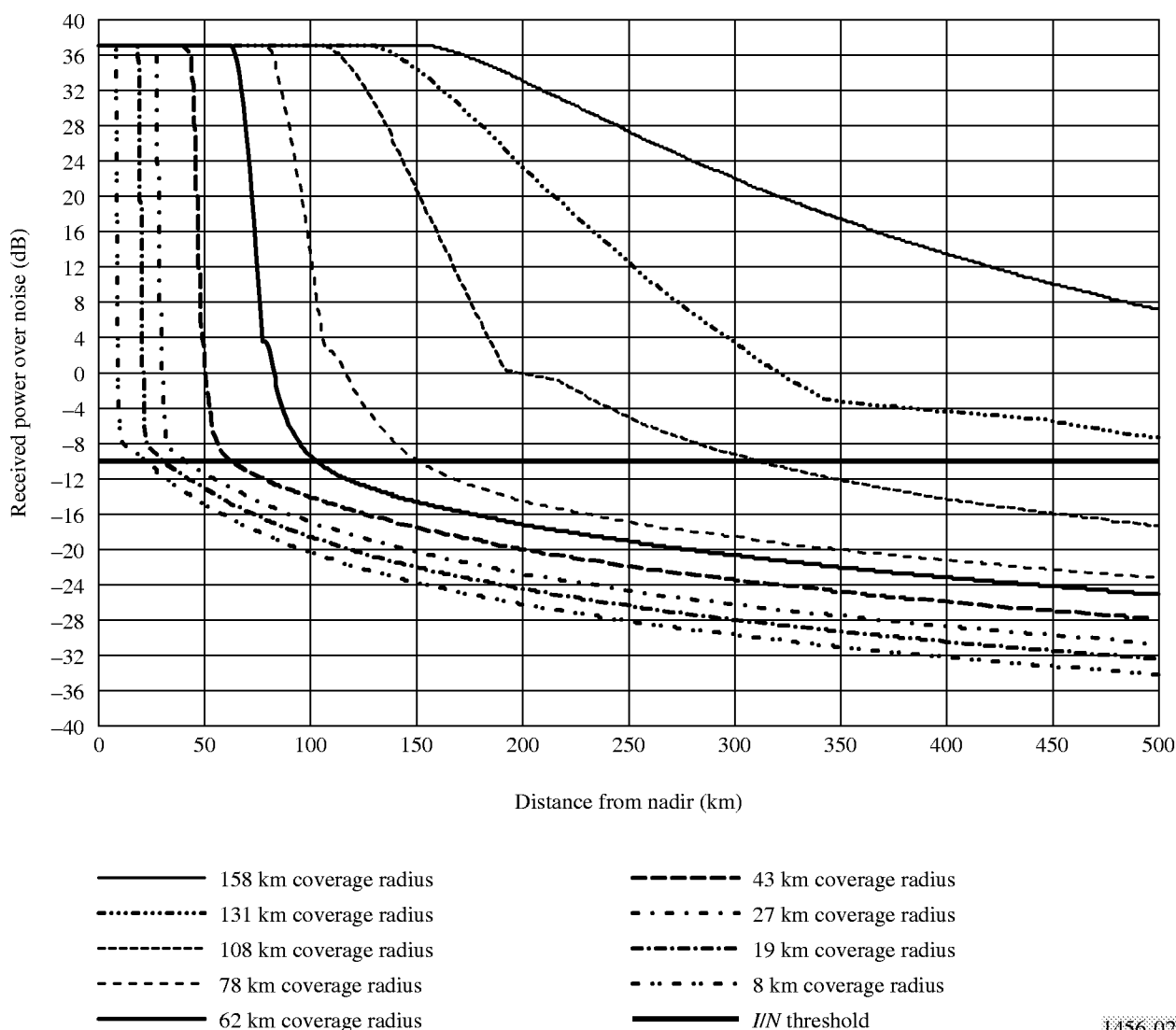
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The isoflux coverage arrangement produces an essentially flat pfd up to the edge of the main coverage zone, and then the pfd falls rapidly owing to both the roll-off of the antenna radiation profile away from the main lobe and the increasing free space path loss. This can be seen in Fig. 2, where the pfd profiles as functions of the distance from nadir are plotted for coverage radius of 8, 19, 27, 43, 62, 78, 108, 131 and 158 km, respectively. The maximum pfd is essentially independent of the coverage radius. To provide a 700-beam coverage of a main radius of only 8 km, a 12.5 m phased array antenna is needed in order to achieve a maximum antenna gain of 45.7 dBi. Figure 3 shows the relationship between the coordination distance and the HAPS coverage radius and Fig. 5 shows the distance between the coordination boundary and the nadir of HAPS as a function of HAPS coverage radius.

