RECOMMENDATION ITU-R S.1779

Characteristics of fixed-satellite service systems using wideband spreading signals

(Question ITU-R 270/4)

(2007)

Scope

This Recommendation provides example approaches on the use of wideband spreading signals in fixed-satellite service (FSS) systems. The three annexes to this Recommendation present an overview of the techniques and implementation approaches of transmission schemes for the benefit of network operators and users.

The ITU Radiocommunication Assembly,

considering

a) that new transmission techniques using wideband spreading signals may be used in fixed-satellite service (FSS) uplinks and/or downlinks;

b) that FSS systems using such technologies may address new applications and new services;

c) that the applications of FSS systems using wideband spreading signals have different features from other FSS systems;

d) that the characteristics of FSS systems using wideband spreading signals are different from those FSS systems currently deployed;

e) that the interference effect of the emissions from a FSS system using wideband spreading signals needs to be defined;

f) that it would be useful for network operators and users to have a source of information on the characteristics of FSS systems using wideband spreading signals,

recommends

1 that the system models and the technical characteristics contained in Annexes 1 through 3 should be used as example approaches for implementation of transmission schemes using wideband spreading signals for FSS systems.

NOTE 1 – Materials in Annexes 1 to 3 correspond to the following approaches, respectively:

Annex 1 – Transmission of additional information overlaid on the conventional FSS frequency-division multiple access (FDMA) signals.

Annex 2 – Improvement of the effective channel capacity in a FSS system with a number of narrow spot beams.

Annex 3 – Reduction of the off-axis e.i.r.p. density level to meet the values in the associated ITU-R recommendations.

Annex 1

A satellite system with wideband spreading signals (direct sequence (DS) technology)

1 Introduction

This Annex provides a description of transmission techniques using wideband spreading signals, referred to as a wideband satellite system, that can be used to transmit additional information without changing the operational frequency plan of the existing FSS system.

One of the applications of the system would be for the transmission of emergency traffic, such as earthquake information, tsunami warnings, etc. Figure 1 illustrates this type of application. For the purposes of emergency signal transmission, user terminals should be compact and inexpensive, so that most people can install and use such receivers at any time. Therefore, those with small (low-gain) antennas would be convenient, which would also facilitate installation and maintenance. Antennas in conventional FDMA FSS systems are usually higher gain and must be oriented towards the satellite direction, due to antenna directivity, and the antenna orientation is easily subject to change by accidental force, such as earthquakes or tropical cyclones.

In contrast to the above advantages, user terminals with low-gain antennas are affected by interference from adjacent satellites. The use of spreading signals is expected to mitigate this deterioration due to inter-system interference because of its spreading gain. This is the reason the spreading signal is used for this type of application.

The following applications have been evaluated to apply the technique:

– A satellite system with wideband spreading signals overlaid on the conventional FSS FDMA signals.

– A satellite system with dedicated bandwidths for both FDMA signals and wideband spreading signals.

In the following section, the link budget analysis in this application is presented using various parameters of the existing FSS system with evaluation results in terms of the data rate. Note that the DS technology is assumed in this analysis.

2 Application 1 – A satellite system with wideband spreading signals overlaid on the conventional FSS FDMA signals

2.1 System models

The conceptual view of the system is shown in Fig. 2. Two system models, Model 1 and 2, are assumed for a preliminary analysis on the wideband satellite system, which is summarized in Table 1. Model 1 is applied to a new satellite system using a regenerative type transponder, and Model 2 is applicable to the existing satellite system with a non-regenerative type one. The following scenarios are also assumed for this analysis.

FIGURE 1

Application of wideband spreading signals for emergency traffic transmission

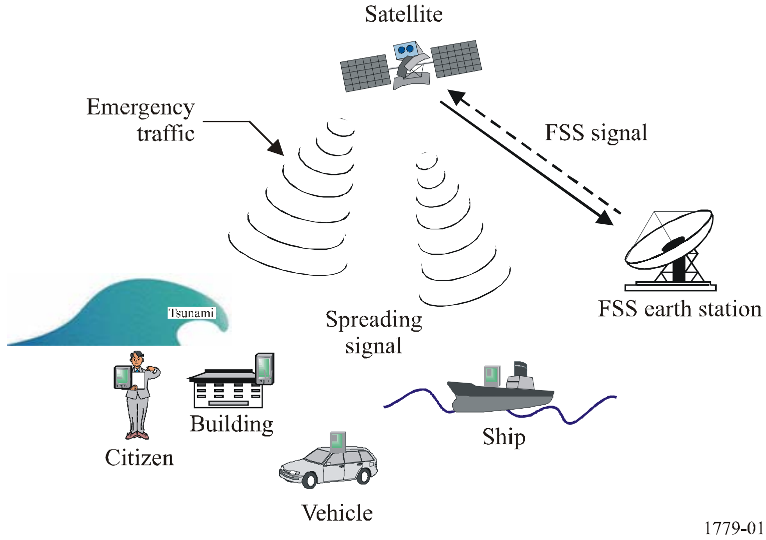


FIGURE 2

System model for satellite systems using wideband spreading signals

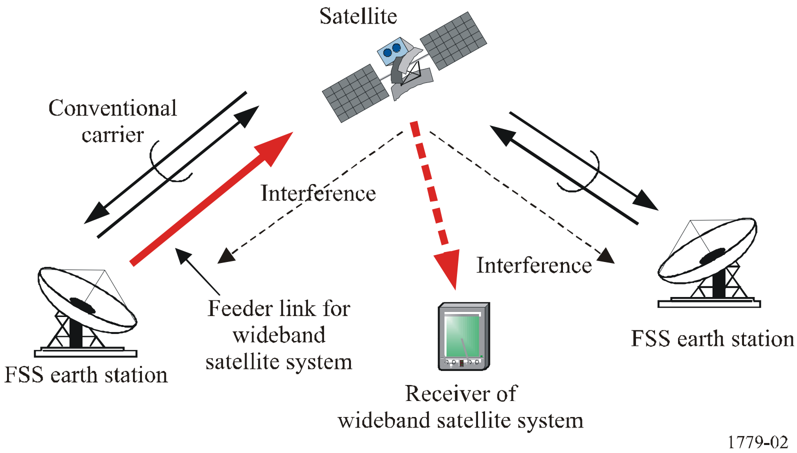


TABLE 1

Assumed link models in a wideband satellite system

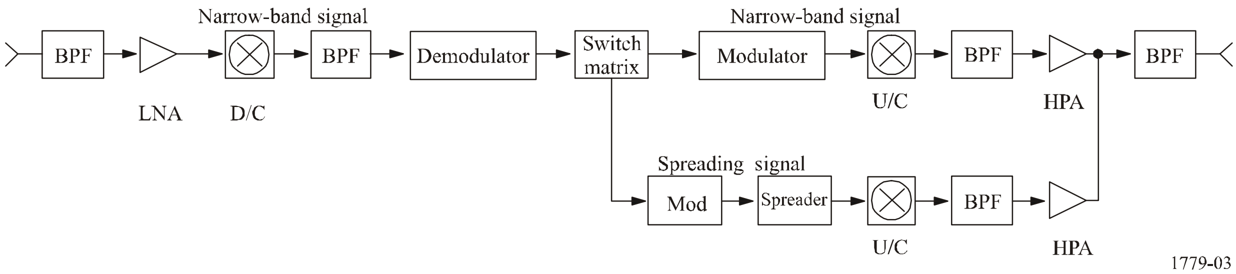
	Model 1	**Model 2**
Transponder type	Regenerative	Non-regenerative
Bandwidth (uplink/downlink)	36/240 MHz	36/36 MHz
Transmission scheme (uplink/downlink)	FDMA/ FDMA and spreading signal	FDMA and spreading signal/ FDMA and spreading signal

2.1.1 The wideband spreading signals are overlaid onto the existing FSS spectrum within the FSS allocation. The bandwidth of the wideband spreading signals is identical to the transponder bandwidth of the FSS, in which multiple FDMA carriers are allocated. Therefore the spread signals would be co-frequency with several adjacent FDMA signals of the same FSS networks, causing intra-system interference.

2.1.2 In Model 1, a conventional narrow-band type transmission is utilized for the uplink. For the downlink, the wideband spreading signals are transmitted through a transponder with very wide bandwidth, designed for the wideband satellite system, while the narrow-band signals are channelled through conventional narrow-band transponders. Figure 3 provides a diagram of a portion of the satellite payload in Model 1 which explains how the uplink signals are processed on board.

FIGURE 3

Diagram of satellite transponder used in Model 1



2.1.3 In Model 2, for the uplink the wideband spreading signals are overlaid onto the existing FDMA spectrum; both the FDMA signals and the wideband spreading signals are transmitted through a conventional transponder. For the downlink, just as for the uplink, both type signals are processed through a conventional transponder.

2.1.4 The space segment consists of a single satellite. Both the wideband and the narrow-band signals are processed at a single space station, and a single antenna is shared to transmit them into a single satellite beam. On the other hand, a new type of terminal, receiving only the spreading signals from the satellite, is assumed. The technical parameters of the wideband satellite system receiver can be independent from those of the existing FSS systems.

2.1.5 For ease of calculation, for the uplink both the FSS FDMA signals and the wideband spreading signals are transmitted from the same earth station; the two types of receivers are located at the same position at the Earth's surface, avoiding the need to take satellite antenna patterns into consideration.

