International Telecommunication Union

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Radiocommunication Sector of ITU

Recommendation ITU-R F.1500

(05/2000)

Preferred characteristics of systems in the fixed service using high altitude platforms operating in the bands 47.2-47.5 GHz and 47.9-48.2 GHz

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
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RECOMMENDATION ITU-R F.1500[*, **]

PREFERRED CHARACTERISTICS OF SYSTEMS IN THE FIXED SERVICE USING HIGH ALTITUDE PLATFORMS OPERATING IN THE BANDS 47.2-47.5 GHz AND 47.9-48.2 GHz

(2000)

Scope

This Recommendation provides the preferred characteristics of systems in the fixed service using high altitude platform stations (HAPS). Annex 1 has been developed for use for the analysis of the frequency reuse and the sharing possibilities between such systems and other systems in the bands 47.2-47.5 GHz and 47.9-48.2 GHz.

The ITU Radiocommunication Assembly,

considering

a) that systems utilizing one or more high altitude platform stations (HAPS) located at a fixed point in the stratosphere may possess desirable attributes for high-speed broadband digital communications, including interactive video and other applications, with significant potential for frequency reuse;

b) that such systems would be able to provide coverage to metropolitan regions with high elevation angles, and to outlying rural areas or neighbouring countries with low elevation angles;

c) that broadband digital services provided by such systems in the fixed service (FS) are intended to provide widespread communications information infrastructures promoting the global information infrastructure;

d) that radio links between HAPS relays may provide a nationwide or regionwide telecommunication network;

e) that the radio spectrum above 30 GHz is allocated to a variety of radio services and that many different systems are already using or planning to use these allocations;

f) that there is an increasing demand for access to these allocations;

g) that because systems in the FS using HAPS can use the full range of elevation angles, sharing with other FS systems and systems in other services in the bands 47.2-47.5 GHz and 47.9-48.2 GHz may present difficulties;

h) that the allocation to the FS in the bands 47.2-47.5 GHz and 47.9-48.2 GHz, is designated for use by HAPS;

j) that preferred characteristics of systems in the FS using HAPS need to be identified to facilitate coordination between HAPS in the FS operating in the bands 47.2-47.5 GHz and 47.9-48.2 GHz and other co-primary services in their territory and adjacent territories,

recommends

1 that the characteristics of systems in the FS using HAPS as shown in Annex 1 be provisionally used in analysing the frequency reuse and the sharing possibilities between such systems and other systems in the FS in the bands 47.2-47.5 GHz and 47.9-48.2 GHz.

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[*] This Recommendation should be brought to the attention of Radiocommunication Study Group 1 and Telecommunication Development Study Group 2.

[**] Study Group made editorial amendments to this Recommendation (on 7-8 December 2009) in accordance with Resolution ITU-R 1.

ANNEX 1

Preferred characteristics of systems in the FS using high altitude platforms operating in the bands 47.2-47.5 GHz and 47.9-48.2 GHz

1 Introduction

Resolution 122 (WRC-97) requested urgent studies on the appropriate technical sharing criteria between systems using HAPS in the FS and systems in the fixed, fixed-satellite and mobile services in the bands 47.2-47.5 GHz and 47.9-48.2 GHz.

As a part of those studies, this Annex presents a set of technical parameters for high-density applications in the FS using high altitude platforms.

2 The high altitude platform system

The system comprises a high altitude platform in a nominally fixed location in the stratosphere at a height of 21 to 25 km. Communication is between the platform and user terminals on the ground in a cellular arrangement permitting substantial frequency reuse. User terminals are described as being within one of three zones: urban, suburban and rural area coverages (UAC, SAC and RAC, respectively).

In addition, communications are established in the same frequency bands, between the platform and a number of gateway stations on the ground, located in the UAC or SAC, which provide interconnection with the fixed telecommunication network.

2.1 Operating characteristics

The high altitude platform is powered by efficient solar cells and regenerative hydrogen-oxygen fuel cells. The components of the regenerative fuel cell and electrolyzer subsystem converts water into fuel during the day and the fuel is used to generate the electrical power needed for night operation. The electrolyzer converts water into hydrogen and oxygen gas for fuel cell operation at night. The propulsion subsystem consists of variable speed electric motor-driven stern propellers, although other types of propulsion means with similar performance characteristics can also be employed. The HAPS uses a differential GPS sensor for closed loop control maintenance of its spatial location to a 400 m radius circle and a vertical dimension to ±700 m at altitude.

The payload will be supported by a 3-axis gimbal system. The payload will have its own stabilization system to compensate for the motion of the platform and maintain a stable coverage pattern on the ground. The payload will also provide its own thermal control. The payload will be cooled by a pressurized forced flow.

