International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R M.1768-1
(04/2013)

Methodology for calculation of spectrum requirements for the terrestrial component of International Mobile Telecommunications

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Recommendations

(Also available online at **http://www.itu.int/publ/R-REC/en**)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	**Mobile, radiodetermination, amateur and related satellite services**
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2014

RECOMMENDATION ITU-R M.1768-1

Methodology for calculation of spectrum requirements for the terrestrial component of International Mobile Telecommunications

(2006-2013)

Scope

This Recommendation describes a methodology for the calculation of terrestrial spectrum requirement estimation for International Mobile Telecommunications (IMT).

It provides a systematic approach that incorporates service categories (a combination of service type and traffic class), service environments (a combination of service usage pattern and teledensity), radio environments, market data analysis and traffic estimation by using these categories and environments, traffic distribution among radio access technique groups (RATGs), required system capacity calculation and resultant spectrum requirement determination. The methodology is applicable to packet switch-based traffic and can accommodate multiple services. It can also accommodate circuit switched emulation traffic using a reservation based concept.

1 Related Recommendations and Reports

Recommendation ITU-R M.1390 – *Methodology for the calculation of IMT-2000 terrestrial spectrum requirements*.

Recommendation ITU-R M.1457 – *Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000)*.

Recommendation ITU-R M.1645 – *Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000*.

Recommendation ITU-R M.2012 – *Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced)*.

Report ITU-R M.2038 – *Technology trends*.

Report ITU-R M.2072 – *World mobile telecommunication market forecast*.

Report ITU-R M.2074 – *Radio aspects for the terrestrial component of IMT-2000 and systems beyond IMT-2000*.

Report ITU-R M.2243 – *Assessment of the global mobile broadband deployments and forecasts for International Mobile Telecommunications*.

The ITU Radiocommunication Assembly,

considering

a) that the radio access technique groups (RATGs) that are appropriate for IMT may have different channel bandwidth requirements, and hence varying impact on the basic frequency usage possibilities;

b) that the methodology in Annex 1 is considered flexible enough to accommodate either a global view or the unique requirements of regional markets relative to terrestrial spectrum needs;

c) that service functionalities in fixed, mobile and broadcasting networks are increasingly converging and interworking;

d) that the total telecommunication market will be provided by various communication means in terms of services and networks according to Recommendations ITU-R M.1645, ITU-R M.1457 and ITU-R M.2012;

d*bis*) that for the determination of spectrum requirements for IMT, new market requirements and network deployment scenarios have been developed and taken into account in Report ITU-R M.2243;

e) that other delivery mechanisms can support some user applications in common and convey their traffic;

f) that traffic distribution to those relevant other RATGs should be taken into account;

g) that Resolution 233 (WRC-12) invites ITU-R to study additional spectrum requirements for IMT;

h) that hence the spectrum requirement should be calculated only for the RATGs that fall in the IMT;

j) that a methodology for calculation of spectrum requirements for IMT should:

- i) accommodate the capabilities described in Recommendations ITU-R M.1645, ITU-R M.1457 and ITU-R M.2012;
- ii) accommodate the complex mixture of services that will require differing bandwidths and quality of service, and significantly higher bit rates than IMT-2000;
- iii) be able to model systems consisting of multiple interworking networks, and have the flexibility to handle different combinations of RSTGs in different environments and the possibility that the up and downlinks of a service may be provisioned on different radio access techniques RATs;
- iv) use market data which is practical to collect as input to the traffic forecasts;
- v) have the flexibility to handle both emerging technologies and enhancements to IMT;
- vi) take account of factors for practical network implementations;
- vii) produce results in a manner that is easily understandable and credible;
- viii) be implementable and verifiable within the available time-scales;
- ix) be suitable to be used during ITU-R meetings in terms of the computing facilities needed and the time required to perform an analysis;
- x) be no more complex than is justified by the uncertainty of the input data;
- xi) take into account improvements in spectrum efficiency due to the advances in technologies employed by enhancements to IMT,

recognizing

a) that the majority of the traffic has changed from speech-oriented communications to multimedia communications;

b) that networks and systems are designed to economically transfer packet data;

c) that services become more diverse and it will be less valid to consider simple peak traffic values that will apply across different environments, geographic areas and time,

recommends

1 that administrations wishing to estimate spectrum requirements for the terrestrial component of IMT use the methodology contained in Annex 1.