2.2 Link budget analysis and performance estimation

The achievable data rate is estimated by the link budgets in the 14/12 GHz bands. Since a conventional transponder and transmission scheme are used for the uplink, the data rate of the wideband satellite system is obtained considering downlink parameters. The calculation is carried out by implementing the following steps:

Step 1: Using typical parameters in FSS systems and the required C/I value for FDMA carriers, the downlink e.i.r.p. in the wideband satellite system is derived, which, accordingly, provides the received C/T at the wideband signal receiver.

Step 2: Using the determined received C/T, an ideal data rate is obtained as the first step of the data rate analysis, assuming a condition where no FDMA carriers exist.

Step 3: Just as in Step 2, the achievable data rate is derived taking the interference from FDMA carriers into the wideband satellite system into consideration.

The procedures of the above steps are presented in more detail in the following sections.

2.2.1 Step 1

As shown in Fig. 4, the conventional FDMA carriers are transmitted in certain portions within the transponder bandwidths while the signals of the wideband satellite system are overlaid within the whole transponder bandwidth.

First, the required C/I value for the FDMA carriers is given where C and I represent the output power of one of the FDMA carriers and that of the wideband satellite system, respectively. A C/I of 20 dB is employed in this analysis.

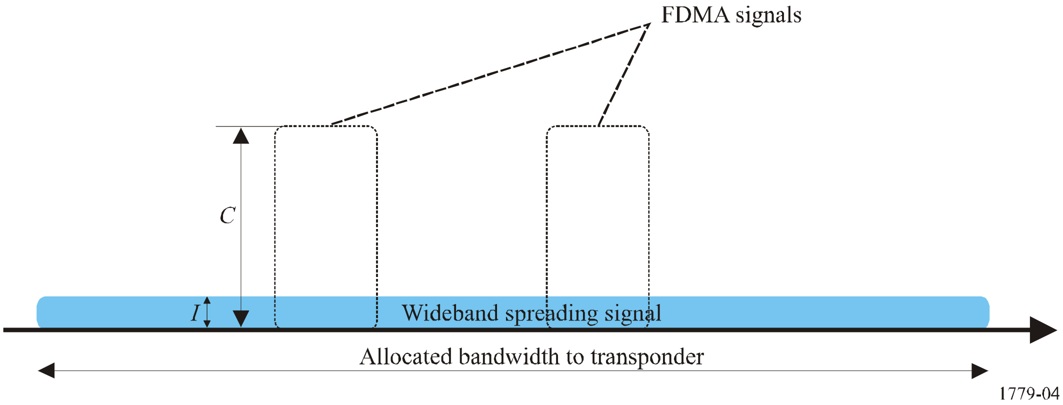
Once the required C/I is given, the permissible e.i.r.p. on the space station for the wideband satellite system is derived with the occupied bandwidth taken into consideration. Hence, the received C/T in the system, Rx C/T, is expressed by the following equation:

$$\text{Rx } C/T = e.i.r.p. - L_p - M_{rain} + G/T \qquad \text{dB} \tag{1}$$

where L_p, M_{rain} and G/T represent the free space path loss between the satellite and the receiver on the Earth's surface, the rain margin and the receiving antenna G/T, respectively.

FIGURE 4

Overlay of wideband satellite signals onto FDMA carriers in downlink



2.2.2 Step 2

When Rx C/T is given, the attainable information rate R is calculated by:

$$R = \text{Rx } C/T - (E_b/N_0)_{req} + 228.6 \qquad \text{dB} \tag{2}$$

where $(E_b/N_0)_{req}$ and "228.6" are the required E_b/N_0 and Boltzmann's constant, respectively.

The above information rate is the ideal data rate estimated under the condition assuming the absence of narrow-band FDMA carriers.

2.2.3 Step 3

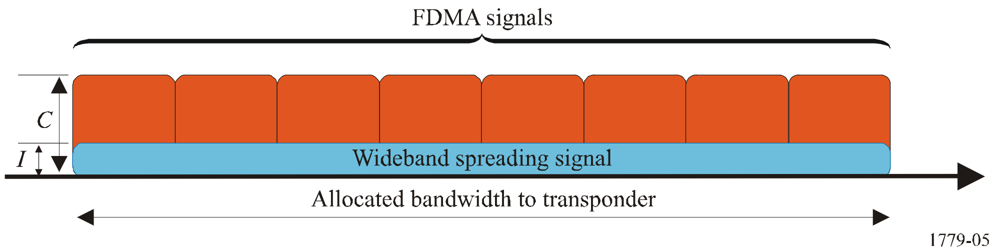
Finally, an achievable data rate is calculated for the wideband satellite systems, considering multiple narrow-band FDMA carriers within the transponder bandwidth. In this case the downlink Rx C/T of the FDMA carriers is regarded as the interference with the wideband satellite system. The overall C/T in the case of Model 1 is obtained by summing up the downlink receiver C/T value of the wideband satellite system and the degradation of the downlink wideband receiver C/T value due to the interference caused by FDMA carriers. This procedure can be also applied to the case of Model 2.

The channel usage of FDMA carriers is modelled for the analysis as shown in Fig. 5 with usage of 100% defined as the whole spectrum in the transponder bandwidth being used by multiple narrow-band FDMA carriers, and a usage of 50% showing half the bandwidth occupied by the FDMA carriers. When the channel usage is 100%, for example, the wideband satellite system requires a higher spreading gain by 20 dB than in Step 2. Note that the guardbands are not considered here for ease of calculation.

The way to calculate the data rate is the same as that presented in Step 2.

FIGURE 5

Channel usage of 100% by FDMA carriers in downlink



2.3 Results of link budget analysis

Typical parameters of the FSS system and e.i.r.p. values in the wideband satellite system are summarized in Tables 2 and 3. Taking a C/I value of 20 dB into account, the e.i.r.p. density of the spreading signals would be 14.4 dB(W/MHz), as shown in Table 3.

TABLE 2

Typical FSS system parameters

Parameter	Uplink	Downlink	Note
Bandwidth per carrier	72.0 MHz	36.0 MHz	
e.i.r.p. per carrier	70.0 dBW	50.0 dBW	
e.i.r.p. density	51.4 dB(W/MHz)	34.4 dB(W/MHz)	

TABLE 3

e.i.r.p. values in wideband satellite system

FDMA system	Uplink	Downlink	Note
e.i.r.p. density of FDMA	51.4 dB(W/MHz)	34.4 dB(W/MHz)	From Table 2
Required *C*/*I* (FDMA/wideband satellite system)	20.0 dB	20.0 dB	
e.i.r.p. density of wideband satellite system	31.4 dB(W/MHz)	14.4 dB(W/MHz)	

To consider a link budget in more detail, take the example of Models 1 and 2 with the summary shown in Tables 4 through 7.

From Table 2, a bandwidth of 72.0 MHz together with an e.i.r.p. value of 70.0 dBW gives an e.i.r.p. of 67.0 dBW in a 36 MHz bandwidth in Model 1. In Model 2, since the spreading signal level is suppressed 20 dB lower than that of the FDMA signal, an e.i.r.p. value of 47.0 dBW is obtained.

The uplink Rx *C*/*T* is calculated by equation (1), deriving an uplink Rx *C*/*T* value of −134.5 and −154.5 dB(W/K) for Models 1 and 2, respectively.

TABLE 4

Link budget − 1 (uplink)

Wideband satellite system	Mode l (Regenerative)	Model 2 (Non-regenerative)	Note
Bandwidth	36 MHz	36 MHz	
Earth station e.i.r.p.	67.0 dBW	47.0 dBW	From Tables 2 and 3
Path loss	206.5 dB	206.5 dB	Operating frequency: 14 GHz
Rain attenuation	0 dB	0 dB	
Rx antenna *G*/*T*	5.0 dB/K	5.0 dB/K	
Uplink Rx *C*/*T*	−134.5 dB(W/K)	−154.5 dB(W/K)	

With an e.i.r.p. density of spreading signals of 14.4 dB(W/MHz) given in Table 3 and a downlink bandwidth of 240 MHz in Model 1, it follows that the satellite e.i.r.p. value is 38.2 dBW. Similarly, a satellite e.i.r.p. value of 30.0 dBW is obtained in Model 2. Using equation (1), the downlink Rx *C*/*T* is calculated: −171.9 and −180.2 dB(W/K) for Models 1 and 2, respectively.

TABLE 5

Link budget – 2 (downlink)

Wideband satellite system	Model 1	Model 2	Note
Bandwidth	240 MHz	36 MHz	
Satellite e.i.r.p.	38.2 dBW	30.0 dBW	From Table 3
Path loss	205.2 dB	205.2 dB	Operating frequency: 12 GHz
Rain attenuation	0 dB	0 dB	
Rx antenna G/T	−5.0 dB/K	−5.0 dB/K	10 cm dish antenna (19.8 dBi), T_{sys} = 300 K
Downlink Rx C/T	−171.9 dB(W/K)	−180.2 dB(W/K)	

User terminals with low-gain antennas could be affected by interference from adjacent satellites, resulting in C/T degradation. However, those effects are neglected in order to evaluate an ideal value in this link budget analysis, which will be discussed in § 2.4.2.

Therefore, an overall C/T is the same as the downlink Rx C/T of −171.9 and −180.2 dB(W/K) for Models 1 and 2, respectively.

