International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R M.1456
(05/2000)

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- 1980 MHz and 2 110-2 160 MHz in Region 2

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International Telecommunication Union

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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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)

Scope

This Recommendation addresses minimum performance characteristics and operational conditions for high-altitude platform stations (HAPS) operating as IMT-2000 base stations in frequency bands around 2 GHz identified for use, on a worldwide basis, by administrations wishing to implement IMT-2000.

A methodology to assess the level of co-channel interference from HAPS operating as IMT-2000 base stations is described and performance criteria are recommended for HAPS antenna patterns to provide co-channel protection to other stations. The Recommendation contains pfd limits for HAPS base stations with reference to both co-channel and out-of-band interference.

The ITU Radiocommunication Assembly,

considering

a) that high altitude platform stations (HAPS)[1] 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;

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

** Radiocommunication Study Group 5 made editorial amendments to this Recommendation in November 2010.

*** 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.

[1] 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.

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;

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:

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

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

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

$$G(\psi) = L_F \qquad \text{dBi} \qquad \text{for} \qquad \psi_3 < \psi \leq 90° \qquad (4)$$

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)

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

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

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

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

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

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

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 dB(W/(m$^2 \cdot$ 1 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 dB(W/(m$^2 \cdot$ 4 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 dB(W/(m$^2 \cdot$ 1 MHz)) for angles of arrival, θ, less than 5° above the horizontal plane;

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

5.3 -130 dB(W/(m$^2 \cdot$ 1 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.

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* 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 dB(W/(m$^2 \cdot$ 4 kHz)), whereas a fully loaded HAPS IMT-2000 CDMA multi-carrier has a pfd of -101.1 dB(W/(m$^2 \cdot$ 4 kHz)).

For HAPS using IMT-2000 TDMA single-carrier format, the maximum pfd for a fully loaded HAPS TDMA system is -96.8 dB(W/(m$^2 \cdot$ 4 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 dB(W/(m$^2 \cdot$ 4 kHz)) and the effective antenna aperture of -27.5 dB(m^2) for the 0 dBi handset antenna. This gives -124.3 dB(W/4 kHz) for the received spectral power density, which is 38.7 dB above the thermal noise level: -135.5 dB(W/(m$^2 \cdot$ 4 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 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.
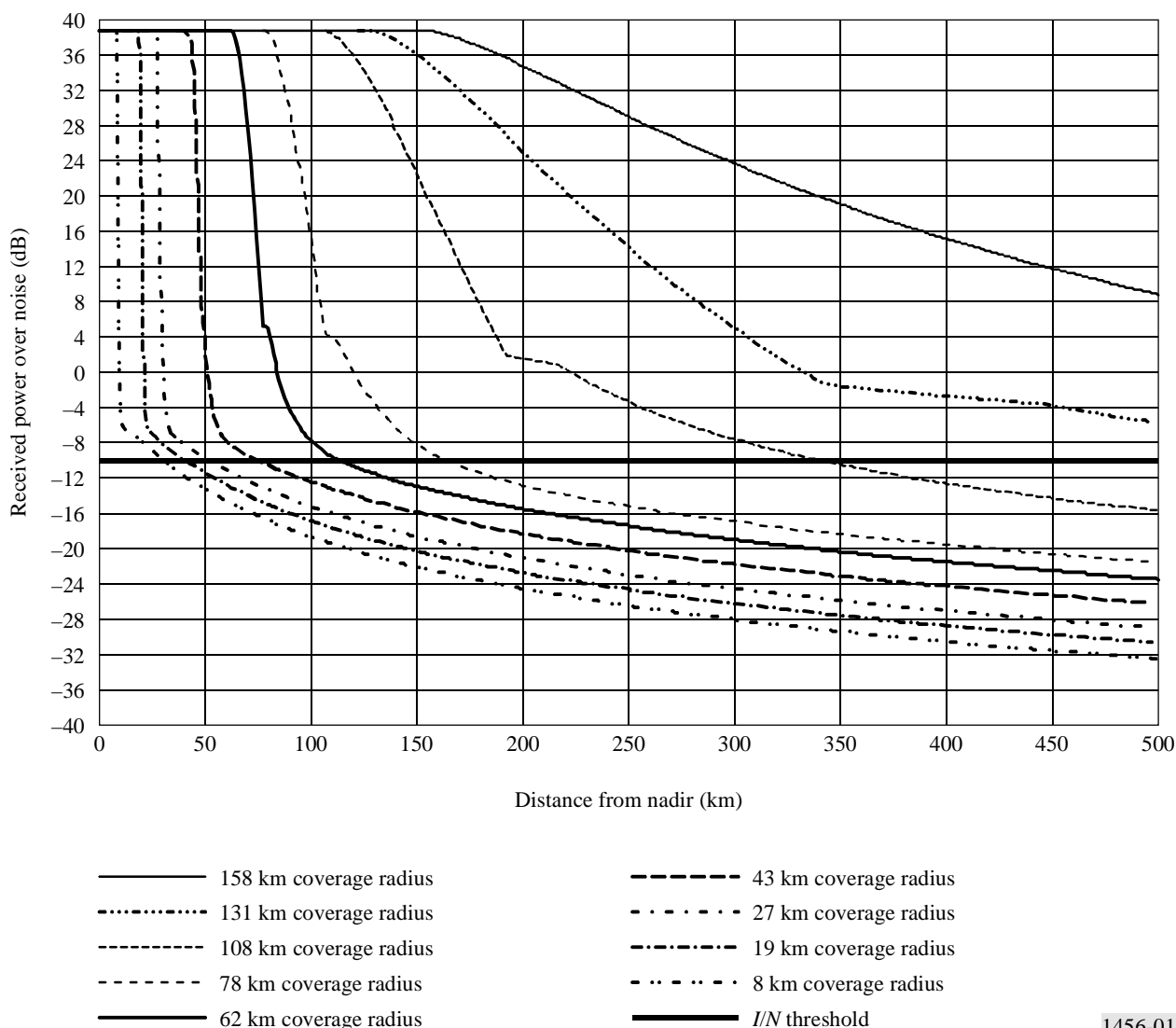
A HAPS using IMT-2000 TDMA single-carrier can provide wide-area coverage from a single HAPS. However, the possibility of interference between such wide-area coverage and the co-channel operation of an existing or planned tower-based IMT-2000 TDMA system within the same geographical area should be considered.

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 dB(W/(m$^2 \cdot$ 4 kHz)) and the effective antenna aperture of -27.5 dB(m^2) for the 0 dBi handset antenna. This gives -125.7 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)**

———————— 158 km coverage radius	– – – – – 43 km coverage radius
·············· 131 km coverage radius	– · – · – · 27 km coverage radius
– – – – – – 108 km coverage radius	– · – · – · 19 km coverage radius
– – – – – 78 km coverage radius	– ·· – ·· · 8 km coverage radius
———————— 62 km coverage radius	———————— *I/N* threshold

