RECOMMENDATION ITU-R M.1468*

TECHNICAL CHARACTERISTICS AND SHARING SCENARIOS OF SATELLITE SYSTEMS OFFERING MULTIPLE SERVICES

(Question ITU-R 104/8)

(2000)

The ITU Radiocommunication Assembly,

considering

a) that some co-primary fixed-satellite service (FSS)/mobile-satellite service (MSS) frequency bands for use by satellite systems offering multiple services (SSOMS) are under active consideration in the frequency range from about 20 to about 50 GHz;

b) that Recommendation 715 (Orb-88) calls for the simplification of the process for bringing into use satellite networks with different classes of user terminals;

c) that technologies are under development which will permit implementing multiple purpose applications (fixed, mobile, other) in a single frequency band;

d) that specific technology development efforts are already under way in a number of countries to develop SSOMS in the frequency bands stated in *considering* a);

e) that Question ITU-R 104/8 asks for studies on what additional technical basis for coordination needs to be applied to allow different SSOMS to operate in a common frequency band;

f) that Question ITU-R 104/8 also calls for studies of technical characteristics and operational procedures for the SSOMS;

g) that the ITU-R is studying orbit/spectrum improvement measures for satellite networks having more than one service in one or more frequency bands, under Question ITU-R 81/4 and has adopted a general Recommendation ITU-R S.744;

h) that ITU-R has adopted Recommendation ITU-R S.1329 on the frequency sharing of the bands 19.7-20.2 GHz and 29.5-30.0 GHz between systems in the MSS and systems in the FSS,

recommends

1 that satellite personal and mobile low data rate terminals operating in a low signal density environment should use access techniques, for example, code division multiple access (CDMA), (other access and modulation techniques are under study) which allow multiple SSOMS to operate in the frequency bands referred to in *considering* a) to maximize sharing possibilities;

2 that other techniques, such as low side-lobe (quasi-rectangular) antenna patterns, also orthogonal to the GSO, and with automatic tracking, and concatenated coding (Reed Solomon (RS) + convolutional) which facilitate frequency sharing between systems in the MSS and systems in the FSS, be used by personal and mobile earth terminals in the frequency bands referred to in *considering* a);

3 that new SSOMS in the frequency bands of *considering* a) should take into account the technical characteristics and the sharing feasibility scenarios of the MSS as described in Annexes 1 and 2.

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* This Recommendation should be brought to the attention of Radiocommunication Study Group 4.

ANNEX 1

Technical characteristics of SSOMS

1 Introduction

Consideration is being given to establishment of SSOMS which would accommodate mobile, personal, point-to-point (P-P) and point-to-multipoint (P-MP) communications on a common spacecraft and all operating in a common frequency band. For brevity, P-P and P-MP communications will be collectively referred to as fixed point communications.

An intent of this Annex is to describe the main technical characteristics of some SSOMS to be taken into account in developing frequency sharing scenarios between FSS and MSS.

2 System architecture of NASA's personal access satellite system

The system design is in part based on spacecraft technology which has been demonstrated with NASA's Advanced Communications Technology Satellite (ACTS) and is extracted from the personal access satellite system (PASS) research being conducted at NASA/Jet Propulsion Laboratory (JPL). The 20/30 GHz PASS utilizes fixed multibeams to provide simultaneous, continuous coverage to users in the service area, i.e. the continental United States (CONUS), and a single CONUS beam for the feeder links. The salient features are tabulated in Table 1.

TABLE 1

Salient features of the ACTS system design

Operating frequency	
Uplink	30 GHz
Downlink	20 GHz
Coverage concept	
SAT/Suppliers	CONUS beam
SAT/Users	142 spot beams
Generic services	Voice and data
Typical channel data rate	4.8 kbit/s
Rain compensation	
Forward	Uplink power control and variable data rate
Return-BPT-type	Variable data rate
Return-EPT-type	Uplink power control and variable data rate
Link availability	98% (BPT type)
	> 98% (EPT type)
Inter-beam power management	9-beam power management
Frequency reuse capability	16 times (spot beams)
System capacity	Equivalent to 7 500 duplex
	BPT: basic personal terminal
	EPT: enhanced personal terminals voice channels (Vox = 35%)

BPT: basic personal terminals
EPT: enhanced personal terminals

The uplink frequency is 30 GHz and the downlink frequency is 20 GHz. The available uplink and downlink spectra are each divided into two parts for the CONUS beams (feeder links) and the spot beams (service links). The spectrum assigned for the spot beams is reused 16 times. The available spectrum in a given beam/transponder will be partitioned into two segments: one for mobile and personal communications and the other for fixed point communications. The portion for mobile and personal communications will be available to all mobile and personal communications users. Similarly, the portion for fixed point communications will be available to all fixed point communications users.

2.1 Satellite design

The satellite employs two spot-beam antennas, with diameters of 2 m and 3 m for transmit and receive respectively. These antennas produce 142 spot beams covering the service area. The spot-beam antennas have a gain of 52.5 dBi and 3 dB beamwidth of 0.35°. The corresponding receive G/T is 23.4 dB(K^{-1}), and the e.i.r.p. is 55 dBW. To facilitate spot-beam frequency reuse, the satellite spot-beam antenna is designed to provide 20 dB inter-beam isolation. The CONUS beam receiver G/T is –1.2 dB(K^{-1}), and the transmitted e.i.r.p. is 40 dBW.

2.2 Earth station design

There are various types of user terminals for different applications: basic personal terminals (BPT), enhanced personal terminals (EPT), vehicular mobile terminals (VMT), aeronautical mobile terminals (AMT), micro terminals (MT), and fixed terminals (FT).

The BPTs are designed to provide personal communications. These terminals will be equipped with a tracking antenna and will be capable of supporting voice and data services at a rate not exceeding 4.8 kbit/s under normal operating condition, i.e. no rain. This type of terminal is required to have an antenna gain in the 20-25 dBi range (for PASS, 23 dBi at the transmit frequency and 19 dBi at the receive frequency), a variable rate modem, 1-W transmitter, and other application-dependent components. The variable rate modem is to combat rain attenuation. The BPTs are intended to be carried around by the user.

The EPTs have 30-35 dBi antenna gain and are also designed to support personal communications. These terminals can support higher data rates and hence more services than the BPTs; but they are not intended to be mobile. As such, they do not have to be very compact.

The VMTs are for mobile applications and are similar to mobile terminals in the 1.5/1.6 GHz bands. The antenna gain ranges from 20 to 25 dBi.