TABLE 6

Link budget – 3 (overall)

Wideband satellite system	Model 1	Model 2	Note
Intra-system overall C/T	−171.9 dB(W/K)	−180.2 dB(W/K)	from Tables 4 and 5
C/T degradation due to interference from adjacent satellites	0 dB	0 dB	
Overall C/T	−171.9 dB(W/K)	−180.2 dB(W/K)	

Finally, using equation (2), the estimated data rate is derived, as shown in Table 7.

TABLE 7

Available data rate in wideband satellite system

Wideband satellite system	Model 1	Model 2	Note
Overall C/T	−171.9 dB(W/K)	−180.2 dB(W/K)	
Required E_b/N_0	4.0 dB	4.0 dB	
Boltzmann's constant	−228.6 dB(W/(K · Hz))	−228.6 dB(W/(K · Hz))	
Estimated data rate	52.7 dB(bit/s) 184.8 kbit/s	44.4 dB(bit/s) 27.7 kbit/s	

From the viewpoint of FSS carrier operation, the above value gives I_0/N_0 of −1.3 dB, assuming 1.2 m antenna (41.3 dBi) and the system temperature of 120 K at an earth station.

2.4 Summary of available data rate

2.4.1 Data rate with a variety of *C*/*I* values

Data rates are given with a variety of *C*/*I* values in the downlink as shown in Table 8 and Fig. 6 for Model 1, where *C* and *I* represent the output power of one of the FDMA carriers and that of the wideband satellite system, respectively. Antenna gain and *C*/*T* degradation due to interference from adjacent satellites are set to be 19.8 dBi and 0 dB (an ideal case), respectively. From the result, with the loading rate of 100% and the *C*/*I* value of 20 dB, the achievable data rate is 154.9 kbit/s, for example.

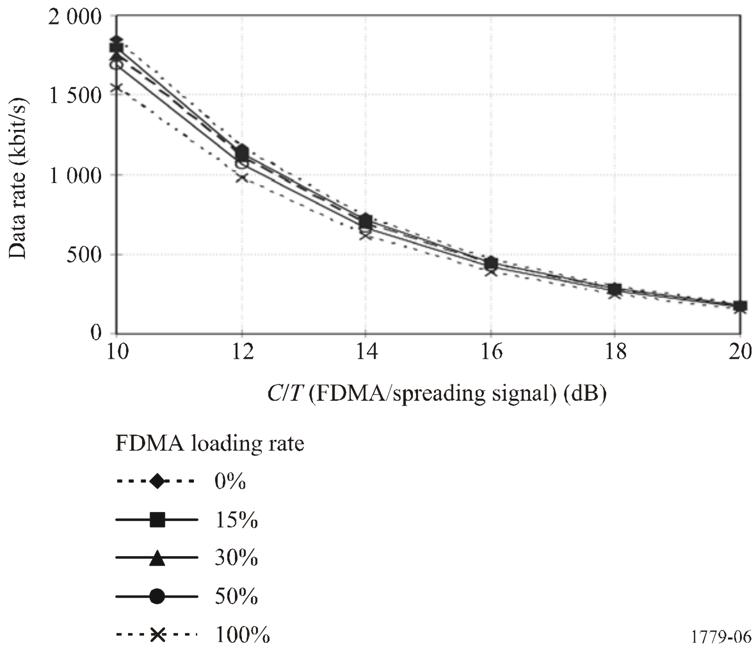
TABLE 8

Data rate (kbit/s) with a variety of *C*/*I* for Model 1

	Loading rate of FDMA carriers (%)				
C/*I* (dB)	0	15	30	50	100
10	1 848.0	1 795.9	1 746.7	1 685.1	1 548.5
12	1 166.0	1 133.2	1 102.1	1 063.2	977.0
14	735.7	715.0	695.4	670.8	616.5
16	464.2	451.1	438.7	423.3	389.0
18	292.9	284.6	276.8	267.1	245.4
20	184.8	179.6	174.7	168.5	154.9

FIGURE 6

Data rate with a variety of *C*/*I* values for Model 1



2.4.2 Data rate with a variety of *C*/*T* degradations due to interference from adjacent satellites

User terminals with low-gain antennas could be affected by interference from adjacent satellites, resulting in *C*/*T* degradation. In order to evaluate such effect by interference, the following parameters are assumed:

– the antenna beamwidth (HPBW: half power beamwidth) is approximately 20º with a 10 cm dish antenna (19.8 dBi);

– adjacent satellites are located with a spacing of 2º. There are 10 satellites within a beamwidth of 20º;

– the receiving level from each adjacent satellite is the same as that from the desired satellite, taking a broad beamwidth into account;

– the half of ten adjacent satellites (five satellites) cause the interference to the desired signal. Hence, *C*/*T* degradation due to interference from five adjacent satellites is 7 dB.

In Table 9 and Fig. 7, data rates with a variety of *C*/*T* degradation levels, due to interference from adjacent satellites, are shown. In this calculation, the *C*/*T* value and the loading rate in adjacent satellites are set to 20 dB and 100%, respectively. It should be noted that although the horizontal axis shows the *C*/*T* degradation values, they can be converted into the number of adjacent satellites.

TABLE 9

Data rate (kbit/s) for *C*/*T* degradation levels due to interference for Model 1

$(C/T)_{deg}$ (N_s) / R_{load}	0 (0)	3 (2)	7 (5)	10 (10)	14 (25)	20 (100)
0%	184.8	133.3	93.8	63.0	31.5	9.1
50%	168.5	121.6	85.6	57.4	28.8	8.3
100%	154.9	111.7	78.6	52.8	26.4	7.6

$(C/T)_{deg}$: *C*/*T* degradation level due to interference from adjacent satellite (dB)

N_s: Number of adjacent satellites

R_{load}: Loading rate in desired satellite.

2.5 Impact of the overlay of wideband spreading signals on FDMA carriers

FDMA carriers could be affected by the co-frequency spreading signals. The effects for the downlink are evaluated in the following link budget analysis.

Typical parameters of the FSS system are given in § 2.3, which gives the downlink Rx *C*/*T* of –140.1 dB(W/K), as shown in Table 10. Note that the effect from spreading signals on FDMA carriers is neglected in this Table, and will be discussed later.

FIGURE 7

Data rate for *C*/*T* degradation levels due to interference for Model 1

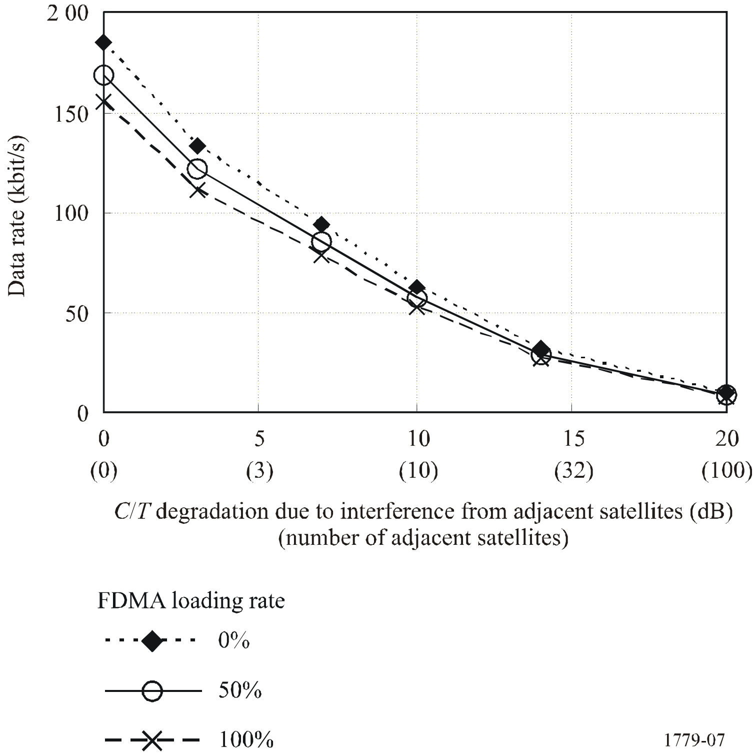


TABLE 10

Link budget of FDMA system (downlink)

FDMA system	Downlink	Note
Bandwidth	36 MHz	
Satellite e.i.r.p.	50.0 dBW	From Table 2
Path loss	205.2 dB	Operating frequency: 12 GHz
Rain attenuation	0 dB	
C/*T* degradation due to interference from overlaid spreading signals	0 dB	
Rx antenna *G*/*T*	15.1 dB/K	
Downlink Rx *C*/*T*	−140.1 dB(W/K)	

Assuming the minimum *C*/*T* value for a 64 kbit/s carrier of –175.9 dB(W/K) and a system margin of 10 dB, the required *C*/*T* value is –165.9 dB(W/K).

TABLE 11

Required *C*/*T* for FDMA system

FDMA system		Note
Minimum *C*/*T* (64 kbit/s)	−175.9 dB(W/K)	BER = 1×10^{-6}, $E_b/N_0 = 4.6$ dB
System margin	10 dB	
Required *C*/*T*	−165.9 dB(W/K)	

Finally, the achievable number of channels is derived, as shown in Table 12.