HAPS total coverage area is divided into three zones. These zones are necessary to ensure users have consistent broadband service across HAPS's wide footprint of about 1 000 km in diameter. The zones are:

– UAC: the UAC extends from 36 to 43 km out from a point directly under the platform. Users in these zones can use portable user terminal modems with a beamwidth of about 11°, or 26 dBi antenna gain, and 10 cm × 10 cm antennas. The antennas on the platform should have a gain of 30 dBi (1 W of RF power per channel). All users in these zones will have a 30° to 90° angle of elevation from the ground to a HAPS platform. The user terminals require approximately 0.15 W of transmission RF power.

– SAC: the SAC extends from the UAC to 76.5/90.5 km, depending on the operating altitude. Users in the SAC will use higher gain (41 dBi) directional antennas with a transmission power of 0.2 W. The same antennas can also be used in the UAC zones for fixed rooftop installation. The platform transmit antennas are the same as in UAC. The elevation angles range from 15° to 30°.

– RAC: the elevation angles are from 15° to 5°. This is reserved for dedicated high-speed point-to-point access and wide-area coverage at lower frequency bands such as 800 MHz to 5 GHz bands. There is too much atmospheric and rain attenuation at 47/48 GHz.

TABLE 1

Coverage zones

Coverage area	Elevation angles (degrees)	Ground range (km)	
		Platform at 21	Platform at 25
UAC	90-30	0-36	0-43
SAC	30-15	36-76.5	43-90.5
RAC	15-5	76.5-203	90.5-234

A typical HAPS platform payload will have gimballed slotted array antennas with polarizer insert to ensure proper cross-polarization isolation. The array antennas will project a total of 700 beams in each of the UAC and SAC zones, and selective coverage in the RAC zone with up to 700 beams. The cell pattern will have a 7:1 frequency reuse factor.

To maximize spectral efficiency, a dynamic assignment multiple access (DAMA) scheme is used to allow users to share bandwidth efficiently, and there are on-board asynchronous transfer mode (ATM) switches and ATM multiplexers to statistically multiplex the user traffic. Both uplink and downlink use QPSK modulation and rate 0.6 concatenated FEC coding (Reed-Solomon + rate 2/3 convolutional coding with constraint length 9). Interleave coding is also used to mitigate burst errors. Because of efficient sharing of bandwidth and the low-duty factor of most types of broadband traffic, all 110 560 users can expect to achieve a maximum upload speed of 2.048 Mbit/s and download speed of 11.24 Mbit/s with a frequency allocation of only 2 × 100 MHz. Assuming an average of 10% of the total subscriber population to be active at any given time, a single HAPS network (HAPN) can thus support a subscriber population of about one million users given the 2 × 100 MHz allocation. If the frequency allocation is increased to 2 × 300 MHz, then a single HAPN can be expected to support more than five million subscribers.

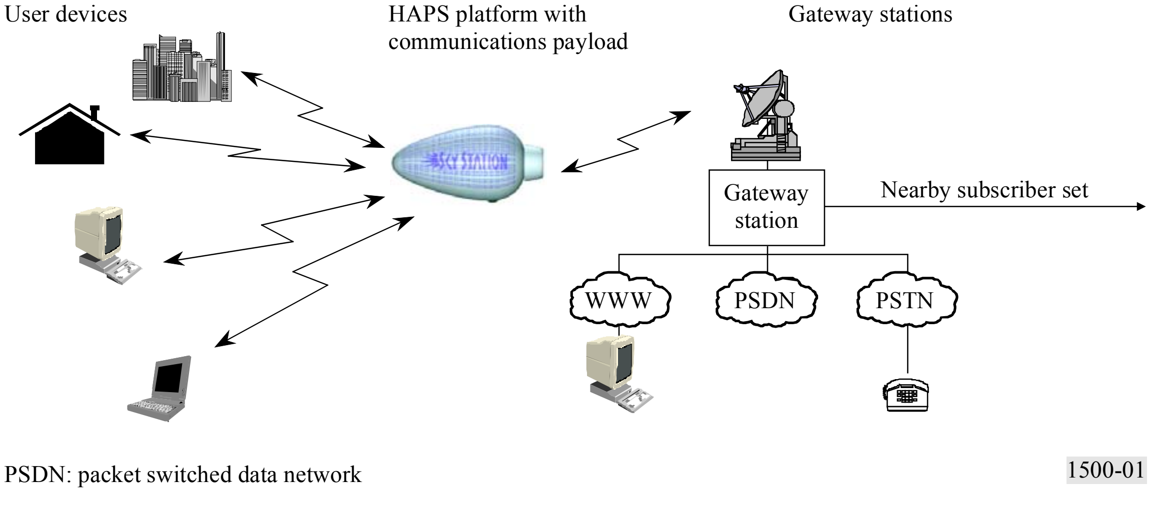
The baseline system also includes multiple gateway ground stations which use high-speed synchronous time division multiplexed (TDM) per link for feeder traffic interconnecting HAPN to PSTN and the Internet. The feeder link speed is up to 0.72 Gbit/s for a 300/300 MHz frequency allocation. 64-QAM modulation and rate 0.71 FEC coding are used to optimize the available bandwidth. Additional high-speed point-to-point links can also be provided for corporate customers and service providers.

