RECOMMENDATION ITU-R M.1641

A methodology for co-channel interference evaluation to determine separation distance from a system using high-altitude platform stations to a cellular system to provide IMT-2000 service within the boundary of an administration

(2003)

Summary

This Recommendation contains a methodology for evaluating co-channel interference and a separation distance between a high altitude platform station (HAPS) system as a base station for IMT-2000 and a terrestrial tower-based cellular system providing IMT-2000 service within the boundary of an administration.

Annex 1 describes a methodology for co-channel interference evaluation from a HAPS base station and cellular base stations to a cellular mobile station to provide IMT-2000. The *C*/*I* ratio is used as a criterion to set separation distance between a HAPS system and a cellular system. For evaluating the interference within a cellular system, a simplified extended version of Hata's model is applied. An example of calculation for the separation distance between a HAPS system and a cellular system is contained in Annex 2.

Appendices 1 and 2 present the equations for interference calculations used in Annex 1 and the antenna radiation pattern, respectively.

The ITU Radiocommunication Assembly,

considering

a) that new technology utilizing high altitude platform stations (HAPS) in the stratosphere is being developed;

b) that WRC-2000 made provision for use 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;

c) that Resolution 221 (WRC-2000) requested studies on sharing between HAPS and other stations within IMT-2000, and considered compatibility of HAPS within IMT-2000 with some services having allocations in the adjacent bands;

d) that, in accordance with Resolution 221, HAPS may be used as base stations within the terrestrial component of 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; the use by IMT-2000 applications using HAPS as base stations does not preclude the use of these bands by any station in the services to which they are allocated and does not establish priority in the Radio Regulations, *recommends*

1 that the methodology in Annex 1 be used as guidance for determining separation distance between HAPS systems and cellular systems to provide IMT-2000 service within the boundary of an administration in the frequency bands in *considering* b).

NOTE 1 – Recommendation ITU-R M.1456 should be referred to for the typical parameters regarding a HAPS system for sharing studies between a HAPS IMT-2000 and a cellular service in the frequency bands in *considering* b).

Annex 1

A methodology for co-channel interference evaluation to determine separation distance from a system using HAPS to a cellular system to provide IMT-2000 service within the boundary of an administration

1 Introduction

Recommendation ITU-R M.1456 provided a co-channel spectral power flux-density (spfd) limit on HAPS emissions at an administration's borders and out-of-band spfd limits on HAPS emissions on the Earth's surface, as well as HAPS performance requirements to protect terrestrial mobile stations and fixed stations operating in bands adjacent to transmissions from HAPS.

However, for designing a cellular system, the multi-users interference in the system should be considered as well as other services' interferences; the spectrum efficiency depends on the interference from the same and adjacent cells.

In this Recommendation, guidance is provided to estimate the co-channel interference effects into the terrestrial cellular IMT-2000 system, which is tower-based, from a HAPS IMT-2000 system within the boundary of an administration, considering two interferers: the same and adjacent cells interference in the cellular system itself, and the HAPS IMT-2000 interference. Since HAPS IMT-2000 interference is based on the HAPS antenna pattern described in Recommendation ITU-R M.1456, this pattern is used to evaluate the appropriate interference power of cellular systems so that all interference power can be derived. The interference to a cellular mobile station from cellular base stations and a HAPS base station is estimated in terms of the carrier to interference ratio (C/I) with the parameters of the HAPS system such as the number of users per cell, cell radius, and transmission power. For each estimated case, the optimum values are determined for the above parameters in the HAPS IMT-2000 system in order to be compatible with the cellular system. This Recommendation will give guidance for evaluating the separation distance between a HAPS IMT-2000 system and a cellular IMT-2000 system to IMT-2000 service providers using those different systems within an administration.

2 System model

2.1 HAPS IMT-2000

HAPS is being developed in accordance with Recommendation ITU-R M.1457 to possibly provide IMT-2000 service in the 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. In addition, HAPS as a base station to provide IMT-2000 will have its antenna pattern complied with the following:

$$G(\psi) = \begin{cases} G_m - 3(\psi/\psi_b)^2 & \text{dBi} \quad \text{for} \quad 0 \le \psi \le \psi_1 \\ G_m + L_N & \text{dBi} \quad \text{for} \quad \psi_1 < \psi \le \psi_2 \\ X - 60\log(\psi) & \text{dBi} \quad \text{for} \quad \psi_2 < \psi \le \psi_3 \\ L_F & \text{dBi} \quad \text{for} \quad \psi_3 < \psi \le 90° \end{cases} \tag{1}$$

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-inside-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)

$\psi_1 =$ $\psi_b \sqrt{-L_N/3}$ degrees

$\psi_2 =$ $3.745\psi_b$ degrees

$X =$ $G_m + L_N + 60\log(\psi_2)$ dB

$\psi_3 =$ $10^{\frac{X - L_F}{60}}$ degrees

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

$$\psi_b = \sqrt{\frac{7\,442}{10^{0.1 G_m}}} \qquad \text{degrees}$$

where G_m is the peak aperture gain (dBi).