NOTE – The methodology is a general one that can be used for differing markets, and for a range of cellular system architectures. Care should be exercised when choosing input parameters to reflect the requirements of particular countries or regions.

Annex 1

1 Introduction

In the past, estimation of spectrum requirements of wireless applications has been considered as a framework focusing on a single system and market scenario. With the advent of a convergence of mobile and fixed telecommunication and multi-network environments as well as supporting attributes like seamless interworking between different complementary access systems, as described in Recommendations ITU-R M.1645, ITU-R M.1457 and ITU-R M.2012, application of such a simple approach is no longer suitable. For the estimation of frequency requirements, new models have to be developed and applied, which allow for consideration of spatial and temporal correlations among telecommunication services, taking into consideration the market requirements and network deployment scenarios.

2 Prerequisite information for application of the methodology

2.1 Forecast on services and market

The starting point for all spectrum considerations concerning IMT are the market expectations for wireless communications services. The key issue in this respect is a market forecast for the users within IMT. The methodology is designed to accommodate a wide variety of applications. The required format of the market information is defined in § 3.5. An example of suitable market information in this format can be found in Report ITU-R M.2072 and updated market information of IMT can be found in Report ITU-R M.2243.

2.2 Technical considerations

The methodology takes a technology-neutral approach in its technical studies of RATs and uses the classification of RATGs defined in Report ITU-R M.2074. The spectrum calculation methodology requires technical parameters to characterize the different RATGs as input to the spectrum calculations. By the RATG approach, the technical consideration for spectrum estimation can easily be conducted without referring to the detailed specification of radio interfaces both of existing and future mobile systems. The technical consideration includes the RATG definitions and radio parameters associated with the RATGs, which are used at different steps of the methodology. These radio technology aspects and values for the radio parameters, such as spectral efficiency, have been considered and are described in Report ITU-R M.2074.

2.3 RATGs

The methodology takes into account the total terrestrial communication market that will be provided by various communication means in terms of services and networks according to Recommendations ITU-R M.1645, ITU-R M.1457 and ITU-R M.2012. There are a number of RATGs which can be identified. The present methodology distributes the total traffic forecasted for the total terrestrial communication market to the identified RATGs, which are:

Group 1: Pre-IMT systems, IMT-2000 and its enhancements.

This group covers the digital cellular mobile systems, IMT-2000 systems and their enhancements.

Group 2: IMT-Advanced systems as described in Recommendation ITU-R M.2012.

Group 3: Existing radio LANs and their enhancements.

Group 4: Digital mobile broadcasting systems and their enhancements.

3 The methodology for spectrum requirement calculations

3.1 Scope of the spectrum calculation methodology for IMT

The methodology considers traffic forecasts for all RATGs (RATG1-RATG4); however, it calculates spectrum requirements only for RATG1 and RATG2, which correspond to IMT systems.

3.2 Approach for spectrum calculation

The technical process of estimating spectrum requirements for mobile communications has to be based on four essential issues:

– Definition of services
– Market expectations
– Technical and operational framework
– Spectrum calculation algorithm.

3.3 Generic flow of the methodology

The generic flow chart for the spectrum requirement calculation methodology is shown in Fig. 1.

Step 1: presents the different definitions used in the methodology, which are given in § 3.4.

Step 2: analyses the market data, which may be obtained from Reports ITU-R M.2072 and ITU-R M.2243. Analysis of market data is described in § 3.5.

Step 3: values for the methodology are computed as described in § 3.5.2.6.

Step 4: distributes traffic to different RATGs and radio environments inside the RATGs, which is presented in § 3.6.

Step 5: determines required system capacity to carry the offered traffic. Capacity calculation algorithms are given separately for circuit switched and packet-switched service categories in §§ 4.1 and 4.2, respectively.