2.2 Communications system performance characteristics

HAPN has a star configuration, with the HAPS platform serving as the main hub. The payload projects multiple spot beams onto the ground and provides ubiquitous coverage over a roughly 150 km diameter circle.

FIGURE 1

Network configuration



PSDN: packet switched data network

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User terminals are portable devices that communicate with the payload directly. A user terminal consists of an antenna unit and a digital interface unit. A variety of digital interface units are envisioned, including PC cards and multi-function set-top boxes. User-to-user communications are switched directly by the payload, which contains a large ATM switch.

Gateway stations are provided to allow user access to the existing public networks, such as PSTN and Internet. The system is designed to allow gateway stations to be located essentially anywhere within the coverage area, so as to minimize the ground infrastructure requirement. Typically they will be co-located in a carrier's central office (CO) or an Internet service provider (ISP) point-of-presence (PoP). Gateway stations on the ground can be added, as business requires.

In the first generation systems there will be no direct link between two HAPNs. Inter-HAPN communications will be carried out via gateway stations. The gateway capacity is 4-12 Gbit/s, capable of handling 60% of all user traffic. The total capacity of the payload is therefore 11-33 Gbit/s.

The HAPS system is designed to provide variable rate, full duplex, digital channels to homes and the so-called small office/home office (SOHO). The intended services are multimedia applications such as videoconferencing and videophones in addition to high-speed Internet access. The high bit rates, a large metropolitan coverage, and the fact that the user terminals are not dependent upon a ground infrastructure, also makes the HAPS an ideal platform for telecommuting and working-at-home, your own home or your client's home. Therefore, the system is designed to support a large number of virtual local area networks (LANs), so users can access their corporate networks as if they were in the office.

In the downlink each user terminal will receive all the time, but it will only keep those cells it has rights to. This way we can take maximum advantage of the statistical multiplexing of the ATM switch.

A gateway station uses the same frequencies except for the one segment used by the cell in which it is located. So each gateway uses a major portion of the total allocated bandwidth. It also uses the other polarization to provide additional isolation.

The HAPS system will use a pair of bands in the 47.2-48.2 GHz, with a bandwidth of 100 MHz to 300 MHz. With a frequency reuse factor of 7, a 2 × 100 MHz allocation will be reused 100 times in each of the coverage zones. Each uplink TDMA time slot carries one ATM cell. The asynchronous nature of ATM provides great flexibility. For example, no burst time plan is required. The aforementioned DAMA scheme will be integrated with ATM call and traffic management to maximize the efficiency of communication resource management.

On the user side, intelligent ATM multiplexers are used to reduce the number of ports on the main switch. Each ATM Mux multiplexes 16 beams into an OC3 (optical carrier, level 3 (155.52 Mbit/s)) port on the switch. At least 44 ports are needed to handle >1 400 beams. The dynamic TDMA turns each beam into a shared bus. Up to 1 000 user terminals can be registered at any time. The design basically requires the ATM Mux to handle the non-standard part of the signalling protocols, so we can use standard ATM switches.

The gateway stations provide interface with the public networks, such as a carrier's long-distance backbone and the Internet. The actual configuration depends on the deployment scenario. It is conceivable that a gateway can be devoted to a large ISP like America Online. The system is designed to be able to recognize users when they log on and allow them to connect to their service providers only.