2.2 Propagation model

For the cellular system, a simplified extended version of Hata's model is considered and for the HAPS system, the free space loss model is used.

This free space loss model is adequate for a high elevation angle and it should be used with precaution for low elevation angles, until a better model is developed for HAPS systems; at that time this methodology should be reviewed.

2.2.1 Simplified model of an extended version of Hata's model

An extended version of the Hata's model in equation (2) is widely used for the radio channel modelling of cellular systems in urban areas with a base station antenna height of 30 m and a mobile antenna height of 1.5 m.

$$L = 25.87 + 33.9 \log_{10}(F) + 35.2 \log_{10}(R) \tag{2}$$

where:

L: path loss (dB)

F: frequency (MHz)

R: range (km).

The general use of the fourth power path loss law in terrestrial cellular networks as a simplified extended version of Hata's model is applied as shown in equation (3) to simplify the derivation of the formula.

$$L = 25.87 + 33.9 \log_{10}(F) + 40 \log_{10}(R) \tag{3}$$

2.2.2 Free space loss model

$$L = 32.4 + 20 \log_{10}(F) + 20 \log_{10}(R) \tag{4}$$

where:

L: path loss (dB)

F: frequency (MHz)

R: range (km).

3 *C*/*I* analysis at a cellular mobile station and the required *C*/*I* to determine the separation distance between HAPS system and cellular system

3.1 *C*/*I* analysis at a cellular mobile station

Figure 1 shows the interference model to a cellular mobile station from cellular base stations and the HAPS base station. An interfered cellular mobile station is assumed to be located at the nearest point of the HAPS service area as shown in Fig. 1. The interference power received by a cellular mobile station can be obtained by equation (5), taking into account the interference from the cellular base stations and the HAPS base station (see Appendix 1). Since the cellular mobile station is located at the border of the coverage of the cellular system, it is assumed that the intra-cell interference is negligible.

$$I = I_{Cellular} + I_{HAPS} = \frac{\alpha_i S_i M_i l_i}{3} \sum_{n=1}^{N} c_{in} d_{in}^{-4} \left[1 + K \frac{c_{hn} d_{hn}^{-2}}{c_{in} d_{in}^{-4}} 10^{\frac{G(\varphi_{hn})}{10}} \right] \tag{5}$$

where:

α_i: voice activity factor in cellular system

S_i: cellular forward link power for the user at the edge of the cell (W)

M_i: number of cellular users per cell

l_i: cellular system path loss

c_{in}: number of interfering cells in cellular system (= $2n + 1$)

c_{hn}: number of interfering beams in HAPS base station (= $2n - 1$)

N: number of tier

d_{in}: distance between a cellular mobile station and cellular base stations (km)

d_{hn}: distance between a cellular mobile station and HAPS base station (km)

φ_{hn}: angle between a cellular mobile station and the beam direction of cell served by the HAPS base station (degrees)