Step 6: calculates the spectrum requirements of RATG1 and RATG2 which is presented in § 4.3.

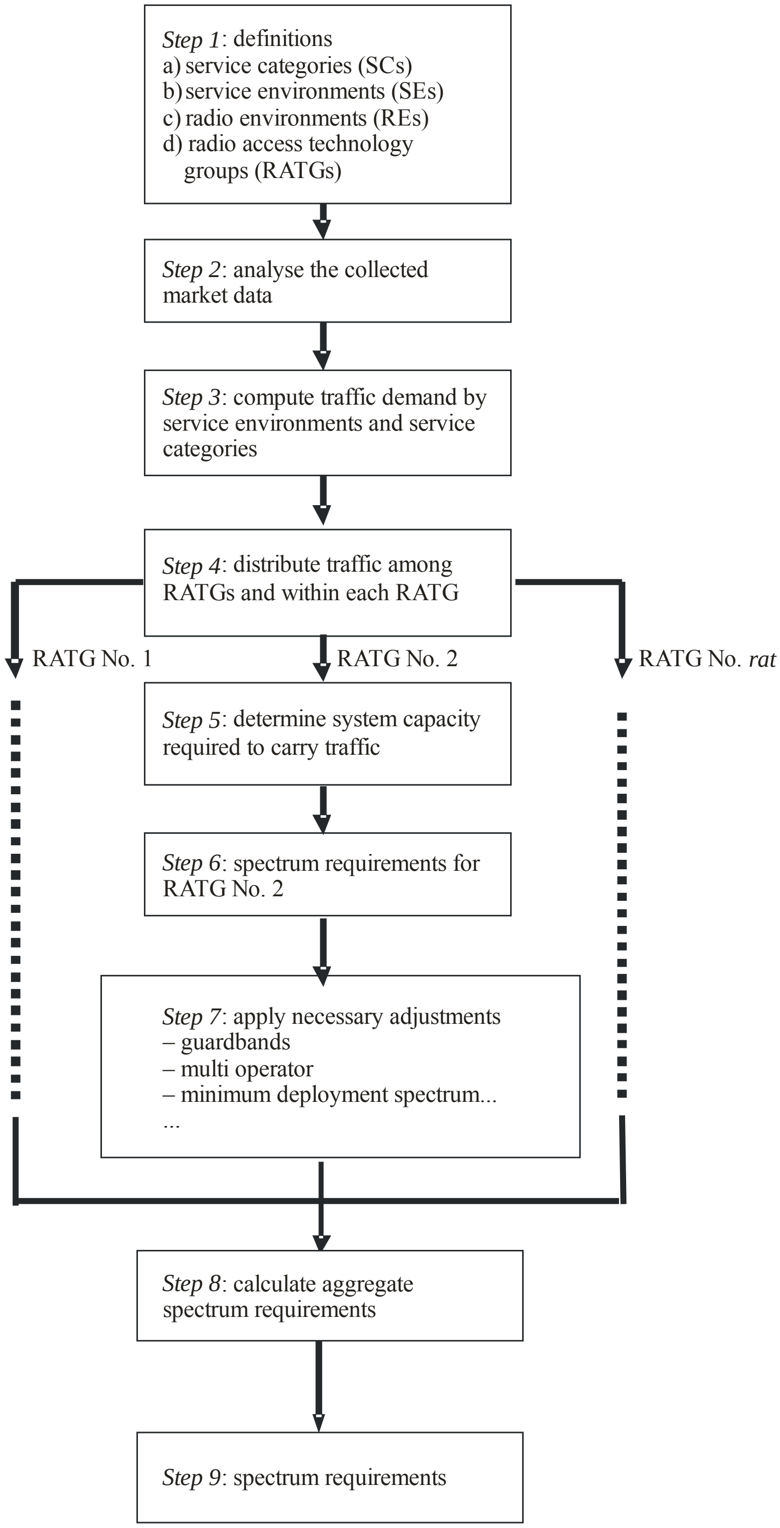
Step 7: applies necessary adjustments to take into account practical network deployments as described in § 5.