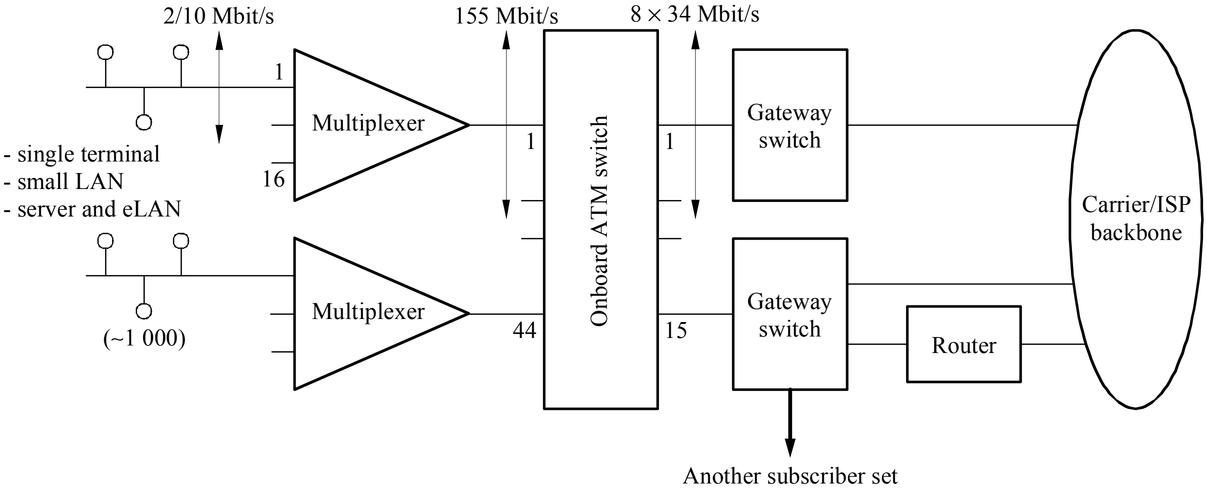
The weight and power budget includes all the baseband equipment, namely the ATM switch and the multiplexers.

The ground system consists of gateway stations and the HAPS control centre. Each gateway station will use high-gain steerable antennas with narrow beams. The RF equipment is similar to those on the payload. The ATM switch required is not large - about four OC3 ports plus whatever is necessary for local servers and/or network management. A multitude of interfaces may be required to connect to the existing public networks, most of which are available today, or soon to be available, as standard options from many vendors. The system is designed to be compliant with existing standards.

For interface with the public ATM network, private network node interface (P-NNI) is preferred because it allows dynamic loading balancing among the multiple gateway stations. The internal addressing scheme is designed to allow load balancing even with broadband-interchange carrier interface (B-ICI), but not as dynamic.

FIGURE 2

End-to-end networking (2 x 100 MHz allocation, single zone)



- 11 Gbit/s full duplex, redundant

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Most of the gateway stations are designed to be unmanned, autonomous units, operated by remote control from the HAPS control centre. The HAPS control centre consists of one gateway station to provide communication with the payload and the rest of the system, and four operations and management entities. The hardware configuration control centre is responsible for the tracking, telemetry, and command of both the platform and the payload. It is much like a satellite operations centre, with around-the-clock operation.

The communications resource control centre is responsible for all the real-time control of the network resources. This includes the user authentication, call control, radio resource management, traffic management, and usage data collection for billing and accounting.

The remote ground station control centre performs all the non real-time management tasks of the whole network, including all the remote gateway stations. It is essentially the network operations centre (NOC). Some functions may even extend to nearby HAPSs.

The regional business centre is responsible for the local business and financial control, including customer billing, carrier accounting, trend analysis, etc. One regional business centre may handle a group of HAPS systems.

2.3 Example frequency plan

An example channelization plan for HAPS with a 300 MHz + 300 MHz spectrum allocation is to divide the 300 MHz frequency spectrum in each direction into seven frequency bands of 33 MHz each, and with two 33 MHz guardbands. The seven frequency bands are arranged in a 7-cell frequency reuse pattern to maximize spectrum efficiency. For forward subscriber links, each 33 MHz band is further channelized into three 11 MHz channels. For reverse subscriber links, each band is channelized into fifteen 2.2 MHz channels. Each reverse link channel is further segmented into thirty-two 64 kbit/s time-slots plus a guard slot, an access control slot, and a pilot slot. Similarly, each forward link channel is divided into multiple 64 kbit/s slots plus all the framing slots. Each frame period is 6 ms. There are 700 cells in each of the UAC, SAC and RAC zones. There are up to 20 gateway stations in each of the UAC and SAC zones. Each gateway station is located in the centre of a cell to minimize co-channel interference with adjacent cells. Each gateway link utilizes the entire allocated spectrum, except for the band used by the host cell, and the necessary guardbands to reduce adjacent channel interference, to maximize link capacity. A total of twenty-two 11 MHz channels are used by each gateway for a total of 242 MHz in each direction, leaving four 11.75 MHz guardbands.

