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(02/2003)

Interference mitigation techniques for use by high altitude platform stations in the 27.5-28.35 GHz and 31.0-31.3 GHz bands

F Series

Fixed service

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 F.1607*

Interference mitigation techniques for use by high altitude platform stations in the 27.5-28.35 GHz and 31.0-31.3 GHz bands

(2003)

Scope

This Recommendation provides interference mitigation techniques for systems utilizing HAPS in the band 27.5-28.35 GHz and 31.0-31.3 GHz. These techniques could mitigate various interference effects to and from other systems sharing the same bands or operating in the adjacent bands. The Annex gives the outline and the advantages of these techniques which include increasing minimum elevation angles, improvement of antenna radiation patterns, shielding effects of HAPS airship envelope, dynamic channel assignment and automatic transmit power control.

The ITU Radiocommunication Assembly,

considering

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

recognizing

a) that the bands 27.9-28.2 GHz and 31.0-31.3 GHz may also be used for HAPS in the fixed service in certain countries on a non-harmful interference, non-protection basis,

recommends

1 that the following general interference mitigation techniques should be considered in the development of a system using HAPS in the 27.5-28.35 GHz and 31.0-31.3 GHz bands:

a) increasing minimum operational elevation angle;

b) improvement of radiation patterns of antennas on board HAPS and their ground stations;

c) shielding effect by HAPS airship envelope;

d) dynamic channel assignment;

e) automatic transmitting power control (ATPC);

2 that the following Notes are considered as part of this Recommendation.

NOTE 1 – Annex 1 describes general principles of the above interference mitigation techniques and Annex 2 gives a more detailed description of dynamic channel assignment.

NOTE 2 – Recommendation ITU-R F.1569 should be referred to for the HAPS system using the frequency bands 27.5-28.35 GHz and 31.0-31.3 GHz.

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* Radiocommunication Study Group 5 made editorial amendments to this Recommendation in December 2009 in accordance with Resolution ITU-R 1.

Annex 1

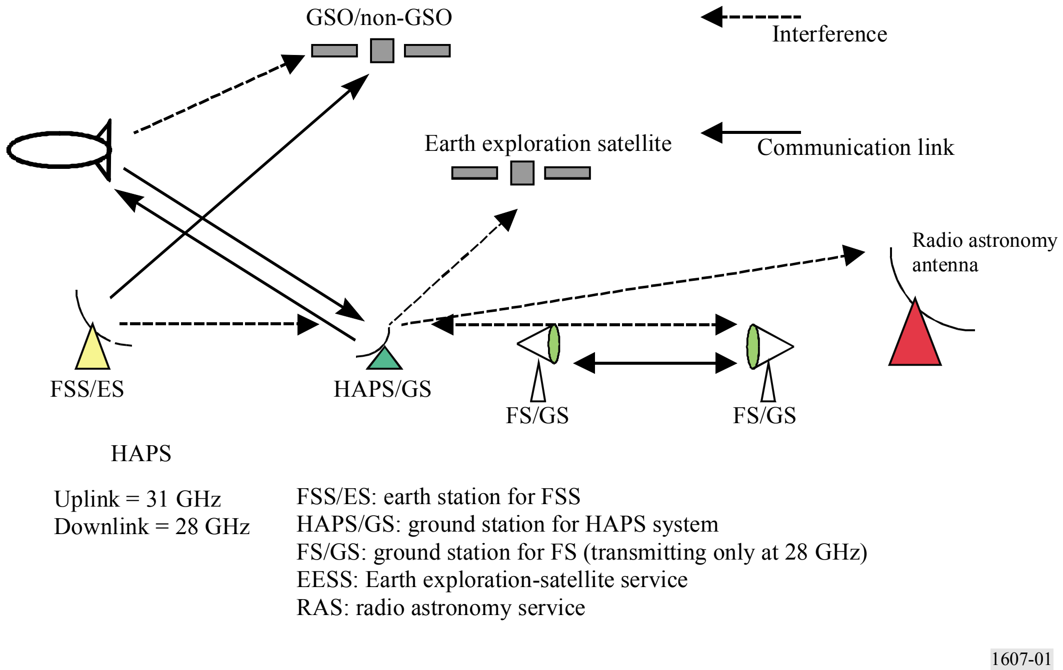
Interference mitigation techniques proposed for use by HAPS in the 27.5-28.35 GHz and 31.0-31.3 GHz bands

1 Interference situation

Figure 1 shows an example of interference situation between HAPS system and other services. This Annex lists the interference mitigation techniques for frequency sharing between the HAPS system with other services and describes their principle and advantages.

FIGURE 1

Interference situation including HAPS, FSS, FS, EESS, and RAS systems for uplink of 31 GHz and downlink of 28 GHz



2 Interference mitigation techniques

Table 1 summarizes the relation between the mitigation technique and its effective interference situation. The technical principle and advantages of each mitigation technique follow Table 1.

TABLE 1

Relation between interference mitigation techniques and interference scenarios

Systems for sharing and interference scenario / Interference mitigation techniques		FSS (in-band interference)		To/from FS (in-band)	Science service (interference to adjacent band)	
		To FSS satellite	From FSS/ES		To EESS satellite	To RAS station
1) Increasing minimum operational elevation angle			√	√		√
2) Improvement of radiation patterns of antennas on board HAPS and ground station		√	√	√		√
3) Shielding effect by HAPS airship envelope		√				
4) Dynamic channel assignment			√	√		
5) Automatic transmitting power control	HAPS uplink			√	√	√
	HAPS downlink	√		√		

√: Effective.

1) *Increasing minimum operational elevation angle*

Interferences from the FSS earth station to the HAPS ground station, that between FS ground station and HAPS ground station and that from the HAPS ground station to the RAS station could be reduced by increasing minimum operational elevation angle of HAPS ground station so as to increase antenna separation angle toward ground stations for other services. As a result, required separation distance could be shortened.

For example, in the case that the minimum operation angle of the HAPS ground station is increased from 20° to 40°, the separation distance is reduced to about half (0.42 in precise) as shown below. In the theoretical analysis, radiation pattern of HAPS ground station antenna in that range of off-axis angle is given by the following equation, Recommendation ITU-R F.1245:

$$G(\varphi) = 39 - 5 \log_{10}(D/\lambda) - 25 \log_{10}(\varphi)$$

where:

φ: off-axis angle (degrees)

D: antenna diameter

λ: wavelength

(D and λ expressed in the same units)

The difference between antenna gain for 20° off-axis and that for 40° is calculated to be about 7.5 dB. Therefore, the reduction is calculated by $1/\sqrt{10^{7.5/10}} = 0.42$, since path loss is proportional to the square of transmission distance. It is noted in the case of minimum elevation angle of 40° that the required number of HAPS airship needs to be increased so as to keep the total service coverage unchanged.

