RECOMMENDATION ITU-R M.1391

METHODOLOGY FOR THE CALCULATION OF IMT-2000 SATELLITE SPECTRUM REQUIREMENTS

(1999)

1 Introduction

International Mobile Telecommunications (IMT-2000) are third generation mobile systems which are scheduled to start service around the year 2000 subject to market considerations. They will provide access, by means of one or more radio links, to a wide range of telecommunication services supported by the fixed telecommunication networks (e.g. PSTN/ISDN), and to other services which are specific to mobile users.

A range of mobile terminal types is encompassed, linking to terrestrial or satellite based networks, and the terminals may be designed for mobile or fixed use.

Key features of IMT-2000 are:

– high degree of commonality of design worldwide;

– compatibility of services within IMT-2000 and with the fixed networks;

– high quality;

– use of a small pocket-terminal with worldwide roaming capability;

– capability for multimedia applications and a wide range of services.

IMT-2000 are defined by a set of interdependent ITU Recommendations of which this one is a member.

The IMT-2000 satellite component will accommodate a portion of the increasing general demands for mobile services. Considering that the satellite and terrestrial components of IMT-2000 are mutually complementary, and provide compatible services, adequate spectrum bandwidth is needed for both. A specific methodology is needed for the calculation of IMT-2000 satellite component requirements. Moreover, the IMT-2000 services will be rich in information and user friendly (e.g. multimedia). Therefore, the need for providing users with access to various services which are compatible with those which are provided by the IMT-2000 terrestrial component, needs to be recognized.

2 Scope

This Recommendation presents a methodology for the calculation of the spectrum requirements of the IMT-2000 satellite component. This methodology is based on the requirements and objectives defined in the relevant IMT-2000 Recommendations[1)].

The methodology is structured to be independent of the details of the various systems which comprise the satellite component (e.g., orbits). The nature of the services likely to be supported by the system capabilities should be taken into account by the choice of appropriate values for the input parameters.

3 Related Recommendations

This Recommendation builds upon Recommendation ITU-R M.818 (Satellite operation within IMT-2000) and Recommendation ITU-R M.1167 (Framework for the satellite component of IMT 2000). It recognizes the requirements defined for the satellite component in Recommendation ITU-R M.1034 (Requirements for the radio interface(s) for IMT-2000), the needs of developing countries (see Recommendation ITU-R M.819) and the increasing interest in the provision of higher bit-rate services.

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1) Examples of the application of the methodology are given in Appendix 1.

4 Background

The starting point for the development of a methodology is necessarily governed by the form of the telecommunication traffic statistics and their availability. It has been recognized in previous related Recommendations that the satellite component of IMT-2000 may have a variety of forms each of which will be the result of an optimization to meet a perceived market. In the absence of publicly available detailed mobile-satellite traffic data, two commercial satellite operators have, however, declared some of their researches which give the expected total yearly traffic in the form of millions of Mbytes for a number of market or service segments. This measure has therefore been used as the traffic basis for the methodology.

In general terms, advances in technology can be expected to result in the spectrum required to support a given amount of user traffic in a given service category to decrease over time. Technical advances associated with source coding and antenna design, for example, have allowed improved frequency reuse to be achieved in systems resulting in overall increases in spectrum efficiencies. For the mix of services to be supported by IMT-2000, the introduction of packet switching and delay tolerance techniques may also contribute to an improvement in spectrum efficiency.

These improvements in the use of spectrum are expected to be incorporated in IMT-2000 systems. They will help to offset requirements for additional spectrum created by projected increasing demands of user traffic, resulting from an increased customer base, which may be stimulated by the availability of new services. These factors have been taken into account in the development and application of the spectrum calculation methodology.

5 Definitions

The parameters used in the methodology are the following. Their dependency on traffic category is indicated by subscript (i). Each value of i denotes a unique combination of: service, environment, types of system, etc.

Traffic (T_i): The input to the methodology is the total IMT-2000 satellite component traffic demand in the market assessment area in million Mbytes/year. The market assessment area is necessarily large (e.g. of continental proportions). There would typically be a number of traffic demand figures, for different traffic categories; e.g. different services (voice, data etc.) environments (urban, rural, remote, maritime, etc.) or types of systems (e.g. multimedia/non-multimedia systems).

Proportion of diurnal traffic in busy hour (p_i): This is determined by the diurnal traffic distribution.

Busy hour offset factor (h_i): The busy hour in different services, environments or systems may not occur at the same time. For example, business and non-business busy hours may occur at different times of the day. The spectrum calculations are therefore performed for an "overall busy hour", for which the sum of the traffic from all services, environments and systems is at its maximum. The "busy hour offset factor" specifies what portion of the busy hour traffic for a particular service/environment/system occurs at the overall busy hour.