2.4 Platform station transmission characteristics

Typical transmitter and antenna characteristics for a platform station are given in Table 2.

Communications with user terminals will use TDM 4-PSK modulation with a bandwidth of 11 MHz for downlink and 2.2 MHz for uplink. Communications with gateway stations will use high-level modulation, 64-QAM, with a bandwidth of 88 MHz (11 MHz per carrier). Both assume a 2 × 100 MHz frequency utilization. If 2 × 300 MHz frequency spectrum were employed, it would be possible for user terminals to communicate with HAPS with a bandwidth of 33 MHz for downlink.

TABLE 2

Platform station transmitter parameters

Communication to	Transmitter power (dBW)	Antenna gain (dBi)(1)
UAC	1.3	30
SAC	1.3	30
RAC	3.5	41
Gateway (UAC)	0	35
Gateway (SAC)	9.7	38

(1) Maximum antenna gains.

2.5 User terminals and gateway stations

The corresponding parameters for the ground stations are given in Table 3. In the up direction the user terminals will use demand assigned multicarrier TDMA with QPSK modulation, while gateway stations will use similar techniques to those from the platform.

TABLE 3

Ground station transmitter characteristics

Communication to	Transmitter power (dBW)	Antenna gain (dBi)
UAC	–8.2	23
SAC	–7	38
RAC	–1.5	38
Gateway (UAC)	1.7	46
Gateway (SAC)	13.4	46

The antenna patterns of the HAPN gateway stations and user terminals described in Table 3 can be estimated by extending the information found in Recommendation ITU-R F.699 to the frequency band 47.2-48.2 GHz, and using the antenna gains found in column 3 of Table 3.

2.6 Antenna radiation patterns

The antenna radiation patterns for platform antennas conform to Recommendation ITU-R S.672. The reference radiation pattern is given by:

$$G(\psi) = G_m - 3\,(\psi/\psi_b)^{\alpha} \quad \text{dBi} \qquad \text{for } \psi_b \leq \psi \leq a\,\psi_b \tag{1}$$

$$G(\psi) = G_m + L_N + 20\log(z) \quad \text{dBi} \qquad \text{for } a\,\psi_b < \psi \leq 0.5b\,\psi_b \tag{2a}$$

$$G(\psi) = G_m + L_N \quad \text{dBi} \qquad \text{for } 0.5b\,\psi_b < \psi \leq b\,\psi_b \tag{2b}$$

$$G(\psi) = X - 25\log(\psi) \quad \text{dBi} \qquad \text{for } b\,\psi_b < \psi \leq Y \tag{3}$$

$$G(\psi) = L_F \quad \text{dBi} \qquad \text{for } Y < \psi \leq 90° \tag{4a}$$

$$G(\psi) = L_B \quad \text{dBi} \qquad \text{for } 90° < \psi \leq 180° \tag{4b}$$

where:

$X = G_m + L_N + 25\log(b\,\psi_b)$ and $Y = b\,\psi_b \times 10^{0.04(G_m + L_N - L_F)}$

$G(\psi)$: 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: ear-in-side-lobe level (dB) relative to the peak gain required by the system design

L_F: 0 dBi far side-lobe level (dBi) (see Note 2)

z: (major axis/minor axis) for the radiated beam

L_B: $15 + L_N + 0.25\,G_m + 5\log z$ dBi or 0 dBi whichever is higher.

NOTE 1 – Patterns applicable to elliptical beams require experimental verification. The values of a in Table 4 are provisional.

NOTE 2 – A far side-lobe level of –10 dBi has been assumed for the high performance HAPS station transmitting and receiving antennas.

TABLE 4

L_N (dB)	a	b	α
–20	$2.58\sqrt{(1 - \log z)}$	6.32	2
–25	$2.58\sqrt{(1 - 0.8\log z)}$	6.32	2
–30	–	6.32	–

