International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R F.1891

(05/2011)

Technical and operational characteristics of gateway links in the fixed service using high altitude platform stations in the band 5 850-7 075 MHz to be used in sharing studies

F Series

Fixed service

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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, 2011

RECOMMENDATION ITU-R F.1891*

Technical and operational characteristics of gateway links in the fixed service using high altitude platform stations in the band 5 850-7 075 MHz to be used in sharing studies

(2011)

Scope

This Recommendation provides the technical and operational characteristics of high altitude platform stations (HAPS) gateway links in the fixed service (FS) in the band 5 850-7 075 MHz. It is intended to provide administrations with information on HAPS gateway links for use in sharing studies with conventional types of FS systems and with systems and networks of other services in the band above and in adjacent bands. Information on the relationship between gateway links and user links can also be found in this text.

The ITU Radiocommunication Assembly,

considering

a) that WRC-07 recognized that it would be desirable to have greater flexibility in the choice of spectrum for gateway operations in support of HAPS networks;

b) that WRC-07 requested the studies to consider identification of spectrum for HAPS gateway links in the range 5 850-7 075 MHz;

c) that HAPS gateway links could be used to support operations in the fixed and mobile services;

d) that HAPS gateway links in this band would need to share with systems operating in the fixed, mobile, and fixed-satellite services and may have an impact on passive services such as the Earth exploration-satellite service (EESS) and radio astronomy;

e) that gateway links in a HAPS system would be limited in number and would need to employ higher performance antennas and higher transmitted power in comparison with user links, which would permit the use of higher order modulation methods and more complex coding;

f) that based on *considering* e), HAPS gateway links would be more spectrally efficient than the user links;

g) that technical and operational characteristics of HAPS gateway links in the FS are required in order to perform studies of sharing with other types of FS system and with systems and networks of other services in the 5 850-7 075 MHz band, as well as to take into account the out-of-band emissions to or from services in nearby or adjacent bands,

recognizing

a) that Resolution 734 (Rev.WRC-07) considered that it is desirable to have adequate provision for gateway links to serve HAPS operations;

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* This Recommendation has been prepared in support of World Radiocommunication Conference 2012 (WRC-12) Agenda item 1.20. In the event that WRC-12 does not identify spectrum for gateway links for high altitude platform stations in this band, the Recommendation will be suppressed.

b) that Resolution 734 (Rev.WRC-07) also resolved to invite ITU-R to extend sharing studies, with a view to identifying two channels of 80 MHz each for gateway links for HAPS in the range from 5 850-7 075 MHz, in bands already allocated to the fixed service, while ensuring the protection of existing services,

recommends

1 that the technical and operational characteristics of HAPS gateway links as contained in Annex 1 to this Recommendation should be used in analysing the feasibility of sharing involving HAPS gateway links in the frequency range from 5 850-7 075 MHz.

Annex 1

Technical and operational characteristics of gateway links for high altitude platform stations in the fixed service operating in the 5 850-7 075 MHz band

1 Introduction

The technical and operational characteristics of the HAPS system described herein are based on a realizable generic design of the HAPS payload, stratospheric platform and network.

2 HAPS platform stability

HAPS obtains its movement stability, relative to the Earth, by controlled flight in the low-density, steady flowing, low-velocity and non-turbulent air stream that exists at particular stratospheric altitudes. HAPS operates at a nominally fixed location in the stratosphere at a height of 20 to 25 km. The relatively smooth flowing air stream combined with state-of-the-art propulsion, aerodynamic, thermodynamic and material design will provide a stable and controlled flight that will result in accurate position maintenance and minimal axial (pitch, roll, yaw) rotation. The rate of change of the velocity of stratospheric winds is well within the capability of the propulsion and control systems of the platform to maintain the desired position and heading. The same levels of stability, altitude and position maintenance can be achieved by the heavier-than-air (HTA) and lighter-than-air (LTA) platforms.