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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)**
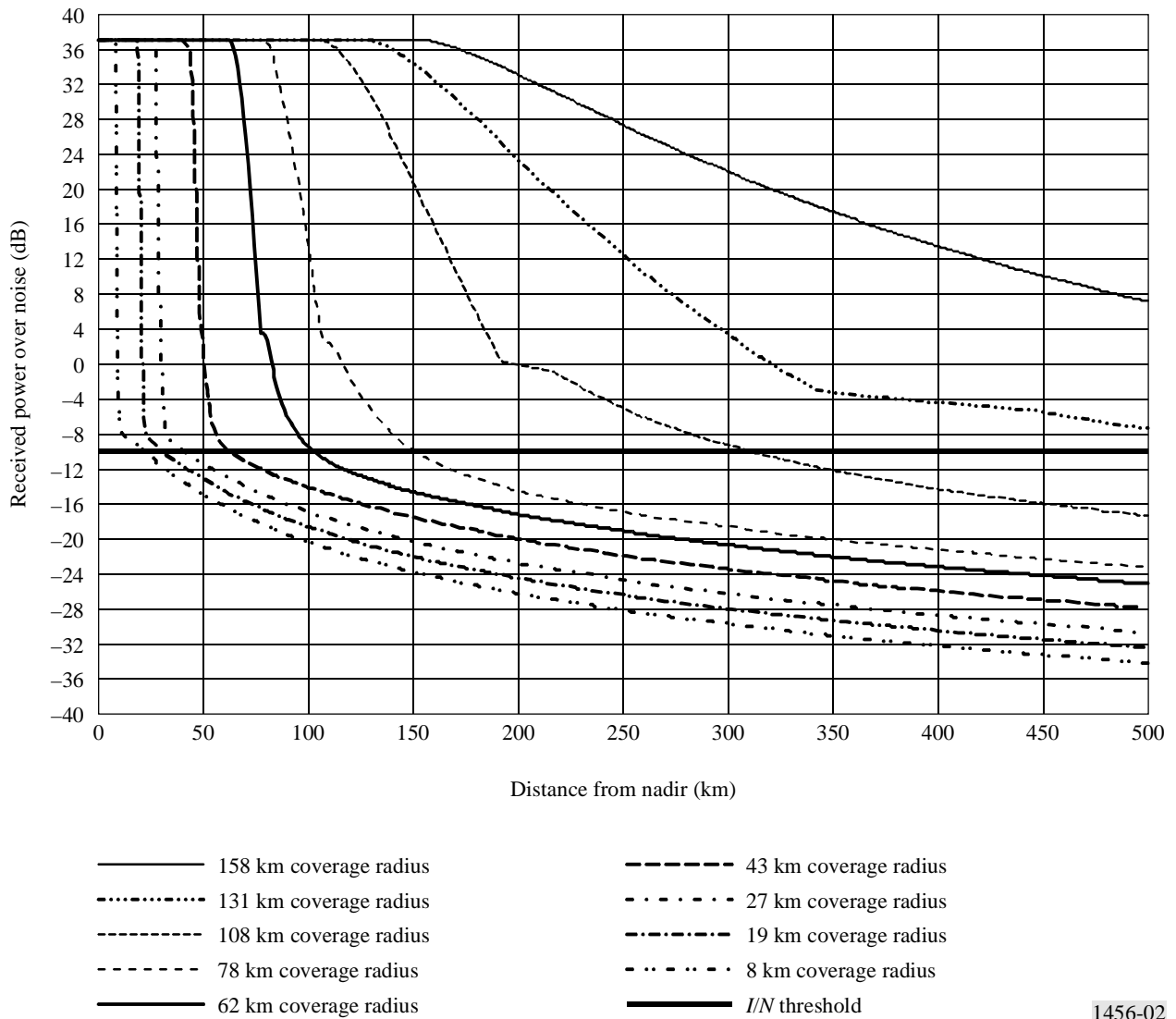
The permissible interference criterion of $I/N_{thermal} = -10$ dB will be used for victim handsets irrespective of the access format of the victim radio interface. The same permissible interference criterion will also be applied to victim base stations. It should be noted that if the victim handset 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:

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

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

$F = 73$ dB: far side lobe relative to peak gain.

From this the coordination distance can be determined as follows:

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

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 $\theta = \theta_0 + (1 + \eta)\psi_2 = \theta_0 + 10^y\ \psi_2$.

$$\delta\, FSL(\theta) \,=\, 20\,\log(\cos(\theta_0)) \,-\, 20\,\log(\cos(\theta_0 \,+\, 10^{y}\,\psi_2))$$

$$\cong 20\,\log(\cos(\theta_0)) \,-\, 20\,\log(\cos(\theta_0 \,+\, \psi_2)) \,+\, 20\,\psi_2\,\tan(\theta_0 \,+\, \psi_2)\,y \qquad (14)$$

$$= 20\,\log(\cos(\theta_0)) \,-\, 20\,\log(\cos(\theta_0 \,+\, \psi_2)) \,+\, 20\,\psi_2\,\tan(\theta_0 \,+\, \psi_2)\,y$$

Let $D = (I_{received}/N)_{centre} - Threshold - L_N$, the coordination distance can be obtained from the solution for y, where $Threshold = -10$ dB is the permissible I/N threshold for HAPS interfering into victim mobile stations.

$$y \,=\, [D \,-\, 20\,\log(\cos(\theta_0)) \,+\, 20\,\log(\cos(\theta_0 \,+\, \psi_2))]/[60 \,+\, 20\,\psi_2\,\tan(\theta_0 \,+\, \psi_2)] \qquad (15)$$

The required coordination distance (relative to nadir of HAPS) follows by using the relationship:

$$R_{coordination} \,=\, \tan(\theta_0 \,+\, 10^{y}\,\psi_2)h \qquad\qquad \text{km} \qquad (16)$$

An empirical formula derived from equation (16) that takes into account the aggregated interference level in equation (11) is given below:

$$R_{coordination} \,=\, \tan(\theta_0 \,+\, 10^{y}\,\psi_2)h \,+\, (1 \,-\, h/(158\,\cos(\theta_0)))(Num \,\times\, 10^{-7.3+B} \,-\, 1)^{1/2}\,h \qquad \text{km} \quad (17)$$

The approximation method yields fairly accurate results when compared to actual multibeam computation. This is shown in Fig. 3:

FIGURE 3

**Comparison of approximate and multibeam computation
(HAPS using CDMA format)**

Multibeam calculation

Approximate formula

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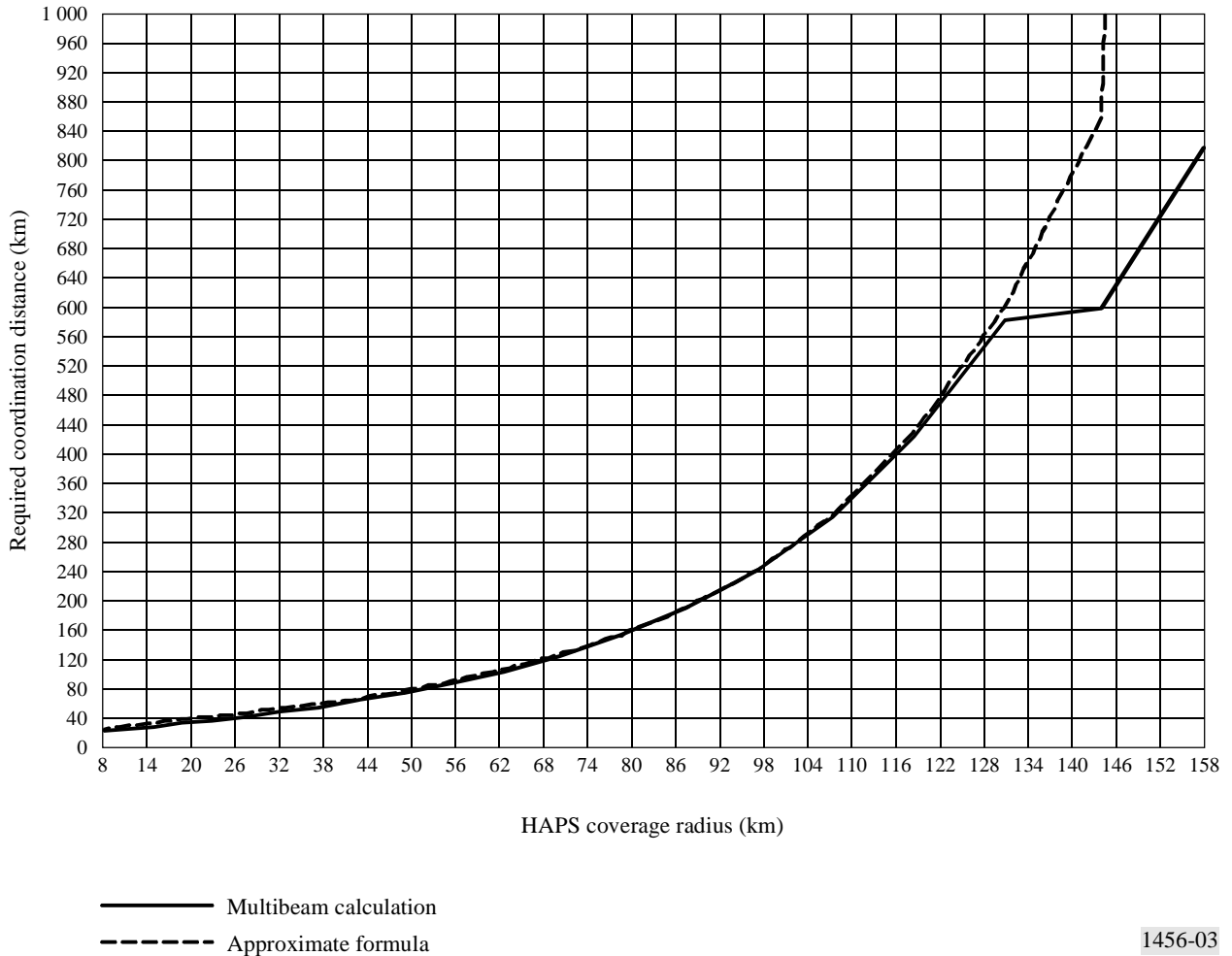
As can be seen from Fig. 3, the approximate formula yields results that are within 1% of those obtained from the explicit multibeam calculation for coverage radius up to 132 km. Note that if a mobile station is beyond the horizon, it should not receive interference from HAPS because of the visibility constraint. If the HAPS is deployed at 22 km altitude, its horizon is approximately 600 km measured from nadir. Because of heavy clutter attenuation, the visible horizon and the radio horizon should be roughly the same.