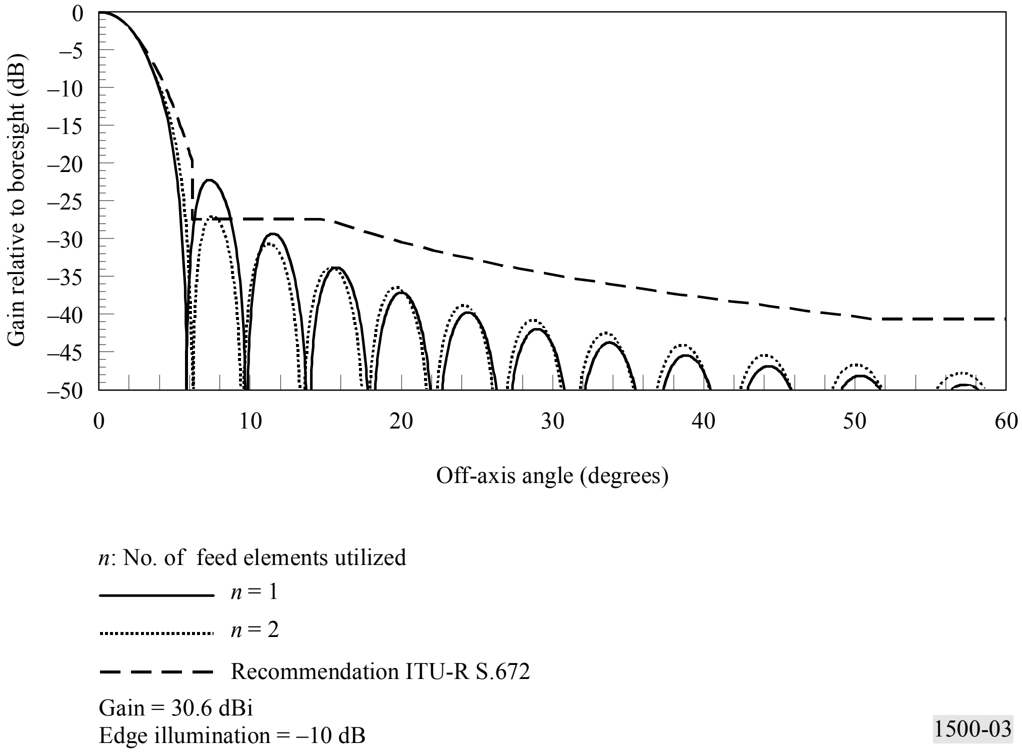
For 3 dB beamwidth ($2\,\psi_b$) (degrees^2):

$$(2\psi_b)^2 = \frac{27\,000}{10^{0.1G_m}} \qquad \text{degrees}^2$$

where G_m is the peak aperture gain (dBi).

FIGURE 3

Comparison between reference radiation patterns given in Recommendation ITU-R S.672 and theoretical patterns for a circular aperture illuminated by a raised parabolic function on a –10 dB pedestal



From Recommendation ITU-R S.672 (1997):

$G_m = 30.62$ dB

$D/\lambda = 14$

$\psi_b = 2.4°$

$a\psi_b = 6.2°$

$b\psi_b = 15.3°$

Side lobe = –27.5 dB

$X = 2.11$

$Y = 51.2°$

$L_F = -10$ dB

Assuming a 700-cell geometry, and a 7-cell frequency reuse pattern, calculation of the peak *C*/*I* for the hex pattern illuminated by a multibeam antenna gives the following:

TABLE 5

Recommendation ITU-R S.672						
Off-axis	Angle	Disc (dB)	Number of beams	Interference (dB)	Aggregate *I*/*C* (dB)	Aggregate *C*/*I* (dB)
1D	11.12	–27.50	6	–19.72	–19.72	19.72
2D	22.25	–31.58	12	–20.78	–17.21	17.21
3D	33.37	–35.98	18	–23.43	–16.28	16.28
4D	44.50	–39.10	24	–25.30	–15.77	15.77
5D	55.62	–40.62	30	–25.85	–15.36	15.36
		Total beams	90			

A worst-case *C*/*I* value of 15.36 dB can be estimated. This leads to an upper bound of –4.36 dB being obtained for the co-channel *I*/*N*. This will reduce link margin for user links by 1.36 dB. This compares with a 0.414 dB reduction for the link margin when the usual criterion that the interference should be smaller than noise by at least 10 dB is applied. Since the ITU-R reference radiation pattern is an upper bound, the actual co-channel interference level may be considerably lower.

2.7 RF filter response and out-of-band (OoB) emission

For user links, coherent QPSK modulation is used. This produces a power spectrum-density, which decreases quadratically as a function of the emission frequency relative to the carrier frequency.

$$S_{QPSK} = C \cdot A^2 \cdot T_b \left| \frac{\sin(2\pi(f - f_c) \cdot T_b)}{2\pi(f - f_c) \cdot T_b} \right|^2$$

$C \cdot A^2$: total infinite bandwidth signal power normalized across 1-Ω resistance

f_b: bit rate

$T_b = 1/f_b$: bit duration

f_c: carrier frequency.

With more advanced modulation techniques, such as the patented 4-PSK-FK [Kato and Feher, 1983], a sharper attenuation with greater frequency separation is possible.