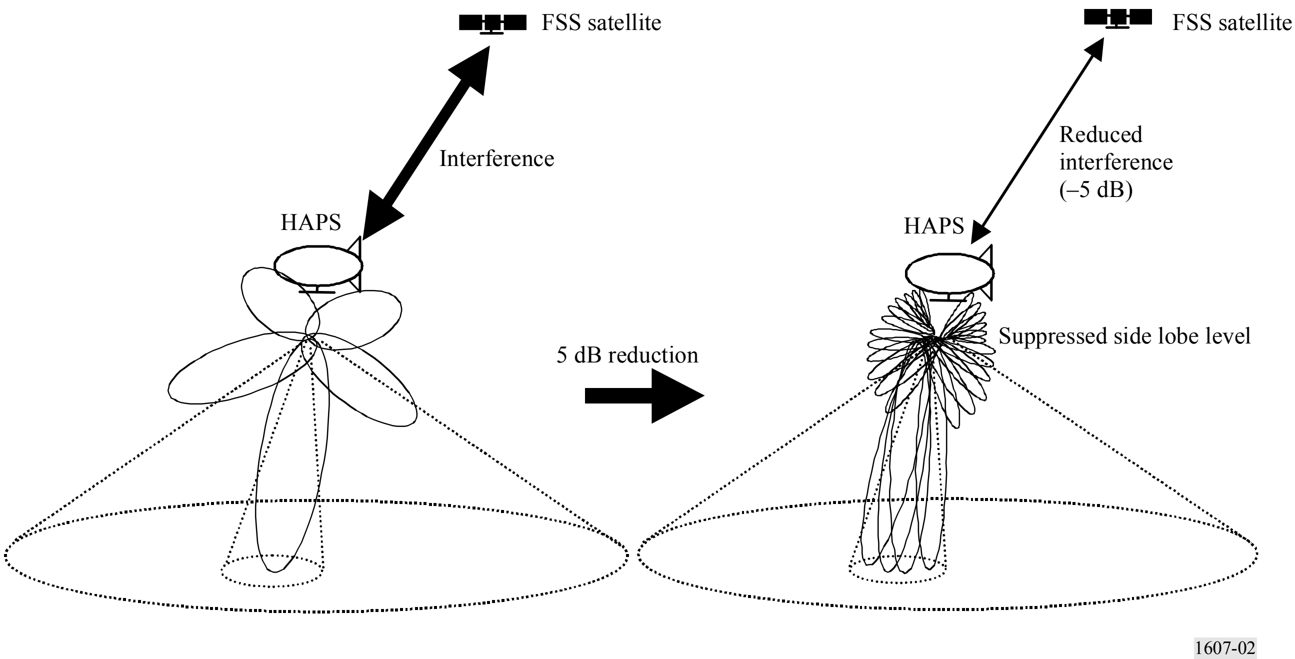
2) *Improvement of radiation patterns of antennas on board HAPS and ground station*

Interference from the HAPS airship to the satellite space segment could be reduced by pattern shaping of each beam of multibeam antenna on board HAPS airship, because the pattern shaping improves main-lobe and side-lobe characteristics.

As a preliminary study result, radiation power of side lobe and back lobe is expected to be reduced by about 5 dB, by shaping the antenna beam pattern having the worst characteristics with four cluster beams as depicted in Fig. 2. The improvement is due to the transmission power reduction by gain increase of the antenna for boresight and also due to side-lobe gain reduction.

FIGURE 2

Improvement of radiation pattern by beam shaping



Improvement of radiation pattern (gain suppression in the elevation angle smaller than the minimum operational elevation angle in HAPS system) of the antenna in the HAPS ground station is also effective to reduce interference between the HAPS ground station and stations on the ground in other services (station in FS, FSS earth station and RAS station).

3) *Shielding effect by HAPS airship envelope*

This effect is given from the metal coating of HAPS airship envelope. Interference calculation between HAPS airship and satellite space segment is reduced by taking into account shielding effect to the side-lobe and back-lobe beam characteristics of the antenna on board the HAPS airship.

The expected shielding effect is examined by electromagnetic scattering analysis using the model of 2-D cylindrical conductor with plane wave normal incidence. According to the analysis and its approximation in equation expression, the following shield effect mask could be used for the maximum diameter of HAPS airship body more than 15 m and frequency of signals higher than 20 GHz.

0 dB	for $0° \leq \theta \leq 90°$
$0.5(\theta - 90)$ dB	for $90° < \theta \leq 120°$
15 dB	for $120° < \theta \leq 180°$

where θ is the separation angle to the direction of interest (such as a satellite) from the nadir direction of HAPS.

The more precise value of shielding effect is required to be investigated by experiments.

4) *Dynamic channel assignment (DCA)*

DCA is the interference mitigation scheme, which searches a non-use frequency or time slot and utilizes it, not so as to give the interference to other services and not so as to be received from other services. When communication systems operate on a demand-assignment basis, DCA using self-controlled scheme is effective for sharing with other services.

As one example, dynamic channel activity assignment system (DCAAS) could be referred, which is facilitated in the LEOTELECOM-1 mobile-satellite service satellite system (non-GSO). In replacing the non-GSO satellite system using DCAAS with HAPS-based system, one example of DCA for HAPS is as follows:

– HAPS airship includes on-board frequency monitoring function;

– it monitors the status of frequency use of other systems with which frequency sharing is done;

– HAPS system assigns monitored non-use frequency slot for communication link.

In the situation that the frequency sharing is required in the same frequency band and the same service area, only the DCA scheme could be effective. Preliminary study results of DCA applied to the frequency sharing between HAPS system and fixed wireless access (FWA) system is attached to Annex 2.

5) *Automatic transmitting power control (ATPC)*

In the radiocommunication system using higher frequency band, the system design takes into account the rain attenuation. To compensate the attenuation, the transmission power is increased by the value of rain attenuation. The ATPC scheme has the function to control the output power in monitoring the weather condition or receiving power. The transmission power is increased under the rain condition and it is decreased under the clear-sky condition.

Since the ATPC is essentially the scheme to avoid the unnecessary higher transmission power of signal, the ATPC is useful from the viewpoint of the interference reduction. In the case of in-band interference between the HAPS ground station and the ground station for FS, its effect directly appears. In the case of interference resulting from unwanted emissions, which may affect the science services such as EESS and RAS using the adjacent band, the ATPC could bring about the reduction of the unwanted emission level.

The ATPC at the HAPS on-board transmitter of individual spot beams reduces the downlink interference into satellites using the same band under the clear-sky condition, whereas the interference power increases under rain condition. The hard rain areas that need high power transmission by ATPC and the time percentage for such needs, however, would actually be very limited and impact of the aggregate interference from all the spot beams and all the HAPSs into the satellites could not be so much.

Regarding the out-of-band noise level of the RF module such as high power amplifier, it is necessary to study the effect of the ATPC to the noise level performance through the hardware manufacturing.

Annex 2

Dynamic channel assignment to facilitate sharing the 27.5-28.35 GHz and 31.0-31.3 GHz bands between the FS using HAPS and conventional FS stations

1 Introduction

For the FS using HAPS, WRC-2000 decided to allow the use of the band 27.5-28.35 GHz for downlink (HAPS-to-ground direction) and 31.0-31.3 GHz for uplink (ground-to-HAPS direction) in interested countries on non-harmful interference and non-protection basis (RR No. 5.537A and No. 5.543A). Because these bands have primary allocation to FS, HAPS-based FS is subject to share those bands with other FS systems.

Among some possible mitigation techniques, DCA is a strong candidate to facilitate sharing between those services. This Annex provides the current status of feasibility study on the DCA in the HAPS-based FS to be introduced to share with other conventional FS systems. The study focuses on the feasibility of sensing FS carriers at the HAPS system when the conventional FS, point-to-multipoint (P-MP) FWA is considered.