2.1 HAPS into the fixed service

The interference to a point-to-point (P-P) fixed service from HAPS operating in the same bands as the fixed service will require a coordination distance between the nadir of HAPS and the fixed service antenna that is a function of fixed service antenna gain, its boresight angle relative to HAPS, and HAPS coverage radius. Such P-P service typically uses antennas with sufficient directivity to optimize long-range communications. Assuming that the fixed service antenna points approximately in the horizontal direction, the interference power received by the fixed service antenna from HAPS can be written as follows:

$$(I_{received}/N) = \left[P_{received}(\theta)/N\right] + G_{victim}(\varphi, r) \tag{18}$$

where:

$P_{received}(\theta)$: power received on the ground as a function of the tilt angle θ

r : distance from nadir of the nearest HAPS beam

$G_{victim}(\varphi, r)$: antenna gain of the fixed service antenna as a function of both the off-boresight angle relative to HAPS nadir and the distance of the fixed service from nadir.

The latter can be expressed as a function of the off-boresight angle α defined by:

$$\alpha = \cos^{-1}\left[r\cos(\varphi/(r^2 + h^2)^{1/2}\right] \tag{19}$$

Owing to the high pfd values of fully loaded HAPS systems within HAPS primary coverage areas, co-channel sharing within HAPS coverage area is clearly not possible, and this is borne out by explicit multibeam computation of the aforementioned scenario. Outside HAPS main coverage area, equation (20) is valid:

$$(I_{received}/N) = (I_{received}/N)_{centre} + \delta\,G(\theta - \theta_0) - \delta\,FSL(\theta) + G_{FS}(\alpha(\varphi, r)) \tag{20}$$

where $\delta\,G(\theta - \theta_0)$ and $\delta\,FSL(\theta)$ have already been defined, and $G_{FS}(\alpha(\varphi, r)) = G_{victim}(\varphi, r)$. This leads to equations (21) and (22):

$$y = [D(\theta_0, \varphi) - 20\log(\cos(\theta_0)) + 20\log(\cos(\theta_0 + \psi_2))]/[60 + 20\,\psi_2\tan(\theta_0 + \psi_2)] \tag{21}$$

$$R_{coordination} = \tan(\theta_0 + 10^y\,\psi_2)h + (1 - h/(158\cos(\theta_0))\,(Num \times 10^{-7.3+B(\theta_0, \varphi)} - 1)^{1/2}\,h \qquad \text{km} \tag{22}$$

where:

$D(\theta_0, \varphi) = (I_{received}/N)_{centre} + G_{victim}(\pi/2 - \theta_0, \varphi) - Threshold - L_N$

$B(\theta_0, \varphi) = 0.1[(I_{received}/N)_{centre} + G_{victim}(\pi/2 - \theta_0, \varphi) - Threshold]$.

Figure 4 gives the required coordination distances as a function of the cosine angle of boresight of the fixed service antenna relative to nadir HAPS for 8, 37, 87, 110 and 158 km HAPS coverage, respectively. The fixed service antenna is assumed to have a 31 dBi gain, and a directivity pattern in accordance with Recommendation ITU-R F.699. The reference antenna radiation patterns for antennas on HAPS platforms are given in Appendix 1 to Annex 1.

The approximation method yields accurate results only when the coverage radius is small ($\leq$ 60 km). This is shown in Fig. 5.
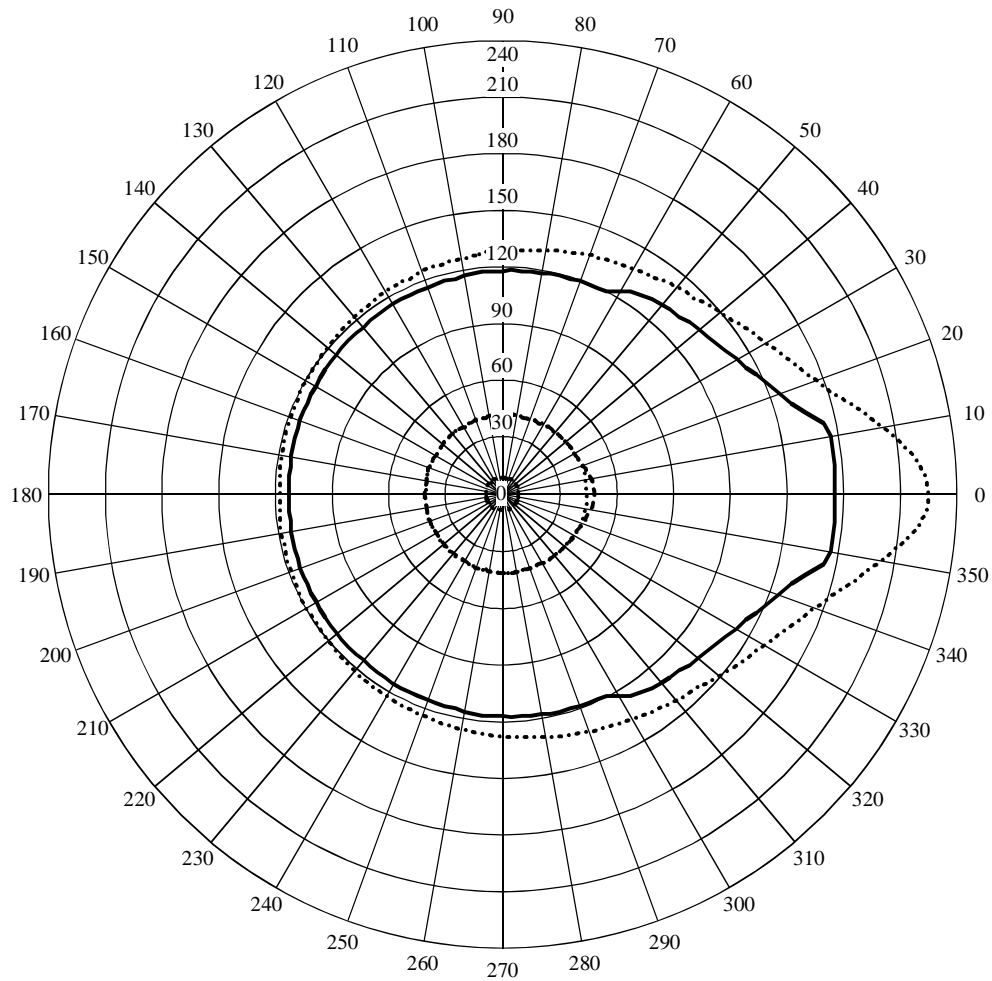
FIGURE 4