TABLE 12

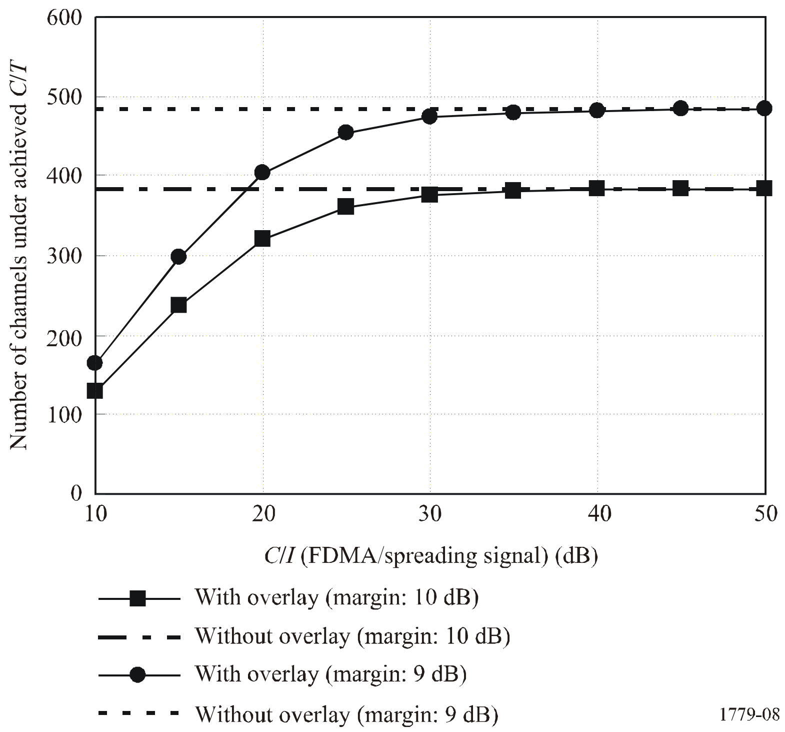
Achievable number of channels

FDMA system		Note
Margin	25.8 dB	From Tables 10 and 11
Number of channels	384	

The number of channels under an overlaid environment would be degraded compared to the above value. The impact of overlay of spreading signals on FDMA carries is evaluated with a variety of *C*/*I* values, where *C* and *I* represent the output power of one of the FDMA carriers and the wideband satellite system, respectively. Figure 8 represents the number of FDMA channels with/without overlaid spreading signals.

FIGURE 8

Number of channels with overlay of spreading signals on FDMA carriers for a variety of *C*/*I*



From the results, the number of FDMA channels decreases with the increase of interference from overlaid spreading signals, i.e. the decrease of *C*/*I* value. In such cases, it is possible to increase the number of available channels by reducing the system link margin. Based on operational considerations, the number of FDMA carriers can be traded against the amount of interference, from the overlaid spreading signals, that must be tolerated by an individual FDMA carrier.

2.6 Discussion

As seen from the results above, the achievable data rate depends on the loading rate of FDMA carriers, *C*/*I* criteria, *C*/*T* degradation levels due to intra- and/or inter-system interference and apportionment of interference to co-frequency FDMA carriers. Although a relatively low data rate is achieved, the data rate is still considered to be enough to deliver the low-rate emergency information.

Since the proposed system model is applied on the basis of the intra-system interference, provided that the total amount of interference to the adjacent satellite system is maintained, the *C*/*I* value and the loading rate can be appropriately selected depending on the operational policy and system design. In the case of natural disasters, it may be possible to transmit only the spreading signals using the whole transponder in order to ensure transmission of the emergency information, without previous assignment of the transponder and/or frequency slots.

The overlay scheme may increase the noise level, i.e. I_0/N_0 from the viewpoint of FDMA carriers, depending on an earth station's receiving antenna gain. From the results in § 2.5, although the number of FDMA channels decreases as the increase of interference from overlaid spreading signals, i.e. the decrease of *C*/*I* value, this channel decrease would be a trade-off for the smaller antenna and data rate supported by the wideband spreading signals. Since it is a matter of intra-system interference (not inter-system interference),this interference is one of the objectives managed by the satellite link designers and/or satellite operators.

3 Application 2 – A satellite system with dedicated bandwidths for both FDMA signals and wideband spreading signals

3.1 System model

The conceptual view of the system and the assumed link models are as in Application 1, i.e. shown in Fig. 2. Meanwhile, the usage of the FSS spectrum is different from that in Application 1. In Application 1, the wideband spreading signals are overlaid onto the existing FSS spectrum within the FSS allocation, while in Application 2, the bandwidths for FDMA signals and spreading signals are separated, i.e. the dedicated bandwidths for spreading signals are allocated. The specific scenarios in Application 2 are as follows. The assumed link model, called Model 3, is shown in Table 13:

– the wideband spreading signals are transmitted within the dedicated bandwidths as shown in Fig. 9. Since the spreading signals and FDMA signals are separately transmitted within the FSS allocation of the same FSS networks, there is no intra-system interference;
– for the uplink, a regenerative type transponder with a narrow bandwidth is used;
– for the downlink, a certain portion within the FSS allocation is allocated for spreading signals;
– user terminals with an omnidirectional or semi-omnidirectional antenna are assumed to facilitate installation and maintenance. Although user terminals with such antennas are affected by interference from adjacent satellites, the deterioration caused by inter-system interference is mitigated by spreading gain.

FIGURE 9

Dedicated allocation for spreading signals in downlink

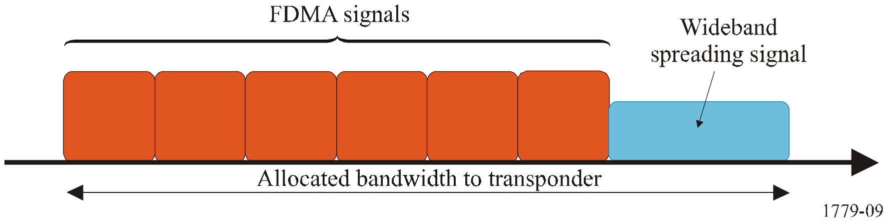


TABLE 13

Link models in Application 2

	Model 3	Note
Transponder type	Regenerative	
Bandwidth/e.i.r.p. (uplink)	36 MHz/77 dBW	
Bandwidth/e.i.r.p. (downlink)	3.6 MHz/52.1 dBW	The maximum e.i.r.p. is assumed to be 62.1 dBW
Transmission scheme (uplink/downlink)	FDMA/FDMA and spreading signal	

3.2 Link budget analysis and performance estimation

The achievable data rate is estimated by the link budgets in the 14/12 GHz bands. The calculation is just as in Application 1, excluding *C*/*I* parameters:

– parameters in FSS systems and the bandwidth allocated for spreading signals provide the Rx *C*/*T* at the wideband signal receiver in the downlink;

– using the determined Rx *C*/*T*, a data rate is obtained.

Since there is no interference between FDMA signals and spreading signals, the *C*/*I* value, which is used in Application 1, is considered to be infinite in this analysis.

3.3 Results of link budget analysis

The uplink Rx *C*/*T* is calculated by equation (1), deriving an uplink Rx *C*/*T* value of –134.5 dB(W/K) as shown in Table 14. In the downlink, equation (1) also gives the downlink receiver *C*/*T* of –172.9 dB(W/K) as shown in Table 15.

TABLE 14

Link budget – 1 (uplink)

Wideband satellite system	Models 3	Note
Bandwidth	36 MHz	
Earth station e.i.r.p.	67.0 dBW	
Path loss	206.5 dB	Operating frequency: 14 GHz
Rain attenuation	0 dB	
Rx antenna *G*/*T*	5.0 dB/K	
Uplink Rx *C*/*T*	−134.5 dB(W/K)	

TABLE 15

Link budget − 2 (downlink)

Wideband satellite system	Model 3	Note
Bandwidth per carrier	3.6 MHz	
Satellite e.i.r.p. per carrier	52.1 dBW	
Path loss	205.2 dB	Operating frequency: 12 GHz
Rain attenuation	0 dB	
Rx antenna G/T	−19.8 dB/K	Patch antenna (5 dBi), T_{sys} = 300 K
Downlink Rx C/T	−172.9 dB(W/K)	Intra-system overall C/T

In Application 2, user terminals with low-gain antennas are also assumed; those could be affected by interference from adjacent satellites. However, an ideal condition assuming no interference is considered in this step; data rates under interference will be summarized in § 3.4.2.

TABLE 16

Link budget − 3 (overall)

Wideband satellite system	Model 3	Note
Intra-system overall C/T	−172.9 dB(W/K)	From Table 15
C/T degradation due to interference from other systems	0 dB	
Overall C/T	−172.9 dB(W/K)	

Finally, equation (2) gives the estimated data rate shown in Table 17.

TABLE 17

Available data rate in wideband satellite system

Wideband satellite system	Model 3	Note
Overall C/T	−172.9 dB(W/K)	
Required E_b/N_0	4.0 dB	
Boltzmann’s constant	−228.6 dB(W/(K · Hz))	
Estimated data rate	51.7 dB(bit/s) 148.9 kbit/s	

3.4 Summary of available data rate

3.4.1 Data rate with a variety of bandwidths for spreading signals

In Application 2, dedicated bandwidths are allocated for spreading signals. To evaluate how the bandwidths affect the data rate, types of bandwidths are taken into account, with results shown in Table 18 and Fig. 10 for Model 3. Note that downlink e.i.r.p. is assumed to change with a corresponding increase in bandwidth. In this analysis, two types of antennas are considered: an omnidirectional antenna (0 dBi) and a patch antenna (5 dBi); *C*/*T* degradation level due to interference from other systems is neglected to evaluate an ideal case.