2 Interference paths and carrier sensing for DCA

There are the following interference paths between HAPS-based FS and P-MP FS sharing the 28 GHz band or the 31 GHz band (see Fig. 3):

(i) interference from HAPS GS to FS SUB (31 GHz);

(ii) interference from HAPS GS to FS HUB (31 GHz);

(iii) interference from HAPS AS to FS SUB (28 GHz);

(iv) interference from HAPS AS to FS HUB (28 GHz);

(v) interference from FS SUB to HAPS GS (28 GHz);

(vi) interference from FS SUB to HAPS AS (31 GHz);

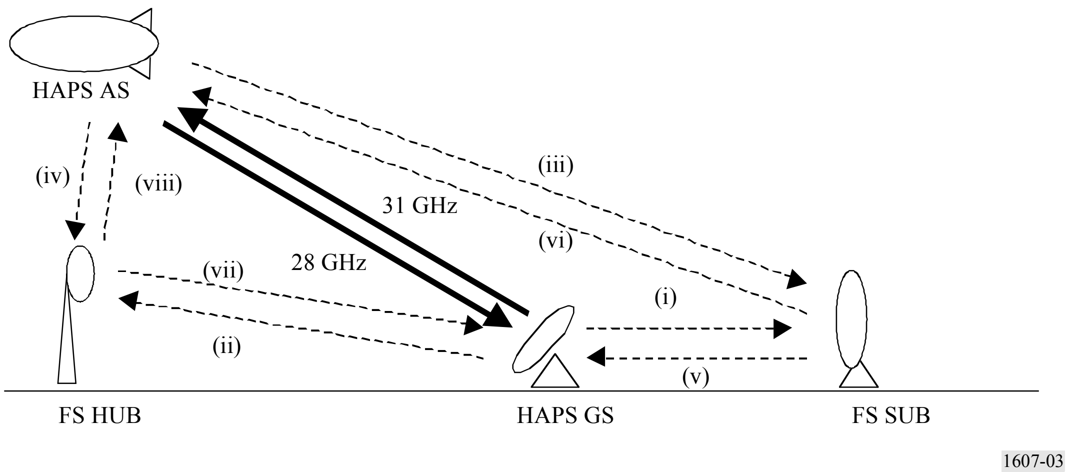
(vii) interference from FS HUB to HAPS GS (28 GHz);

(viii) interference from FS HUB to HAPS AS (31 GHz).

NOTE 1 – HAPS GS: HAPS ground station
HAPS AS: HAPS airship station
FS SUB: FS subscriber station
FS HUB: FS hub station.

FIGURE 3

Interference paths



This Annex deals with the paths (i), (ii), (iii) and (iv), which could give a serious impact on the conventional FS stations. The interference in other paths will be dealt with in further studies. However, the paths (v)-(viii) could be easily manageable in the HAPS system by channel assignment avoiding channels in which interference is detected at the stations in HAPS system.

In order to use DCA in HAPS system, first of all, HAPS system should sense channels in use by other FS system. Then HAPS system can avoid interfering to the FS system or being interfered by the FS system by assigning channels that are not in use by the FS system. There are two options to sense channels in use by the FS system, assuming HAPS system does not have any prior information on the channels:

– HAPS GS senses carriers transmitted by FS SUB or FS HUB;

– HAPS AS senses carriers transmitted by FS SUB or FS HUB.

However, the sensing could not be easy, particularly when the interference paths are (i) and (ii) and the FS system uses frequency division duplex (FDD). In some cases the HAPS GS could give a large interference to an FS station but neither HAPS AS nor HAPS GS can sense any carrier in use by the FS station because both HAPS system and FS system use directional antennas with low side lobes in high frequency. HAPS system could sense channels in use by FS system only when FS system uses time division duplex (TDD) or when HAPS system knows pair channels used for FDD in the FS system.

3 Methodology for calculation and assumed system parameters

Sensing levels of FS signal at HAPS GS and AS are calculated as:

$$P_{GS} = P_{FSTX} + G_{FSTX}(a_{GS}) - L(d_{FS-GS}) + G_{GSRX}(a_{FS}) - L_{GSRX} - 10 \log B_{FS} \quad \text{dB(W/MHz)} \qquad (1)$$

$$P_{AS} = P_{FSTX} + G_{FSTX}(a_{AS}) - L(d_{FS-AS}) - L_{atm}(h,\theta) + G_{ASRX}(a_{FS}) - L_{ASRX} - 10 \log B_{FS} \quad \text{dB(W/MHz)} \qquad (2)$$

where:

P_{GS}: receiving power at HAPS GS (dBW)

P_{AS}: receiving power at HAPS AS (dBW)

P_{FSTX}: transmitting power at FS station (HUB or SUB) (dBW)

$G_{FSTX}(a)$: transmitting antenna gain of FS station in the angle a from boresight (dBi)

a_{GS}: off-axis angle at FS station to HAPS GS (degrees)

a_{AS}: off-axis angle at FS station to HAPS AS (degrees)

$L(d)$: free space loss for distance d (dB)

$L_{atm}(h,\theta)$: atmospheric absorption loss for altitude of FS station h and elevation angle θ (dB)

d_{FS-GS}: distance between FS station and HAPS GS (km)

d_{FS-AS}: distance between FS station and HAPS AS (km)

$G_{GSRX}(a)$: receiving antenna gain of HAPS GS in the angle a from the boresight (dBi)

$G_{ASRX}(a)$: receiving antenna gain of HAPS AS in the angle a from the boresight (dBi)

a_{FS}: off-axis angle at HAPS GS or AS to FS station (degrees)

L_{GSRX}: internal loss in the receiver of HAPS GS (dB)

L_{ASRX}: internal loss in the receiver of HAPS AS (dB)

B_{FS}: bandwidth of FS signal (MHz).

Raised noise level by sensing FS signals at the receivers of HAPS GS and AS is calculated as:

$$\Delta N_{GS} = 10 \log\left(10^{\frac{P_{GS}}{10}} + 10^{\frac{N_{GS}}{10}}\right) - N_{GS} \qquad \text{dB} \tag{3}$$

$$\Delta N_{AS} = 10 \log\left(10^{\frac{P_{AS}}{10}} + 10^{\frac{N_{AS}}{10}}\right) - N_{AS} \qquad \text{dB} \tag{4}$$

where:

ΔN_{GS}: raised noise level at the receiver of HAPS GS (dB)

ΔN_{AS}: raised noise level at the receiver of HAPS AS (dB)

N_{GS}: system noise power density at the receiver of HAPS GS (dB(W/MHz))

N_{AS}: system noise power density at the receiver of HAPS AS (dB(W/MHz)).

Interference power from HAPS GS to the FS station is calculated as:

$$I_{FS} = P_{GSTX} + G_{GSTX}(a_{FS}) - L(d_{GS-FS}) + G_{FSRX}(a_{GS}) - L_{FSRX} - 10 \log B_{FS} \qquad \text{dB(W/MHz)} \tag{5}$$

where:

I_{FS}: interference power received at FS station (HUB or SUB) (dBW)

P_{GSTX}: transmitting power at HAPS GS (dBW)

$G_{GSTX}(a)$: transmitting antenna gain of HAPS GS in the angle a from boresight (dBi)

$G_{FSRX}(a)$: receiving antenna gain of FS station in the angle a from the boresight (dBi)

L_{FSRX}: internal loss in the receiver of FS station (dB).

I/N (interference-to-noise power ratio) at the FS station is given by:

$$I/N = I_{FS} - N_{FS} \qquad \text{dB} \tag{6}$$

where:

N_{FS}: noise power density in the receiver of FS station (HUB or SUB) (dB(W/MHz)).