**Coordination distance versus azimuth and coverage radius
(HAPS using TDMA format)**
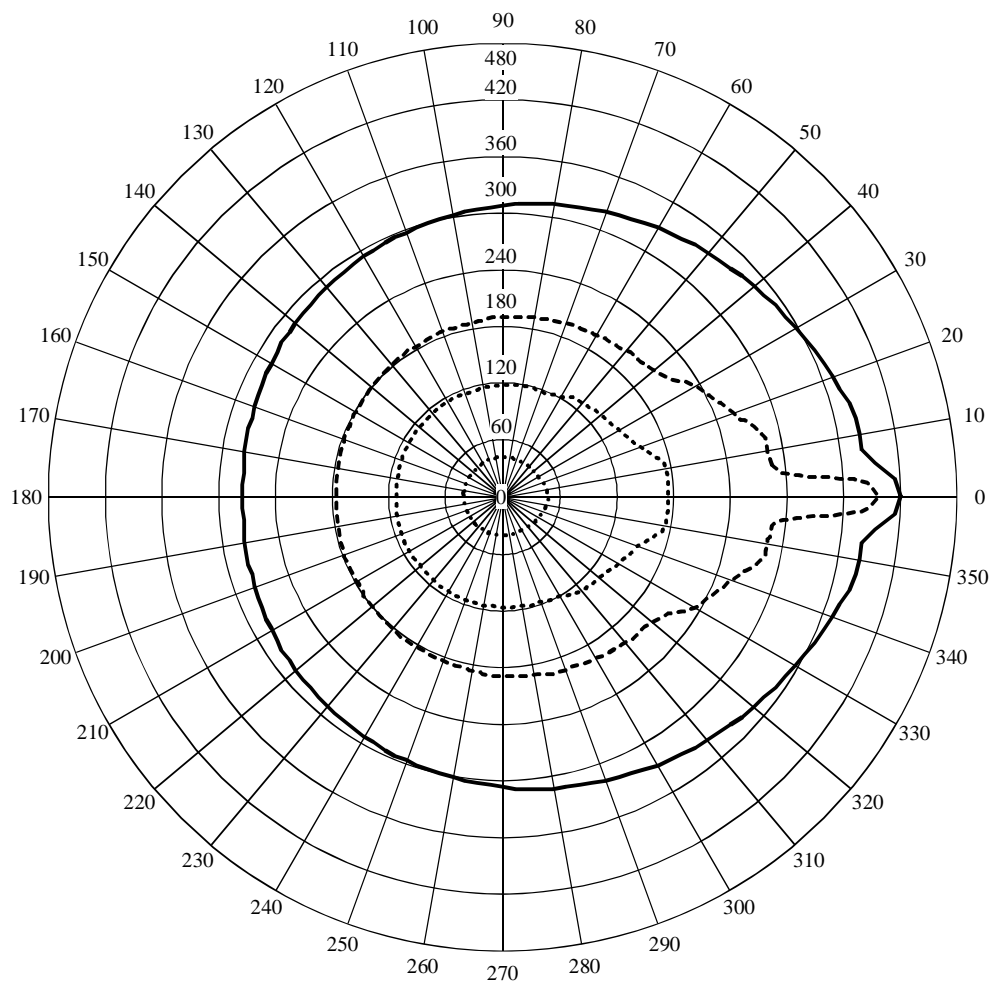
——————— 158 km coverage radius

- - - - - - 110 km coverage

············· 87 km coverage

············· 37 km coverage

············· 8 km coverage

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FIGURE 5

**Coordination distance versus azimuth and coverage radius, comparison of exact and
approximate results (HAPS using CDMA format)**

————	87 km coverage radius
– – – – – – –	37 km coverage
··········	8 km coverage
··············	87 km coverage (approximately)
··············	37 km coverage (approximately)
– · – · – · –	8 km coverage (approximately)

1456-05

2.2   Interference from HAPS using IMT-2000 CDMA format into IMT-2000 mobile stations

The interference criterion of $I/N = -10$ dB will be used. It makes no difference whether the interfered mobile station uses an IMT-2000 CDMA or TDMA format or not, only the level of interference from HAPS matters.

It is clear from Fig. 1 that such sharing is entirely feasible for smaller radius HAPS coverage. Even for a main coverage radius of 62 km, a victim tower-based system can provide the IMT-2000 service in the same frequency band assuming that its coverage area is at least 33 km from the nearest HAPS main beam. Figure 6 shows the relationship between the coordination distance and the HAPS coverage, and Fig. 7 shows the distance between the coordination boundary and the nadir of HAPS as a function of HAPS coverage radius. The results in Fig. 7 are summarized in Table 1.

FIGURE 6

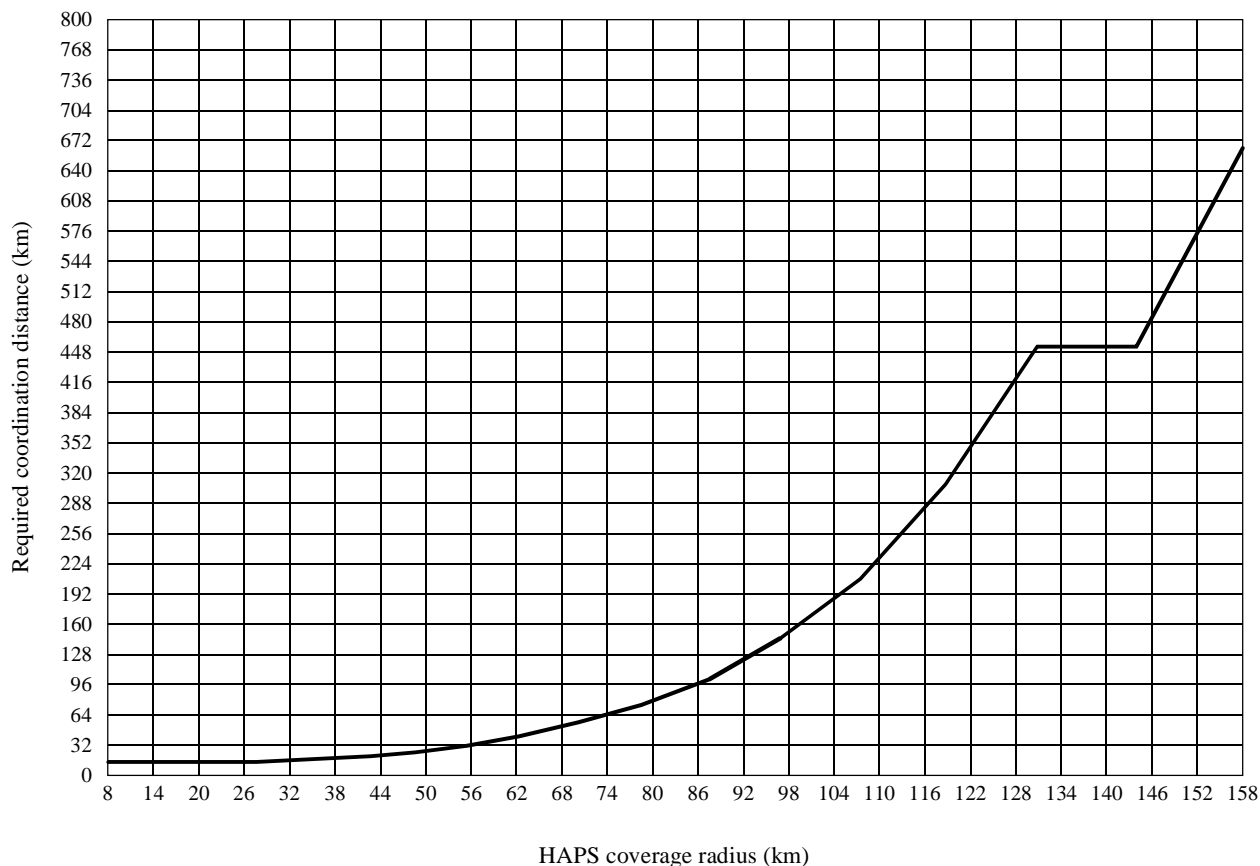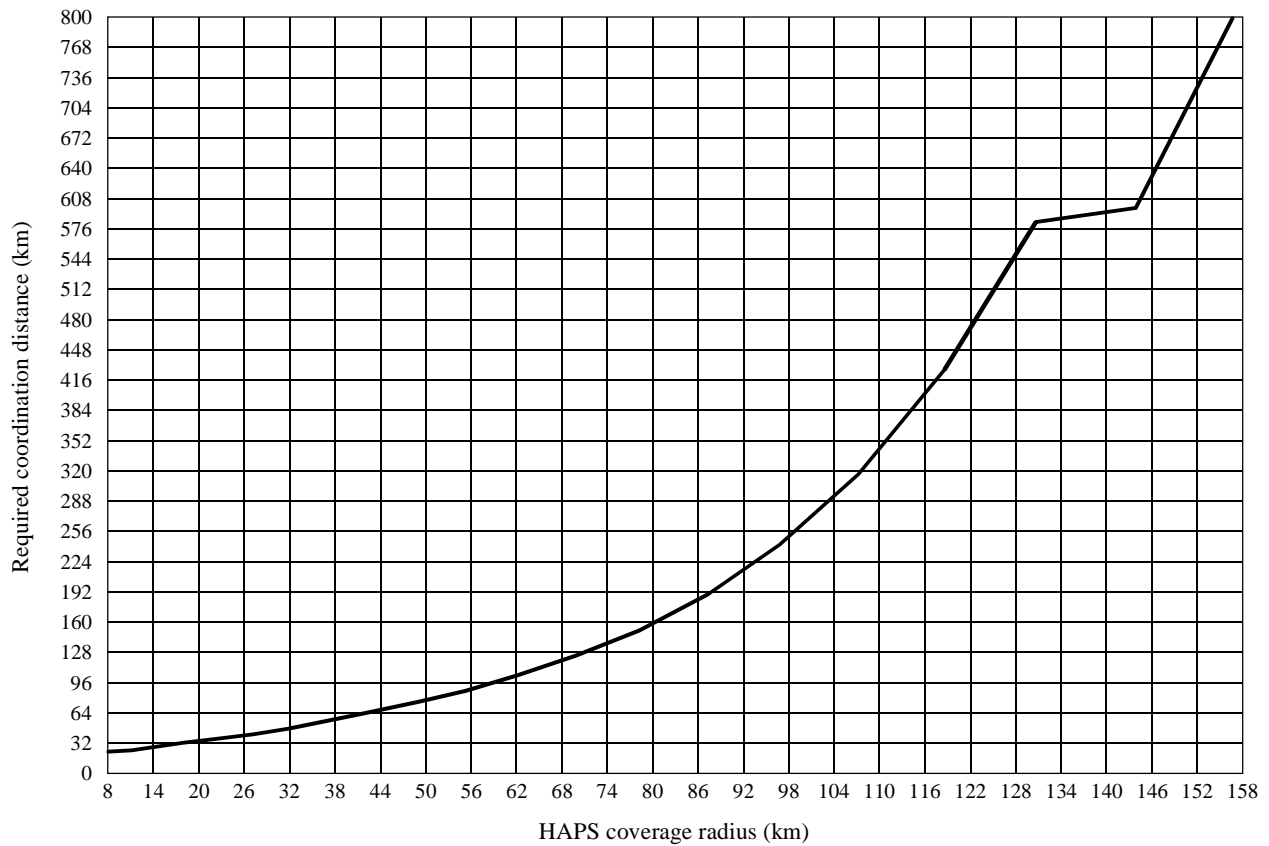**Coordination distance versus radius of main HAPS coverage area
(HAPS using CDMA format)**