The AMTs are for aeronautical mobile applications and are similar to the VMTs.

P-MP communications (i.e. very small aperture terminal (VSAT)-type communications) is supported by the MTs that are similar to today's VSAT terminals. The antenna gain is about 40 dBi.

P-MP communications is similar to the conventional fixed-satellite communications. The earth stations for this application are expected to employ large antennas having 50 dBi or more gain.

3 System architecture of the SECOMS project

SECOMS (Satellite EHF Communications for Multimedia Mobile Services) is a project approved by the European Commission to define and design a new satellite system to provide multimedia mobile services in SHF band (20 to 30 GHz band) and EHF band (40 to 50 GHz) to portable/mobile and pocket-size terminals.

The SECOMS system concept adopts the following evolutionary approach:

– *Phase 1*: 20 to 30 GHz band system component with coverage over Europe and neighbouring countries (extended Europe) to provide multimedia-mobile services to medium-sized portable/mobile terminals up to 2 048 kbit/s.

– *Phase 2*: 40 to 50 GHz band system component to increase capacity, expand set of services, and enhance mobility and interactivity, for data rate up to 64 kbit/s for telephony and data services with pocket-size terminals.

3.1 Satellite design

The satellite orbit selected is the GSO. Main points of the project are:

– Use of multiple satellites.

– Multi-spot coverage of extended Europe with many high-gain beams on board.

– Adoption of inter-satellite links between the satellite hosting the 20 to 30 GHz band payload and that hosting the 40 to 50 GHz band one.

– On board fast digital processing (OFDP).

– Multi-frequency-time division multiple access/time division multiplexing (MF-TDMA/TDM) selected as the multiple access/distribution (MA/D) technique.

– QPSK differentially encoded modulation.

– Concatenated encoding (RS + convolutional).

For Phase 1 subsystem on board configuration assumes usage of three 1.5 m antennas at 20 GHz and three 1 m antennas at 30 GHz having the same 3 dB spot beamwidth of about 0.7°, and provides coverage of service area with 32 spots. Maximum capacity of a single satellite is 1.4 Gbit/s (nominal). Frequency reuse pattern by spatial discrimination is assumed to be 4 in the uplink and 3 in the downlink. The total bandwidth needed, on the basis of estimated traffic requirement, is 215 MHz and 470 MHz respectively in uplink and downlink for mobile users and 240 MHz (up) and 120 MHz (down) for fixed stations.

The 40 to 50 GHz band system component assumes usage of three 1.1 m antennas at 40 GHz and three 1 m antennas at 45 GHz, thus achieving 3 dB spot beamwidth of about 0.5°. It provides 64 spots for the same coverage area as the 20 to 30 GHz band system component. Maximum capacity of a single satellite is 200 Mbit/s (nominal). Frequency reuse pattern by spatial discrimination is assumed to be 9 both in the uplink and in the downlink. The total bandwidth needed, on the basis of estimated traffic requirement, is 103 MHz and 125 MHz respectively in uplink and downlink for mobile users and 107 MHz (up) and 107 MHz (down) for fixed stations.

The need for inter-satellite and inter-beam connectivity asks for OFDP techniques, i.e. block demodulation, digital processing, routing, and remodulation. A particularly important requirement is dynamical interference reduction and filtering of individual signals that can be accomplished through fast digital signal processing techniques. Regarding the MA/D technique selection, in the SECOMS project the most mature MF-TDMA/TDM approach has been selected after trade-off analyses vs. CDMA approach, due to its better link performances and less demanding feasibility. For reasons of flexibility and efficient use of resources, demand assignment both for bit rate and time plan adjustment has been also assumed.

3.2 Earth terminals characteristics

Three types of user terminals have been identified in the 20 to 30 GHz band:

– Sat-A type terminal, providing connections among low-medium data rate users (up to 160 kbit/s in the uplink, and 2.048 Mbit/s in the downlink). The transmitter average power over the various beams is 5.5 W, the antenna dimension is 27.5 × 27.5 cm^2 and the receiving antenna peak gain is 34 dB. In the worst case the transmitter power is 6.5 W.

– Sat-B type terminal, providing connections among medium-high data rate users (up to 512 kbit/s in the uplink and 2.048 Mbit/s in the downlink). The transmitter average power over the various beams is 3.8 W, the antenna dimension is 35.4 × 35.4 cm^2 and the receiving antenna peak gain is 36.2 dB. In the worst case the transmitter power is 4.4 W.

– Sat-C type terminal, providing connections among high data rate users (up to 2.048 Mbit/s both in uplink and downlink). The transmitter average power over the various beams is 15 W, the antenna dimension is 35.4 × 35.4 cm^2 and the receiving antenna peak gain is 36.2 dB. In the worst case the transmitter power is 17 W.

In the 40 to 50 GHz band only one type of user terminal is envisaged:

– Sat-D type terminal, providing connections among low data rate users (up to 64 kbit/s both in uplink and downlink). The transmitter average power over the various beams is 1.8 W, the antenna dimension is 10×10 cm^2 and the receiving antenna peak gain is 36.2 dB. In the worst case the transmitter power is 3.2 W.

Two types of fixed earth stations have been envisaged: Gat for interconnections with public terrestrial networks and service provider stations (SPS) to be utilized by service providers aiming to a direct connection with the satellite. The main difference between the two types of earth stations is the link availability (99.9% for Gat and 99.5% for SPS).

3.3 Link design and frequency sharing characteristics

Tables 2a and 2b summarize the SECOMS main system parameters.

It should be noted that the main features of the SECOMS project envisaged in order to facilitate frequency sharing between systems in the MSS and systems in the FSS are:

– extensive use of concatenated coding (RS + convolutional) which allow a reduction in the power flux-density (pfd) at the GSO and at the Earth's surface of more than 6 dB; and

– advanced technology for the pointing, acquisition and tracking system of the user terminals which allow an overall expected pointing accuracy better than 1°.

