International Telecommunication Union

# ITU-R

Radiocommunication Sector of ITU

**Recommendation ITU-R M.1641-1**
**(03/2006)**

# 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

**M Series**

**Mobile, radiodetermination, amateur and related satellite services**

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.*

*Electronic Publication*
Geneva, 2010

# RECOMMENDATION ITU-R M.1641-1*

## 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

(2003-2006)

**Scope**

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

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-03) requested studies on sharing between HAPS and other stations within IMT-2000, and considered the compatibility of HAPS within IMT-2000 with some services having allocations in the adjacent bands;

d) that, in accordance with No. 5.388A of the Radio Regulations (RR), 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 RR,

*recommends*

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

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* This Recommendation should be brought to the attention of Radiocommunication Study Group 9.

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) above.

# 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

## 1 Introduction

Recommendation ITU-R M.1456 provided a co-channel spectral power flux-density (spfd) limit on HAPS emissions 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 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 $C/I$ 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.

## 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:

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

where:

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

$G_m$: maximum gain in the main lobe (dBi)

$\psi_b$: 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:

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

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.

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

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.

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

### 2.2.2 Free space loss model

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

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.

$$I = I_{Cellular} + I_{HAPS} = \sum_{n=1}^{N} \left\{ K_c S_i 10^{\frac{G_i}{10}} \left[ \sum_{m=1}^{c_{in}} d_{inm}{}^{-4} \right] + K_h S_{hn} d_h{}^{-2} \left[ \sum_{m=1}^{c_{hn}} 10^{\frac{G_{hn}(\varphi_{hnm})}{10}} \right] \right\} \quad (5)$$

where:

$\alpha_i$: voice activity factor in cellular system

$S_i$: cellular forward link power from cellular base station to the user at the edge of each cell (mW)

$M_i$: number of cellular users per cell

$l_i$: cellular system path loss per kilometre

$c_{in}$: number of interfering cells of $n$-th tier in cellular system (= $2n + 1$, $n$: integer)

$N$: number of tier

$c_{hn}$: number of HAPS interfering beams in $n$-th tier within a distance of $(2N\text{-}1) \times$ (HAPS cell radius) around the edge of the victim cell under consideration

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

$d_h$: distance between a cellular mobile station and HAPS base station (km)

$\varphi_{hnm}$: angle between a cellular mobile station and the beam direction of cell served by the HAPS base station (degrees)

$S_{hn}$: HAPS forward link power from HAPS base station to the user at the edge of HAPS cell located in $n$-th tier (mW)

$G_i$: antenna gain of the base station in cellular system

$G_{hn}$: gain of the antenna as expressed in equation (1) according to tier

$$K_c = \frac{\alpha_i M_i l_i}{3}$$

$$K_h = \alpha_h M_h l_h$$

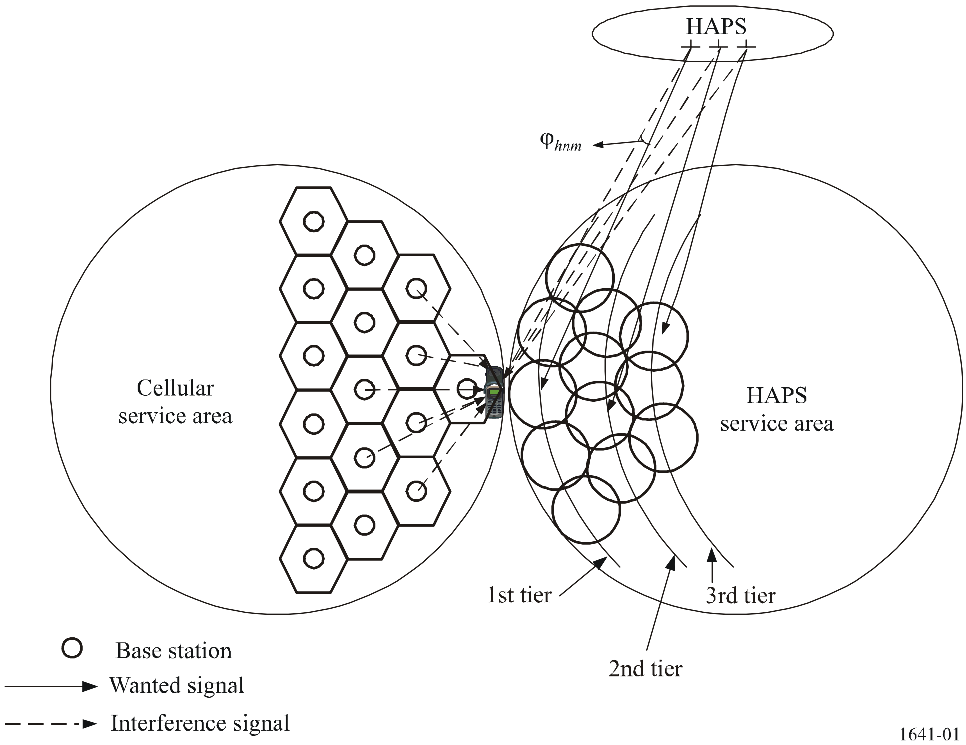
$\alpha_h$: voice activity factor in the HAPS system