1456-06

FIGURE 7

**Coordination boundary measured from nadir versus coverage radius
(HAPS using CDMA format)**

1456-07

TABLE 1

**Coordination distances (km) for different radius of coverage (km)
using equation (22) (HAPS using CDMA format)**

Radius of coverage	8	11	15	19	23	27	32	37	43	49	55	62	70	78	87	97	107	119
Coordination distance (measured from nadir)	27	30	34	38	43	48	54	61	69	79	91	106	126	153	190	242	319	433
Coordination distance (measured from the nearest beam centre)	19	19	19	19	20	21	22	26	26	30	36	44	56	75	103	145	212	314

If the number of beams of the interfering HAPS system is different from 700, or if the permissible interference criterion is different from the $I/N = -10$ dB used above, then equation (22) should be used for the determination of the minimum coordination distance.

2.3 Interference from HAPS using IMT-2000 TDMA format into IMT-2000 mobile stations

It is clear from Fig. 2 that such sharing is entirely feasible for smaller radius HAPS coverage. Even for a main coverage radius of 62 km, a victim tower-based system can provide the IMT-2000 service in the same frequency band provided that its coverage area is at least 50 km from the nearest HAPS main beam. Fig. 8 shows the relationship between the coordination distance and the HAPS coverage radius, and Fig. 9 shows the distance between the coordination boundary and the nadir of HAPS as a function of HAPS coverage radius. The results in Fig. 9 are summarized in Table 2.

FIGURE 8

Coordination distance versus radius of main HAPS coverage area
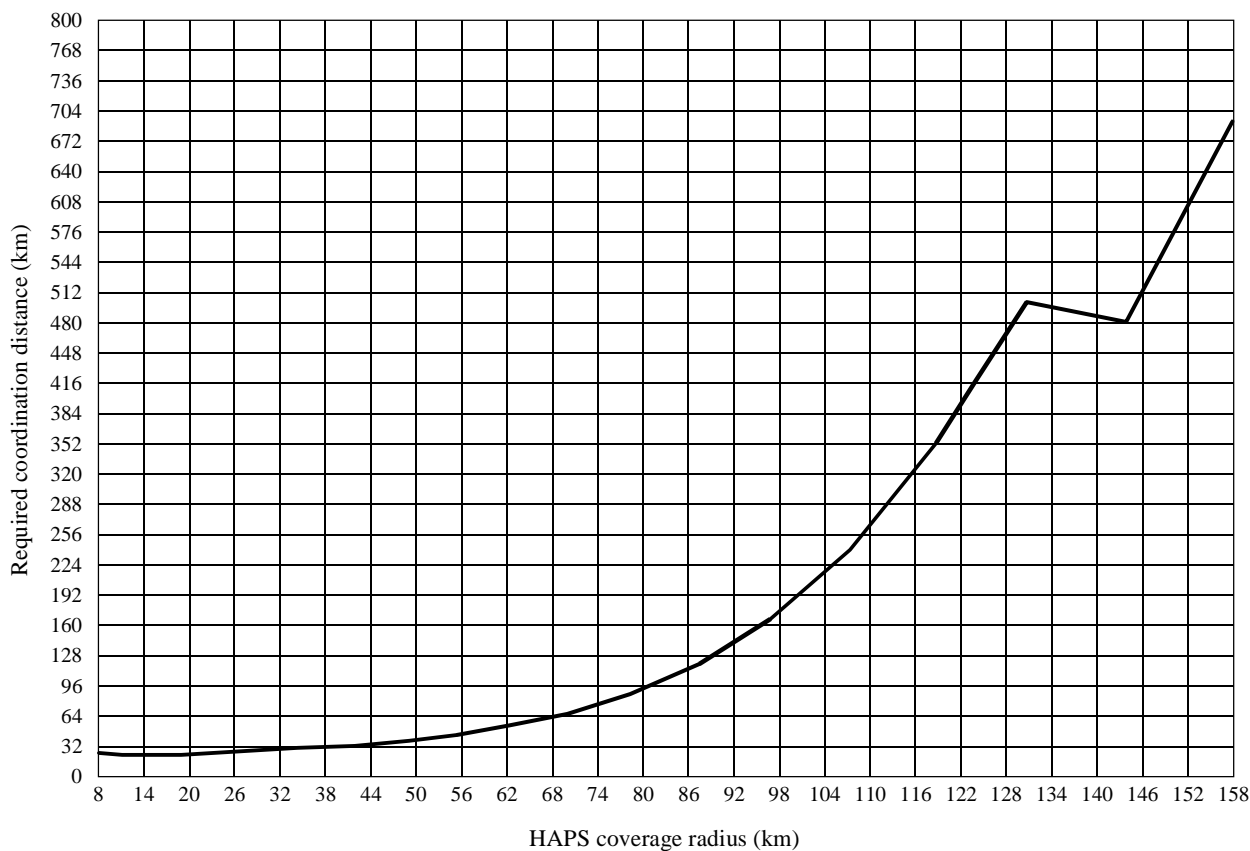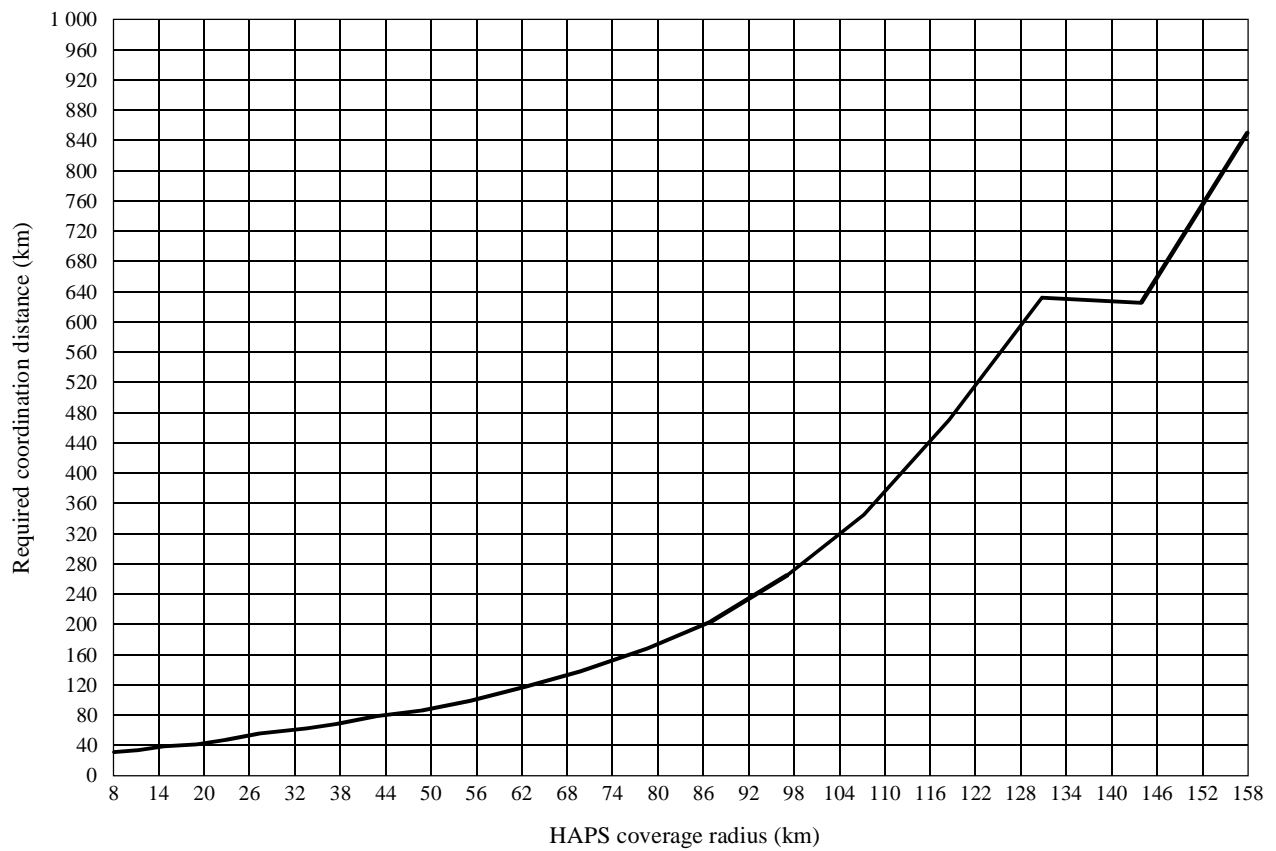**(HAPS using TDMA format)**