From the result, the ability to obtain a data rate of several tens of kbit/s is apparent, despite the considerably narrow bandwidth. It can be seen that the narrow bandwidth is sufficient to transmit the low-rate information under a normal operation, while higher data rate can be achieved, changing the bandwidths of spreading signals and FDMA signals.

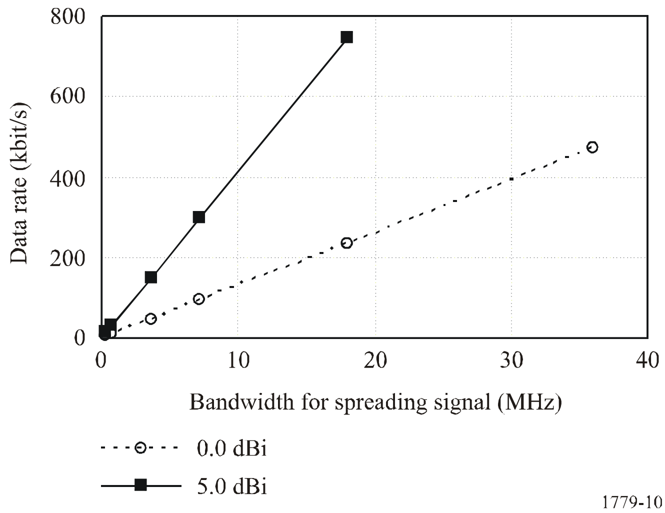
TABLE 18

Data rate (kbit/s) with a variety of bandwidths for spreading signals

	Bandwidth for spreading signals (MHz)					
Antenna type	0.36	0.72	3.6	7.2	18	36
0.0 dBi (omni)	4.7	9.4	47.1	94.2	235.4	470.8
5.0 dBi (patch)	14.9	29.8	148.9	297.8	744.4	1 488.7

FIGURE 10

Data rate with a variety of bandwidths for spreading signals



3.4.2 Data rate for *C*/*T* degradation levels due to interference from adjacent satellites

In order to evaluate *C*/*T* degradation due to interference from adjacent satellites, the following steps are assumed just as in Application 1:

Step 1: Most part of the geostationary orbit (i.e. 100º) is within the main beam of a nearly omnidirectional antenna of 5 dBi gain.

Step 2: Adjacent satellites are located with a spacing of 2º. There are 50 satellites within a beamwidth of 100º.

Step 3: With such low-gain antennas, there is no difference in gain in a range of several tens of degrees from the main axis; hence the receiving level from each adjacent satellite is the same as that from the desired satellite.

Step 4: The half of 50 adjacent satellites (25 satellites) cause the interference to the desired signal, resulting in *C*/*T* degradation of 14 dB.

Table 19 and Fig. 11 give the data rates with a variety of C/T degradation levels due to interference from adjacent satellites for Model 3. In this calculation, the dedicated bandwidth for spreading signals and the loading rate in adjacent satellites are set to be 3.6 MHz and 100%, respectively, and two types of antennas are considered.

TABLE 19

Data rate (kbit/s) for *C/T* degradation levels due to interference from adjacent satellites for Model 3

G_r \ $(C/T)_{deg}$ (N_s)	0 (0)	3 (2)	7 (5)	10 (10)	14 (25)	20 (100)
0.0 dBi (omni)	47.1	44.2	40.4	35.4	25.8	11.0
5.0 dBi (patch)	148.9	123.3	97.9	73.0	41.3	13.1

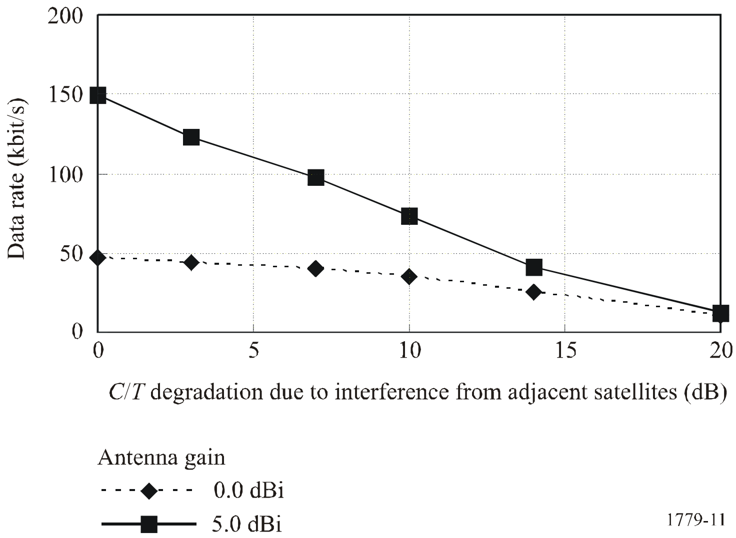
$(C/T)_{deg}$: C/T degradation level due to interference from adjacent satellite (dB)

N_s: number of adjacent satellites

G_r: antenna gain of user terminals

FIGURE 11

Data rate with a variety of *C/T* degradation level due to interference from adjacent satellites for Model 3



3.5 Discussion

In order to facilitate installation and maintenance for the event of natural disasters and similar emergencies, it is desirable that user terminals with low-gain antenna be used. Although the intra-system interference level can be determined by an operational policy, C/T degradation due to interference from adjacent satellites cannot be avoided; the latter uncontrolled interference will significantly affect the data rate.

The result shows that a data rate of several tens of kbit/s can be achieved, even if the interference from adjacent satellites affects the desired signals. Since the bandwidth separation is the main advantage compared to Application 1, system designers could employ the spreading signal without interfering to the conventional FDMA signals.

4 Summary

This Annex provided the characteristics of a satellite system with wideband spreading signals in two applications where:

– the spreading signals are overlaid on conventional FDMA signals within the same FSS networks;

– the dedicated bandwidths are allocated to spreading signals.

System designers could comprehensively understand FSS systems using the wideband spreading signals through the system models and the technical characteristics presented here.

Considering natural disasters these days, it is very important to notify those living in possible disaster areas of emergency information immediately after any such disaster occurs. With such natural disasters and similar emergencies in mind, the proposed system would be of use in those events for warning and relief operations.

Annex 2

An FSS system with a number of narrow spot beams using the CDMA (wideband spreading signals)

1 Overview

In this Annex, the use of CDMA techniques for an FSS system using a satellite with a number of narrow spot beams is discussed. The conceptual view of the FSS system is shown in Fig. 12. Basic parameters of the FSS system are listed in Table 20. In order to verify the effectiveness of the use of CDMA technique for this type of FSS system, the channel capacity in the CDMA case is analysed in contrast with those of the FDMA cases. For simplicity in analysis, only downlinks are considered. The antenna diameter of the user terminal is assumed to be 45 cm. 3 dB of rain margin (moderate rain) is assumed for a 12.5 GHz downlink frequency. The number of spot beams is assumed to be 14 (see Fig. 13 and Fig. 16 for alignment).

FIGURE 12

FSS system with a number of narrow spot beams

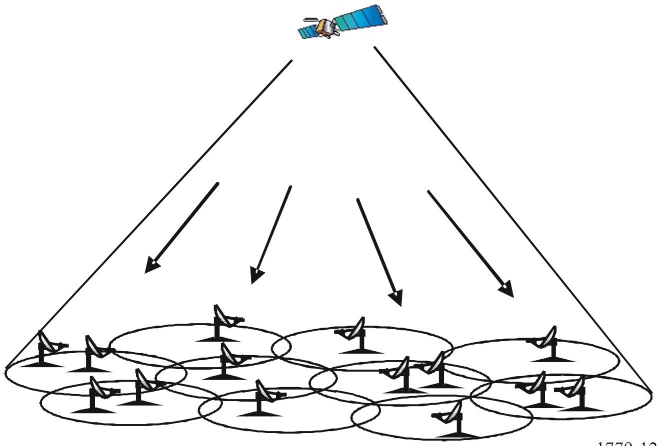


TABLE 20

Basic parameters of the FSS system with a number of narrow spot beams

Parameters	Values	Notes
Downlink frequency (GHz)	12.5	
Transponder bandwidth (MHz)	36.0	
Saturation satellite e.i.r.p. (dBW)	61.02	
Downlink propagation loss (dB)	205.5	
Downlink rain margin (dB)	3.0	Moderate rain
G/T of user terminal (dB/K)	11.19	45 cm of diameter
Number of spot beams	14	

2 Channel capacity in the FDMA case

When the FDMA is employed as a multiple access scheme in the FSS system with a number of spot beams, frequency segmentation over spot beams is needed in order to avoid interference from adjacent spot beams as shown in Fig. 13 and Fig. 14.

As employed in terrestrial cellular networks, hexagon cells could be used in designing the satellite coverage by a number of spot beams. There are several frequency reuse schemes (i.e. frequency reuse factor with 3, 4, 7, 9, 13, etc. bands). The frequency reuse scheme is determined by the trade off between spectral efficiency and the amount of co-channel interference from other cells (i.e. spot beams). In this study, the frequency reuse factor of 7 is assumed, as typically implemented in cellular systems, for 14 spot beams.