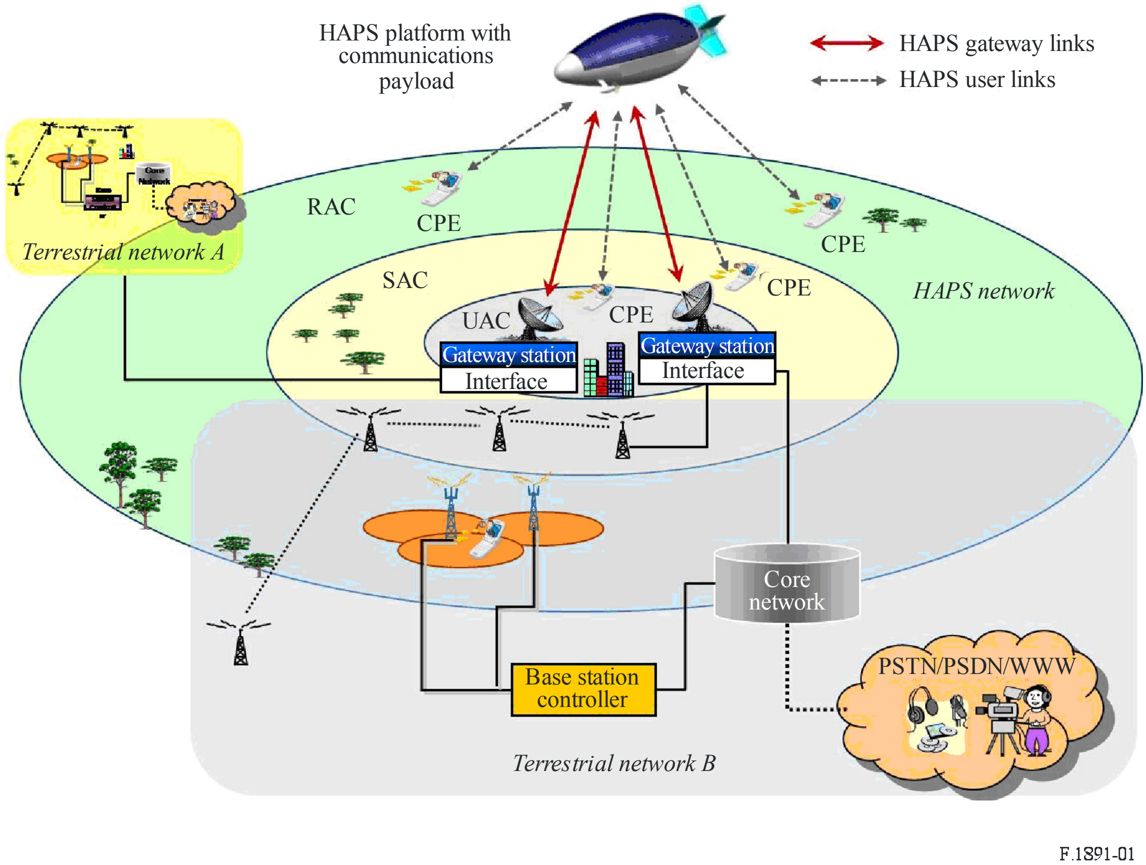
Typically HAPS will maintain its position to well within 0.5 km, will have less than 1/2°/h change in heading, will have changes of altitude less than 45 m/h and will have virtually no axial rotation. In addition, the application of electronically steerable beam-forming antennas on the HAPS and at its ground stations will further add to the directivity, selectivity and effectiveness of the gateway links and easily neutralize any minimal platform movement.

3 HAPS network architecture

HAPS have the capability of carrying a large variety of wireless communication payloads that can deliver high-capacity broadband services to end users. The high-level HAPS telecommunication network architecture is shown in Fig. 1, and described in more detail in this, and other, sections that follow. There are two types of links between the payload and the ground equipment: gateway links and user links. This text only describes the technical and operational characteristics of the HAPS gateway links which are proposed to operate in the 5 850-7 075 MHz band.