Internal losses in the receivers of HAPS GS, AS, and FS stations are assumed to be 0.5 dB. The atmospheric absorption loss $L_{atm}(h,\theta)$ between FS stations and HAPS AS can be calculated from the formulas given in Annex 1 of Recommendation ITU-R F.1609. Table 2 shows major parameters in FS system used in the calculation. Parameters of HAPS system are shown in Table 5 b) in Recommendation ITU-R F.1569. The example parameters of FS (P-MP) system include relatively low transmitting power in order to evaluate the feasibility of sensing FS signals at stations in HAPS system under the severe condition. Figure 4 shows the sector antenna pattern of FS HUB used in this study. The elevation pattern is calculated from the method given in Recommendation ITU-R F.1336-1 and the azimuth pattern is provisionally derived as a mask pattern from the pattern given in Fig. 15 in Annex 3 of Recommendation ITU-R F.1336-1. The antenna height of FS HUB and SUB are assumed to be zero metres from the ground in this study. The evaluation with FS SUB with some elevation angles may be included in further study.

TABLE 2

Parameters in FS system (P-MP)

Frequency	GHz	31.15
Altitude of FS HUB and FS SUB	km	0
Bandwidth	MHz	26
FS HUB		
Transmitter power	dBW	–4
Transmitter antenna gain	dBi	15
Receiver antenna gain	dBi	15
Noise figure	dB	6
Reference antenna pattern	Recommendation ITU-R F.1336	
FS SUB		
Transmitter power	dBW	–20
Transmitter antenna gain	dBi	32
Receiver antenna gain	dBi	32
Noise figure	dB	6
Reference antenna pattern	Recommendation ITU-R F.1245	

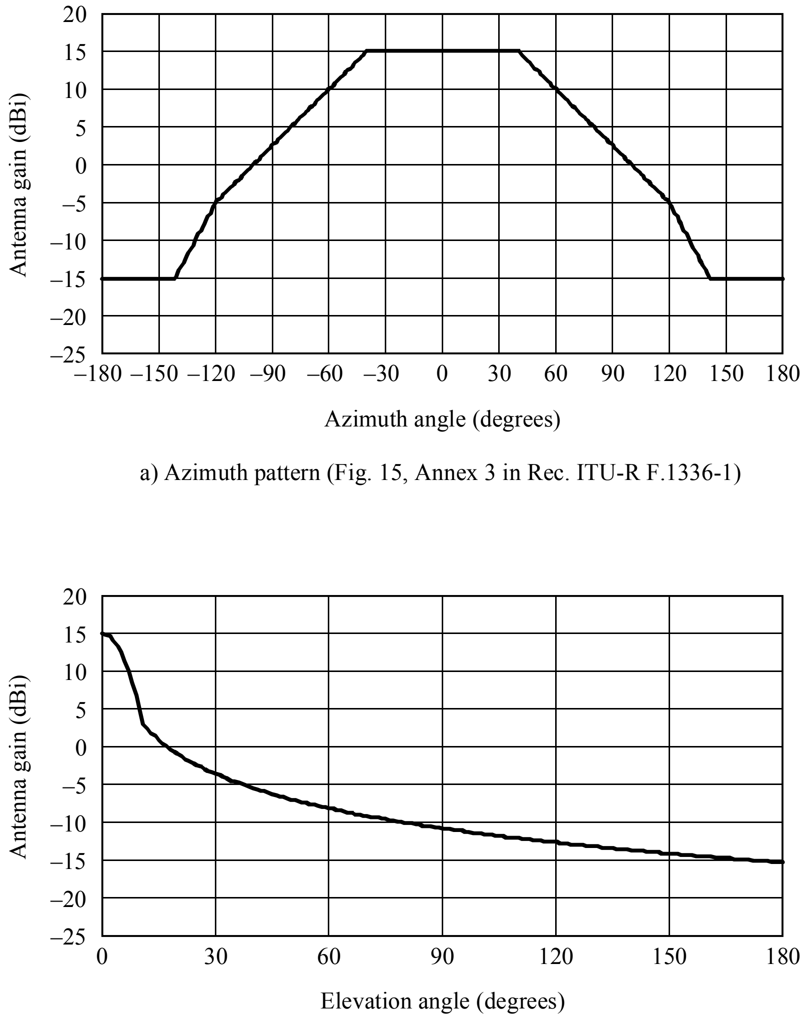
4 Calculation results

In the calculation, three cases of typical geographical location of HAPS and the FS stations are assumed according to the relative location of FS stations as shown in Fig. 5. In the figure, G_a, G_b, G_c and G_d represent the typical location of HAPS GS and F_o, F_a, F_b and F_c represent the typical location of FS HUB or SUB. Distance between FS SUB and HUB and that between F_o and the nadir of HAPS AS is fixed to 2 km and 50 km, respectively. In those cases, HAPS GS is about to transmit a signal to HAPS AS or HAPS AS is about to transmit a signal to HAPS GS, and HAPS GS or HAPS AS monitors channels in use by the FS system. If HAPS GS or HAPS AS can sense the channels in use, HAPS system can search other channels that are not in use and can assign the channel for use by HAPS system to avoid interference to the FS system.

The following calculation examines the sensing level of the signal transmitted by FS HUB or FS SUB and the expected interference level given to the FS receiver in HUB or SUB, in terms of the distance between F_o and HAPS GS. The signal sensing threshold is assumed to be 1 dB in raised noise level in the receiver of HAPS GS or AS and the interference criteria for FS system is assumed to be $I/N = -10$ dB.

FIGURE 4

Sector antenna patterns for FS HUB used in this study



a) Azimuth pattern (Fig. 15, Annex 3 in Rec. ITU-R F.1336-1)

b) Elevation pattern (Fig. 16, Annex 3 in Rec. ITU-R F.1336-1)

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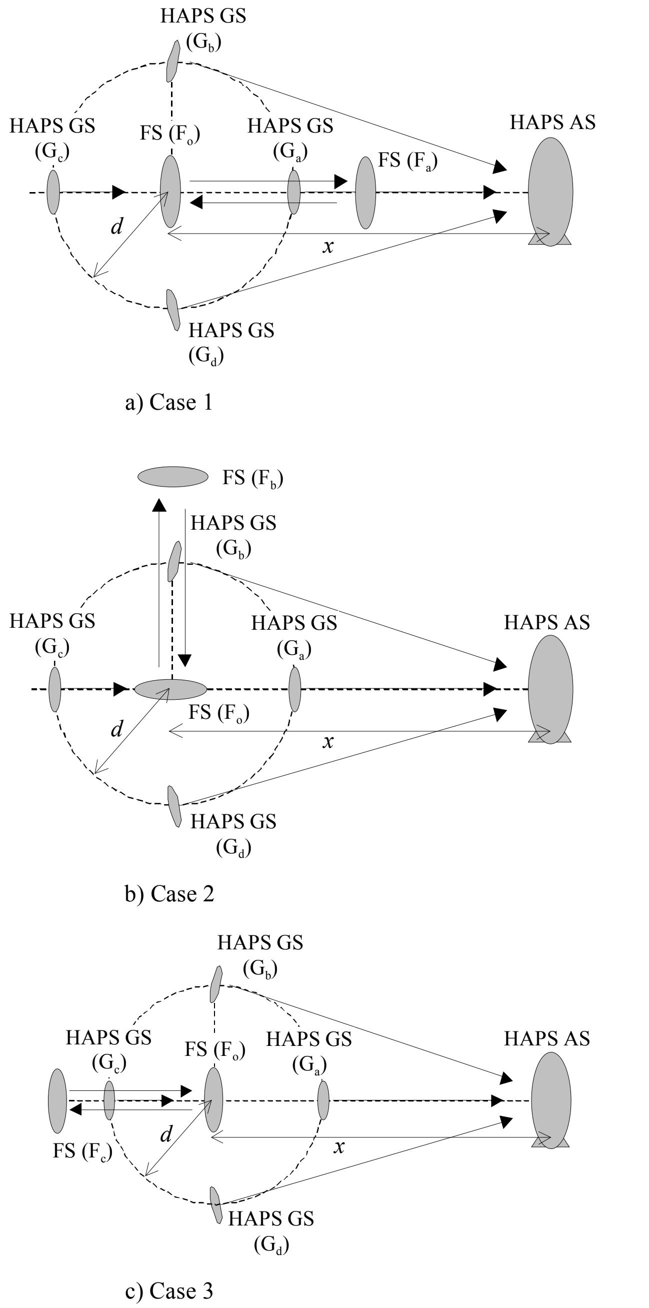
FIGURE 5