2 Interference criteria

Co-channel interference between a HAPS-based terrestrial IMT-2000 system and a tower-based terrestrial IMT-2000 system or that of a fixed service system operating in the same band is most likely to occur at the boundary between the two coverage areas.

FIGURE 2
Received power over the thermal noise level versus distance from nadir
(HAPS using IMT-2000 CDMA)



The permissible interference criterion of $I/N_{thermal} = -10$ dB will be used for victim handsets irrespective of the access format of the victim radio interface. The same permissible interference criterion will also be applied to victim base stations. It should be noted that if the victim handset uses a CDMA access format, it is less susceptible to co-channel interference since in a CDMA system, self interference is usually far greater than thermal noise level. However, at the fringe of the victim CDMA coverage, where self interference falls far below noise level, the presence of interference from HAPS can still reduce the range of the victim CDMA coverage. Hence in this Recommendation, the $I/N_{thermal} = -10$ dB permissible interference criterion is uniformly applied irrespective of the victim access format.

Note that the criterion $I/N_{thermal} = -10$ dB allows the aggregate interference to the receiving system of a single beam to degrade the performance by no more than 0.4 dB.

An approximate formula for the computation of the required coordination distance between HAPS-based base station and victim mobile stations is given below.

Owing to high antenna gains, it is possible to approximate the coordination distance calculation with the following formulae. The formulae are valid for main coverage radius (for HAPS) of less than 132 km. Two cases will be considered. They are distinguished by whether the far side-lobe aggregation is the dominant contribution or not. A unified formula is given that bridges the gap.

In the case where the victim handset is predominantly interfered by the aggregated far side-lobe, emission is considered first.

The interference power received by the victim handset in this case is given by:

$$I = P_{victim} = P_{centre} - 10 \log(r^2 + h^2) + 10 \log(r_{centre}^2 + h^2) + 10 \log(Num) - F \quad \text{dB} \quad (10)$$

where:

- h : altitude of HAPS
- r : distance of the victim handset from nadir
- $P_{victim} - P_{centre}$: level of received interference power below the main lobe power at the boresight of the nearest HAPS beam
- r_{centre} : distance of the beam centre relative to nadir
- Num : total number of beams
- $F = 73 \text{ dB}$: far side lobe relative to peak gain.

From this the coordination distance can be determined as follows:

$$R_{coordination} = r = \left((h^2 + r_{centre}^2) Num \times 10^{-7.3+B} - h^2 \right)^{1/2} \quad \text{km} \quad (11)$$

where:

$$B = 0.1 \left(P_{centre}/N \right) + 1.$$

Equation (11) is only valid for $B + \log(Num) > 7.3 = 0.1 F$, the condition for the dominance of the aggregated far side-lobe level in the determination of the coordination distance. Equation (11) is only valid for very narrow HAPS coverage. In the opposite limit where because of the rapid side-lobe attenuation, the interference is dominated by a single beam, the interference power to thermal noise ratio of the victim handset receiver is approximately:

$$(I_{received}/N) = (I_{received}/N)_{centre} + \delta G(\theta - \theta_0) - \delta FSL(\theta) \quad (12)$$

where:

- $(I_{received}/N)_{centre}$: received aggregate interference power-to-noise ratio measured at the boresight of the outermost HAPS beam
- θ_0 : tilt angle of the last HAPS beam
- θ : tilt angle of the victim handset relative to HAPS
- $\delta G(\theta - \theta_0) = G(\theta - \theta_0) - G_m$: differential antenna gain
- $\delta FSL(\theta) = 20 \log(\cos(\theta_0)) - 20 \log(\cos(\theta))$: differential free space path loss (FSL) between the HAPS transmitters and the victim handset relative to the free space path loss at the boresight of the last beam.

Since the interference power received by the victim handset inside the main lobe of the HAPS emission is typically too large to be permissible, only the inverse sixth power law regime of the antenna radiation pattern will be of relevance for this discussion.

In the inverse sixth power law regime, $\delta G(\theta - \theta_0)$ can be expressed, by setting $\theta - \theta_0 = \psi_2 \eta + \psi_2$, as

$$\delta G(\theta - \theta_0) = -L_N - 60 \log(1 + \eta) = -L_N - 60 y \quad \text{dB} \quad (13)$$

where:

$$y = \log(1 + \eta)$$

L_N : near side-lobe level relative to the peak gain (dB) as required by the system design.

For this study L_N is taken to be 32 dB. For main coverage radius less than 132 km, the free space path loss is a much slower function of the tilt angle θ than the antenna gain variation. Hence it is a good approximation to replace the differential free space loss term with just the first two terms of its Taylor series expansion, using $\theta = \theta_0 + (1 + \eta)\psi_2 = \theta_0 + 10^y \psi_2$.