1456-08

FIGURE 9

**Coordination boundary measured from nadir versus coverage
(HAPS using TDMA format)**

1456-09

TABLE 2

**Coordination distances (km) for different radius of coverage (km)
using equation (22) (HAPS using TDMA format)**

Radius of coverage	8	11	15	19	23	27	32	37	43	49	55	62	70	78	87	97	107	119
Coordination distance (measured from nadir)	34	38	41	45	50	55	61	68	76	86	98	114	136	164	205	264	353	490
Coordination distance (measured from the nearest beam centre)	26	26	26	27	27	28	29	30	33	37	43	52	65	86	118	167	246	371

If the number of beams of the interfering HAPS system is different from 700, or if the permissible interference criterion is different from the $I/N = -10$ dB used above, then equation (22) should be used for the determination of the minimum coordination distance.

2.4   HAPS into IMT-2000 CDMA TDD base stations

There are two kinds of base station antennas, omnidirectional and sectoral. Typical omnidirectional base station antennas have a peak horizontal gain of about 15 dBi, and a 3 dB vertical beamwidth of ~5.1°. For sectoral antennas, a typical example is a 90° sector antenna with a 3 dB beamwidth of 90° in the horizontal (azimuthal) plane and a 2.5° beamwidth in the elevation plane for a peak gain of 21.5 dBi. Because of the very small beamwidth of the sectoral antennas, even if the victim base station is at an elevation angle of 5° relative to HAPS with its sector antenna pointing in the direction of HAPS, the peak effective antenna gain for the sector antenna is still negative. At larger elevation angles, the effective antenna gain becomes strongly negative. Hence one can expect a much smaller coordination distance in general between HAPS and base stations with sectoral antennas. For that reason only omnidirectional antennas will be considered for the remainder of this Recommendation.

The antenna radiation patterns used for this study follow the reference radiation patterns of omnidirectional and sectoral antennas in P-MP systems for use in sharing studies in the 1-50 GHz range (see Recommendation ITU-R F.1336).

In the FDD mode, a HAPS-based IMT-2000 base station does not cause any co-channel interference to a tower-based base station operated within the terrestrial IMT-2000 bands. By the same token, a HAPS-based mobile station operating in the terrestrial IMT-2000 bands cannot cause co-channel interference with a tower-based mobile station operating in the same spectrum. The interference power received by a victim base station antenna from HAPS can be written as follows:

$$I_{victim} = pfd_{HAPS}(\theta) + G_{victim}(\varphi) + Area_0 - \delta\, FSL(\theta_0, \theta) \tag{23}$$

where $Area_0$ is the effective antenna aperture of -27.5 dB(m^2) for the 0 dBi handset antenna.

This gives

$$(I_{received}/N) = (I_{received}/N)_{centre} + \delta\, G(\theta - \theta_0) - \delta\, FSL(\theta) + G_{victim}(\varphi) \tag{24}$$

where φ is the elevation angle of the base station antenna with respect to HAPS. For base station antenna with a finite down tilt, the elevation plane of the antenna is no longer the horizontal plane. For sectoral base station antennas, the antenna is assumed to point in the direction of the nadir of HAPS. Since down tilt reduces the potential for receiving interference from HAPS, no down tilt is assumed here. This leads to $\varphi = \pi/2 - \theta$.

Since typical base station antennas have relatively low directivity in comparison with the directivity of HAPS antennas, it is possible to arrive at the following formula:

$$y = \left[D(\theta_0) - 20\log(\cos(\theta_0)) + 20\log(\cos(\theta_0 + \psi_2))\right]/\left[60 + 20\,\psi_2\tan(\theta_0 + \psi_2)\right] \tag{25}$$

$$R_{coordination} = \tan(\theta_0 + 10^y\,\psi_2)h + (1 - h/(158\cos(\theta_0))\,(Num \times 10^{-7.3 + B(\theta_0)} - 1)^{1/2}\,h \qquad \text{km} \tag{26}$$

where:

$$D(\theta_0) = (I_{received}/N)_{centre} + G_{victim}(\pi/2 - \theta_0) - Threshold - L_N$$

$$B(\theta_0) = 0.1\left[(I_{received}/N)_{centre} + G_{victim}(\pi/2 - \theta_0) - Threshold\right].$$

Since even at the largest coverage radius of 158 km considered here, the elevation angle, and hence φ if the base station is assumed to be right next to the HAPS coverage boundary, is around 8°, which is already well outside the main lobe of the base station's elevation plane. It follows that for smaller HAPS coverage radius (< 100 km), the base station antenna gain is essentially 0 dBi. For HAPS having a coverage radius between 100 km and 160 km, the effective base station antenna gain can range from 3 dBi to 4 dBi. This will drastically increase the coordination radius.

Figure 10 gives the required coordination distance between the tower-based base station and the interfering HAPS for the case of 13 dBi base station antenna. Also plotted is the required coordination distance between HAPS and a tower-based mobile station. The HAPS parameters are assumed to be the same. HAPS is assumed to use IMT-2000 CDMA direct Spread access format. It is seen that owing to the higher directivity of the base station antenna, the required coordination distance is actually less than the corresponding one for the mobile station.