TABLE 2a

SECOMS main system parameters

Parameter	20 to 30 GHz band	40 to 50 GHz band	Remarks
Satellite position	12° E	12° E	Study case only
Maximum satellite traffic capacity	~1.4 Gbit/s	200 Mbit/s	
Number of spot beams	32	64	
Type of satellite terminals	3 (Sat-A, Sat-B, Sat-C)	1 (Sat-D)	
Type of fixed earth stations	2 (Gat-K, SPS-K)	2 (Gat-E, SPS-E)	Interferes with the terrestrial network
Uplink information rate (kbit/s)	From 16 to 160 (Sat-A) From 16 to 512 (Sat-B) From 16 to 2 048 (Sat-C)	– From 8 to 64 –	
Downlink information rate	4 096 kbit/s (Sat-A) 16.384 Mbit/s (Sat B, C)	512 kbit/s	
Gateways information rate (Mbit/s)	32.768	1.024	Uplink and downlink
Frequency (GHz): Uplink Downlink	 30 20	 45 40	
Coverage	Regional	Regional	
Spot beamwidth (degrees)	0.7 (at –3 dB)	0.49 (at –3 dB)	
Polarization	Circular	Circular	
Satellite G/T (dB(K^{-1}))	15.7	18.7	At triple cross point (tcp)

TABLE 2a (*end*)

Parameter	20 to 30 GHz band	40 to 50 GHz band	Remarks
Satellite maximum e.i.r.p./carrier (dBW)	60.9 48.9	59.6 47.7	For mobile users (at tcp) For fixed stations (at tcp)
User terminals G/T (dB(K^{-1}))	5.1 (Sat-A) 11.7 (Sat-B) 11.7 (Sat-C)	5.1	
User terminals maximum e.i.r.p. (dBW)	39.8 (Sat-A) 44.9 (Sat-B) 50.9 (Sat-C)	33.1	
User terminals antenna dimensions (cm^2)	27.5 × 27.5 (Sat-A) 35.4 × 35.4 (Sat-B) 35.4 × 35.4 (Sat-C)	10 × 10	
Link quality	BER < 1×10^{-10}	BER < 5×10^{-6}	
User terminals carrier bandwidths	170 kHz (Sat-A) 543 kHz (Sat-B) 2.17 MHz (Sat-C)	136 kHz (Sat-D)	
Downlink carrier bandwidth	5 MHz (Sat-A) 20 MHz (Sat-B and C)	938 kHz (Sat-D)	
User terminals expected pointing accuracy (degrees)	1	1	

TABLE 2b

SECOMS coding and decoding schemes

Coding	20 to 30 GHz band		40 to 50 GHz band	
	User terminals	Gat/SPS	User terminals	Gat/SPS
Uplink	RS (80,64) + Diff. (321,320)	RS (208,192)	RS (80,64) + convolutional rate 1/2 + Diff. (321,320)	RS (208,192) + convolutional rate 1/2
Downlink	RS (208,192) + convolutional rate 3/4		RS (208,192) + convolutional rate 1/2	
Decoding				
On board	RS		Concatenated	
On ground	Concatenated			

ANNEX 2

Sharing scenarios of SSOMS

1 Introduction

This Annex examines the sharing feasibility under various sharing scenarios. The analysis will be performed for the service links (spot beams). Feeder links will not be analysed because little or no interference is expected on these links. The capacity of a satellite without spot-beam frequency reuse nor orbit/spectrum reuse is first determined. The impact of spot-beam reuse orbit/spectrum reuse will then be examined. The number of users per channel (for system using CDMA only), and the overall spectral efficiency (bit/Hz) will be determined and used as a measure of system capacity. For the purpose of this analysis, system capacity refers only to the capacity of the service links.

2 Assumptions

The following assumptions are made for the purpose of determining the sharing feasibility:

Personal and mobile communications terminals:

– User antenna gain: 19 dBi (at 20 GHz) and 23 dBi (at 30 GHz) for BPTs and MTs, about 30 dBi (at 30 GHz) for EPTs.

– BPTs account for a small percentage of the personal and mobile communications (around 10% of the capacity).

– Backhaul earth station antenna gain: ≥ 50 dBi.

P-MP communications terminals:

– User antenna gain: ~ 40 dBi.

– Backhaul earth station antenna gain: ≥ 50 dBi.

P-P communications terminals:

– User antenna gain: ≥ about 50 dBi.

– Backhaul earth station antenna gain: ≥ 50 dBi.

Satellite and links characteristics:

– All satellites are homogeneous, with equal transponder bandwidth, equal downlink e.i.r.p., and hence equal downlink pfd.

– Spot-beam frequency reuse will be employed for the satellite/user links with 20 dB inter-beam isolation and 16 times frequency reuse.

– The overall link performance is limited by the performance of the user/satellite links.

– There will be no significant interference for the backhaul links due to the highly directive earth station antennas.

3 Sharing between satellites for personal and mobile applications

3.1 Choice of multiple access techniques

Both spread spectrum multiple access (SSMA) (also called CDMA), and frequency division multiple access (FDMA) are viable candidates for these applications. SSMA is selected for this analysis due to its ability to enable users to gain instant access to the system, and its multipath rejection capability. In addition, SSMA allows operators of adjacent satellites sharing the same spectrum relatively unrestricted freedom of spectrum usage.

Since there are two types of terminals used for personal and mobile communications with 10 dB difference in antenna gain, it is assumed here that the data rates supported by these terminals are directly proportional to the antenna gain of these terminals (i.e. 4.8 kbit/s and 48 kbit/s for BPTs, and EPTs, respectively). However, the spreading ratio (or spread spectrum processing gain) is assumed to be the same (30 dB) for both types of terminals.

3.2 System capacity in the absence of inter-beam and inter-satellite interference

The overall spectral efficiency, β, is a figure of merit commonly used to compare one system against another. It is equal to the system capacity divided by the available bandwidth and can be computed directly from the number of users per channel as follows:

$$\beta = (\text{Number of users/channel})\ (FR)\ (\eta)\ (PG)$$

where:

FR: number of frequency reuse

η: overall transmission efficiency

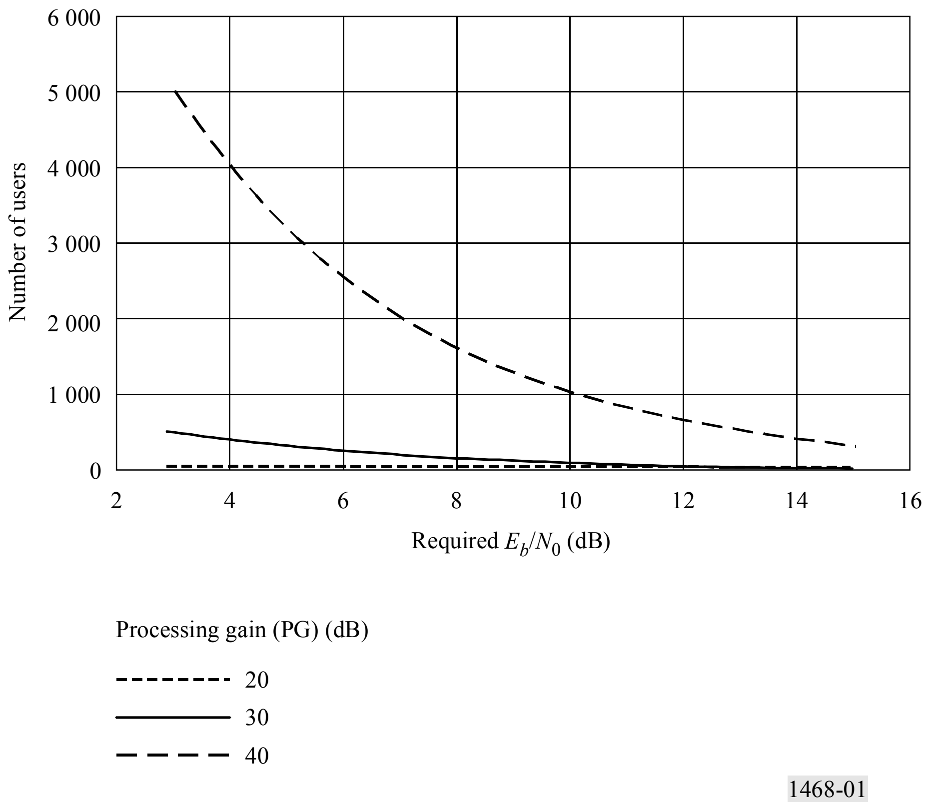
PG: spread spectrum processing gain.

For the purpose of this analysis, we assume an overall transmission efficiency of 1 chip/Hz, including the effects of Doppler, guardband, frequency errors, etc.

Figure 1 sets the maximum number of users/channel for a single-beam, satellite system and it will serve as a reference to assess the impacts of intersystem frequency sharing and intrasystem frequency reuse. Assuming 30 dB processing gain, 3 dB E_b/N_0, the maximum number of users is 500 users/channel. The corresponding spectral efficiency for a single beam system without frequency reuse is 0.5 bit/Hz, which can be obtained from the above equation by setting $FR = 1$.

FIGURE 1

Maximum number of users/channel vs. required E_b/N_0 for selected PG
(no inter-beam and inter-satellite interference)

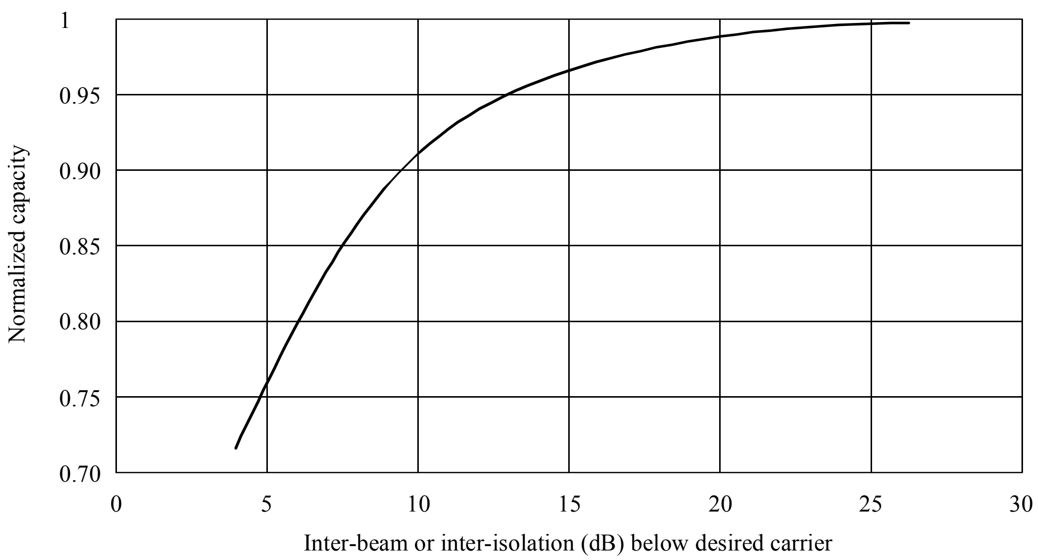


3.3 System capacity in the presence of inter-beam and inter-satellite interference

The presence of inter-beam interference reduces the maximum number of active users (per channel per beam). Figure 2 gives the maximum number of users (per channel per beam) as a function of inter-beam isolation, normalized to the theoretical maximum capacity obtainable in the absence of inter-beam and inter-satellite interference. Although the number of users (per channel per beam) is reduced, systems with spot-beam frequency reuse will have a larger total system capacity (i.e. the total number of users in the entire satellite system) than systems without frequency reuse. For the proposed satellite system with 20 dB inter-beam isolation and 16 times frequency reuse (for the spot beams only) spot-beam frequency reuse increases the total capacity for the service links by a factor of 15.8 giving a spectral of 7.9 bit/Hz.

FIGURE 2

Normalized system capacity vs. inter-beam/inter-satellite isolation for homogeneous systems



Note 1 – Capacity has been normalized to the maximum capacity obtainable in the absence of inter-beam and inter-satellite interference.