K: $\left(= 3 \frac{\alpha_h S_h M_h l_h}{\alpha_i S_i M_i l_i} \right)$

α_h: voice activity factor in the HAPS system

M_h: number of HAPS users per cell

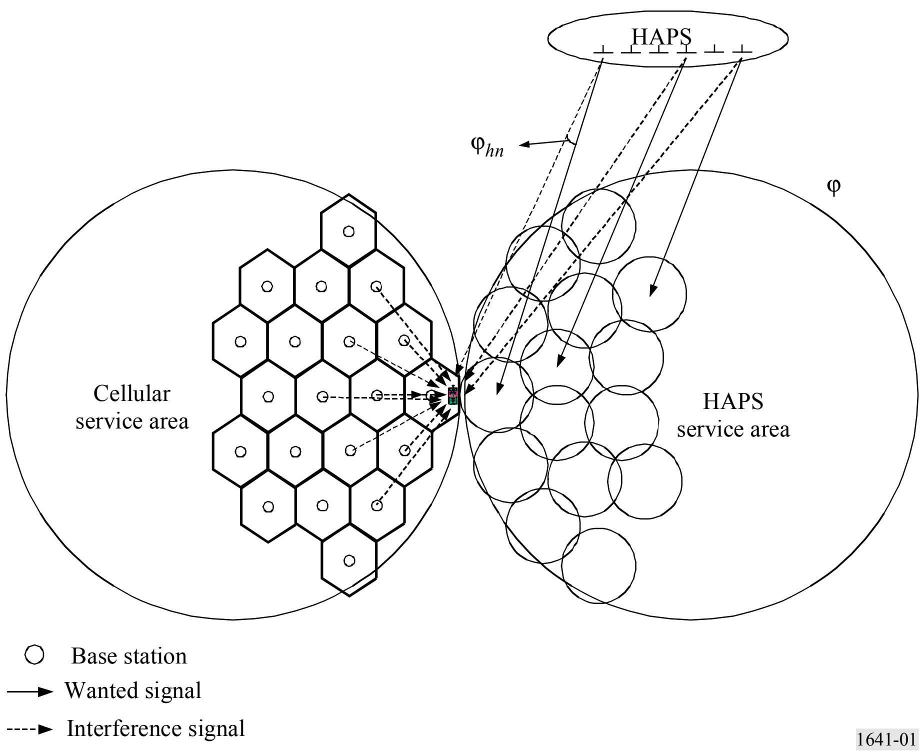
S_h: HAPS forward link power (W)

l_h: HAPS path loss

G: gain of the antenna as expressed in equation (1).

FIGURE 1

The interference model to a cellular mobile station



The C/I ratio of a cellular mobile station can be obtained by equation (6).

$$C/I = \frac{P_F(r_j) \times l_i \times R_i^{-4}}{I} \tag{6}$$

where:

$P_F(r_j)$: transmitted power dedicated for one user link at distance r_j

r_j: distance between the cellular base station for carrier and the j-th cellular user

R_i: cellular cell radius (km).

C/I is not the only method to be used for evaluating the separation distance, other methods such as the increase of noise can be used.

3.2 The required *C/I* to determine the separation distance

In this Recommendation, the separation distance is defined as a distance from the HAPS coverage contour to the coverage contour of the nearest cell serving the interfered cellular mobile station. In order to share the spectrum between the HAPS system and the cellular system to provide IMT-2000 service in adjacent area, it is necessary to set an appropriate separation distance. The required C/I in a cellular CDMA is expressed by equation (7):

$$(C/I)_{req} = \left(\frac{E_b}{I_0}\right)\left(\frac{R_b}{B_c}\right) \tag{7}$$

where:

E_b: the energy/bit

I_0: interference power/Hz

R_b: bit/s

B_c: radio channel bandwidth (Hz).

Annex 2

Example of calculation of separation distance between a HAPS system and a cellular system to provide IMT-2000 service

1 Parameters for *C/I* calculation

Table 1 shows parameters and values used to calculate the C/I at a cellular mobile station from a HAPS base station and cellular base stations.

TABLE 1

Parameters for *C*/*I* calculation

Parameter	Value
Frequency (MHz)	1 950
Number of users per cell	50
Number of interfering tiers	5
Cellular cell radius (km)	1
Cellular transmission power per user (mW)	100
HAPS altitude (km)	20
Radius of HAPS cell coverage (km)	55

With E_b/I_0 = 4.5 dB, R_b = 8 kbit/s and B_c = 1.25 MHz, $(C/I)_{req}$ = –17.438 dB.

Without the interference from adjacent cell, the required *C*/*I* is expressed by:

$$(C/I)_{req} = \frac{R^{-4}}{(M-1)R^{-4}} = \frac{1}{M-1} \tag{8}$$

where:

M: the total number of traffic channels

R: cell radius in cellular system.

If $(C/I)_{req}$ = –17.438 dB, *M* = 56.44. Equation (8) provides the radio capacity without the interference from other cells in the cellular system. The *C*/*I* obtained by equation (7) is used as a criterion to determine the separation distance between a HAPS system and a cellular system for IMT-2000 service.

The voice activity factors used, α_i and α_h, are 0.375.

2 Calculation of separation distance

For the interference analysis of a cellular system, in this example –17.4 dB of *C*/*I* is used as a criterion and is used to determine the separation distance between a HAPS system and a cellular system. This criterion should be considered as a limit for an operation of a mobile station; normally the criteria used is more stringent.