Number of beam clusters in market assessment area (b_i): A beam cluster is a group of beams within which no frequency reuse is possible. The size of a beam cluster is determined by the frequency reuse pattern together with the average size of a beam footprint. Since the spectrum requirement is calculated for a given area, the number of clusters within that area has to be accounted for in the calculation.

Delay factor (d_i): This factor takes account of the fact that for packet-switched services it is possible to save bandwidth by delaying the transmission of data when there is a high demand, particularly during busy hour, thus smoothing out the time variations in traffic.

Capacity per carrier (C_i): Carrier information bit rate in kbit/s.

Carrier bandwidth (W_i): This is the bandwidth required to transmit the information plus all overheads, including any necessary guard bands between carriers (in kHz).

6 Recommended methodology

The ITU Radiocommunication Assembly,

recommends

that the following methodology be used for the calculation of the frequency spectrum requirements of the satellite component of IMT-2000.

6.1 Overview

In outline form the satellite methodology can be stated as:

– determine the traffic statistics for a very large area (e.g. global, continental, regional);

– convert to bit rate in busy hour for the area;

– convert to bit rate in an area defined as that within which frequencies are not reused;

– determine the conversion between bit rate and bandwidth occupied on a modular basis (e.g. per carrier);

– calculate overall spectrum requirements for the area under study.

6.2 Detailed description

A flow-chart illustrating the methodology is given in Fig. 1.

The calculation of spectrum requirements proceeds as follows:

For each type of service and each environment the traffic can be converted to the average bit rate in the busy hour.

$$R_i = \frac{T_i \cdot 8 \cdot 10^6 \cdot p_i}{365 \cdot 3600}$$

Applying the busy hour offset gives the traffic in the overall busy hour bit rate for each service and environment:

$$R_i' = R_i \cdot h_i$$

Next, the number of carriers required to carry this traffic is calculated:

$$ni = \frac{1000 \cdot R_i'}{C_i \cdot d_i \cdot b_i}$$

The frequency bandwidth requirement becomes :

$$F_i = \frac{n_i \cdot W_i}{1000}$$

or in terms of the primary parameters :

$$F_i = \frac{W_i \cdot 8 \cdot 10^6}{b_i \cdot C_i \cdot 365 \cdot 3600} \; \frac{T_i \cdot p_i \cdot h_i}{d_i}$$

The total spectrum requirement may be calculated by summing over all relevant services and environments:

$$F = \sum_i F_i$$

These calculation steps are shown in Fig. 1 for a single service type and traffic environment.

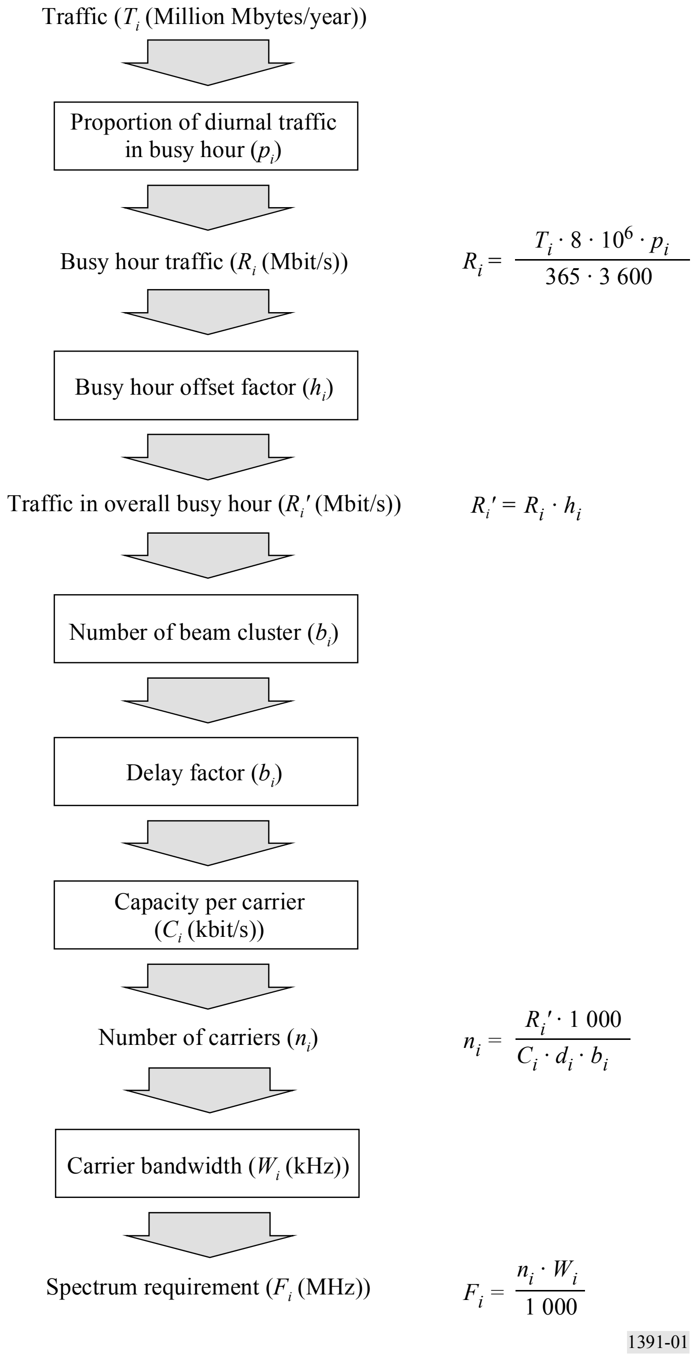
Adjustments may have to be applied to account for:

1) inefficiencies due to spectrum being divided up between several operators;

2) granularity due to minimum spectrum requirements per operator.

FIGURE 1

Flowchart of IMT-2000 satellite spectrum requirements calculation methodology (the flow-chart shows the calculation steps for a single traffic category)



The spectrum calculations should be carried out for several regions of the world, e.g. the three ITU Regions. To determine the peak spectrum requirement in a region, geographic peaking factors may have to be applied, depending on the resolution of the input traffic data.

Examples of the application of the methodology are given in Appendix 1.

APPENDIX 1

Examples of application of the methodology

1 Traffic data

Traffic forecasts for the satellite component of IMT-2000 for the years 2005 and 2010 have been provided from two mobile-satellite operators. These forecasts will be referred to as Source A and Source B.

A summary of the forecasts and a short discussion on their relationship can be found in Attachment 1.

2 Spectrum calculations

Examples of the application of the methodology are given in Tables 1 and 2, which show the input parameters and the intermediate stages in the calculation of spectrum requirement for global peak demand. The example calculations use subsets of the data provided by Source A and the Source B covering the situation for IMT-2000 traffic for the year 2010. As shown in Tables 1 and 2, in both cases the traffic forecasts are split into 4 different services. In the case of the Source A forecasts, the forecasts also differentiate between “multimedia” and “non-multimedia” traffic. This refers to the type of system carrying the traffic; a multimedia system would offer all four services (including “broadband” services), while a non-multimedia system would offer only voice and low-speed data.

Tables 1 and 2 give the predicted traffic demand for one transmission direction. The Source A market studies have shown that satellite based asymmetric services can be characterized as having a balanced overall traffic demand in both transmission directions. Therefore the total spectrum requirements will be twice the figures shown. The same assumption was taken for the Source B forecasts.

TABLE 1

Spectrum calculation based on the Source A traffic data for IMT-2000 traffic in the year 2010 (MHz per transmission direction)

	Non-multimedia voice	Non-multimedia low speed data	Multimedia voice	Multimedia low speed data	Multimedia asymmetric data	Multimedia interactive data
Total global traffic (million Mbytes/year)	123	119	206	445	4510	307
% of traffic in hot spot	12	12	10	10	10	10
Traffic in area, T (million Mbytes)	14.76	14.28	20.6	44.5	451	30.7
Proportion in busy hour (BH), p	0.15	0.15	0.1	0.1	0.1	0.1
Average busy hour bit rate, R (Mbit/s)	13.48	13.04	12.54	27.09	274.58	18.69
BH offset factor, h	0.82	0.81	0.79	0.81	0.79	0.79

TABLE 1 *(end)*

	Non-multimedia voice	Non-multimedia low speed data	Multimedia voice	Multimedia low speed data	Multimedia asymmetric data	Multimedia interactive data
Traffic in overall busy hour, R′ (Mbit/s)	11.05	10.56	9.91	21.95	216.92	14.77
Number of beam clusters in area, b	2	2	2	2	2	2
Delay factor, d	1	2	1	2	5	1
Capacity per carrier, C (kbit/s)	144	144	144	144	144	144
Number of carriers, n	38.38	18.34	34.40	38.10	150.64	51.27
Carrier bandwidth, W (kHz)	200	200	200	200	200	200
Spectrum required, F (MHz)	7.68	3.67	6.88	7.62	30.13	10.25

The following factors have been considered in choosing values for the input parameters shown in Table 1:

– % in hot spot: The calculations have been carried out for a global "hot spot", which is approximately 3 million km^2 in area. The % of traffic in the hot spot specifies the percentage of the total worldwide traffic which originates from this area as predicted by the market forecast;

– proportion of diurnal traffic in the busy hour: based on the market forecasts, this has been chosen as $p = 0.1$ for multimedia traffic and $p = 0.15$ for non-multimedia traffic;

– the busy hour offset factor, h: this factor has been calculated by considering 12 different traffic environments and calculating the weighted average of the busy hour offset factors for these environments;

– number of beam clusters in the area, b: in choosing this value, it has been considered that already planned non-IMT-2000 mobile-satellite system (MSS) systems would typically cover the area in question with 1 beam cluster or less. Future MSS systems are expected to provide improved reuse, however, it is unlikely that any MSS systems will be able to provide more than 2 beam clusters in the area by 2010. For the purpose of this worked example, it has been assumed that IMT-2000 satellites will have 2 beam clusters in the area ($b = 2$). This corresponds to, for example, an average footprint of around 200 000 km^2 and a frequency reuse pattern of 7. This frequency reuse has not yet been achieved, but is expected to be possible in the planned IMT-2000 time-frame;

– the choice of the factor b has been considered together with the choice of modulation efficiency, i.e. C/W, since neither can be improved without considering the effect on the other. For example, an improved modulation efficiency will require a higher carrier-to-noise ratio, leading to a degradation in reuse. Also, in determining these factors, it was considered that actual frequency reuse can never be perfect, due to geographical variations in traffic volume;

– delay factor, $d = 1$ for the circuit-switched voice and interactive services. Based on the market studies, for the packet-switched low-speed data and asymmetric services, d has been taken as 2 and 5 respectively;

– the capacity per carrier, C, is assumed to be 144 kbit/s;

– the carrier bandwidth, W, has been taken as 200 kHz;

– the information bit rate of 144 kbit/s plus overhead of approximately 30 kbit/s is thus assumed to be accommodated in a carrier bandwidth of 200 kHz, which can be achieved for example by quadrature phase shift keying (QPSK) modulation with a forward error correction (FEC) rate approximately 0.6.

TABLE 2

Spectrum calculation based on the Source B traffic data for IMT-2000 traffic in the year 2010 (MHz per transmission direction)

	Voice	Messaging	Medium multimedia	High interactive multimedia
Traffic in area, T (million Mbytes/year)	38.3	3.8	46.7	2.7
Proportion in busy hour, p	0.1	0.15	0.15	0.15
Average busy hour bit rate, R (Mbit/s)	23.34	3.49	42.62	2.46
BH offset factor, h	1	1	1	0.9
Traffic in overall busy hour, R′ (Mbit/s)	23.34	3.49	42.62	2.22
Number of beam clusters in area, b	1	1	1	1
Delay factor, d	1	2	2	1
Capacity per carrier, C (kbit/s)	144	144	144	144
Number of carriers, n	162.06	12.12	147.97	15.39
Carrier bandwidth, W (kHz)	200	200	200	200
Spectrum required, F (MHz)	32.39	2.41	29.62	3.08

The following factors have been considered in choosing values for the input parameters shown in Table 2:

– as for the Source A forecasts, the size of a beam cluster was assumed to be 1.5 million km^2. The Source B market forecasts were given for several large geographical regions. Based on preliminary estimates the traffic was further subdivided to calculate the portion of the total traffic in a beam cluster in the global "hot spot"; this resulted in the figures shown in Table 2. These estimates may need further consideration, taking into account the size of the (land mass of) each geographical region and the traffic variations within the regions;

– proportion of diurnal traffic in the busy hour: based on the market forecasts, this has been chosen as p = 0.1 for voice traffic and p = 0.15 for other services;

– the busy hour offset factor, h: as these forecasts are focused primarily on the business/industrial user, the busy hour offset factor is close to one (1), since there is no non-business vs. business busy hour to take into consideration;

– number of beam clusters in the area, b: the calculations are done for one beam cluster, see also the comments made re. the Source A calculations;

– delay factor, d = 1 for the circuit-switched voice and interactive services. Based on the market studies, for the packet-switched low-speed data and asymmetric services d has been taken as 2;

– as with the Source A calculations, the capacity per carrier, C, is assumed to be 144 kbit/s;

– as with the Source A calculations, the carrier bandwidth W = 200 kHz.

3 Discussion of example results

The example results shown above are based on the available traffic information. However, the results only present calculations for a subset of the forecasts for an estimated global peak demand. Furthermore, the worked examples verify the robustness of the methodology. The accuracy of any estimates of spectrum requirements, of course, will be dependent upon the accuracy of the input data.