Typical geographical location of HAPS and the FS stations (top views)



Note – F_o, F_a, F_b, F_c: location of the FS stations
G_a, G_b, G_c, G_d: location of HAPS ground stations
AS: airship station
d: distance between F_o and HAPS ground stations
x: ground distance between airship station and FS (F_o)

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a) Case 1

The calculated result in Case 1 is shown in Figs 6A and 6B when FS SUB or FS HUB is located at F_o or F_a. These Figures show the following features:

– When the FS SUB and FS HUB are located at F_a and F_o, respectively (Fig. 6A), the FS SUB seriously receives interference from HAPS GS at G_a and G_c (Fig. 6A c)).

– However, only the HAPS GS at G_a can sense the FS HUB signal as long as $d > 1$ km and the DCA may not be feasible (Fig. 6A a)).

– Signal sensing at HAPS AS could also be very difficult.

– If the FS system uses TDD or the HAPS system knows one of the pair channels of FS SUB signal in the uplink of the FS system using FDD, the HAPS system can get channel information of FS HUB signal in downlink by sensing FS SUB signal. Figure 6A b) shows that HAPS GS at G_a and G_c can sense the FS SUB signal, which are almost the same as those giving interference to FS SUB, and that the DCA could be feasible.

– Almost the same situation takes place in Figure 6B, which shows the result when FS SUB and FS HUB are located at F_o and F_a, respectively.

– HAPS AS may not give interference to both FS HUB and SUB c) in Figs 6A and B).

FIGURE 6A

FS HUB at the location F_o and FS SUB at the location F_a in Case 1 ($F_x = F_a$)

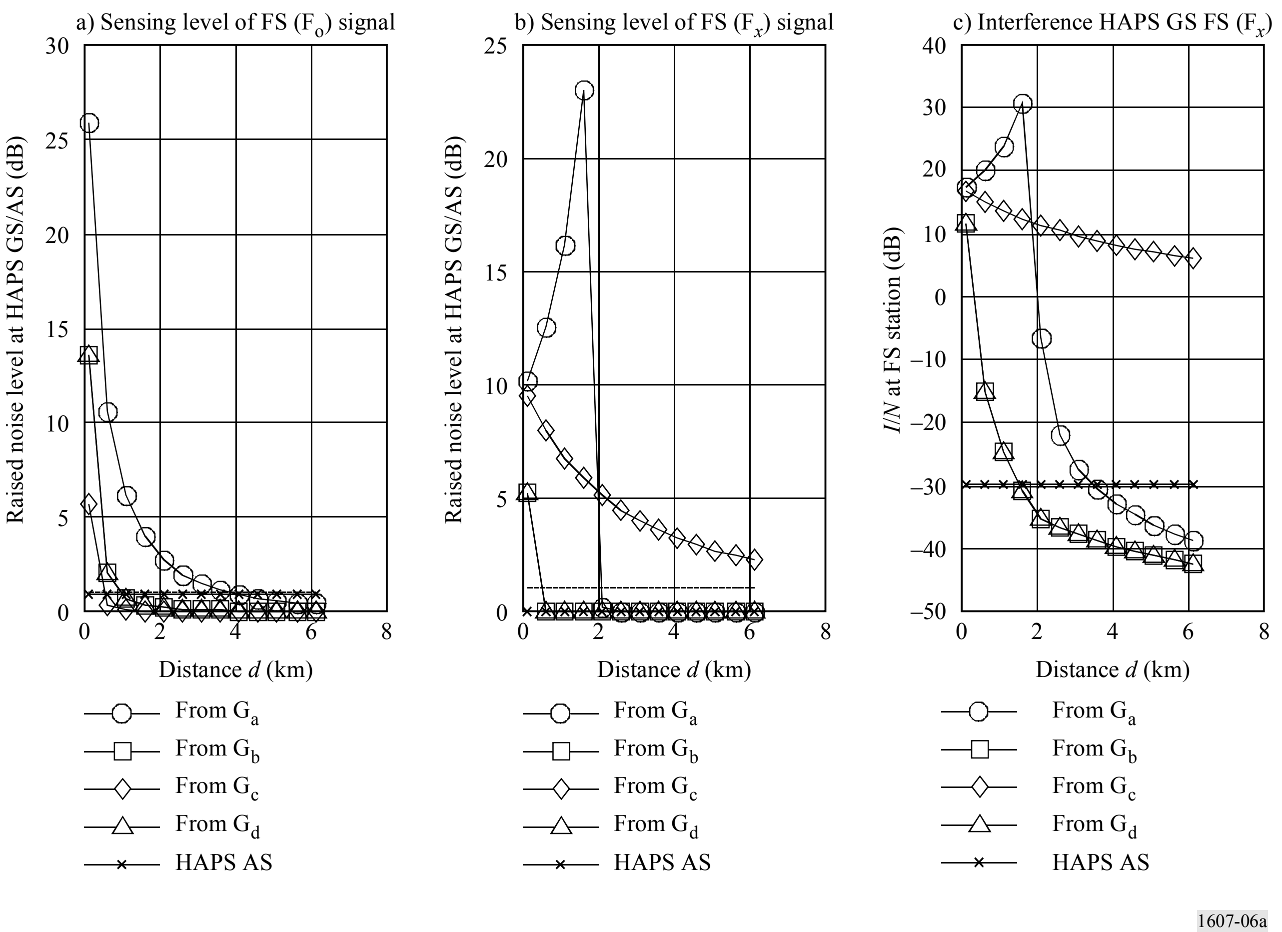
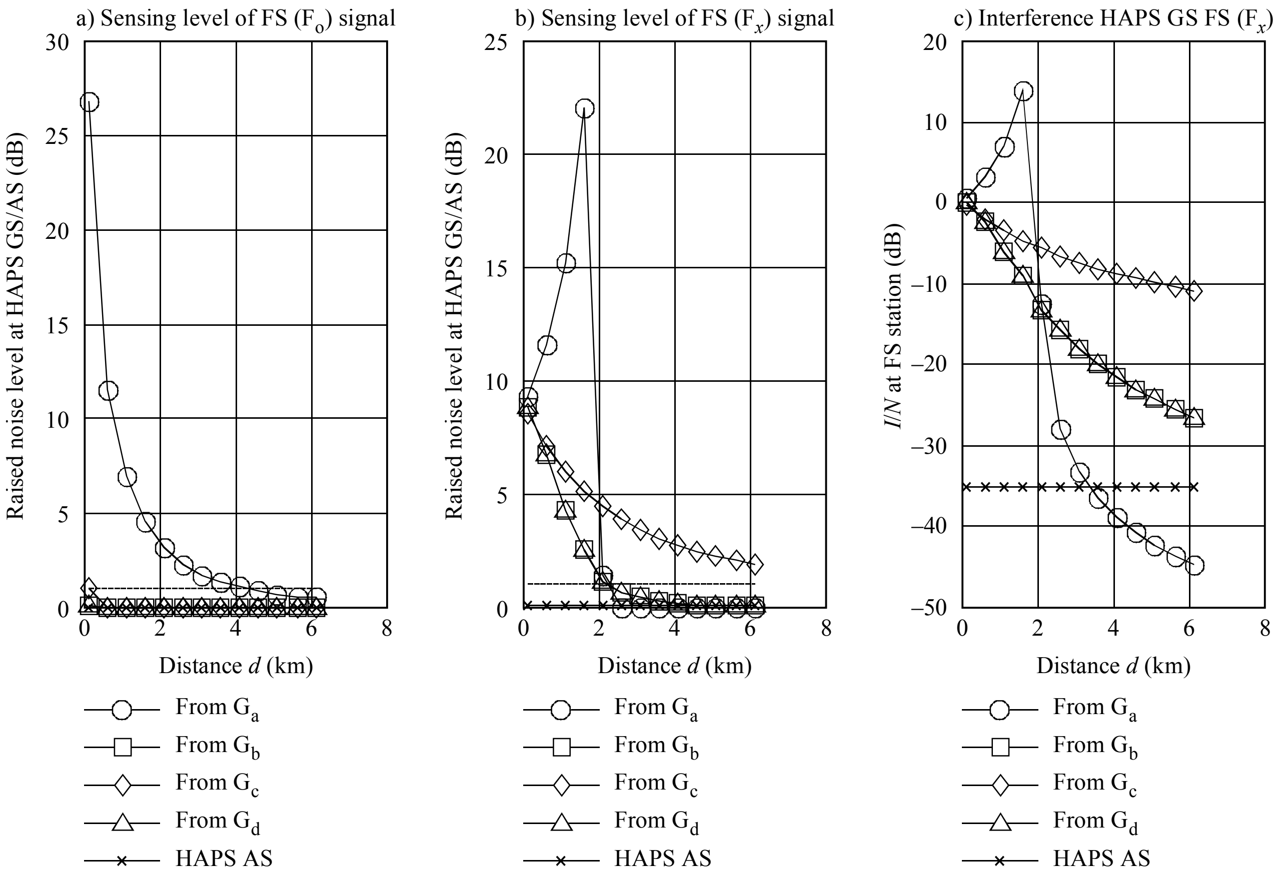