The bandwidth limited channel capacity in the FDMA case, $N_{FDMA\text{-}BW}$, is calculated by the following equation:

$$N_{FDMA\text{-}BW} = B_t/(B_c \cdot K) \cdot M = B_t/(R/\eta \cdot K) \cdot M \tag{3}$$

where B_t, B_C, R, η, K and M represent the whole bandwidth, the channel bandwidth, the information rate, the bandwidth efficiency (the ratio of information rate per unit bandwidth), the frequency reuse factor and the number of spot beams, respectively.

On the other hand, the power limited channel capacity in the FDMA case, $N_{FDMA\text{-}POW}$, is calculated by the following equation:

$$N_{FDMA\text{-}POW} = (C/N_0) \,/\, (E_b/N_0)_{th} \cdot \alpha \tag{4}$$

where C, N_0, $(E_b/N_0)_{th}$ and α represent the total received power available in the FSS system, the system noise (AWGN) density, the required E_b/N_0 and the advantage of the data (voice) activation effect, respectively.

Consequently, the channel capacity of FDMA is determined as the smaller of $N_{FDMA\text{-}BW}$ and $N_{FDMA\text{-}POW}$.

FIGURE 13

Spot beam alignment and frequency reuse in an FSS system with FDMA

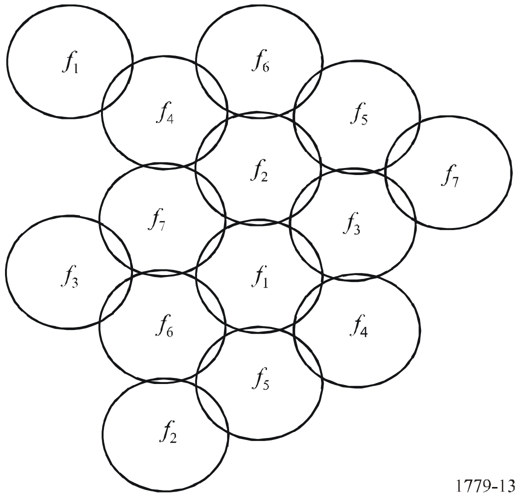
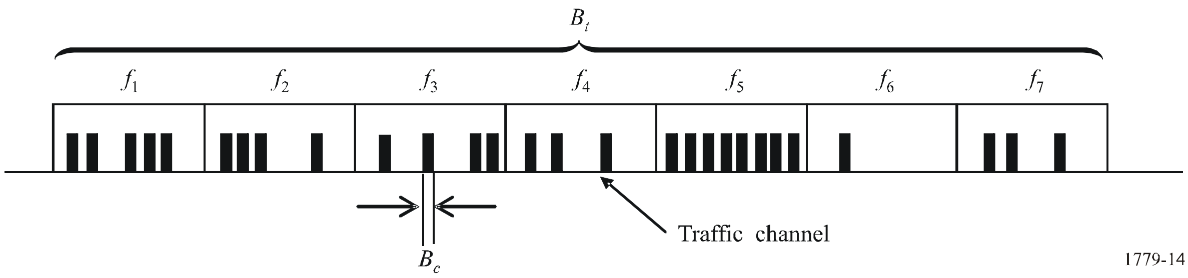


FIGURE 14

Frequency allocation of an FSS system with FDMA



3 Channel capacity in the CDMA case

When the CDMA is employed as a multiple access scheme, no frequency segmentation over spot beams is required (see Fig. 15 and Fig. 16). The whole bandwidth (i.e. B_t) can be used in all the spot beams in this case unlike in the case of FDMA. In the CDMA case, the channel capacity is determined principally by the amount of interference from other CDMA channels operating in the same spot beam and adjacent spot beams.

Figure 17 shows the modulation process (the primary modulation and secondary modulation) in the CDMA. The r_1 and r_2 is the transmission rate after the primary modulation (including the FEC) and the secondary modulation, respectively. The b_1 and b_2 is the equivalent noise bandwidth of the primary modulation and the secondary modulation, respectively. The spreading gain, G_p, is defined as the ratio of b_2 and r_1 (i.e. $G_p = b_2/r_1$).

FIGURE 15

Spot beam alignment in an FSS system with CDMA

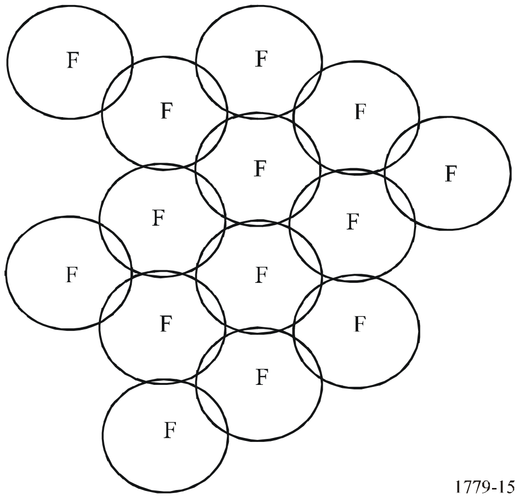


FIGURE 16

Frequency allocation of an FSS system with CDMA

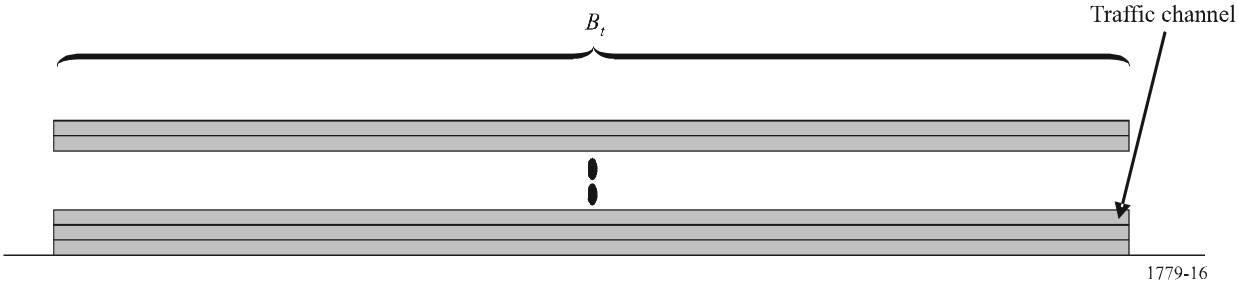
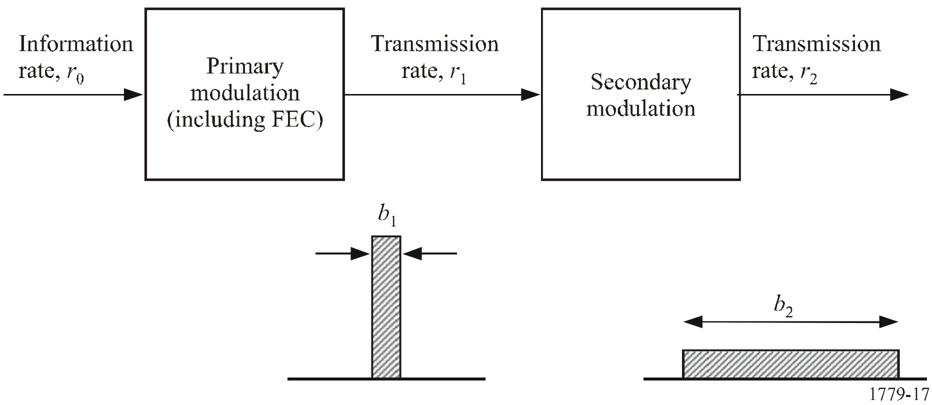


FIGURE 17

Modulation process of the CDMA signal



As shown in Fig. 18, the desired signal, the system noise and the interference from other CDMA channels are observed at the input of a receiver in the CDMA case. The calculation steps of the channel capacity in the CDMA case are as follows:

Step 1: The received power of a single desired channel C' is expressed as $C' = C/N_{CDMA}$ where C and N_{CDMA} represent the total received power available in the FSS system and the channel capacity of the CDMA case respectively.

Step 2: The density of interference from other CDMA channels I_0 is expressed as $I_0 = C/N_{CDMA} * (N_{CDMA} - 1)/b_2$. Note that b_2 is the equivalent bandwidth of the secondary modulation as shown in Fig. 17. The density of system noise without considering the interference from other CDMA channels is defined as N_0 (the density of additive white Gaussian noise (AWGN)).