Additional filtering is needed in order to minimize ISI (inter-symbol-interference) and to further reduce OoB emission. This can be achieved with a raised cosine filter, which can be implemented either with surface acoustic wave (SAW) filters alone, or with a combination of digital (baseband) filtering and analogue filtering using SAW filter(s). SAW filter techniques are extremely flexible: any linear bandpass filter may be synthesized, with arbitrary amplitude and phase, limited only by line width and crystal size. Typically single-phase unidirectional transducer (SPUDT) type SAW filters can attenuate OoB emission by up to 60 dB, with a passband flatness of less than 0.5 dB peak-to-peak, and a phase ripple of less than 1°. This, together with another 16 dB (10 log $4\pi^2$) attenuation at the first side lobe of the QPSK power spectral-density curve, a 75 dB reduction of the OoB emission is readily achievable.

To achieve more than 80 dB adjacent channel rejections, a cascade of two SAW filters is the only practical solution, with an insertion loss of as small as 6 dB. This is precisely the technique used by CDMA handset manufacturers to reduce adjacent channel interference with PCS base stations to less than –80 dB. Modern low insertion loss SPUDT filters have relatively large saturation amplitudes and power handling capabilities, and since it is not necessary to drive SPUDT filters to near saturation in order to maximize power efficiency, any nonlinear generation of spurious emission can be safely neglected.

2.8 HAPS system's radio emission characteristics

The arrangement of frequency usage for HAPS system will depend upon the specific requirements in each service area, which will affect the bandwidth, assigned to an individual platform and its associated ground terminals.

An isolated HAPS system located in an area remote from other HAPS system could be equipped to utilize up to the total bandwidth of 2 × 300 MHz, dependent on the number of users subscribing to the system.

Another scenario more appropriate to HAPS services over a wide regional area may be to assume an equilateral deployment of a number of HAPS platforms operating within a three times frequency reuse lattice; i.e. with each platform employing 2 × 100 MHz.

Other scenarios will be more appropriate for other environments and demand patterns.

As an example the 2 × 100 MHz usage from a single platform will be considered. Assuming burst information rates from the user terminals at 2 Mbit/s, and allowing for coding and other overheads, and also adopting a 7 × reuse pattern, the 100 MHz is divided into seven 11 MHz slots, plus a 23 MHz guardband. Each 11 MHz slot can support a single user at the full burst rate downlink and one-fifth the full burst rate uplink with an uplink channelization factor of 5. Uplink channelization reduces the burst power to average power ratio of the user terminals, which reduces the cost of the user terminals. If all platforms are operated by the same service provider, the guardbands are not needed.

Dependent on the activity factor assumed for an average user, each 11 MHz slot can provide maybe up to 10 high-speed users. Each enjoys an average bit rate of more than 1 Mbit/s, burstable to 10 Mbit/s on the downlink, and 2 Mbit/s on the uplink. Efficient time sharing among different users is ensured by a fast demand assignment multiple access scheme which dynamically reassigns user channels on the fly every 20 ms.

Within each of the zones, urban, suburban and rural, 700 cells are provided. Thus for UAC zone the power density from the user terminals is –8.2 dB(W/2 MHz), multiplied by 100 times frequency reuse and modified by the user terminal side-lobe radiation pattern. For SAC the figure is –7.0 dB(W/2 MHz) times 100, and for RAC it is –1.55 dB(W/2 MHz) times 100 at the maximum.

To carry the concentrated user traffic, up to 20 gateway stations are needed in UAC and SAC zones. These operate with 64-QAM across an 88 MHz bandwidth (100 MHz minus 12 MHz), each with a power density of about –8 dB(W/2 MHz) for gateway stations in the urban area and 4 dB(W/2 MHz) for gateway in the suburban area and in the rural area. Excluding FEC, framing, and other overheads, 64-QAM can provide about 4 bit/s/Hz of spectrum efficiency, or 352 Mbit/s per gateway. 20 gateways per zone will provide 14.8 Gbit/s of gateway throughput or 60% of the maximum user traffic that can be supported.

Transmission from the platform uses the whole of the available bandwidth on a time and frequency shared basis and a power density of 20.6 dB(W/2 MHz). This is based on the estimated power density for both user links and gateway links. For user links, the power density is 0 dB(W/11 MHz) for both UAC and SAC zones, and 2.2 dB(W/11 MHz) for the RAC zone. For gateways the power density is 0 dB(W/11 MHz) for UAC and 9.7 dB(W/11 MHz) for SAC. Total platform RF power is about 10 kW.