The number of interfered tiers is assumed to be up to 5, because the additional interference is negligible for a number of tiers greater than 5. The maximum antenna gain of the HAPS base station is considered to be adequate according to the HAPS cell radius.

From equation (5) and the above considerations, the calculated *C*/*I* as a function of the separation distance are shown in Figs. 2, 3 and 4 for the simplified extended Hata's model, taking into account the number of users per cell, transmission power and cell radius for HAPS, respectively.

FIGURE 2

***C/I* vs. separation distance with different numbers of HAPS users per cell**

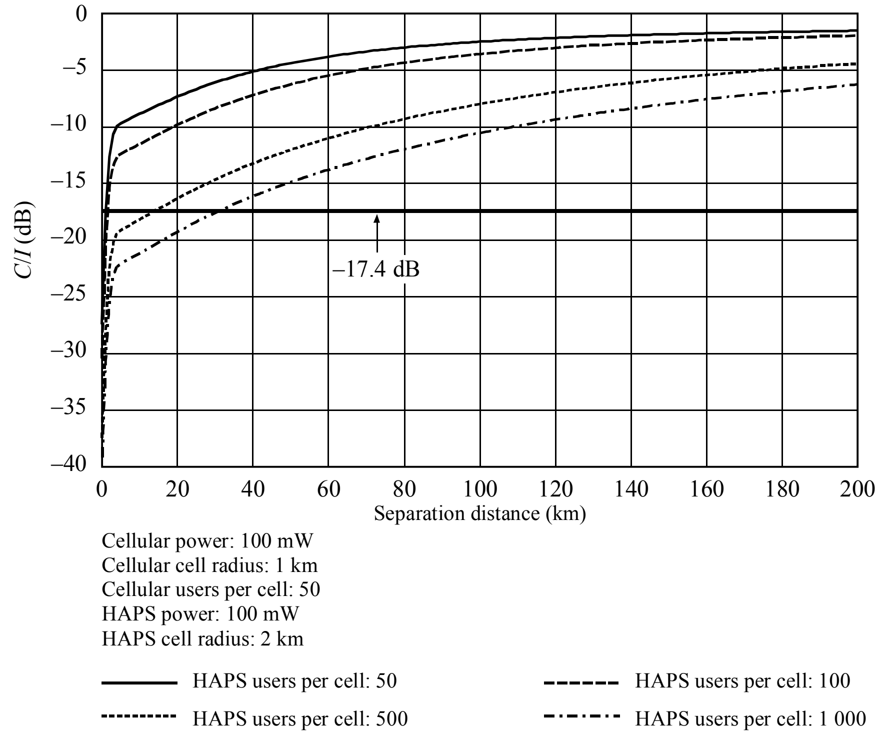


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FIGURE 3

***C/I* vs. separation distance with different transmission powers**

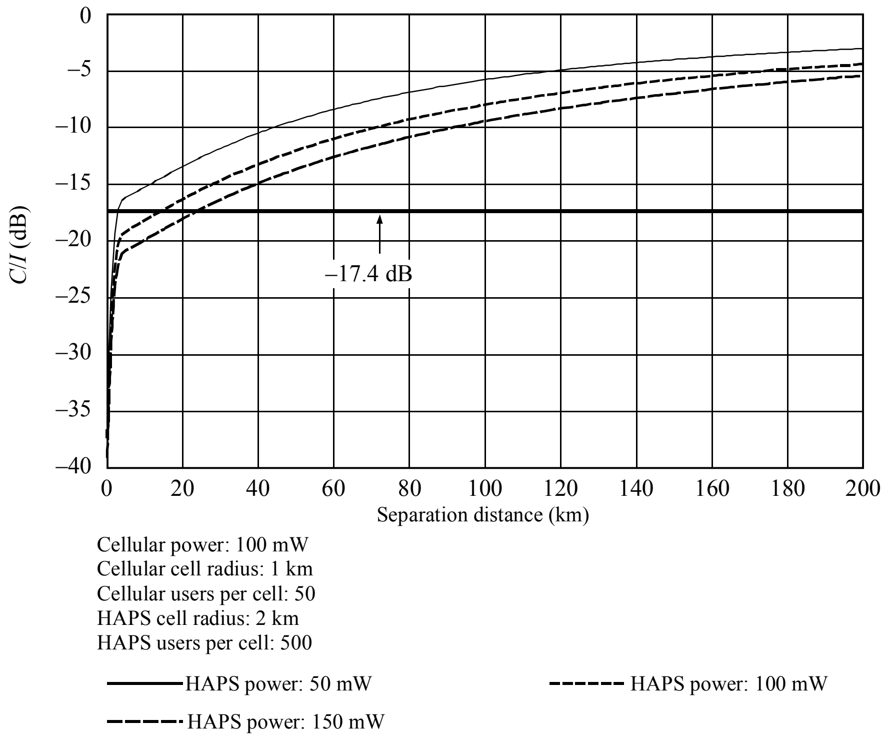

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FIGURE 4

***C/I* vs. separation distance with different HAPS cell radii**

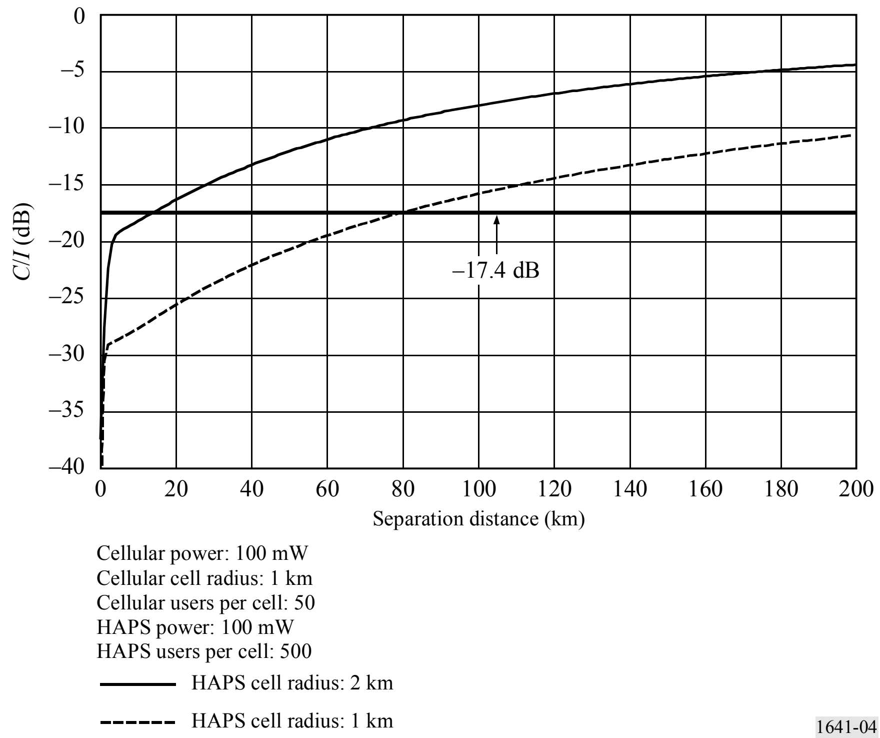

Figure 2 shows *C*/*I* as a function of the separation distance, taking into account the number of HAPS users per cell. The *C*/*I* values at a cellular mobile station are below the threshold value of –17.4 dB at the contact point of the two systems. When the HAPS transmission power per user is 100 mW and the HAPS cell radius is 2 km, the separation distances needed between the two systems are: 1.1, 1.6, 14 and 31.1 km for the numbers of HAPS users per cell of 50, 100, 500 and 1 000 respectively, as shown in Table 2.

Figure 3 shows *C*/*I* as a function of the separation distance, taking into account HAPS transmission power per user. The *C*/*I* values at a cellular mobile station are below the threshold value at the contact point of the two systems. When the number of HAPS users per cell is 500 and the HAPS cell radius is 2 km, the separation distances needed between the two systems are: 3.2, 14.2 and 23.5 km for the transmission powers per user of 50, 100 and 150 mW respectively, as shown in Table 3.

Figure 4 shows *C*/*I* as a function of the separation distance, taking into account HAPS cell radius. The *C*/*I* values at a cellular mobile station depend on the HAPS cell radius. When the number of HAPS users per cell is 500 and the transmission power per cell is 100 mW, the separation distances needed between two systems are: 14 and 80 km for HAPS cell radii of 2 and 1 km respectively, as shown in Table 4.

In the example of calculation with *C*/*I* = –17.4 dB, the *C*/*I* which would have been obtained assuming cellular deployment only (i.e. without HAPS) is about –8 dB, which means that a significant margin is allowed for external interference. In the second example of calculation, it is assumed that *C*/*I* would be limited to –12 dB.