FIGURE 6B

FS SUB at the location F_o and FS HUB at the location F_a in Case 1 ($F_x = F_a$)



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b) Case 2

The calculated result in Case 2 is shown in Figs 7A and 7B when FS SUB or FS HUB is located at F_o or F_b. These Figures show the following features:

– When FS HUB and SUB are located at F_o and F_b, respectively (Fig. 7A), FS SUB is interfered by HAPS GS at G_b and G_d (Fig. 7A c)).

– However, HAPS GS at G_b and G_c can sense the FS SUB signal as long as d > 1 km and the DCA may not be feasible (Fig. 7A a)).

– Signal sensing at HAPS AS could also be very difficult.

– If the FS system uses TDD or the HAPS system knows one of the pair channels of FS SUB signal in uplink of the FS system using FDD, the HAPS system can get channel information of FS HUB signal in downlink by sensing FS SUB signal. Figure 7A b) shows that HAPS GS at G_b can sense the FS SUB signal and also HAPS GS at G_d can sense it when d < 2 km.

Therefore DCA is feasible when $d < 2$ km. For $d > 2$ km, the off-axis transmitting antenna gain of HAPS GS needs to be reduced by at least about 15 dB or the carrier sensing threshold at HAPS GS needs to be decreased to about 0.3 dB to make DCA available.

– When FS HUB and SUB are located at F_b and F_o, respectively (Fig. 7B), only HAPS GS at G_b interferes FS HUB and HAPS GS at G_b can sense both FS HUB signal and SUB signal. Therefore the DCA could be feasible.

– HAPS AS may not give interference to both FS HUB and SUB in Figs 7A c) and B c)).

FIGURE 7A

FS HUB at the location F_o and FS SUB at the location F_b in Case 2 ($F_x = F_b$)