$M_h$: number of HAPS users per cell

$l_h$: HAPS path loss per kilometre.

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).

$$C / I = \frac{P_F(r_j) \times 10^{\frac{G_i}{10}} \times l_i \times R_i^{-4}}{I} \tag{6}$$

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).

### 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 cellular 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 |
| Cellular voice activity factor ($\alpha_i$) | 0.375 |
| HAPS voice activity factor ($\alpha_h$) | 0.375 |

If $E_b/I_0$,$R_b$ and $B_c$ is 4.5 dB, 8 kbit/s, and 1.25 MHz, respectively, required $C/I$, $(C/I)_{req}$ is obtained −17.438 dB by equation (7).

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.

## 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 for the internal design $C/I$ of the terrestrial cellular system 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**

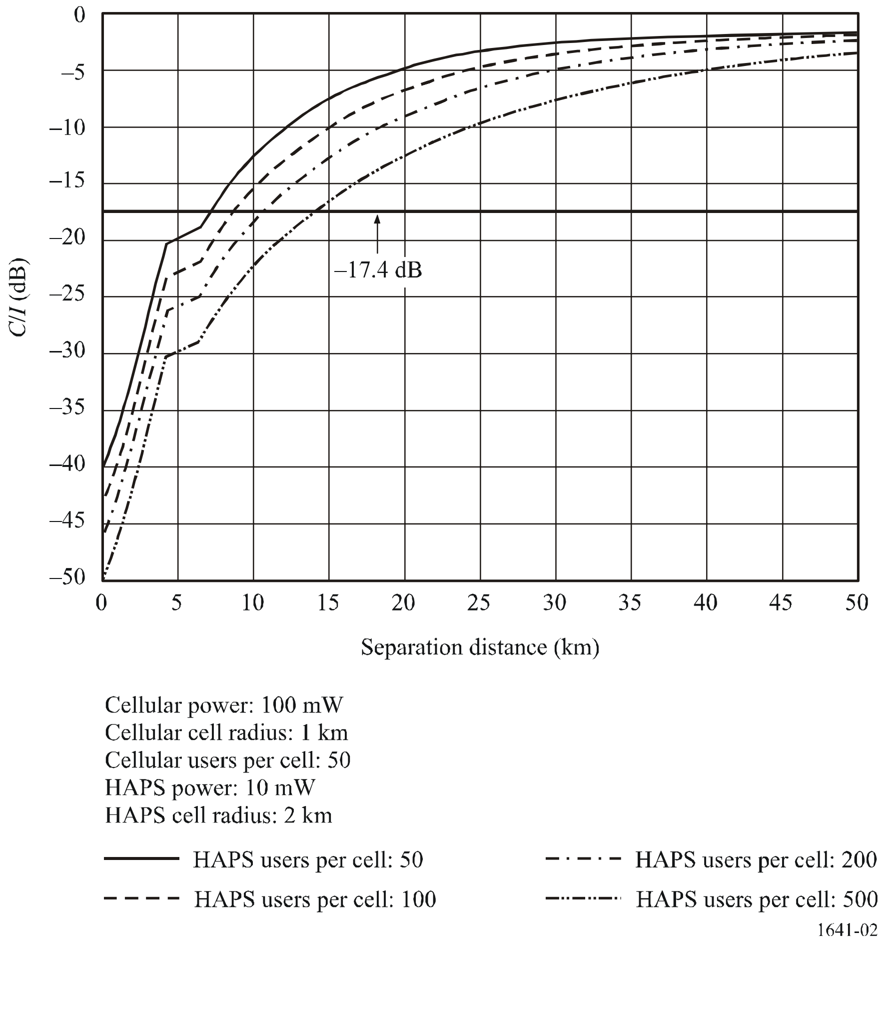


FIGURE 3

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

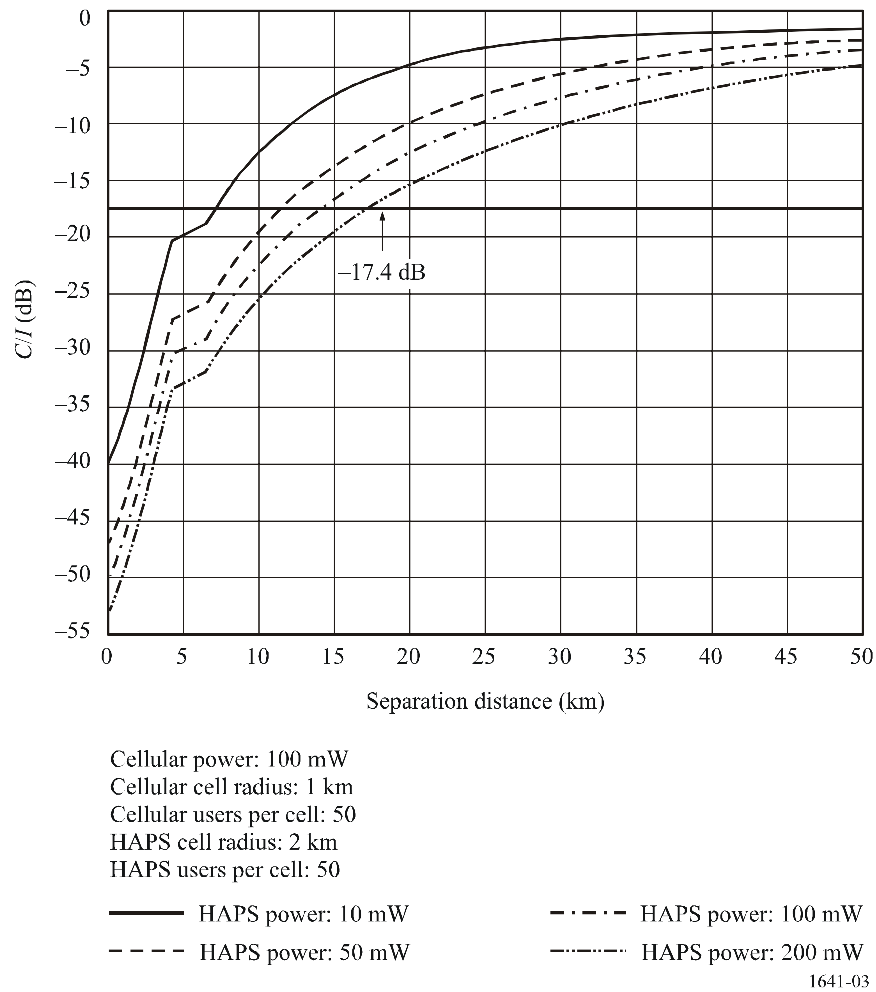


FIGURE 4

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

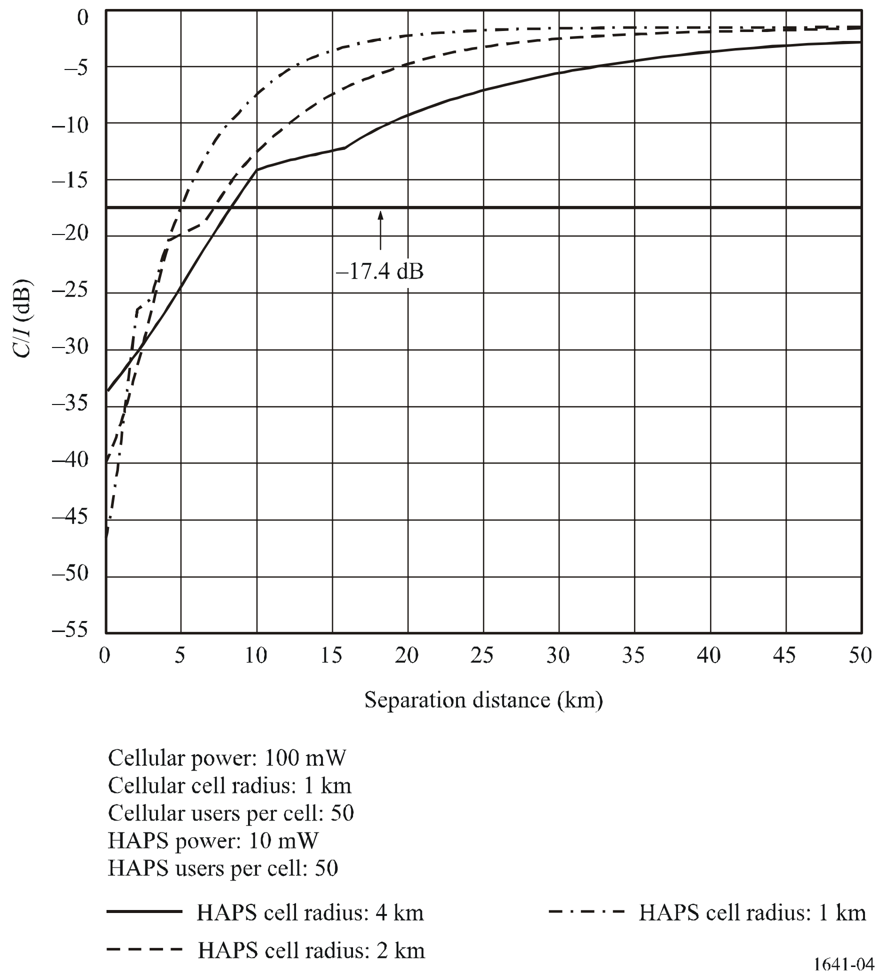



Figure 2 shows *C*/*I* as a function of the separation distance, taking into account the number of HAPS users per cell. The *C*/*I* values at a cellular mobile station are below the threshold value of –17.4 dB at the contact point of the two systems. When the HAPS transmission power per user is 10 mW and the HAPS cell radius is 2 km, the separation distances needed between the two systems are: 7.2, 8.8, 10.8 and 14.1 km for the numbers of HAPS users per cell of 50, 100, 200 and 500 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 50 and the HAPS cell radius is 2 km, the separation distances needed between the two systems are: 7.2, 11.5, 14.1 and 17.4 km for the transmission powers per user of 10, 50, 100 and 200 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 50 and the transmission power per cell is 10 mW, the separation distances needed between two systems are: 8.3, 7.2 and 5 km for HAPS cell radii of 4, 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 | 7.2 | 10.6 |
| 100 | 8.8 | 12.9 |
| 200 | 10.8 | 15.9 |
| 500 | 14.1 | 20.9 |

TABLE 3

**Separation distance with transmission power**

| **HAPS power (mW)** | **Separation distance (km)** | |
|---|---|---|
| | ***C*/*I* = –17.4 dB** | ***C*/*I* = –12 dB** |
| 10 | 7.2 | 10.6 |
| 50 | 11.5 | 17 |
| 100 | 14.1 | 20.9 |
| 200 | 17.4 | 25.7 |