Step 8: calculates aggregate spectrum requirements in § 6.

Step 9: gives the spectrum requirements for RATG1 and RATG2 as an output.

FIGURE 1

Flow chart for a generic spectrum calculation methodology



M.1768-01

3.4 Definitions

In this section all the needed input parameters and associated categorizations are defined.

The following sections include tables for the required parameters for the methodology. The parameter values in these tables should be considered as examples as indicated in the corresponding tables.

First service types and traffic classes are introduced to reflect the likely peak data rates available and the likely traffic profile of a service. A service category is defined as a combination of the service type and traffic class.

Service environments are defined to categorize the area of where the user is when they are assessing a service and the traffic profile of that geographical area. Service environments are defined as a combination of service usage pattern and teledensity.

The radio environment is defined to reflect the radio infrastructure that provides the services to the users in service environment. Radio environments are defined to reflect the different radio deployments concepts.

Different RATGs are defined to take into account the wider terrestrial communication market available to provide the services.

3.4.1 Service categories

A service category (SC) is defined as a combination of service type and traffic class as shown in Table 1.

TABLE 1

Service categorization

Traffic class / Service type	Conversational	Streaming	Interactive	Background
Super-high multimedia	SC1	SC6	SC11	SC16
High multimedia	SC2	SC7	SC12	SC17
Medium multimedia	SC3	SC8	SC13	SC18
Low rate data and low multimedia	SC4	SC9	SC14	SC19
Very low rate data(1)	SC5	SC10	SC15	SC20

(1) This includes speech and SMS.

3.4.1.1 Service types

The peak bit rates are used to categorize the service types. It is possible to group together services demanding similar data rates into a common category. The different services are divided into five service types as shown in Table 2.

TABLE 2

Service types and their peak bit rates

Service type	Peak bit rate
Very low rate data	< 16 kbit/s
Low rate data and low multimedia	< 144 kbit/s
Medium multimedia	< 2 Mbit/s
High multimedia	< 30 Mbit/s
Super-high multimedia	30 Mbit/s to 100 Mbit/s/1 Gbit/s

a) *Very low rate data*

This service type requires a peak bit rates up to 16 kbit/s. In the year 2010 onwards, there will be a demand for these very low data rate applications of speech and simple message service. In addition, some applications in the field of sensor communication and/or low bit rate data telemetry would also be expected to be in this category, as ubiquitous communications.

b) *Low rate data and low multimedia*

This service type supports data rates of up to 144 kbit/s. This service type takes into account of pre-IMT-2000 data communication applications.

c) *Medium multimedia*

This service type supports a peak bit rate of up to 2 Mbit/s. This type would be required to sustain the compatibility with the IMT-2000 applications.

d) *High multimedia*

This service type accommodates high data rate applications, including multimedia video streaming services, which are provided with xDSL service in fixed wired communication systems.

e) *Super-high multimedia*

This service type accommodates super-high data rates multimedia applications, which are currently provided with fibre-to-the-home (FTTH) services in case of wired communication systems.

3.4.1.2 Traffic classes

Methodology applies the traffic classes presented in Recommendation ITU-R M.1079, which defines four quality of service (QoS) classes for IMT-2000 from the user perspective:

– conversational class of service;

– interactive class of service;

– streaming class of service;

– background class of service.

The main distinguishing factor between these classes is how delay-sensitive the application is: conversational class refers to applications which are very delay-sensitive while background class is the most delay-insensitive QoS class.

For traffic classes based on Recommendation ITU-R M.1079 the conversational and streaming class are served with circuit switching and the background and interactive class with packet switching.

a) Conversational class

The most well-known use of this scheme is telephony speech. But with internet and multimedia a number of new applications will require this scheme, for example voice over Internet Protocol (VoIP) and videoconferencing tools. Real-time conversation is always performed between peers (or groups) of live (human) end users. The real-time conversation scheme is characterized by the transfer time that must be low because of:

– the conversational nature of the scheme;
– at the same time the time relation (variation) between information entities of the stream must be preserved in the same way as for real-time streams.