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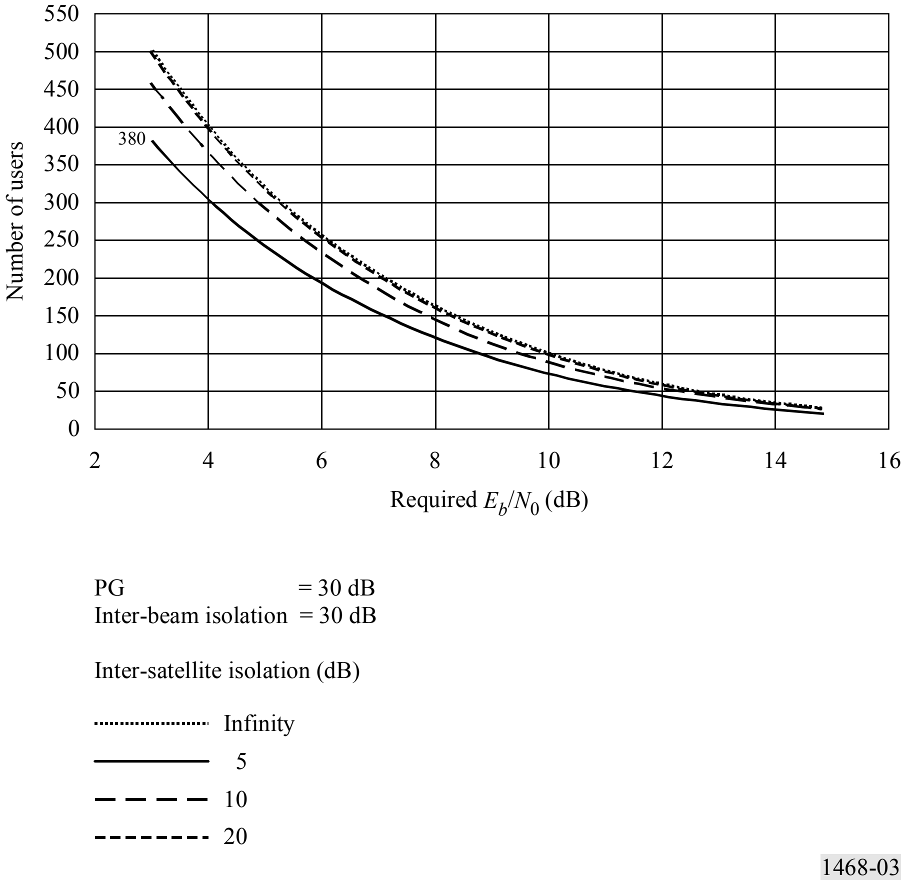
Inter-satellite (including adjacent satellite) interference has a similar effect as inter-beam interference does on the total and individual system capacities. Figure 3 gives the number of users as a function of the required E_b/N_0 for selected processing gain, inter-beam isolation and inter-satellite isolation. Although individual system capacities will be reduced in the presence of inter-satellite interference, systems without inter-beam interference and adjacent satellite interference can support 500 users/channel, as previously stated. For two co-channel adjacent satellites with 20 dB inter-beam isolation and 5 dB inter-satellite isolation, the capacity of each satellite will be reduced to about 380 users/channel as indicated by Fig. 3. The total capacity of the two satellites combined is therefore 760 users/channel, about 50% higher than that of a single satellite without orbit reuse. The resulting spectral efficiency for the two satellites combined is 12.2 bit/Hz.

One can conclude in general that spectrum sharing between adjacent satellites for mobile and personal communications is feasible using CDMA. However, there is a reduction in individual system capacities, and the amount of reduction depends on orbit spacing and user antenna characteristics.

FIGURE 3

Maximum number of users/channel vs. required E_b/N_0 for selected PG with inter-beam isolation and inter-satellite isolation as parameters



3.4 The effect of orbit separation on sharing feasibility and capacity

The impact of spectrum sharing between adjacent satellites on their individual system capacities can be minimized through orbit separation. For a given inter-satellite isolation and, hence, the amount of capacity reduction, orbit separation strongly depends on the type of user antennas and their radiation patterns. To examine the impacts of orbit separation on system capacity, the Reference-plus-7 dB model will be employed to model the radiation pattern of the SSOMS user antennas. This model is based on the reference radiation pattern described in Recommandation ITU-R M.694, with the following two improvements to increase inter-satellite isolation:

– 4 dB cross-polarization discrimination uniformly across the entire pattern.

– 4 dB cross-side-lobe improvement to reflect the fact that the side-lobe levels of the reference radiation pattern is about 3 dB more pessimistic than the actual Inmarsat Standard-A antenna.

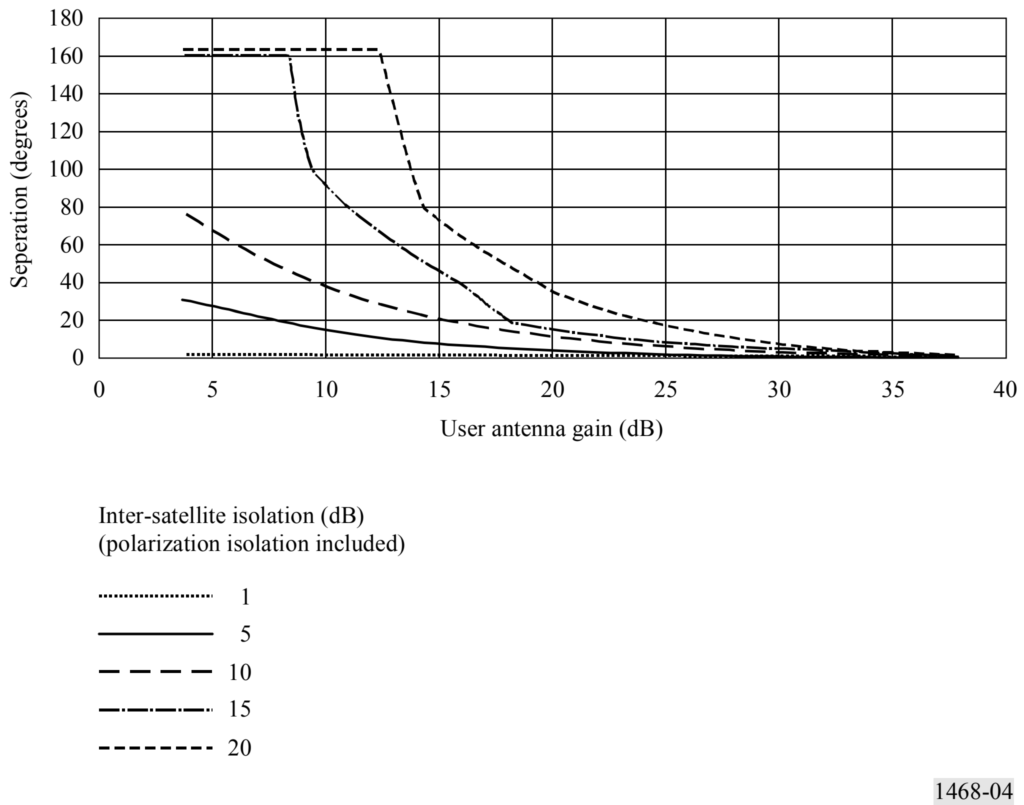
Using the Reference-Plus-7 dB model, the inter-satellite isolation as a function of user antenna gain has been computed (see Fig. 4). One can estimate the total system capacity from Figs. 3 and 4 for given orbit separation. For example, the inter-satellite isolation at 10° orbit spacing is about 10 dB for 10%. The total capacity of two satellites combined is thus 80% higher than that of a single satellite without orbit reuse.