TABLE 2

Separation distance with number of HAPS users per cell

HAPS users per cell	Separation distance (km)	
	C/*I* = –17.4 (dB)	*C*/*I* = –12 (dB)
50	1.1	2.1
100	1.6	7.2
500	14	50.2
1 000	31.1	79.5

TABLE 3

Separation distance with transmission power

HAPS power (mW)	Separation distance (km)	
	C/*I* = –17.4 (dB)	*C*/*I* = –12 (dB)
50	3.2	28.5
100	14.2	50.1
150	23.5	66.1

TABLE 4

Separation distance with HAPS cell radius

HAPS cell radius (km)	Separation distance (km)	
	C/*I* = –17.4 (dB)	*C*/*I* = –12 (dB)
1	80	165
2	14	50.1

Appendix 1
to Annex 1

Derivations of the interference between a HAPS system and a cellular system

1 Interference to a cellular mobile station

1.1 Interference from a cellular base station

The transmission power of a cellular base station considering simplified power control laws is given by:

$$P_F(r_j) = \begin{cases} \left(\frac{r_{i0}}{R_i}\right)^4 S_i & \text{for } 0 < r_j \le r_{i0} \\ \left(\frac{r_j}{R_i}\right)^4 S_i & \text{for } r_{i0} < r_j \le R_i \end{cases} \tag{9}$$

where:

R_i: cellular cell radius

r_j: distance to j-th mobile station within one cell

$P_F(r_j)$: power transmitted from the cell site to the j-th cellular user.

Let P_c denote the average power transmitted from a cell site. Following the power control law in equation (9):

$$\begin{aligned} P_c &= \alpha_i \rho_i \int_0^{R_i} P_F(r_j) \times 2\pi r_j \, \mathrm{d}r_j \\ &= 2\pi\alpha_i\rho_i \left[\int_0^{r_{i0}} \left(\frac{r_{i0}}{R_i}\right)^4 S_i r_j \, \mathrm{d}r_j + \int_{r_{i0}}^{R_i} \left(\frac{r_j}{R_i}\right)^4 S_i r_j \, \mathrm{d}r_j \right] \\ &= \frac{\pi\alpha_i\rho_i S_i R_i^2}{3} \left[1 + \left(\frac{r_{i0}}{R_i}\right)^6 \right] \end{aligned} \tag{10}$$

Let ρ_i denote user density and if $\rho_i = \frac{M_i}{\pi R_i^2}$, then P_c is rewritten by:

$$P_c = \frac{\alpha_i S_i M_i}{3} \left[1 + \left(\frac{r_{i0}}{R_i}\right)^6 \right] \tag{11}$$

Let $r_{i0} = 0.55\ R_i$, then $\left[1 + \left(\frac{r_{i0}}{R_i}\right)^6 \right] \approx 1.027 \approx 1$.

Therefore, equation (11) becomes:

$$P_c = \frac{\alpha_i S_i M_i}{3} \tag{12}$$

The total interference from cellular base stations into a cellular mobile station is given by:

$$I_{Cellular} = \sum_{n=1}^{N} c_{in} l_i P_c d_{in}^{-4} = \frac{\alpha_i S_i M_i l_i}{3} \left[\sum_{n=1}^{N} c_{in} d_{in}^{-4} \right] \tag{13}$$

1.2 Interference from a HAPS base station

The power per cell transmitted from a HAPS base station, P_h, is expressed by:

$$P_h = \alpha_h S_h M_h \tag{14}$$

The total interference from HAPS base stations to a cellular mobile station is given by:

$$I_{HAPS} = \sum_{n=1}^{N} c_{hn} l_h P_h 10^{\frac{G(\varphi_{hn})}{10}} d_{hn}^{-2} = \alpha_h S_h M_h l_h \left[\sum_{n=1}^{N} c_{hn} d_{hn}^{-2} 10^{\frac{G(\varphi_{hn})}{10}} \right] \tag{15}$$

where:

$l_h = 1.41 \times 10^{-10}$

$d_{hn} = \sqrt{r_{hn}^2 + h_s^2}$

r_{hn}: distance from a HAPS nadir to a cellular mobile station

h_s: altitude of a HAPS.

Appendix 2
to Annex 1

Antenna radiation patterns

1 Reference radiation pattern used (Recommendation ITU-R M.1456)

The characteristics assumed for the reference radiation pattern are shown in Fig. 5 considering antenna maximum gains of 23 dBi, 35 dBi and 50 dBi, respectively.

FIGURE 5

Antenna radiation patterns