The maximum transfer delay is given by the human perception of video and audio conversation. Therefore the limit for acceptable transfer delay is very strict, as failure to provide low enough transfer delay will result in unacceptable lack of quality. The transfer delay requirement is therefore both significantly lower and more stringent than the round trip delay of interactive applications.

b) Interactive class

When the end-user, that is either a machine or a human, is online requesting data from remote equipment (e.g. a server) this scheme applies. Examples of human interaction with the remote equipment are: Web browsing, database retrieval, server access. Examples of machine interaction with remote equipment are: polling for measurement records and automatic database enquiries (tele-machines).

Interactive traffic is the other classical data communication scheme that on an overall level is characterized by the request response pattern of the end-user. At the message destination there is an entity expecting the message (response) within a certain time. Round-trip delay time is therefore one of the key attributes. Another characteristic is that the content of the packets must be transparently transferred (with low BER).

Interactive traffic – fundamental characteristics for QoS:

– request response pattern;
– preserve payload content.

c) Streaming class

When the user is looking at (listening to) real-time video (audio) the scheme of real-time streams applies. The real-time data flow is always aiming at a live (human) destination. It is a one-way transport.

This scheme is one of the newcomers in data communication, raising a number of new requirements in both telecommunication and data communication systems. It is characterized by the time relations (variation) between information entities (i.e. samples, packets) within a flow which must be preserved, although it does not have any requirements on low transfer delay.

The delay variation of the end-to-end flow must be limited, to preserve the time relation (variation) between information entities of the stream. But as the stream normally is time aligned at the receiving end (in the user equipment), the highest acceptable delay variation over the transmission media is given by the capability of the time alignment function of the application. Acceptable delay variation is thus much greater than the delay variation given by the limits of human perception.

Real-time streams – fundamental characteristics for QoS:

– unidirectional continuous stream;
– preserve time relation (variation) between information entities of the stream.

d) *Background class*

When the end-user, that typically is a computer, sends and receives data-files in the background, this scheme applies. Examples are background delivery of e-mails, SMS, download of databases and reception of measurement records.

Background traffic is one of the classical data communication schemes where an overall level is characterized by the absence of a parameter at the destination expecting to receive the data within a certain time limit, with the exception that there is still a delay constraint, since data is effectively useless if it is received too late for any practical purpose. The scheme is thus more or less delivery time insensitive. Another characteristic is that the content of the packets must be transparently transferred (with low BER).

Background traffic – fundamental characteristics for QoS:

– the destination is not expecting the data within a certain time;

– preserve payload content.

A background application is one that does not carry delay information. In principle, the only requirement for applications in this category is that information should be delivered to the user essentially error free. However, it is emphasized that there is still a delay constraint, since data is effectively useless if it is received too late for any practical purpose.

3.4.1.3 Service category parameters

Service categories are characterized with parameters which are obtained either from market studies or from other sources. The following parameters are obtained from Report ITU-R M.2072:

– User density (users/km^2)

– Session arrival rate per user (sessions/(s · user))

– Mean service bit rate (bit/s)

– Mean session duration (s/session)

– Mobility ratio.

The first four parameters characterize the demand of different service categories, while the mobility parameter is used in traffic distribution in § 3.6. Terminal mobility is closely related to application usage scenarios. Recommendation ITU-R M.1390 defines mobility as:

– in-building;

– pedestrian;

– vehicular.

The requirements depend upon the speed of the mobile stations. In market studies in Report ITU-R M.2072, the mobility classes are categorized as follows:

– Stationary (0 km/h)

– Low (> 0 km/h and < 4 km/h)

– High (> 4 km/h and < 100 km/h)

– Super-high (>100 km/h and < 250 km/h).