The results shown in these examples should not be considered as providing an answer to the question of future spectrum requirements for the IMT-2000 satellite component, as all figures given in these examples are still under study and all environments and services that must be considered for completeness may have not been included in the examples.

Attachment 1

(To Appendix 1)

Traffic forecast data and commentary

1 Traffic forecast summary

Extensive market information has been obtained by Source A and by the Source B. For the purpose of illustrating the application of the methodology in this Recommendation this is presented in a summarized and condensed form in Table 3.

TABLE 3

Traffic forecast data

Source A (MSS and IMT-2000 compliant forecast)			Source B (IMT-2000 compliant)		
	2005	**2010**		**2005**	**2010**
Subscribers (000s)			*Subscribers (000s)*		
Non-Multimedia	4 875	7 500	Voice, Messaging,		
Multimedia	6 585	10 975	Medium Multimedia	12 000	24 000
			Interactive	4 800	9 600
Usage per subscriber (KBs per month)			*Usage per subscriber (KBs per month)*		
Non-Multimedia			Voice	2 700	2 700
Voice	8 709	8 491	Messaging	540	540
Low Speed Data	6 208	5 587	Medium Multimedia	6 263	6 576
Multimedia			Interactive	450	473
Voice	1 194	1 561			
Low Speed Data	2 584	3 380			
Asymmetric	26 154	34 247			
Interactive	1 781	2 334			
Total Annual Traffic (Million MB's)					
Non-Multimedia					
Voice	509	764			
Low Speed Data	491	736			
Multimedia					
Voice	94	206			
Low Speed Data	204	445			
Asymmetric	2 067	4 510			
Interactive	141	307			
Total	3 506	6 968			
Annual Traffic (Million MB's) – IMT-2000 Traffic			*Annual Traffic (Million MB's)*		
			Voice	389	778
Non-Multimedia			Messaging	78	156
Voice	34	123	Medium Multimedia	902	1 894
Low Speed Data	33	119	Interactive	26	54
Multimedia			Total	1 394	2 881
Voice	94	206			
Low Speed Data	206	445			
Asymmetric	2 067	4 510			
Interactive	141	307			
Total	2 573	5 710			

2 Comments on traffic data

2.1 Similarities

The Source A and Source B forecasts are similar in the following respects:

– both focus exclusively on “mobile” applications only (none of the services identified are for fixed terminals);

– both focus on services that have been identified specifically as IMT-2000 types of applications (voice and multimedia services);

– both focus on forecast usage in 2005 and 2010; and

– both forecasts include “frequent users” (i.e., those people who require and use satellite communications as a key part of their day-to-day communications needs) and “infrequent users” (i.e. predominantly terrestrial wireless IMT-2000 subscribers who rely on satellite communications when they occasionally roam outside of terrestrial wireless coverage).

2.2 Differences

The Source A and Source B forecasts differ in the following respects:

– both forecasts include frequent and infrequent users. The Source A forecast, however, provides more information on the frequency user of multimedia services; and

– while both forecasts use primary market research as a basis for their projections, the research has been focused on different areas. The Source A primary research focused on frequent users (and usage) of multimedia services, whereas the Source B primary research focused on global subscribers and voice usage.

2.3 General

The variations between the two traffic forecasts are easily attributable to differences in the underlying focus of each companys market research and approach. Such variations are to be expected in a forward-looking time-frame, particularly in an industry that spans such a large customer base. Both forecasts are highly defensible.

3 Definition of services

– Messaging services: Defined to include both SMS (Short Message Service), paging, and email, messaging services will not differ dramatically in concept from those available over terrestrial wireless today. However, MSS quality will be enhanced to include extended message length, better delivery rates, and two-way paging. File length will range between 10 kbytes/s to 40 kbytes/s.

– Voice – quality basic voice at 8/16 kbit/s.

– Low speed data – predominantly messaging and email (without attachments) type services at 9.6/16 kbit/s.

– Asymmetric services – this includes the predominantly one way services including file transfer, database/LAN access, Intranet/Internet, WWW, Email (with attachments), image transfer etc. Rates of transmission will be up to and around 144 kbit/s.

– Interactive multimedia – predominantly relating to videoconferencing and videotelephony at data speeds of around 144 kbit/s.

– Medium multimedia services: Defined as asymmetric and “bursty” in nature, medium multimedia services will require relatively high transmission capabilities (up to 144 kbit/s), with typical file sizes averaging 500 kbytes.

– High interactive multimedia services: Defined as symmetric applications requiring continuous high-speed connections. These types of services will require the highest available speeds (up to 384 kbit/s).