FIGURE 10

Coordination distances versus the distance from nadir
(HAPS using CDMA format)
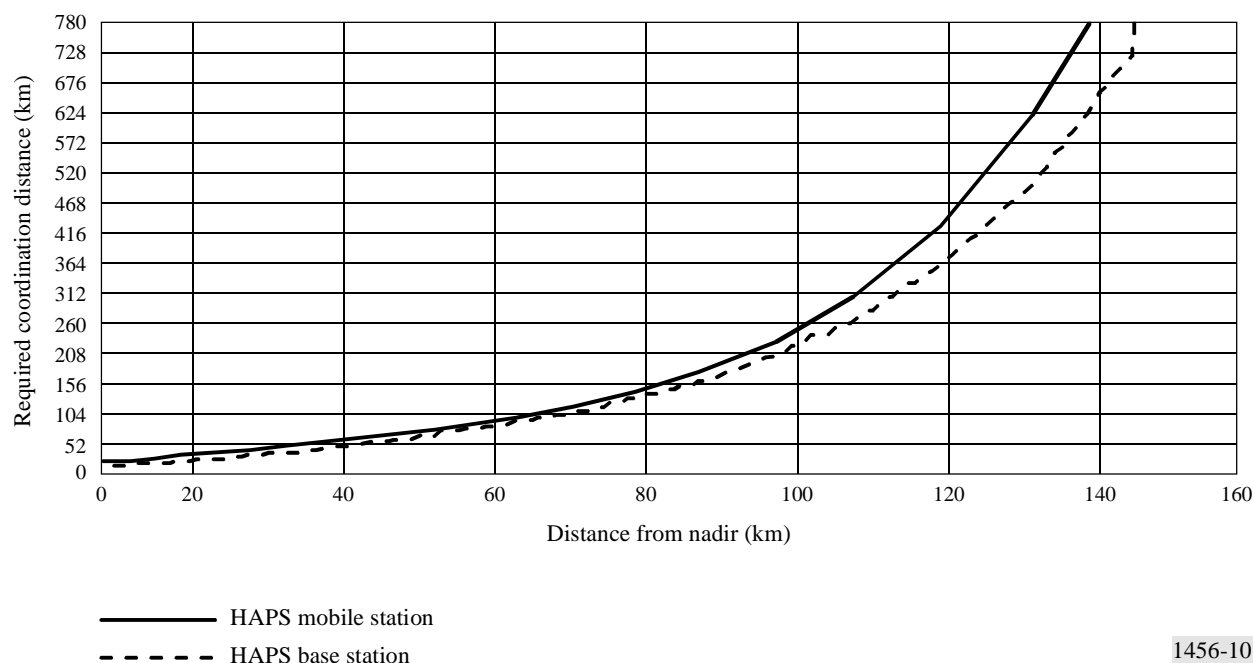
APPENDIX 1

TO ANNEX 1

**Reference antenna radiation patterns for HAPS**

1 Reference antenna radiation patterns for HAPS CDMA and TDMA systems

The antenna radiation pattern for platform antennas is based on a high-performance, multi-beam phased array using digital beam-forming technology and a cosine square illumination profile. The roll-off assumed is 60 dB/decade, which is much better than the 25 dB/decade performance of a parabolic antenna. The improved roll-off enables a significant capacity improvement for interference-limited CDMA and TDMA systems. Thus, the reference radiation pattern is given in *recommends* 2.

The far side-lobe level of $G_m - 73$ dBi is consistent with a manufacturing tolerance of 0.002 in. If the manufacturing tolerance is better than 0.002 in., the effect of phase error is insignificant.

Figure 11 shows the radiation pattern of a phased array antenna with 10×10 m sub-aperture illumination and the mask as defined in equations (1) to (9).

FIGURE 11

Antenna radiation pattern and mask

1456-11
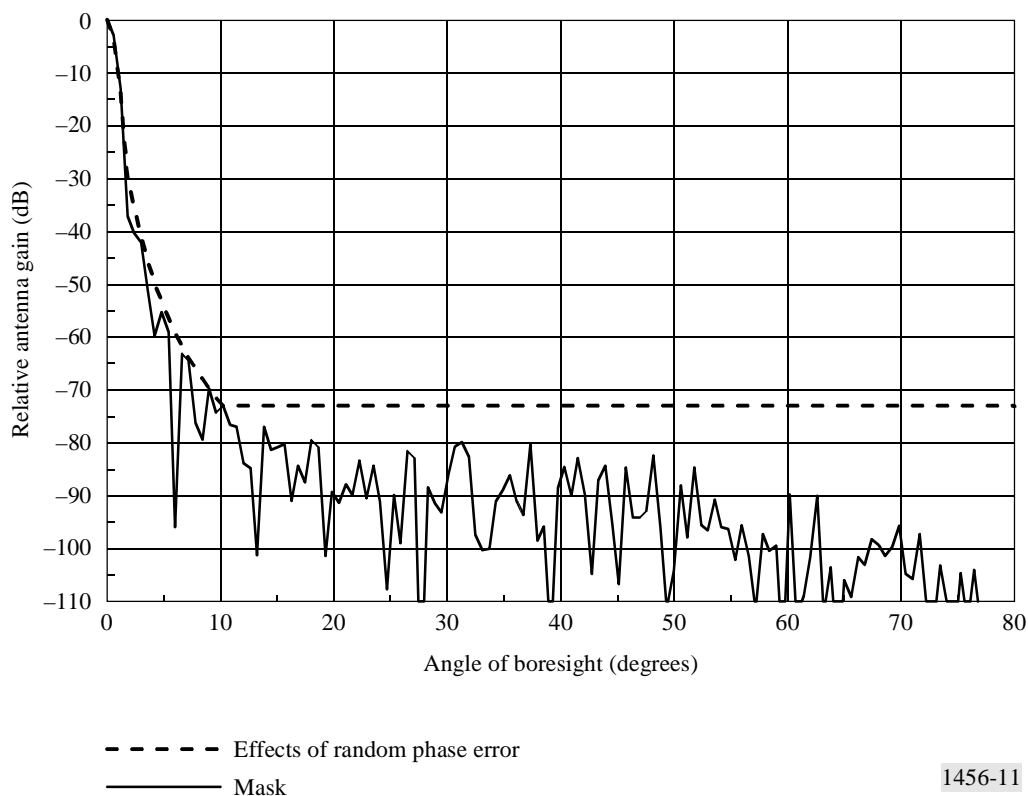
ANNEX 2

Basis for the pfd levels in *recommends* 4 and 5

1 OoB pfd levels established for HAPS in the bands 2 160-2 200 MHz in Region 2 and 2 170-2 200 MHz in Regions 1 and 3

The pfd level of -165 dB(W/(m^2 · 4 kHz)) provided in *recommends* 4 is based on the following.

The permissible OoB emission interference level is determined from the requirement that the interference from HAPS into a MES with a 15 dBi antenna gain should be no greater than 10 dB below the thermal noise level of -167.8 dB(W/4 kHz). Since this corresponds to a pfd of -155 dB(W/(m^2 · 4 kHz)), assuming a feeder loss of 0.5 dB, this gives the permissible interference level of -165 dB(W/(m^2 · 4 kHz)). Note that this gives a permissible interference level that is as much as 24.5 dB below the thermal noise level for omnidirectional MES antennas, and 4.5 dB below the thermal noise level for a MES antenna with 20 dBi antenna gain.

The justification for allowing a higher interference level for MES antennas with higher antenna gain is that, because of the higher directivity, only those MES that point close to HAPS receive these higher interference levels. Those higher gain MES that point in other directions will receive lower interference power.

For HAPS operating IMT-2000 CDMA-DS, the minimum OoB attenuation needed in order to satisfy the interference criterion is determined by the following inequality:

$$-98, \text{dB(W/(m}^2 \cdot 4 \text{ kHz))} - ATTENUATION_{OoB} \leq -165 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))} \tag{27}$$

or $ATTENUATION_{OoB} = 66.8$ dB. Likewise, for HAPS TDMA systems, the OoB attenuation should satisfy the following inequality:

$$-96.8 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))} - ATTENUATION_{OoB} \leq -165 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))} \tag{28}$$

or $ATTENUATION_{OoB} = 68.2$ dB.