The range limits of the categories should be related to typical characteristics of cellular radio networks. For small cells the minimum time a user stay in a cell between handovers needs to be significantly longer than the handover initiation and execution time. Therefore for small cells the cell size limits the maximum supported velocity. For this reason, pico cells are typically limited to support up to pedestrian velocities (up to 3-10 km/h), micro cells up to urban vehicular speeds of 50 km/h and macro cells of mobile cellular radio networks cover the remaining range of user velocity. For application of the mobility classes in the methodology, the mobility classes from market studies are re-interpreted as follows:

– Stationary/Pedestrian (0-4 km/h)

– Low (> 4 km/h and < 50 km/h)

– High (> 50 km/h).

The traffic of the "high" mobility class obtained from market studies is split into the "low" and "high" mobility classes for the methodology. The splitting needs to take into account the attributes of the considered service environments introduced in § 3.4.2 which can result in different splitting factors J_m in different service environments m. The mapping of traffic to the mobility classes is presented in Tables 3 and 4, where the J_m values are only examples:

TABLE 3

Mapping of mobility class

<table>
<tr><th>Mobility in market study</th><th>Mobility in methodology</th></tr>
<tr><td>Stationary</td><td rowspan="2">Stationary/pedestrian</td></tr>
<tr><td>Low</td></tr>
<tr><td rowspan="2">High</td><td>Low (fraction J_m)</td></tr>
<tr><td rowspan="2">High (fraction $1 - J_m$)</td></tr>
<tr><td>Super-high</td></tr>
</table>

TABLE 4

Example *J*-values for mapping of mobility classes in different service environments

Service environment *m*	J_m-value
1	1
2	1
3	1
4	1
5	0.5
6	0

In addition to the market related service category parameters which are calculated in § 3.5.2, the methodology requires parameters which are not obtainable from Report ITU-R M.2072. These parameters are listed in Table 5 and they are needed in capacity calculations in § 4.

TABLE 5

Service category parameters as inputs for spectrum calculation algorithm

Service category	SC1	SC2		–		SC20
Mean packet size (bit/packet)		–		–		
Second moment(1) of packet size (bit/packet)		–		–		
Allowed mean packet delay (s)		–		–		
Allowed blocking rate (%)		–		–		

(1) The second moment of a random variable is a scalar value that is related to the variance of the random variable.

3.4.2 Service environment

Service environments represent common service usage and volume conditions.

Service environment (SE) is defined as a combination of service usage pattern and teledensity.

3.4.2.1 Service usage patterns

A service usage pattern is defined as a common user(s) behaviour in a given service area.

The service usage pattern is categorized according to an area where users exploit similar services and expect similar quality of service. The following service usage patterns are used in the methodology:

– Home
– Office
– Public area.

3.4.2.2 Teledensity

As defined in Recommendation ITU-R M.1390, population density and the number of devices per person are also important factors when considering service environments. The geographical area is therefore divided according to these factors into teledensity categories.

Each teledensity parameter is characterized by population density and communication device density. Teledensity is categorized into the following:

– Dense urban
– Suburban
– Rural.

3.4.2.3 Definition and attributes of service environments

Service environments are defined for the following combinations of teledensity and service usage patterns which are shown in Table 6.

In order to provide readers a more clear view of every service environments, Table 7 shows possible user group and exemplary application of each SE.

Spectrum requirements shall first be calculated separately for each teledensity. The final spectrum requirements is calculated by taking the maximum value among spectrum requirements for the three teledensity areas (dense urban, suburban and rural).

TABLE 6

The identification of service environments

Teledensity / Service usage pattern	Dense urban	Suburban	Rural
Home	SE1	SE4	SE6
Office	SE2	SE5	
Public area	SE3		

TABLE 7

Examples of user groups and applications of service environments

	User groups	Applications
SE1	Private user, business user	Voice, Internet access, games, e-commerce, remote education, multimedia applications
SE2	Business user, small and medium size enterprise	Voice, Internet access, video conferencing, e-commerce, mobile business applications
SE3	Private user, business user, public service user (e.g. bus driver, emergency service), tourist, sales people	Voice, Internet access, video conferencing, mobile business applications, tourist information, e-commerce
SE4	Private user, business user	Voice, Internet access, games, e-commerce, multimedia applications, remote education
SE5	Business user, enterprise	Voice, Internet access, e-commerce, video conferencing, mobile business applications
SE6	Private user, farm, public service user	Voice, information application