4 Sharing between satellites for P-P and P-MP applications

The feasibility of frequency sharing between satellites for P-P and P-MP communications is examined in this section.

FIGURE 4

Orbit spacing required to achieve a given inter-satellite isolation vs. SSOMS user antenna gain (Reference-plus-7 dB)



4.1 Choice of multiple access techniques

Although many multiple access techniques including CDMA, FDMA and TDMA are applicable for these applications, fixed point communications (i.e. P-P and P-MP) traditionally employs FDMA. The following analysis hence assumes that FDMA will be employed for these applications.

4.2 System capacity in the absence of inter-beam and inter-satellite interference

For a bandwidth-limited system, its capacity is determined by the transmission efficiency, which is a function of the modulation and coding schemes and the amount of signal filtering. In general, one can improve the transmission efficiency by using bandwidth efficient modulation and by heavily filtering the transmit signal, at the expense of an increase in the required signal power, or E_b/N_0. For the purpose of this analysis, we again assume an overall transmission efficiency of 1 bit/Hz, including the effects of Doppler, guardband, frequency errors, etc. The actual system capacity for a bandwidth-limited system is given by the product of the transmission efficiency, the available bandwidth, and frequency reuse.

4.3 System capacity in the presence of inter-beam and inter-satellite interference

Due to the highly directive user antennas for the P-P and P-MP applications, more than 20 dB inter-beam isolation can be achieved for orbital separation of 2.5° between satellites. With 20 dB inter-beam isolation, the total amount of inter-beam and inter-satellite interference is more than 17 dB below the desired carrier. The resulting degradation is negligible and can easily be compensated for. The capacity (spectral efficiency) for a two-satellite system with spot-beam reuse and orbit/spectrum reuse is 32 bit/Hz.

4.4 The effect of orbit separation on sharing feasibility and capacity

In general, spectrum sharing between two closely spaced (2 or more degrees apart) adjacent satellites is feasible and will not result in a reduction in individual system capacities due to the relatively high directivity of the user antennas. Orbit/spectrum reuse will therefore significantly improve the total capacity.

5 Sharing between satellites for personal and mobile applications with satellites for P-P and P-MP applications

5.1 Choice of multiple access techniques

As previously stated, the chosen multiple access technique is CDMA for personal and mobile applications and FDMA for fixed point communications.

5.2 Reference system capacity in the absence of inter-beam and inter-satellite interference

The reference capacity (spectral efficiency) for personal and mobile communications satellite system without spot-beam frequency reuse nor orbit/spectrum reuse is 0.5 bit/Hz. Similarly, the reference capacity (spectral efficiency) for P-P and P-MP satellite communications system is 1 bit/Hz.

5.3 System capacity in the presence of inter-beam interference

For a satellite that employs multibeam frequency reuse technology and provides personal, mobile, and fixed point communications mutual interference between personal and mobile communications users and fixed point communications users may exist. The inter-beam isolation provided by the satellite is the only protection against inter-beam interference for both the CDMA and FDMA users. The 20 dB inter-beam isolation stated in § 2 is based on the assumption that the aggregated pfd of all CDMA signals is the same as that for the FDMA signals. Any difference will result in an unbalanced situation which favours one type of user at the expense of the other. While this problem might have significant impact on system capacity, it can be mitigated by the system operator through a combination of different techniques:

– impose a requirement for homogeneous pfd for CDMA and FDMA users, which can be achieved by either adjusting the uplink and downlink power and/or reducing the number of CDMA users;

– accept a lower C/I for the FDMA users; or

– a combination of both.

Relative downlink pfd: The relative pfd is a function of the number of active CDMA users, link performance requirements, and the difference of antenna gain between the CDMA terminals and the FDMA terminals (MTs and FTs). The relative downlink pfd has been estimated and is shown in Fig. 5, under a set of assumptions:

– fixed point communications is used mainly for business and hence have a much more stringent performance requirement than the BPTs and EPTs. It is therefore assumed that 10 dB more link margin will be needed for fixed point communications to account for lower error rate, higher rain margin, etc.;

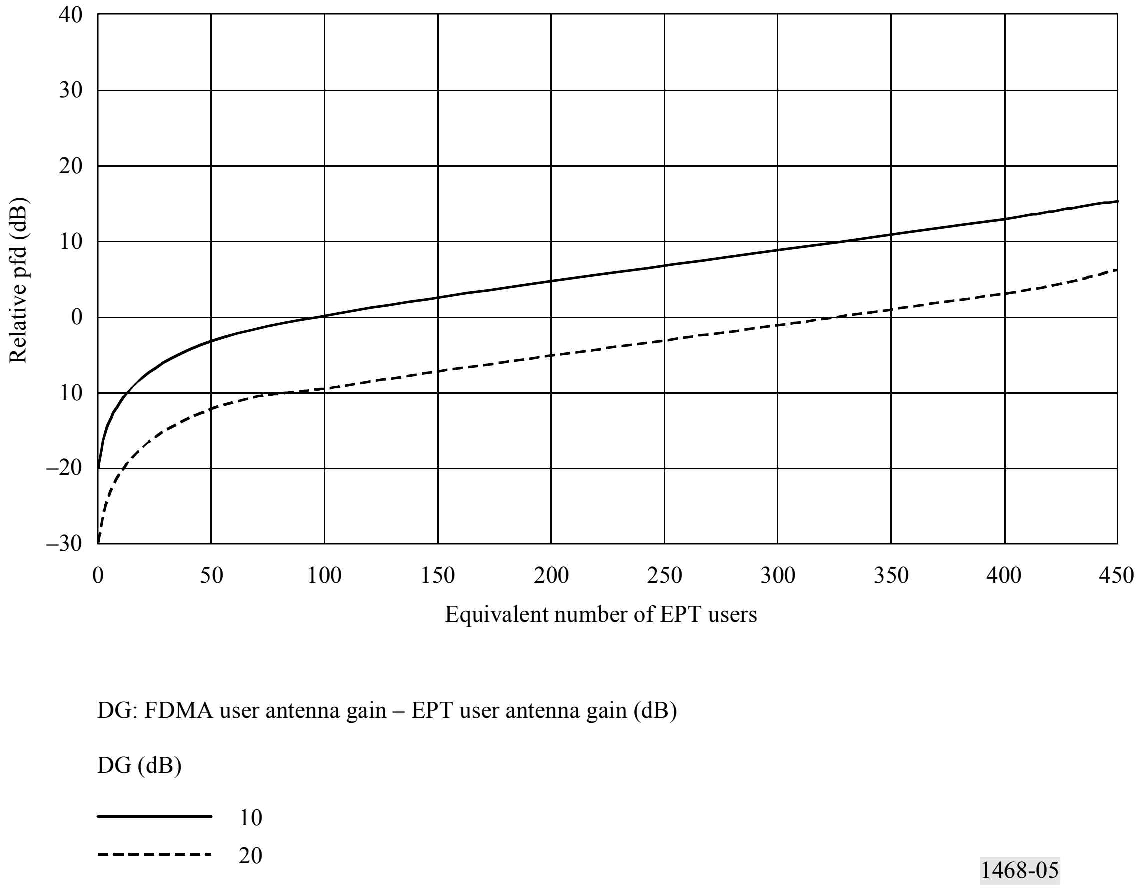
– BPT users account for only 10% of the total CDMA communications.