FIGURE 1

HAPS network configuration including gateway links and user links



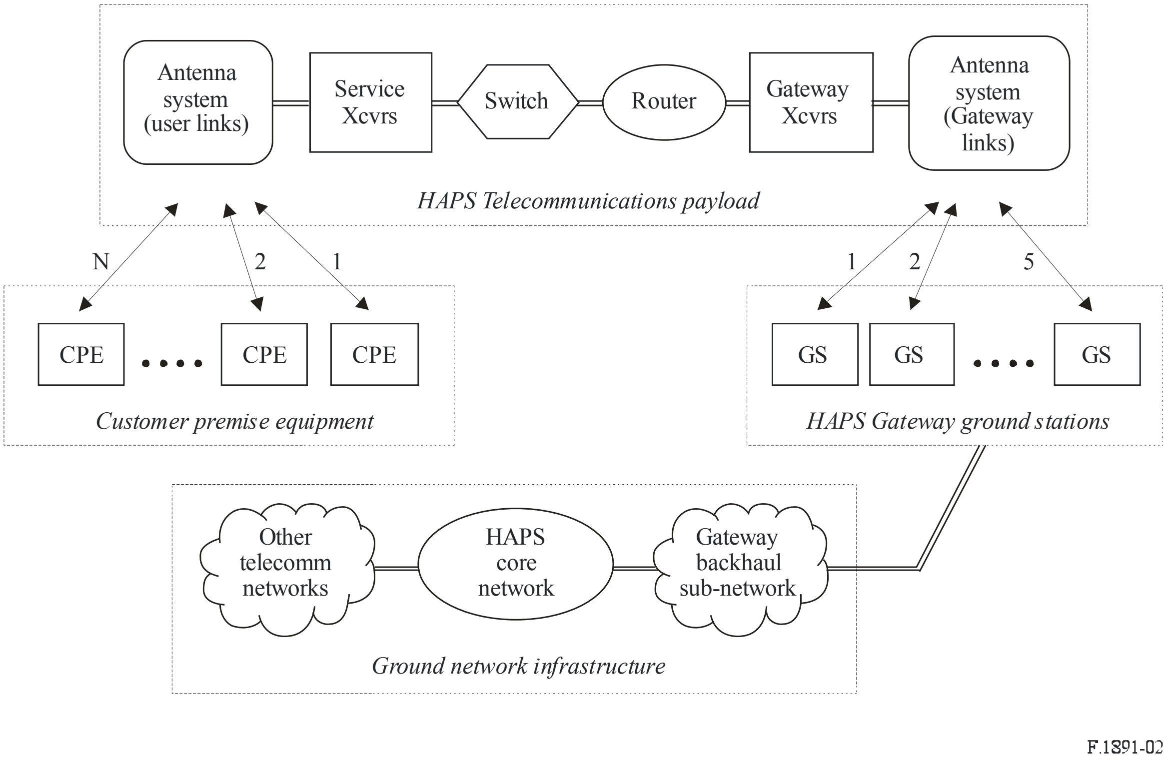
For the user links, the communication is between the platform and customer premises equipment (CPE) on the ground in a cellular arrangement permitting substantial frequency reuse. The CPE is described as being within one of three zones: urban, suburban and rural area coverage (UAC, SAC and RAC, respectively)[1]. HAPS CPE may communicate with the payload on the HAPS platform directly and communications between HAPS CPE is switched by the payload containing a large switch through the user links. The transmitted signal from a HAPS CPE is transferred into the receiving section of payload in the HAPS platform. The on-board switch in the payload determines the cell to link the signal. Then, it is transferred to the cell in which other HAPS CPE to be connected exists. It is emphasized that the user links utilize frequency spectrum outside of the 5 850-7 075 MHz band in accordance with the relevant provisions of the RR. For the gateway links, communication is established in the 5 850-7 075 MHz band between the platform and gateway stations on the ground, located in the UAC, which provide interconnection with other telecommunication networks.

The HAPS telecommunication payload architecture consists of six basic subsystems as depicted in Fig. 2.

[1] See Recommendation ITU-R F.1500 for a more detailed description of these coverage areas.

FIGURE 2

HAPS telecommunication network architecture



The central switching and routing subsystems connect the gateway transceivers and antennas to the service delivery portion of the payload (antennas and transceivers). The service delivery subsystems contain the direct user links (HAPS-CPE) which are completely separate and different from the HAPS gateway links. Network management, telecommunication network connectivity, and other core network functions are contained in the ground infrastructure portion of the network.

A backhaul terrestrial sub-network will also be required to control, integrate and provide a terrestrial concentration and connection for all of the gateway links to the core network. Each of the five gateway stations will need a baseline fibre optic data link to the core network on the order of 1 Gbit/s per GS. The HAPS gateway station network topology is described in Figs 1, 2 and 3.

4 HAPS gateway link description and use

As applied in this document, a HAPS gateway link is defined[2] as a one-way radio link between a relatively fixed HAPS platform and a HAPS gateway station. Specifically, the HAPS gateway link consists of a separate 80 MHz (ground-to-air) uplink and a separate 80 MHz (air-to-ground) downlink. Within each 80 MHz bandwidth, a HAPS gateway link operates unidirectionally and contains information flows, such as aggregated end-user traffic for voice, data and video communications. Telemetry, tracking, command and control information related to the operation of the HAPS vehicle itself can also be contained in the HAPS gateway link. Each 80 MHz HAPS gateway bandwidth, may be divided into a number of subchannels, with all subchannels supporting

[2] In the scope of this Recommendation, the "HAPS gateway link" is a radio link from a HAPS ground-based gateway station at a given location to a HAPS platform, or vice versa, conveying information for a HAPS communication link including telemetry and telecommand, and providing interconnection with other ground telecommunication networks.