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 | 5 | 7.1 |
| 2 | 7.2 | 10.6 |
| 4 | 8.3 | 16.1 |

# 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:

$$P_F(r_j) = \begin{cases} \left(\dfrac{r_{i0}}{R_i}\right)^4 S_i & \text{for} \quad 0 < r_j \le r_{i0} \\ \left(\dfrac{r_j}{R_i}\right)^4 S_i & \text{for} \quad r_{i0} < r_j \le R_i \end{cases} \tag{8}$$

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 the cellular base station. Following the power control law in equation (8), $P_c$ is expressed by:

$$\begin{aligned} P_c &= \alpha_i \rho_i \int_0^{R_i} P_F(r_j) \times 2\pi r_j \mathrm{d}r_j \\ &= 2\pi\alpha_i\rho_i \left[ \int_0^{r_{i0}} \left(\frac{r_{i0}}{R_i}\right)^4 S_i r_j \mathrm{d}r_j + \int_{r_{i0}}^{R_i} \left(\frac{r_j}{R_i}\right)^4 S_i r_j \mathrm{d}r_j \right] \\ &= \frac{\pi\alpha_i\rho_i S_i R_i^2}{3} \left[ 1 + \left(\frac{r_{i0}}{R_i}\right)^6 \right] \end{aligned} \tag{9}$$

where:

$\rho_i$: user density.

If $\rho_i = \dfrac{M_i}{\pi R_i^2}$, then $P_c$ is rewritten by:

$$P_c = \frac{\alpha_i S_i M_i}{3} \left[ 1 + \left(\frac{r_{i0}}{R_i}\right)^6 \right] \tag{10}$$

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

Therefore, equation (10) becomes:

$$P_c = \frac{\alpha_i S_i M_i}{3} \tag{11}$$

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

$$I_{Cellular} = \sum_{n=1}^{N}\left[\sum_{m=1}^{c_{in}} l_i P_c 10^{\frac{G_i}{10}} d_{inm}{}^{-4}\right] = \frac{\alpha_i S_i M_i l_i}{3} 10^{\frac{G_i}{10}} \sum_{n=1}^{N}\left[\sum_{m=1}^{c_{in}} d_{inm}{}^{-4}\right] \tag{12}$$

## 1.2 Interference from a HAPS base station

The power per cell in $n$-th tier transmitted from a HAPS base station, $P_{hn}$, is expressed by equation (14).To scale the same received power level at the edge of the cell in each service region, HAPS transmitting power per user in service area would be assumed as the following.

$$P_{hn} = \alpha_h S_{hn} M_h \tag{13}$$

$$S_{hn} = \begin{cases} \dfrac{l_i}{l_h}\dfrac{10^{(Gi/10)}}{10^{(G_{hn}/10)}}\dfrac{d_h{}^2}{r_i^4} S_i, & n=1 \\ \dfrac{10^{(G_{h(n-1)}/10)}}{10^{(G_{hn}/10)}}\dfrac{d_{hn}{}^2}{d_{h(n-1)}{}^2} S_{h(n-1)}, & n \geq 2 \end{cases}$$

where:

$S_{hn}$: HAPS forward-link power for the user at the edge of HAPS cell located in $n$-th tier

$d_{hn}$: distance from a HAPS base station to a HAPS mobile station of $n$-th tier located in the nearest point of cellular coverage.

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

$$I_{HAPS} = \sum_{n=1}^{N}\left[\sum_{m=1}^{c_{hn}} l_h P_h 10^{\frac{G_{hn}(\varphi_{hnm})}{10}} d_h{}^{-2}\right] = \alpha_h M_h l_h d_h{}^{-2}\left[\sum_{n=1}^{N} S_{hn} \sum_{m=1}^{c_{hn}} 10^{\frac{G_{hn}(\varphi_{hnm})}{10}}\right] \tag{14}$$

where:

$d_h = \sqrt{r_h{}^2 + h_s^2}$

$r_h$: 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**