Figure 5 gives the relative downlink pfd as a function of the number of equivalent EPT users, with antenna gain difference between the EPT and the FTs as a parameter. The antenna gain difference is 10 dB between the EPT and the P-MP communications terminals, and 20 dB between EPTs and the P-P communications terminals. It should be noted that the relative pfd is expressed as a function of the number of equivalent EPT users which establishes the upper bound of the system capacity of a CDMA system serving both BPTs and EPTs.

Once can reduce the number of CDMA users to achieve a desired C/I to protect the FDMA users from CDMA interference. For example, by lowering the number of equivalent EPT users to 200/channel, the CDMA pfd would be 5 dB higher than that of the FDMA, giving an effective inter-beam isolation of 15 dB (20 dB – 5 dB) for the FDMA users, and 25 dB (20 dB + 5 dB) for the CDMA users.

FIGURE 5

CDMA downlink pfd relative to FDMA pfd as a function of number of EPT users



Relative uplink pfd: The relative uplink pfd has been computed and shown in Fig. 6 under the same assumptions stated above. As shown, the CDMA pfd is lower than the FDMA pfd, creating a situation which favors the FDMA users at the expense of the CDMA users. If the number of CDMA users is 200 users/channel (which can consist of a mix of BPTs), the CDMA pfd is lower than the FDMA pfd by about 15 dB. The effective inter-beam isolation for the protection of the CDMA users from FDMA uplink interference is thus 5 dB (20 dB – 15 dB).

The FDMA users will benefit from the unbalanced pfd significantly. The pfd advantage increases the effective inter-beam isolation from 20 dB to 35 dB (20 dB + 15 dB), which should have no noticeable degradation. The system capacity therefore remains at 16 bit/Hz.

In summary, by placing an upper limit on the number of CDMA users to 200 equivalent EPT users/channel, the non-homogeneous pfd problem can be mitigated and will not cause performance degradation.

5.4 System capacity in the presence of inter-satellite interference

Inter-satellite interference can affect satellite capacity. There are three interference scenarios:

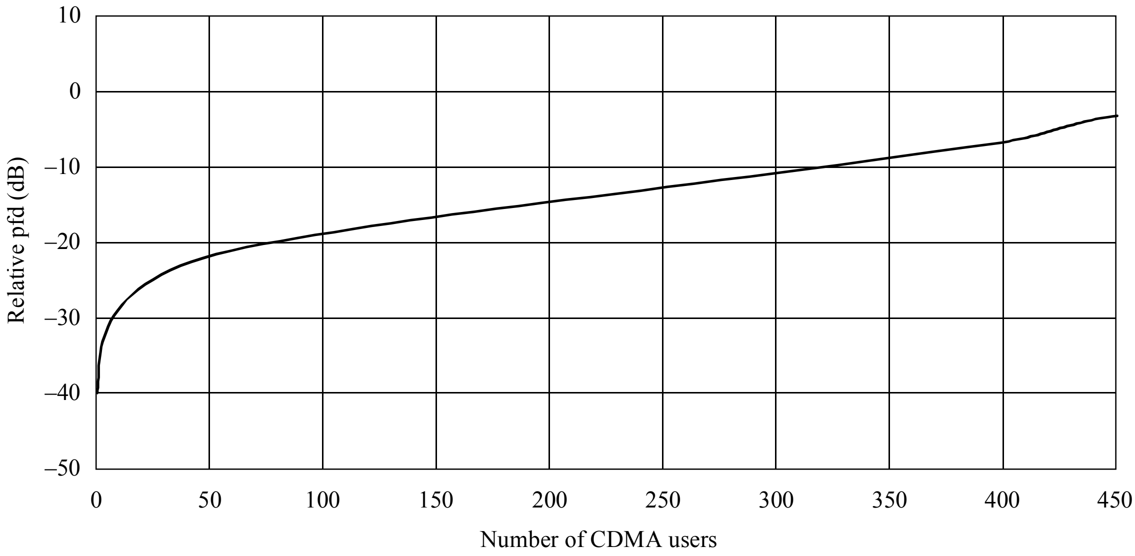
– CDMA users (personal and mobile communications) of one satellite interfere with those of another satellite.

– FDMA users (fixed point communications) of one satellite interfere with those of another satellite.

– CDMA users of one satellite interfere with the FDMA users of another satellite, and vice versa.

FIGURE 6

CDMA uplink (return) pfd relative to FDMA pfd vs. number of CDMA users



The first two scenarios are similar to the inter-satellite interference analyses given in § 3.3 and 4.3 and their results are applicable. The following analysis applies to the third scenario, assuming a reasonable orbit separation (3°) between two adjacent satellites.

Capacity in the forward direction: To account for interference from the FDMA downlink signals of an adjacent satellite, the number of active CDMA users must be reduced from its maximum by a factor which is a function of orbit spacing, the inter-satellite isolation of the BPT is 8.5 dB including 4 dB polarization discrimination. Including the effect of different downlink pfds, the effective inter-satellite isolation becomes 13.5 dB (8.5 dB + 5 dB). The CDMA capacity will correspondingly be reduced by a factor 0.96. It should be noted that the reduction is to account for inter-satellite interference only.

Reduction due to inter-beam interference has not been included. It should also be noted that only two satellites have been considered in this section. Additional adjacent satellites will also result in further capacity reduction, which will be addressed in § 7.