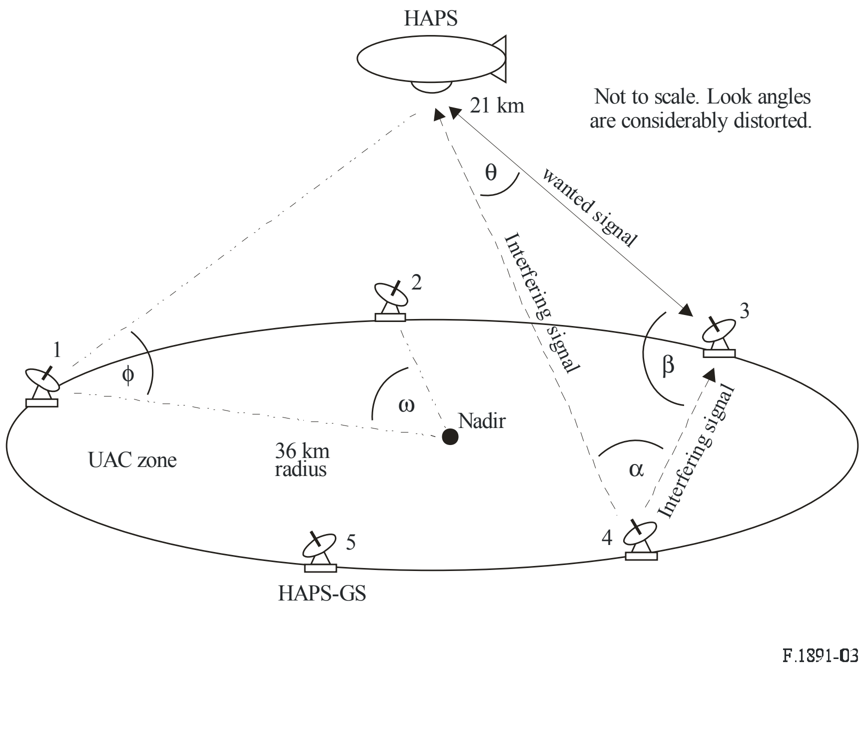
radio links in the same (air-to-ground or ground-to-air) direction using any polarization, modulation and coding methods.

A single HAPS platform will use a maximum of five gateway station links to support the maximum projected traffic load for that entire single platform. The number of gateway links deployed for each HAPS depends on the amount of end-user application traffic the HAPS-based network or system must support on a backhaul basis. As the actual traffic increases, more same-frequency gateway links can be deployed (up to a maximum of five, as needed). Figure 3 illustrates a maximum ground configuration of five same-frequency gateway links that reuse the 2 × 80 MHz frequency spectrum identified for HAPS use, and this configuration should be used in sharing studies.

HAPS platforms would be on the order of about 300 km to 1 000 km apart. Each associated gateway station serves a single HAPS. Typically, the gateway station grid would not overlap with an adjacent HAPS gateway station grid. The gateway grid will likely be within an approximately 72 km diameter circle centred close to the nadir ground point of the HAPS as illustrated in Fig. 3. As shown in this HAPS gateway station (GS) configuration, the elevation angle Φ referenced to the HAPS nadir is 30° for the UAC zone shown. β is the angle at the wanted gateway station between the HAPS platform and interfering gateway station. α is the angle at interfering gateway station, between the HAPS platform and the wanted gateway station. Angles α and β are 59.4 or 34.6°, depending on the particular gateway station pairs and their associated geometry. θ, which is the angle at the HAPS between the wanted HAPS gateway station for that link and a particular interfering HAPS gateway station, is 61 or 111°. ω is the angle at the ground nadir point between any two gateway stations. Table 1 is a summary of the four angles (α, β, θ, Φ) for all the various combinations of gateway station pairs. Table 2 is a summary of the five possible angles for ω.

FIGURE 3

Example of HAPS gateway station configuration and internal HAPS network interference



It should be emphasized that Fig. 3 is not to scale.

TABLE 1

HAPS gateway link angles (degrees)

Φ	**θ**	**β**	**α**	**Station pairs[(1)]**
30	61	59.4	59.4	1-2, 2-1, 2-3, 3-2, 3-4, 4-3, 4-5, 5-4, 1-5, 5-1
30	111	34.6	34.6	1-3, 3-1, 2-4, 4-2, 3-5, 5-3, 1-4, 4-1, 2-5, 5-2

(1) Station pairs X-Y where X is the wanted station and Y is the interfering station.

TABLE 2

Ground station separation angles (degrees)

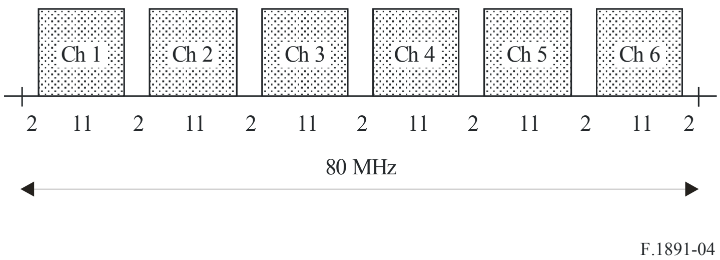
ω	**Station pairs**
0	1-1
72	1-2
144	1-3
216	1-4
288	1-5

5 Spectrum identification and channelization

The spectrum identification for the HAPS gateway links is expected to be two 80 MHz channels in the 5 850-7 075 MHz band[3] for a total of 160 MHz. The subchannelization plan can be used to divide each 80 MHz channel into six equally spaced 11 MHz subchannels separated by 2 MHz guardbands as shown in Fig. 4. Other subchannelization frequency plans could possibly[4] be utilized but the channelization plan shown in Fig. 4 should be utilized in the sharing studies. All subchannels, within each 80 MHz bandwidth, are always utilized to accommodate radio links in the same direction. Only FDD/FDM will be used.