3.4.3 Radio environment (RE)

REs are defined by the cell layers in a network consisting of hierarchical cell layers, i.e. macro, micro, pico and hot-spot cells. Methodology uses the cell area of the different radio environments as input to the calculations. The cell area has a direct impact on the traffic volume dependent spectrum requirement. Naturally, a trade-off has to be found between network deployment costs and the spectrum requirement. Apart from the limits on sizes that are related to these two factors, there are also technical limits. The upper technical limit is determined by the propagation conditions, terminal transmit power limitations and to a smaller extent by the delay spread.

The lower limits for the cell sizes are determined by an increase of unfavourable interference conditions, e.g. the appearance of too frequent line-of-sight conditions between interfering cells. The lower limit is assumed to be negligible compared to the limit imposed by deployment costs.

Since the deployment of micro, pico and hot spot do not greatly vary between different teledensity areas, it is assumed that same "maximum" cell area for those cell layers can be utilized in the spectrum calculation method. However for macro cell the situation is different, the teledensity has impact to the targeted cell area as well as to the deployment of base stations. Thus the cell area of macro cell is made teledensity dependent in spectrum requirement calculations. Example maximum cell area for each RE and teledensity is defined in Table 8. The cell area values are characteristic values for the considered teledensities.

TABLE 8

Example maximum cell area per RE (km^2)*

RE	Teledensity		
	Dense urban	**Sub-urban**	**Rural**
Macro cell	0.65	1.5	8.0
Micro cell(1)	0.1	0.1	0.1
Pico cell(1)	1.6E-3	1.6E-3	1.6E-3
Hot spot(1)	6.5E-5	6.5E-5	6.5E-5

* This example is not applicable to the scenario of large areas with low teledensity coverage.

(1) It is assumed that the cell size of these environments is not teledensity dependent.

The availability of REs depends on the service environment. In practice the total area of a particular service environment is only covered to a certain percentage *X* by each radio environment, e.g. by pico cells. For this reason, Table 9 defines the population coverage percentage of each RE in each SE. The values in Table 9 are example values. Table 9 also identifies possible combinations of SEs and REs. The population coverage percentage can be zero for certain combinations, meaning that the particular RE is not deployed in the particular SE. The population coverage percentages are used in distributing the traffic among REs in § 3.6.

TABLE 9

Example population coverage percentage of the radio deployment environments in each SE

SE	RE			
	Macro cell	**Micro cell**	**Pico cell**	**Hot spot**
SE1	100	0	0	80
SE2	100	0	20	80
SE3	100	80	20	10
SE4	100	0	0	80
SE5	100	20	20	20
SE6	100	0	10	50

3.4.4 RATGs

The methodology takes into account the total terrestrial communication market that will be provided by various communication means in terms of services and networks according to Recommendations ITU-R M.1645, ITU-R M.1457 and ITU-R M.2012. There a number of RATGs can be identified. The present methodology distributes the total traffic forecasted for the total terrestrial communication market to the identified RATGs, which are:

Group 1: Pre-IMT systems, IMT-2000 and its enhancements.

This group covers the digital cellular mobile systems, IMT-2000 systems and their enhancements.

Group 2: IMT-Advanced systems as described in Recommendation ITU-R M.2012.

Group 3: Existing radio LANs and their enhancements.

Group 4: Digital mobile broadcasting systems and their enhancements.

All four RATGs are considered up to Step 4 in methodology flow chart of Fig. 1, while from Step 5 onwards only RATG1 and RATG2 are considered.

Each RATG is characterized by parameters as presented in Tables 10a to 10d. The parameters are assumed to be the same in uplink and downlink, therefore only a single value for each parameter is required.