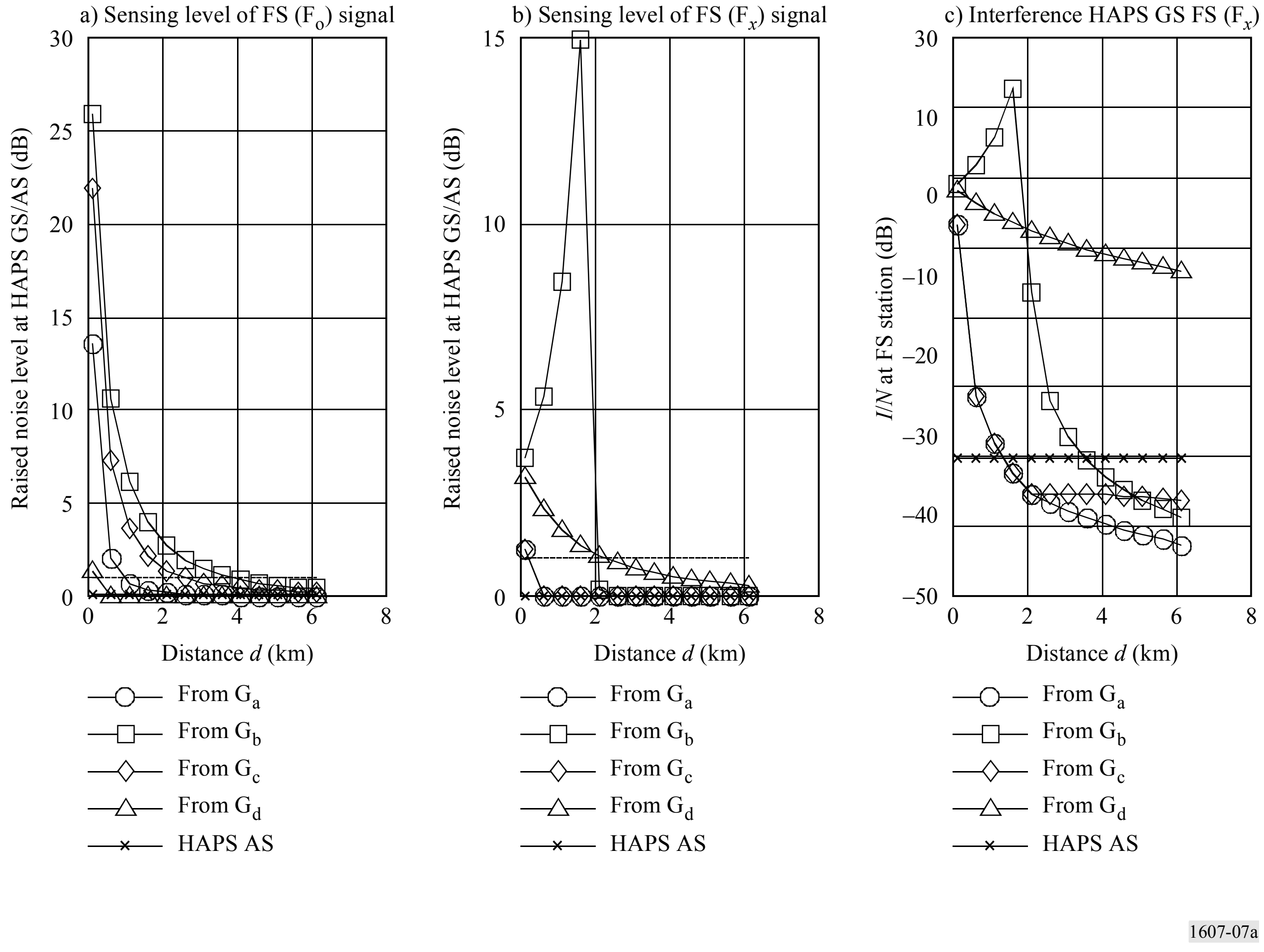
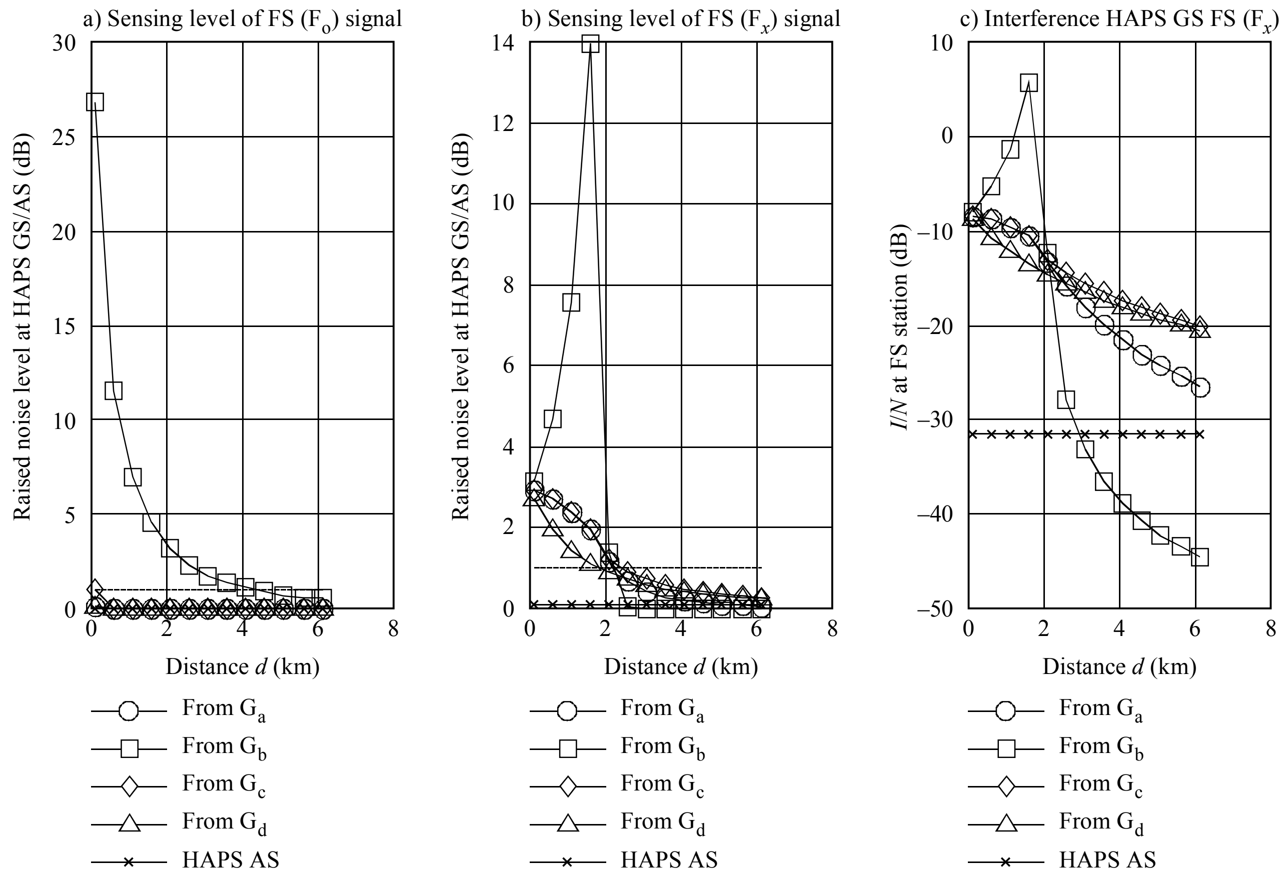


FIGURE 7B

FS SUB at the location F_o and FS HUB at the location F_b in Case 2 ($F_x = F_b$)



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c) Case 3

The calculated result in Case 3 is shown in Figs 8A and 8B when FS SUB or FS HUB is located at F_o or F_c. These Figures show the following features:

– When the FS SUB and FS HUB are located at F_c and F_o, respectively (Fig. 8A), the FS SUB seriously receives interference from HAPS GS at G_a and G_c (Fig. 8A c)).

– However, only the HAPS GS at G_c can sense the FS HUB signal as long as $d > 1$ km and the DCA may not be feasible (Fig. 8A a)).

– Signal sensing at HAPS AS could also be very difficult.

– If the FS system uses TDD or the HAPS system knows one of the pair channels of FS SUB signal in uplink of the FS system using FDD, the HAPS system can get channel information of FS HUB signal in downlink by sensing FS SUB signal. Fig. 8A b) shows that HAPS GS at G_a and G_c can sense the FS SUB signal when $d < 2$ km, but not when $d > 2$ km. Therefore, DCA is feasible when $d < 2$ km. For $d > 2$ km, the off-axis transmitting antenna gain of HAPS GS needs to be reduced by at least about 15 dB or the carrier sensing threshold at HAPS GS needs to be decreased to about 0.3 dB to make DCA available.

– When FS HUB and SUB are located at F_c and F_o, respectively (Fig. 8B), HAPS GS at G_b, G_c and G_d interfere FS HUB and HAPS GS at any location can sense both FS HUB signal. Therefore the DCA could be feasible.

– HAPS AS may not give interference to both FS HUB and SUB in Figs 8A c) and B c)).

FIGURE 8A

FS HUB at the location F_o and FS SUB at the location F_c in Case 3 ($F_x = F_c$)