Step 3: From Steps 1 and 2 above, $C'/(N_0+I_0)$ is expressed as follows:

$$C'/(N_0+I_0) = (C/N_{CDMA})/(N_0 + C/N_{CDMA} *(N_{CDMA} - 1)/b_2) \tag{5}$$

Step 4: With the approximation of $N_{CDMA} \fallingdotseq N_{CDMA}$ -1, equation (5) can be simplified as:

$$C'/(N_0+I_0) = (C/N_{CDMA})/(N_0 + C/b_2) \tag{5bis}$$

Step 5: On the other hand, $C'/(N_0+I_0)$ can be expressed by the required E_b/N_0 (denoted as $(E_b/N_0)_{th}$) and the information rate before spreading b_1 as follows:

$$C'/(N_0+I_0) = (E_b/N_0)_{th} * r_1 \tag{6}$$

Step 6: With the equation (5*bis*) and (6) as well as the relationship of $G_p = b_2/r_1$ and $C/N = \{C/N_0\}/b_2$, the following equation is obtained:

$$N_{CDMA} = \{G_p / (E_b/N_0)_{th}\} * \{(C/N) / (C/N + 1)\} \tag{7}$$

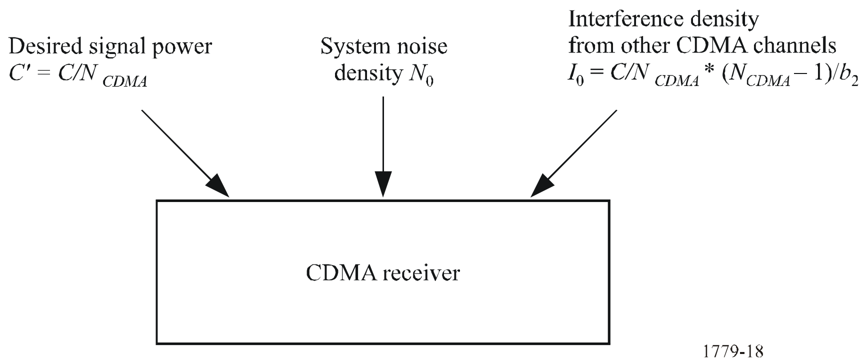
Step 7: In equation (7), the interference from other CDMA channels only in the same spot beam is considered. However, the interference from CDMA channels in adjacent spot beams should be considered in reality. In addition, the data (voice) activation effect, α, is considered in the same way as in the FDMA case. Taking into account these factors, the channel capacity of CDMA case is expressed as:

$$N_{CDMA} = \{G_p / (E_b/N_0)_{th}\} * \{(C/N) / (C*(1 + \beta)/N + 1)\} * \alpha \tag{8}$$

where β represents the ratio of interference contribution from adjacent spot beams to that from the same spot beam.

FIGURE 18

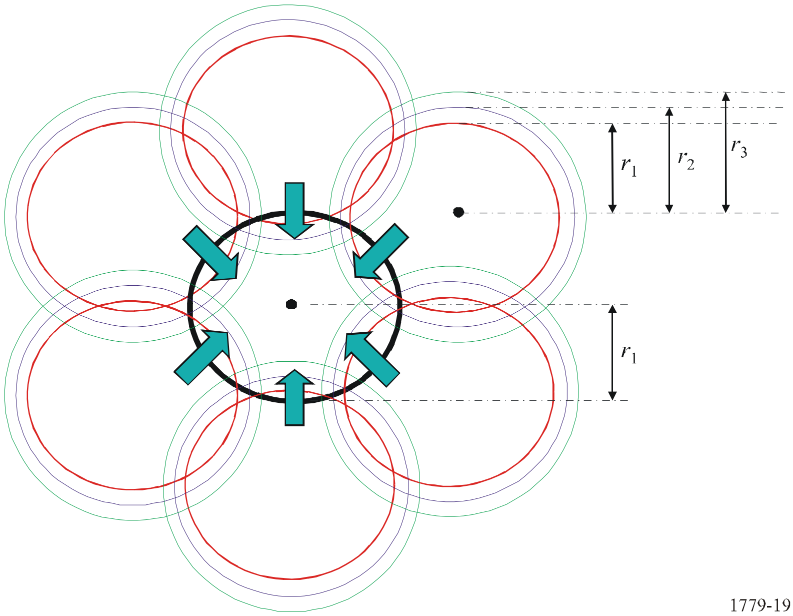
Signal and noise/interference at the input of CDMA receiver



In order to estimate the value of β in equation (8), the model of spot beams are considered as depicted in Fig. 19. The desired channel is present in the beam located in the centre of the figure. The power leaked from six adjacent beams into the 3 dB contour of the centre beam (thick black circle) is calculated on assumption that the traffic is uniformly distributed over locations in each spot beam. The radius of 3 dB contour of each spot beam is defined as r_1. For adjacent beams, 6 dB and 10 dB contour with radius of r_2 (= 1.2*r_1) and r_3 (= 1.5*r_1) are also assumed for calculation of power leakage. As a result of summation, 0.75 is obtained as the β value.

FIGURE 19

Model of spot beams to calculate leakage from adjacent beams



4 Channel capacity evaluation using parameters of the system example

For evaluation of the capacity of a FSS system with a number of narrow spot beams, transmission parameters when using the FDMA and CDMA are assumed as shown in Table 21. In order to assess the sensitivity of channel capacity to the satellite power and bandwidth resources in the FDMA case, various modulation/FEC methods are assumed. In the CDMA case, applications of a higher order modulation (i.e. 8-PSK or 16-QAM) for the primary modulation is of no use since it does not lead to a larger spreading gain. With these views, the following combination of modulation and FEC are considered in this analysis:

Case 1: FDMA; QPSK with 1/2 Turbo code.

Case 2: FDMA; 8-PSK with 2/3 TCM and (201, 219) Reed-Solomon code.

Case 3: FDMA; 16-QAM with 3/4 TCM and (201, 219) Reed-Solomon code.

Case 4: CDMA; QPSK with 1/2 Turbo code.

The required $E_b/(N_0 + I_0)$ values for modulation/FEC methods for this evaluation are shown in Table 21 and correspond to BER of 1×10^{-8}. The FEC rate shows the composite rate of an inner code and an outer code.

TABLE 21

Transmission parameters for channel capacity evaluation

Parameters	Case 1	Case 2	Case 3	Case 4
FDMA/CDMA	FDMA	FDMA	FDMA	CDMA
Primary modulation				
Information rate, r_1 (kbit/s)	64	64	64	64
Modulation	QPSK	8-PSK	16-QAM	QPSK
FEC rate	0.50	0.61	0.69	0.50
Equivalent noise bandwidth, b_1 (kHz)	64.0	34.9	23.3	64.0
Occupied bandwidth, b_1' (kHz)	89.6	48.8	32.5	89.6
Spectral efficiency (bit/s/Hz)	0.71	1.31	1.97	0.71
Required $E_b/(N_0+I_0)$ (dB)	3.2	6.9	9.4	3.2
Secondary modulation				
Modulation	N/A	N/A	N/A	BPSK
Equivalent noise bandwidth, b_2 (MHz)	N/A	N/A	N/A	25.6
Occupied bandwidth, b_2' (MHz)	N/A	N/A	N/A	36

N/A: Not applicable

The channel capacity of the FDMA cases of Table 21 (Case 1 to Case 3) was calculated as shown in Table 22. The basic parameters are derived from Table 21. The transponder back off is 3 dB for QPSK and 8-PSK and 6 dB for 16-QAM.

TABLE 22

Calculation of channel capacity of FDMA cases

Parameters	Case 1	Case 2	Case 3
Saturation satellite e.i.r.p. (dBW)	61.02	61.02	61.02
Transponder back off (dB)	3.0	3.0	6.0
Propagation loss (dB)	205.5	205.5	205.5
Rain margin (dB)	3.0	3.0	3.0
G/T of user terminal (dB/K)	11.19	11.19	11.19
Receive C/N_0 (dBHz)	89.31	89.31	86.31
Required $E_b/(N_0+I_0)$ (dB)	3.2	6.9	9.4
Data activation advantage	2.5	2.5	2.5
Power limited channel capacity (Mbit/s)	1 020.3	435.25	122.68
Transponder bandwidth (MHz)	36.0	36.0	36.0
Spectral efficiency (bit/s/Hz)	0.71	1.31	1.97
Frequency reuse factor	7	7	7
Number of spot beams	14	14	14
BW limited channel capacity (Mbit/s)	51.12	94.32	141.84
Resultant channel capacity (Mbit/s)	51.12	94.32	122.68

In Table 22, the power limited channel capacity and the bandwidth limited channel capacity are calculated by equations (3) and (4) respectively.

The channel capacity of the CDMA case of Table 21 (Case 4) is calculated as shown in Table 23. The basic parameters are derived from Table 21. In Table 23, the channel capacity is calculated with equation (8). Note that the ideal uniform traffic distribution over spot beams is assumed in this analysis.

TABLE 23

Calculation of channel capacity in the CDMA case

Parameters	Case 4
Information rate, r_1 (kbit/s)	64
Noise bandwidth for the secondary modulation, b_2 (MHz)	25.71
Spreading gain, G_p	401.79
Saturation satellite e.i.r.p. (dBW)	61.02
Transponder back off (dB)	3.0
Propagation loss (dB)	205.5
Rain margin (dB)	3.0
G/T of user terminal (dB/K)	11.9
the number of spot beam	14
Receive C/N_0 (total system) (dBHz)	89.31
Receive C/N_0 (per spot beam) (dBHz)	77.84
Achieved C/N with respect to the bandwidth b_2 (per spot beam) (dB)	3.74
Required $E_b/(N_0+I_0)$ (dB)	3.2
Ratio of interference contribution from adjacent spot beams to that from the same spot beam, β	0.75
$C\,(1+\beta)/N + 1$	5.2
Data activation advantage, α	2.5
Channel capacity (per spot beam) (Mbit/s)	14.16
Channel capacity (total system) (Mbit/s)	198.3

5 Summary

From the calculation in Tables 22 and 23, it can be seen that the channel capacity in the CDMA case (Case 4) is the largest for the FSS system with this set of assumed parameters. This result occurs for the following reasons:

– Most FSS systems have been operating within power limited situations. In such situations, the use of CDMA does not provide larger system capacity than FDMA cases. However, as satellite systems with a large number of narrow spot beams are realized, bandwidth limited situations are emerging.