2 OoB pfd levels established for HAPS in the band 2 025-2 110 MHz

The pfd level of -165 dB(W/(m$^2 \cdot$ 1 MHz)) provided in *recommends* 5.1 for elevation angles between 0° and 5° is based on the following. The permissible OoB emission interference level is determined from the requirement that the interference from HAPS into a fixed service station with a 33 dBi antenna gain and a 5 dB noise figure should be no greater than 20 dB below the thermal noise level of -139 dB(W/MHz).

The pfd level of -130 dB(W/(m$^2 \cdot$ 1 MHz)) provided in *recommends* 5.3 for elevation angles between 25° and 90° is based on the same receiver protection characteristics but a fixed service antenna gain in the direction of the HAPS of 3.5 dBi.

ANNEX 3

Compatibility between HAPS IMT-2000 systems and space research (SR), space operation (SO), and Earth-exploration satellite (EES) services operating in the adjacent band 2 025-2 110 MHz

The space network consists of space-to-space links between a data-relay satellite (DRS) in GSO orbit and a low Earth-orbiting (LEO) satellite. The DRS transmit to a LEO in the band 2 025-2 110 MHz and receives transmission from LEO in the band 2 200-2 290 MHz. Thus the LEO satellite is susceptible to interference from emissions in the band 2 025-2 110 MHz. A LEO satellite may also communicate with earth stations in the ground network using Earth-space links. The Earth-space link transmits in the band 2 025-2 110 MHz to a LEO satellite and receives in the band 2 200-2 290 MHz from a LEO satellite.

RR No. S5.391 refers to Recommendation ITU-R SA.1154 which recommends:

"**1** that the following provisions are suitable to protect the SR, SO and EES services from aggregate interference from emissions of mobile systems in the 2 025-2 110 MHz band:

1.1 that the aggregate interference at the input terminals of the spacecraft receiver, except in the case of a space-to-space link, should not exceed -180 dB(W/kHz) for more than 0.1% of the time;

1.2 that in the case of space-to-space links the aggregate interference at the input terminals of the spacecraft receiver should not exceed -184 dB(W/kHz) for more than 0.1% of the time;".

Notwithstanding Recommendation 622 (WRC-97), which recommends to implement enhancements in technology to minimize the total bandwidth required by the space services, RR No. S5.391 and Recommendation ITU-R SA.1154 recommend that only low-density mobile systems be allowed to operate in these bands.

Since RR No. S5.391 pertains only to in-band interference, it is deemed necessary to decrease the recommended in-band spectral density level by 5 dB. This gives a level of –159 dB(W/MHz) for the allowable aggregate interference at the input terminals of the receiver in the earth station for 99.9% of the time.

Consider now the potential interference from HAPS to LEO satellites operating in the space network and receiving in the band 2 025-2 110 MHz. The geometries involved are sketched in Figs. 12a and 12b. The aggregate interference at the input terminals of the LEO receiver should not exceed –219 dB(W/Hz) for more than 0.1% of the time.
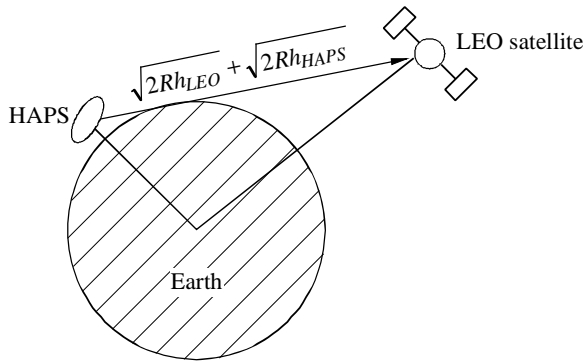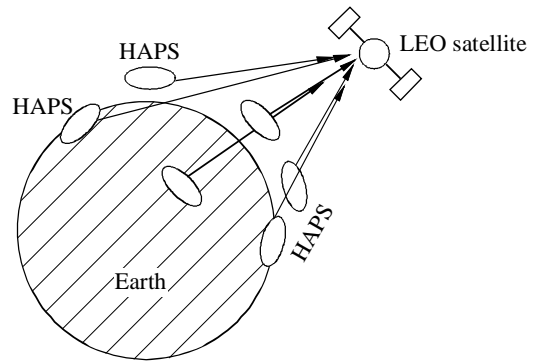
FIGURE 12a

Interference from HAPS into SR, SO and EES LEO satellite

FIGURE 12b

Interference from several HAPS into SR, SO and EES LEO satellite

1456-12

HAPS antennas do not point towards LEO satellites, hence main-lobe to side-lobe interference is not possible. For near side-lobe to main-lobe interference, only a single HAPS beam can be involved because different HAPS transmission beams point in different directions. This situation is not much different from that between HAPS and the DRS satellite, with the exception that the free space loss is slightly less because of the low altitude of the satellite (~250 km). In this interference scenario the LEO satellite is just visible from HAPS, hence the distance between HAPS and the LEO satellite is given approximately by $\sqrt{2Rh_{LEO}} + \sqrt{2Rh_{HAPS}}$, or 2 295 km, which yields a free space loss of 166 dB. The interference to the LEO satellite is coupled into the receiving system through antenna side lobes that exhibit 0 dBi gain.

$$\text{Threshold e.i.r.p.} = -159 \text{ dB(W/MHz)} + 166 \text{ dB} - 0 \text{ dBi} + 2 \text{ dB} = 9 \text{ dB(W/MHz)} \tag{29}$$

Hence even without any OoB attenuation, the probability for interference is zero.

Within the visible area of the LEO satellite, there is typically more than one HAPS network providing overlay coverage. For a satellite altitude of around 250 km, which has a visible area roughly 12 times the HAPS coverage area, hence 12 can be considered to be the upper limit for the number of HAPS that can be seen from a single space science LEO satellite. For simplicity, the HAPS networks can be assumed to be roughly evenly distributed throughout the visible area of the satellite. Since each HAPS station has a large number of antennas, the potential for aggregated interference exists.

Because the side-lobe antenna gain is a function of the centre frequency of the antenna array, it is assumed here conservatively that the far side lobes of the HAPS antennas have essentially 0 dBi gain. For 700 HAPS beams, this gives an aggregated e.i.r.p. spectral density of at most 11.5 dB(W/MHz). About 12 HAPS platforms can be located within

a LEO satellite coverage area. The cumulative interfering spectral density arriving at the LEO satellite from 12 HAPS is given by:

$$P_{\Sigma_i} = P_s \frac{n_a(h) c^2}{(4 \pi f)^2 R h} [In(d_m) - In(h)]$$

$$d_m = \sqrt{(R + h)^2 - R^2}$$

(30)

where:

P_s :   e.i.r.p. spectral density contribution from a single HAPS (11.5 dB(W/MHz))

f :   transmission frequency

$n_a(h)$:   total number of HAPS in the interference area (~12)

c :   speed of light

d_m :   maximum distance to interferer

R :   Earth radius

h :   LEO orbit height minus HAPS altitude.

The average path loss can be computed from equation (30). For a satellite altitude of 250 km, it is 158 dB. This gives the aggregate interference at the input terminals of the LEO receiver of –138 dB(W/MHz) (allowing 2 dB polarization discrimination), as follows:

Threshold e.i.r.p. $= -159$ dB(W/MHz) $+ 158$ dB $- 0$ dBi $+ 2$ dB $- 10 \log(12) = -9.8$ dB(W/MHz) (31)

which requires OoB attenuation of at least 21 dB in order to reach the threshold level of –159 dB(W/MHz).

The same considerations can be applied to the LEO satellite operating in the ground network with its antennas pointing to the earth station. Here the allowable aggregate OoB interference at the input receiver of –215 dB(W/Hz) (99.9% of the time) is 4 dB higher than that of the space-to-space link. Hence the required minimum OoB attenuation is 17 dB.

Since HAPS IMT-2000 mobile stations have exactly the same specification as that of the conventional mobile stations, the sharing analysis would only be different if the number of active users per unit area is considerably different between tower-based IMT-2000 systems and HAPS-based terrestrial IMT-2000 systems. Since the number densities estimated for HAPS is about the same as those of the tower-based systems, except in a central business district, where tower-based systems are expected to be able to support higher user density, the sharing criterion between HAPS mobile terminals and space science services should be no different.