FIGURE 4

HAPS channelization plan for an up or down channel



3 See Resolution 734 (Rev.WRC-07).

4 For example, two 34 MHz subchannels with 4 MHz guardbands and each subchannel being FDD.

The location of the spectrum for HAPS gateway links within the 5 850-7 075 MHz band will largely be dependent on mutual interference factors among the services sharing the spectrum. The HAPS payload and ground station architecture and design provide the flexibility to operate the gateway links virtually anywhere in the 5 850-7 075 MHz band. The subsequent detailed sharing studies will determine the best location for the HAPS spectrum identification.

It is important to note that the HAPS gateway links spectrum would be in a different frequency band than the individual user links between the HAPS platform and its CPE on the ground as illustrated in Fig. 1.

6 HAPS gateway link characteristics

Table 3 provides the link analysis for a typical HAPS gateway link for both up- and downlinks showing the value of various parameters of the link using 64-QAM 2/3 modulation. It is important to note that this case (64-QAM 2/3 case in Table 3) should be used in the sharing studies to determine compatibility in the frequency band 5 850-7 075 MHz.

The gateway link budget is based on an 11 MHz subchannel (plus guardbands)[5] which corresponds to a 44 Mbit/s[6] subchannel bit rate for 64-QAM 2/3. High availability and bit-error ratio, on the order of 99.999% and 10^{-9} respectively, are important for the gateway links so as to allow a high grade of service for the end user application and service being provided. This link analysis calculates the power flux-density (pfd) and margin at the boresight of the antennas. The pfd and radiated power level will be substantially reduced as a function of the antenna pattern characteristics and the offset angle from boresight. The use of beam-forming antennas can also provide additional mutual interference mitigation. Therefore, this link budget analysis is a worst-case scenario with regard to HAPS interference to and from other systems.

Also included in the link budgets is a preliminary assessment of the internal interference from other same-frequency gateway links supporting the same HAPS system. The cases of one, three and five total gateway stations were evaluated to determine the increase in interference and the corresponding reduction of margin. The three GS interference cases used wanted GS 4 and unwanted (interfering) GS 1 and 2. In the 64-QAM 2/3 case shown in Table 3 a high performance phased array antenna is used in both the HAPS platform and the GS. The antenna gain pattern masks used for this link budget are described in detail in § 8 herein. This case should be used for sharing studies. It is noted that the phased array antenna employed on the HAPS platform and GS will reduce the level of interference to systems of existing services and achieve more effective sharing with such services. Table 3 also contains the link budget for a clear sky and a 0.01% rain rate ($R_{0.01}$) was taken to be 63 mm/h.

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[5] A 34 MHz subchannel (plus guardbands) results in the same link margin.

[6] Based on utilizing 64-QAM modulation with a 2/3 coding rate for the FDM gateway link.

TABLE 3

Example of HAPS gateway station link budget analysis using 64-QAM 2/3 modulation

Item	UAC – Rain	UAC – Rain	UAC – Clear Sky	UAC – Clear Sky
	TDM down (per carrier)	TDM up (per carrier)	TDM down (per carrier)	TDM up (per carrier)
Frequency (GHz)(1)	6.5	6.6	6.5	6.6
Bandwidth (MHz)	11	11	11	11
Tx power (dBW)	–22	–19	–22	–19
Tx antenna gain (dBi)	30	47	30	47
Hardware implementation loss (dB)	4.1	4.1	4.1	4.1
Power control gain (dB)	8.0	8.0	0.0	0.0
Nominal e.i.r.p. (dBW)	3.9	23.9	3.9	23.9
e.i.r.p. (dBW) after power control(2)	11.9	31.9	3.9	23.9
Slant range (km)	42.0	42.0	42.0	42.0
Free space loss (dB)	141.2	141.3	141.2	141.3
Atmospheric loss (dB)(3)	0.3	0.3	0.3	0.3
Rain attenuation (dB) (99.999% availability)(3)	9.0	9.5	0.0	0.0
pfd on the ground (dB(W/m^2 · MHz))	–111.2		–110.2	
Receiver G/T (dB/K)	17.5	0.0	17.5	0.0
Rx antenna gain (dBi)	47.0	30.0	47.0	30.0
Polarization loss (dB)	0.5	0.5	0.5	0.5
Boltzmann's constant (dB(W/K*Hz))	–228.6	–228.6	–228.6	–228.6
Bit rate (dB(Hz))	76.4	76.4	76.4	76.4
$E_b/(N_0 + I_0)$ $(I = 0)$ (dB) $E_b/(N_0 + I_0)$ *(3 GS)* (dB) $E_b/(N_0 + I_0)$ *(5 GS)* (dB)	30.6 29.6 28.6	32.5 31.5 30.5	31.6 30.6 29.6	34.0 33.0 32.0
Required $E_b/(N_0 + I_0)$ (dB) (64-QAM)	20.3	20.3	20.3	20.3
Required $C/(N+I)$ *w/I = Itot*(4)	26.3	26.3	26.3	26.3
Margin (I=0) (dB)	10.3	12.2	11.3	13.7
Margin (3 GS) (dB)	9.3	11.2	10.3	12.7
Margin (5 GS) (dB)	8.3	10.2	9.3	11.7