– In the frequency segmentation scheme employed in the FDMA case (see Figs. 13 and 14), the use of frequencies, which may be used in adjacent beams, is prohibited regardless of the location of an earth station in a spot beam although it is unlikely that the channel in use is interfered with simultaneously by channels in multiple adjacent beams. Operation with such frequency usage is necessary particularly in the situation where a number of earth stations share channels on a demand basis (e.g. an FSS system with a large number of small VSATs or USATs). CDMA has an advantage in flexibility of channels assignment since there is no frequency segmentation over spot beams unlike FDMA cases. As a result, the bandwidth can be efficiently used in the CDMA case.

On the other hand, the system designer should pay sufficient attention to the traffic distribution over the FSS system since the only uniform traffic distribution over the coverage by spot beams is assumed in this analysis.

It should be noted that the result of this calculation is scalable to a wider bandwidth although the transponder bandwidth of 36 MHz is taken as an example in this analysis.

Another advantage of the CDMA technique would be the operation of FSS system with various different information rates in the uplink. If such a system were to be configured with the FDMA scheme, a complicated frequency assignment control procedure using a number of carriers with different sizes would be required. The evaluation of such a CDMA system is worthwhile as a further study area.

Annex 3

A satellite system using wideband spreading signals in uplinks to reduce the off-axis emission

1 Overview

In the FSS band at 27.5-30 GHz, the off-axis e.i.r.p. density values recommended in Recommendation ITU-R S.524 are very tight as compared to those for the FSS band in 12.75-13.25 GHz/13.75-14.5 GHz and 6 GHz band. In order to meet the recommended values particularly when the satellite *G*/*T* is relatively low, it would be useful to apply signal spreading as a secondary modulation.

2 Example of the system parameters

Example system parameters are shown in Table 24. The information rate is 1, 10 and 100 Mbit/s using modulation of BPSK and the convolutional coding/Viterbi decoding with the FEC rate of 1/2 targeting 1×10^{-8} of BER. The satellite *G*/*T* is 10 dB/K. The antenna diameter is 45 or 75 cm and RR Appendix 8 Annex III is applied as the reference antenna pattern.

TABLE 24

System parameters

Parameter	Value
Transmit frequency (GHz)	29.25
Information rate (Mbit/s)	1/10/100
Modulation	BPSK
FEC	Convolutional coding
FEC rate	1/2
BER objective	10^{-8}
Satellite G/T (dB/K)	10
Antenna diameter (cm)	45 cm (D/λ = 43.9), 75 cm (D/λ = 73.1)
Reference antenna pattern	RR Appendix 8, Annex III (D/λ < 100)

The equivalent noise bandwidth and required C/N is calculated as listed in Table 25.

TABLE 25

Equivalent noise bandwidth and required C/N

Information rate (Mbit/s)	Equivalent noise bandwidth (MHz)	Required E_b/N_0 (dB)	Required C/N (dB)
1	2.0	5.9	2.9
10	20.0	5.9	2.9
100	200.0	5.9	2.9

The C/N value is calculated with equation (9) using the link parameters as listed in Table 26.

$$C/N = P_t - L_{feed} - L_p + G_t - L_f - L_a + G/T + 228.6 - B - \alpha \tag{9}$$

Note that the same amount of noise as the uplink is allocated to other noise sources including the downlink noise in equation (9). In other words, the C/N degradation due to such noise sources is assumed to be 3 dB (see the value α in Table 26).

TABLE 26

Link parameters

Parameter	Value	Note
Feed loss, L_{feed} (dB)	0.5	
Antenna pointing error, L_p (dB)	0.2	
Transmit antenna gain, G_t (dBi)	40.6 (45 cm antenna) 45.0 (75 cm antenna)	Efficiency 60% Frequency 29.25 GHz
Propagation loss, L_f (dB)	213.3	
Atmosphere absorption, L_a (dB)	0.4	
Satellite G/T (dB/K)	10	Ref. Table 24
Equivalent noise bandwidth, B (MHz)	–	Ref. Table 25
C/N degradation due to other noise sources, α (dB)	3	Including downlink noise

3 Results

From equation (9), Table 25 and Table 26, the required output power at the earth station HPA, P_t, is calculated as shown in Table 27.

TABLE 27

Required output power (W) at the earth station HPA, P_t

Information rate (Mbit/s)	Antenna diameter	
	45 cm	75 cm
1	2.6	0.9
10	25.8	9.4
100	257.6	93.5

The off-axis e.i.r.p. densities calculated using the values in Table 27 and the reference antenna pattern stipulated in RR Appendix 8, Annex III, exceed the values in *recommends* 4 of Recommendation ITU-R S.524. For instance, at 5° offset in the case of 45 cm antenna diameter it exceeds the recommended value by about 3.3 dB. The off-axis e.i.r.p. density can be reduced by employing the signal spreading as a secondary modulation.

The off-axis e.i.r.p. density values for each case with/without the employment of spreading techniques are depicted in Table 28, Figs. 20 and 21. The spreading factor of 4 is used in the application of the spreading technique.

TABLE 28

Off-axis e.i.r.p. density (dB(W/40 kHz)) with/without spreading signals

Off-axis angle (degrees)	Values in Rec. ITU-R S.524	45 cm antenna		75 cm antenna	
		Without spread	With spread	Without spread	With spread
2.0	11.5	13.3	7.3	11.1	5.1
3.0	7.1	10.3	4.2	6.7	0.7
4.0	3.9	7.2	1.2	3.6	–2.4
5.0	1.5	4.8	–1.2	1.2	–4.8
6.0	–0.5	2.8	–3.2	–0.8	–6.8
7.0	–2.0	1.1	–4.9	–2.4	–8.4
8.0	–2.0	–0.3	–6.3	–3.9	–9.9
9.0	–2.0	–1.6	–7.6	–5.1	–11.2
10.0	–3.0	–2.7	–8.7	–6.3	–12.3

FIGURE 20

Off-axis e.i.r.p. density with/without spreading signals (45 cm antenna)

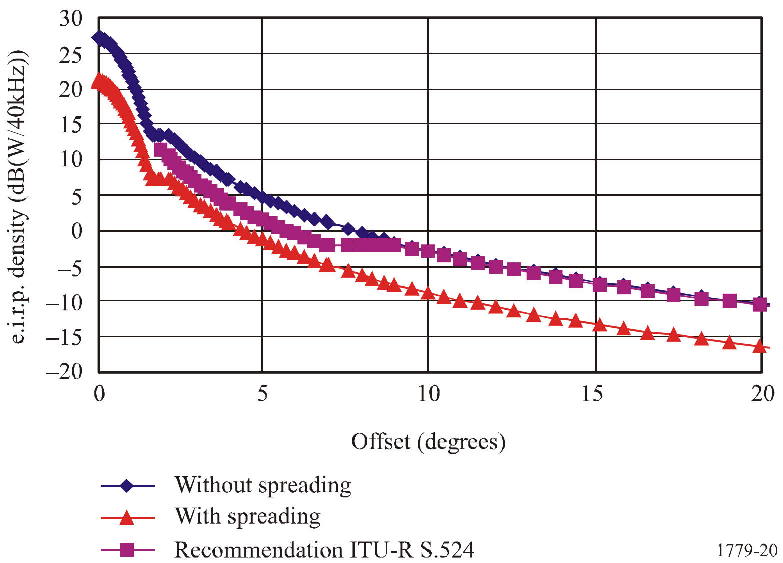
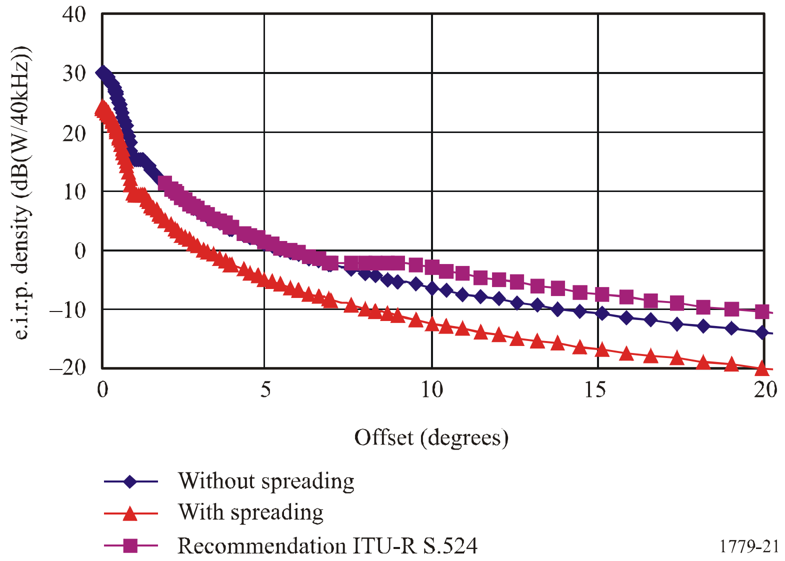


FIGURE 21

Off-axis e.i.r.p. density with/without spreading signals (75 cm antenna)



4 Summary

In 30/20 GHz band uplink, the wideband spreading signals as a secondary modulation is useful to reduce the level of off-axis e.i.r.p. density to meet the values in the associated ITU-R Recommendations (i.e. Recommendation ITU-R S.524). This reduction of the off-axis e.i.r.p. density involves the use of a larger bandwidth. It should be noted that the example shown in this Recommendation does not assume multiple earth station transmit carriers in the same bandwidth, i.e., CDMA, but such effects should be taken into consideration if a system designer employs the CDMA access in this type of application.