2.9 Example link budget computation

A representative link budget calculation is presented below. The platform antenna gains for user terminal links are edge-of-cell antenna gains, down from the maximum antenna gains by 3 dB. The required $E_b/(N_0 + I_0)$ is based on QPSK modulation with a rate 2/3 convolution code of $k = 7$ for a BER of under 1×10^{-7}. The user information rates take into account overheads of ATM headers and framing. Rain attenuation is based on >99.5% availability for ITU-R Region K statistics. Receiver G/T assumes a receiver noise temperature of 900 K for both user terminals and gateways, and 500 K for platforms.

TABLE 6

User terminal links

	UAC	UAC	SAC	SAC	RAC	RAC
	TDM down	FDMA up	TDM down	FDMA up	TDM down	FDMA up
Frequency (GHz)	47.0	48.0	47.0	48.0	47.0	48.0
Bandwidth (MHz)	11.0	2.0	11.0	2.0	11.0	2.0
Tx power (dBW)	1.3	–8.2	1.3	–7.0	3.5	–1.5
Antenna gain (dBi)	27.0	23.0	27.0	38.0	38.0	38.0
Hybrid (H)/waveguide (W) loss (dB)	0.5	0.5	0.5	0.5	0.5	0.5
e.i.r.p. (dBW)	27.8	14.3	27.8	30.6	41.0	36.1
Slant range (km)	42.0	42.0	81.1	81.1	240.9	240.9
Free space loss (dB)	158.3	158.5	164.1	164.3	173.5	173.7
Atmospheric loss (dB)	2.3	2.8	5.2	5.8	6.3	7.7
Rain attenuation (dB)	11.2	11.2	14.8	14.9	20.2	22.4
pfd on the ground (dB(W/(m^2 · MHz))	–99.6	–	–111.8	–	–114.5	–
Receiver G/T (dB(K^{-1}))	–6.5	0.0	8.5	0.0	8.5	11.1
Polarisation loss (dB)	0.5	0.5	0.5	0.5	0.5	0.5
Boltzmann constant (dB(W/K))	–228.6	–228.6	–228.6	–228.6	–228.6	–228.6
Bit rate (dB(Hz))	70.0	63.1	70.0	63.1	70.0	63.1
$E_b/(N_0 + I_0)$ $(I = 0)$ (dB)	7.5	6.8	10.3	10.6	7.6	8.3
Required $E_b/(N_0 + I_0)$ (dB)	6.1	6.1	6.1	6.1	6.1	6.1
Margin (dB)	1.4	0.7	4.2	4.5	1.5	2.2

For gateway links, adaptive power control is used to combat rain fade. Each gateway power amplifier can increase its power by up to 4 dB for those links that are most seriously affected by rain. This produces a power control gain of 4 dB. Gateway links are 44 Mbit/s per carrier. The required $E_b/(N_0 + I_0)$ for gateway is based on 64-QAM modulation with a rate 4/5 convolution coding ($k = 9$) concatenated with a high rate Reed-Solomon outer code with long interleaving coding to achieve a BER of better than 1×10^{-10} (See Note 1).

NOTE 1 – Note that the depth of the interleaver will be several hundred times the constraint length of the convolutional code and that its purpose is to randomize the burst errors produced by the Viterbi decoder.

TABLE 7

Gateway station links

	UAC	UAC	SAC	SAC
	TDM down (per carrier)	TDM up (per carrier)	TDM down (per carrier)	FDMA up (per carrier)
Frequency (GHz)	47.0	48.0	47.0	48.0
Bandwidth (MHz)	11.0	11.0	11.0	11.0
Tx power (dBW)	0.0	1.7	9.7	13.4
Antenna gain (dBi)	35.0	46.0	38.0	46.0
H/W loss (dB)	8.5	8.5	8.5	8.5
e.i.r.p. (dBW)	26.5	39.3	39.2	50.9
Slant range (km)	42.0	42.0	81.1	81.1
Free space loss (dB)	158.3	158.5	164.1	164.3
Atmospheric loss (dB)	2.3	2.8	5.2	5.8
Rain attenuation (dB)	11.2	11.2	14.8	14.9
Power control gain (dB)	4.0	4.0	4.0	4.0
pfd on the ground (dB(W/m^2 · MHz))	–96.8	–	–96.4	–
Receiver G/T (dB(K^{-1}))	16.5	5.5	16.5	8.5
Polarization loss (dB)	0.5	0.5	0.5	0.5
Boltzmann constant (dB(W/K))	–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)	26.8	27.9	27.3	30.1
Required $E_b/(N_0 + I_0)$ (dB)	20.3	20.3	20.3	20.3
Margin (dB)	6.5	7.6	7.0	9.8