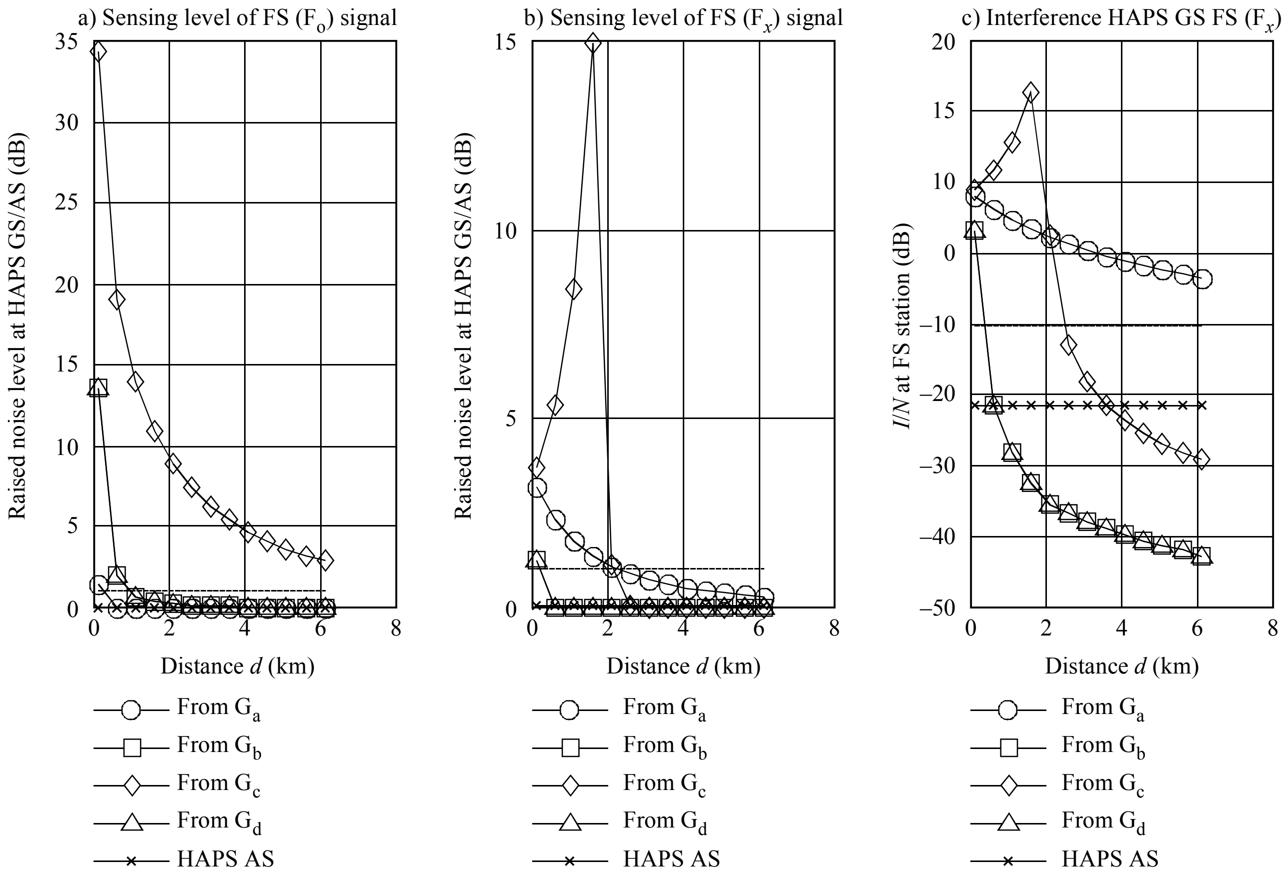

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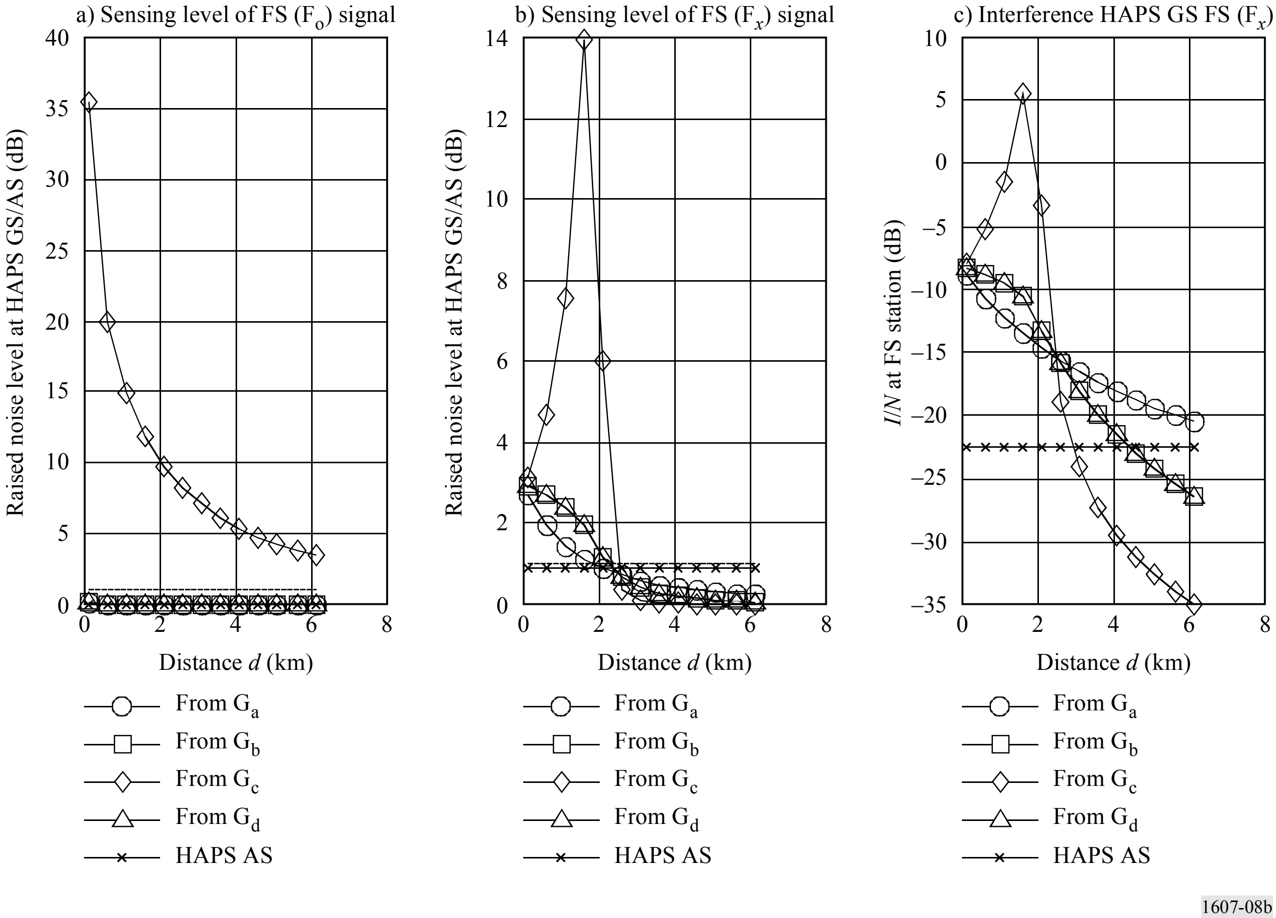
FIGURE 8B

FS SUB at the location F_o and FS HUB at the location F_c in Case 3 ($F_x = F_c$)



5 Summary

The DCA technique to avoid interference from HAPS GS to FS stations in the 31 GHz band could be feasible in most of the patterns of station location in HAPS and FS systems, if HAPS GS have a function of carrier sensing in use by the FS system. The antenna and receiver for carrier sensing in HAPS GS may be shared with those for HAPS communication link. It was found that carrier sensing at HAPS AS is not practical when HAPS GS could interfere FS stations. It was also found that there are some cases that HAPS GS cannot sense the FS signal and it interferes to the receiver in FS station. The interference could be avoided by using improved antenna pattern in HAPS GS with low side and back lobes by at least 15 dB or by decreasing the carrier sensing threshold to about 0.3 dB. This carrier sensing threshold could be increased and relaxed if the side and back lobes of the antenna pattern in HAPS GS is raised by several dB. HAPS AS may not give serious interference to both FS HUB and SUB in any location scenario, so that sharing is feasible between them without special techniques.