(1) The frequency specified in Table 3 corresponds to the centre of the 5 850-7 075 MHz band. The use of this (specific) frequency is not intended to bias the work of ITU-R with regard to the identification of the spectrum within the 5 850-7 075 MHz band for use by HAPS gateway links.

(2) Nominal e.i.r.p. denotes the initial power setting. After automatic power control (APC), the TX power is increased by from 0 to up to 8 dB, depending on the carrier level. Note that the e.i.r.p. above applies within the UAC, and regulatory and/or interference protection limits may apply outside the UAC. The HAPS platform antenna will not point outside of the UAC.

(3) Rain attenuation and atmospheric loss as described in Recommendations ITU-R P.618 and ITU-R SF.1395 respectively. The 0.01% rain rate was taken to be 63 mm/h.

(4) C/N = (E_b/N_0) • (spectral efficiency(5)).

(5) The spectral efficiency in this case is 4 bit/s/Hz.

7 HAPS gateway link capacity utilization

The gateway links will provide the backhaul connectivity capacity to support the type service and application being offered to end users and the associated aggregated end-user traffic load funnelled through the bidirectional gateway links.

The minimum total system gateway bit rate capacity requirement of 2.67 Gbit/s[7] will be needed to support the projected maximum system user traffic load[8]. This will require considerable frequency reuse of the 160 MHz (2 × 80 MHz or 4 × 40 MHz) spectrum identification currently contemplated for gateway link use by HAPS-based telecommunication systems in the 5 850-7 075 MHz band. The bit-rate capability for the 160 MHz of spectrum in the 5 850-7 075 MHz band is 2.67 Gbit/s, utilizing five same-frequency gateway links for each HAPS, a modulation/coding method that has a spectral efficiency of 4 bit/s/Hz[9] and about 17% for guardbands. That means the 160 MHz spectrum will be reused up to five (5) times to obtain the maximum gateway link capability from this spectrum utilization. The gateway links in this band are designed with modulation and coding schemes that obtain high spectral efficiency (e.g. 64-QAM with 2/3 coding rate) so as to maximize the bit-rate capability of each link. The available capability must also take into account the potential individual link failures.

Most importantly, no additional 5 850-7 075 MHz spectrum beyond the 160 MHz will be required in this band and the spectrum will be reused up to five times so as to obtain a substantial amount of spectral reuse efficiency.

8 Antenna gain pattern

Described below is the antenna radiation pattern that is used in the link budgets provided herein. A phased array as described in, and that complies with, Resolution 221 (Rev.WRC-07) will be used in both the HAPS gateway (ground) station and in the HAPS (airborne) platform. For the purposes of sharing studies, the peak gain of the platform and ground station antennas are 30 dBi and 47 dBi, respectively. The antenna radiation pattern mask equation used for the HAPS gateway station and HAPS platform is described below and illustrated in Figs 5 and 6 respectively using L_N of −25 dB. This radiation pattern mask is used for both the up- and downlinks and is based on a phased array type antenna that will be used for the HAPS gateway links.

$$G(\psi) = G_m - 3(\psi/\psi b)^2 \quad \text{dBi} \quad \text{for} \quad 0° \le \psi \le \psi_1$$

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

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

$$G(\psi) = L_F \quad \text{dBi} \quad \text{for} \quad \psi_3 < \psi \le 90°$$

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7 Bit rate and channel bandwidth are interchangeable using the spectral efficiency of the channel modulation and coding used, expressed in bits per second per hertz.

8 The 2.67 Gbit/s minimum requirement is based on the 64-QAM 2/3 case and a total subscriber capacity of 3 million per HAPS with 300 thousand (10%) subscribers on-line during the busy hour. This is for a baseline case of primarily voice-user access with a modest amount of Internet and data traffic mixed in. This corresponds to a user (not gateway) capacity of 300 K Erlangs using an Erlang B traffic model with 1% blocking.