With 3° of spacing, the FDMA user terminals should be able to achieve about 30 dB reduction. Inter-satellite isolation is 25 dB (30 dB – 5 dB (downlink pfd difference)) in the forward direction (receive). Therefore, there will be little or no interference to the FDMA terminals (or users). The FDMA capacity is thus not effected by the CDMA users.

Capacity in the return direction: In the return direction, it may be necessary to reduce the CDMA capacity to

– account for the FDMA uplink interference from an adjacent satellite, and/or

– protect the FDMA users.

With 30 dB of inter-satellite isolation and 15 dB pfd difference, the effective inter-satellite isolation for the FDMA users is 15 dB (30 dB – 15 dB) in the return direction (transmit). This will reduce the CDMA capacity by a factor approximately equal to 0.97. Similarly, the uplink signals from the CDMA users can interfere with the proper reception of the FDMA signals by an adjacent satellite. The amount of acceptable interference is usually expressed in terms of the *C*/*I* requirement. If the uplink pfd for both systems is the same and uniformly distributed across the bandwidth of interest, the *C*/*I* is simply equal to the inter-satellite isolation of the CDMA user terminals. At 3° spacing the inter-satellite isolation is 8.5 dB and 12 dB for the BPT and EPT, respectively. Making use of the assumption that BPT users account for only 10% of the total CDMA capacity, the weighed inter-satellite isolation is found to be 11.49 dB. Adjusting for the 15 dB difference in uplink pfds, the effective inter-satellite isolation of the BPTs and EPTs combined becomes 26.5 dB (11.49 dB + 15 dB). The corresponding FDMA C/I is thus 26.5 dB. No degradation on the FDMA signals is expected.

6 Sharing with terrestrial systems

Sharing between SSOMS and terrestrial fixed systems in general is not feasible due to the mobile nature and the relatively low directivity of the users antenna for personal and mobile applications. Coordinations between these systems would be complex and impractical.

7 Orbit/spectrum utilization

This section gives the orbit/spectrum capacity for the CDMA users and FDMA users.

7.1 CDMA orbit/spectrum capacity

The following assumptions are made for the purpose of this analysis:

– 21° of useful arc;

– 16 times of spot-beam frequency reuse;

– 8 satellites spaced 3° apart;

– opposite polarization for adjacent satellites; and

– use of fan-beam antennas for all CDMA users.

7.1.1 Effects of FDMA interference

To determine the system capacity, it is necessary to first determine the inter-satellite isolation, which then must be adjusted to account for the pfd difference between the CDMA and FDMA signals. For the assumed satellite spacing, the inter-satellite isolation is estimated to be 0.1 dB for BPT users. Because the FDMA downlink pfd is 5 dB below the CDMA downlink pfd, the BPT effectively has 5.7 dB of inter-satellite isolation against FDMA downlink interference. This reduces the CDMA capacity in the forward direction by an additional factor of 0.79. The number of users in the forward direction is thus reduced to 157 users/channel (200 × 0.79). It is noted that 4 dB additional discrimination due to the use of fan-beam antennas has been assumed in the above computation.

In the return direction, the impact of orbit, the impact of orbit/spectrum reuse is determined by the inter-satellite isolation of the FDMA terminals. With eight satellites spaced 3° apart, the inter-satellite isolation of FDMA terminals is assumed to be about 25 dB including polarization discrimination. Adjusting for the 1.5 dB difference in uplink pfd, the effective inter-satellite isolation becomes 10 dB, which will reduce the CDMA capacity in the return direction by a factor approximately equal to 0.91, or to about 180 users (200 × 0.91/channel).

7.1.2 Effects of CDMA interference

In the forward direction, the amount of protection (inter-satellite isolation) that the BPT has against CDMA downlink interference from adjacent satellites is 0.7 dB, or 5 dB less than what it has against FDMA interference. The resulting capacity reduction factor is 0.54 (see Fig. 4), or 108 users (200 × 0.54)/channel.

In the return direction, uplink interference originated from CDMA users of adjacent satellites can result in capacity reduction. The amount of interference is determined by the inter-satellite isolation of the CDMA user terminals, i.e. BPTs and EPTs. The effective inter-satellite isolation is about 1.3 dB and 7.8 dB for the BPT and EPT respectively. Considering the BPT capacity allocation (10% of the total CDMA capacity), one obtains an effective inter-satellite isolation of 6.5 dB for the CDMA users (BPTs and EPTs combined). The resulting capacity reduction factor is 0.82 or 163 (200 × 0.82) users/channel.

7.2 FDMA orbit/spectrum capacity

7.2.1 Effects of CDMA interference

In the forward direction, the effective inter-satellite isolation of FDMA terminals is about 20 dB after adjusting for the 5 dB difference in downlink pfd. At this level, inter-satellite interference will have little or no impact on the individual satellite capacity.

In the return direction, uplink CDMA signals from adjacent satellite may interfere with the FDMA uplink. As indicated in § 7.1.2 the weighted inter-satellite isolation is 6.5 dB. Adjusting for uplink pfd difference, one obtains an effective inter-satellite isolation of 21.5 dB (6.5 dB + 15 dB).

Again, no significant performance degradation is expected.

7.2.2 Effects of FDMA interference

The inter-satellite interference among homogeneous systems is insignificant in both forward and return direction due the highly directive antenna.

In summary, the FDMA capacity per satellite remains the same as in the absence of inter-satellite interference, i.e. 16 bit/Hz. The total capacity in a 21° arc is thus 64 bit/Hz. It is noted that the use of fan-beam antennas by all CDMA users has been assumed in § 3 and 4. While this is desirable and enhances sharing, intersystem sharing can also be achieved without using fan-beam antennas. Without the 4 dB additional discrimination, the effective inter-satellite isolation would be 4 dB lower. The resulting CDMA capacity would be about 120 users/channel.

8 Conclusions

The major characteristics of some SSOMS have been presented. The sharing feasibility and orbit/spectrum capacity have also been examined. By varying the number of CDMA users/channel, results show that SSOMS can accommodate non-homogeneous user equipment (BPTs and EPTs) and support the use of different multiple access schemes (CDMA and FDMA) for different applications. The analysis also shows that SSOMS can achieve orbit/spectrum reuse despite the relatively low directivity of the BPT. Interference budgets and equipment characteristics have been proposed with the objective to maintain compatibility among all users/applications and to maximize resource utility.