9 64-QAM modulation with a coding rate of 2/3 provides a spectral efficiency of 4 bit/s/Hz. Each 160 MHz gateway link with this modulation will provide 533 Mbit/s of bit-rate capacity. Five same-frequency gateway links provide a total gateway capacity of 2.67 Gbit/s (533 Mbit/s times 5 GS).

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 of the 3 dB beamwidth in the plane considered (3 dB below G_m) (degrees)

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

L_F: far side-lobe level, $G_m - 73$ dBi

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

$\psi_2 = 3.745\ \psi_b$ degrees

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

$\psi_3 = 10^{(X - L_F)/60}$ degrees.

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

$$(\psi_b)^2 = 7\,442/(10^{0.1 G_m}) \qquad \text{degrees}^2.$$

The antenna roll-off factor of 60 dB per decade is used for these high performance multibeam phased array antennas in accordance with the antenna radiation mask as specified in Resolution 221 (Rev.WRC-07).

FIGURE 5

HAPS gateway station reference antenna pattern for 47 dBi antenna

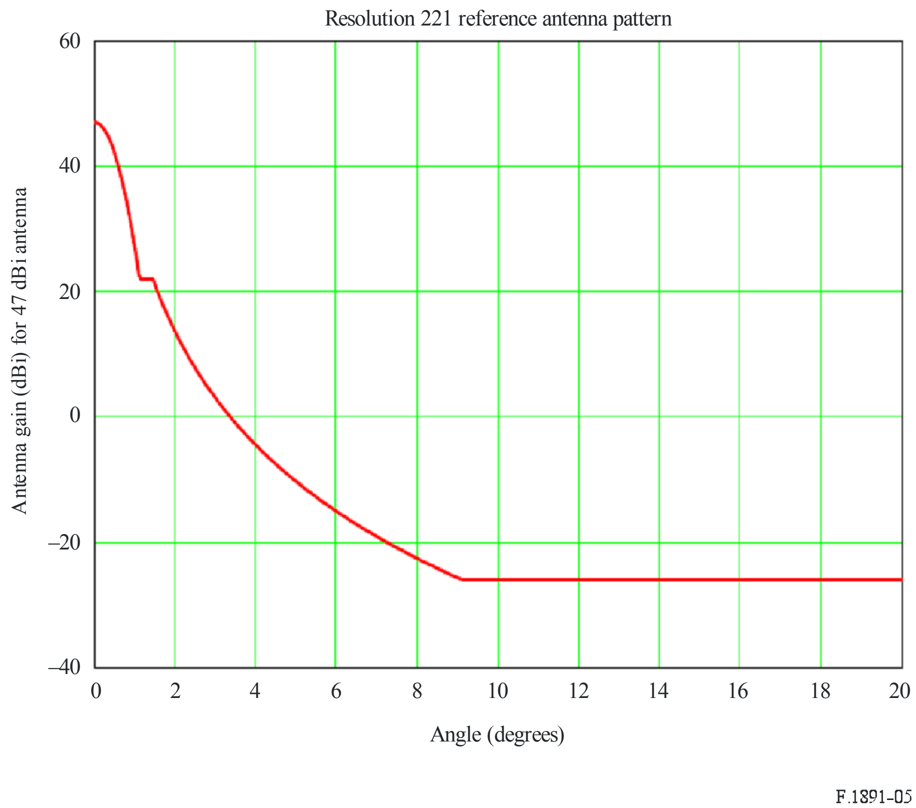
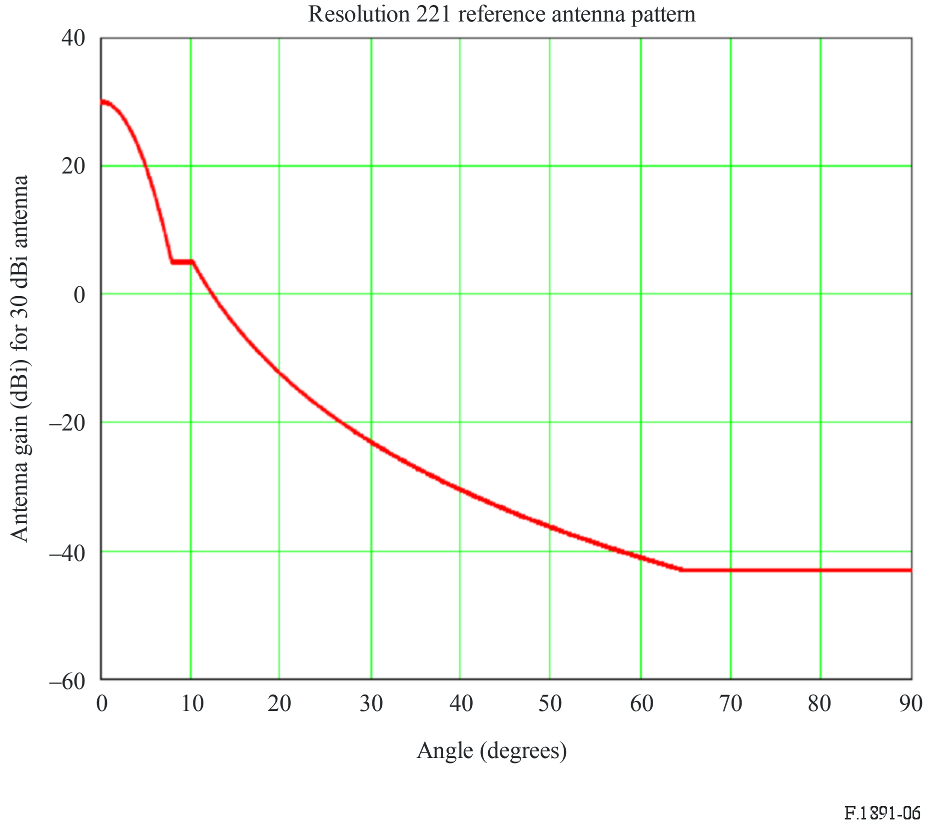


FIGURE 6

HAPS platform station reference antenna pattern for 30 dBi antenna



9 Adaptive modulation for gateway links

Each individual gateway link uses adaptive modulation which provides capacity resilience by automatically reducing the modulation level in the event of higher intermittent interference and noise levels. Each gateway link can adjust its modulation level independent of each other gateway link and depending on the $C/(N + I_{ToT})$ level each one receives. Table 4 shows the specific $C/(N + I_{ToT})$ needed to maintain a particular gateway modulation level and the single-link capacity for a given gateway link spectrum available. Each of the five gateway links reuses the same 160 MHz spectrum.

The short-term C/I_{EX} should not be smaller than 12 dB for more than 0.001% of the time and the long-term C/I_{EX} should not be less than 27 dB for more than 20% of the time. $C/I_{EX} = 12$ dB corresponds to 16-QAM with 1/2 coding, which reduces the *single* HAPS gateway capacity by 2 (or 50%) as shown in Fig. 7.

Adaptive modulation is a standard technology used in many communication systems so as to optimize and obtain communication availability and performance for channels that experience certain levels of congestion intermittently on a short- or long-term basis. It allows links to maintain a reduced level of communications when there is considerable noise and/or interference, whereas without adaptive modulation the link would not function below its particular minimum required $C/(N + I_{ToT})$ needed to operate that link at its single designated modulation level.

TABLE 4

Gateway capacity vs. modulation and coding

Gateway link modulation	Gateway link coding	Required $C/(N + I_{ToT})$(1) dB	One gateway capacity(2) Mbit/s	Gateway capacity ~ – %	Spec. eff. bit/s/Hz
64-QAM	2/3	26.3	533	100	4
16-QAM	3/4	20.2	396	75	3
16-QAM	1/2	11.9	267	50	2
QPSK	1/2	4.5	133	25	1

(1) $I_{ToT} = I_{nGW} + I_{EX}$.
I_{nGW} = self interference from other $n - 1$ gateway stations.
n is equal to from 1 to 5 depending on the number of HAPS gateway stations.
I_{EX} = external interference from non-HAPS earth station and airborne platform.
$I_{EX} = I_{ES} + I_{AS}$ = earth station interference + airborne station interference.

(2) Capacity of each of the five gateway links.

~ Compared to 64-QAM 2/3 case.

In the baseline case of five symmetrically located gateway links, and as shown in Table 4, a single gateway link can for example have the actual $C/(N + I_{ToT})$ drop as much as 14 dB below its required amount for 64-QAM and still maintain 50% of its capacity by operating at 16-QAM 1/2. In that case, the total gateway capacity for the five gateway stations would in effect be 90% of full capacity, even with one gateway station temporarily operating at 50% of its capacity and the other four at full capacity. This modulation and capacity adaptation is illustrated in Fig. 7. If as much as two of the five gateway links are temporarily operating at as low as 25% (at QPSK 1/2), then the total capacity of the five gateway links would be operating at as much as 70% of total capacity. In addition, if one of the five links is completely (100%) lost for whatever reason and the other four links remain at maximum capacity, the total link capacity will still be 80%. If this capacity reduction does not occur at the busy hour, then there would not be a need to have the full capacity for that period of time. If it occurs intermittently, but at the busy hour[10], then the particular affected gateway links will have to operate at a lower grade of service corresponding to the lower capacity until the gateway link is restored to a higher capacity.

10 The busy hour is estimated to occur an average of about 15% of the time total during a 24 h period. The lowest traffic level at any time of the day is estimated to be 20% of total capacity.

FIGURE 7

Gateway link modulation and capacity adaption example