Some service categories can further get benefit from applying mobile multicast modes by the specific RATG. Mobile multicast is to be understood as a transmission that is intended for a group of receivers. An uplink is required, e.g. for group management. Examples of services that can be provided efficiently in mobile multicast transmission modes include mobile TV type services and low data rate messaging services. Since the spectral efficiencies of the two transmission modes can be significantly different, separate area spectral efficiency values are needed.

TABLE 10a

Example required radio parameters for RATG1

Attribute	**RATG1**				
	Value				
	Unit	**Macro cell**	**Micro cell**	**Pico cell**	**Hot spot**
Application data rate	Mbit/s	1	1	2.5	
Supported mobility classes		Stationary/ pedestrian, low, high	Stationary/ pedestrian, low	Stationary/ pedestrian	
Guardband between operators	MHz	0	0	0	
Minimum deployment per operator per RE	MHz	20	20	20	
Number of overlapping network deployment	No.	5	5	5	
Granularity of deployment per operator per RE	MHz	20	20	20	
Possibility to flexible spectrum usage (FSU)	Boolean	No	No	No	
FSU margin	Multiplier	1	1	1	
Typical operating frequency	MHz	< 2 700	< 2 700	< 2 700	
Support for multicast	Boolean	Yes	Yes	Yes	

This example is not applicable to the scenario of large areas with low teledensity coverage.

TABLE 10b

Example required radio parameters for RATG2

Attribute	RATG2				
	Value				
	Unit	Macro cell	Micro cell	Pico cell	Hot spot
Application data rate	Mbit/s	50	100	1 000	1 000
Supported mobility classes		Stationary/ pedestrian, low high	Stationary/ pedestrian, low	Stationary/ pedestrian	Stationary/ pedestrian
Guardband between operators	MHz	0	0	0	0
Minimum deployment per operator per RE	MHz	50-100	50-100	100	100
Granularity of deployment per operator per RE	MHz	20	20	20	20
Number of overlapping network deployment	No.	1-4	1-4	1-4	1-4
Possibility to flexible spectrum usage (FSU)	Boolean	Yes	Yes	Yes	Yes
FSU margin	Multiplier	1	1	1	1
Area spectral efficiency	bit/s/Hz/ cell	2-4	2-5	3-6	5-10
Area spectral efficiency for multicasting	bit/s/Hz/ cell	1-1.5	1-2.5	1.5-3	2.5-5
Typical operating frequency	MHz	< 6 000	< 6 000	< 6 000	< 6 000
Support for multicast	Boolean	Yes	Yes	Yes	Yes

TABLE 10c

Required radio parameters for RATG3

Attribute	RATG3				
	Value				
	Unit	Macro cell	Micro cell	Pico cell	Hot spot
Application data rate	Mbit/s	–	–	50	100
Supported mobility classes		–	–	Stationary/ pedestrian	Stationary/ pedestrian
Support for multicast (yes = 1, no = 0)		Yes			

TABLE 10d

Required radio parameters for RATG4

Attribute	RATG4	
	Unit	**Macro cell**
Application data rate	Mbit/s	2
Supported mobility classes		All (Stationary/pedestrian, low and high)

NOTE 1 – Only macro cell is considered for RATG4.

The spectral efficiencies are presented in Table 11. The methodology considers the area spectral efficiency values as inputs for the methodology. For the multicast transmission mode, the area spectral efficiency table has different values. The area spectral efficiency will be understood and used as being calculated from the mean data throughput achieved over all users, which are homogeneously distributed in the area of the radio deployment environment, on IP layer for packet-switched services and on application layer for circuit switched services, for fully loaded radio networks. The spectral efficiency and the maximum achievable cell edge data rates should correspond with the typical operating frequency. Possible retransmissions in the packet-switched services are taken into account in the spectral efficiency values.

TABLE 11

Area spectral efficiency matrix for one RATG

Teledensity	RATG No. *rat*			
	Radio environments			
	Macro cell	**Micro cell**	**Pico cell**	**Hot-spot cell**
Dense urban	$\eta_{1,rat,1}$ (bit/s/Hz/cell)			
Suburban				
Rural				

3.4.5 Relationship among service environments, RATGs, and radio environments

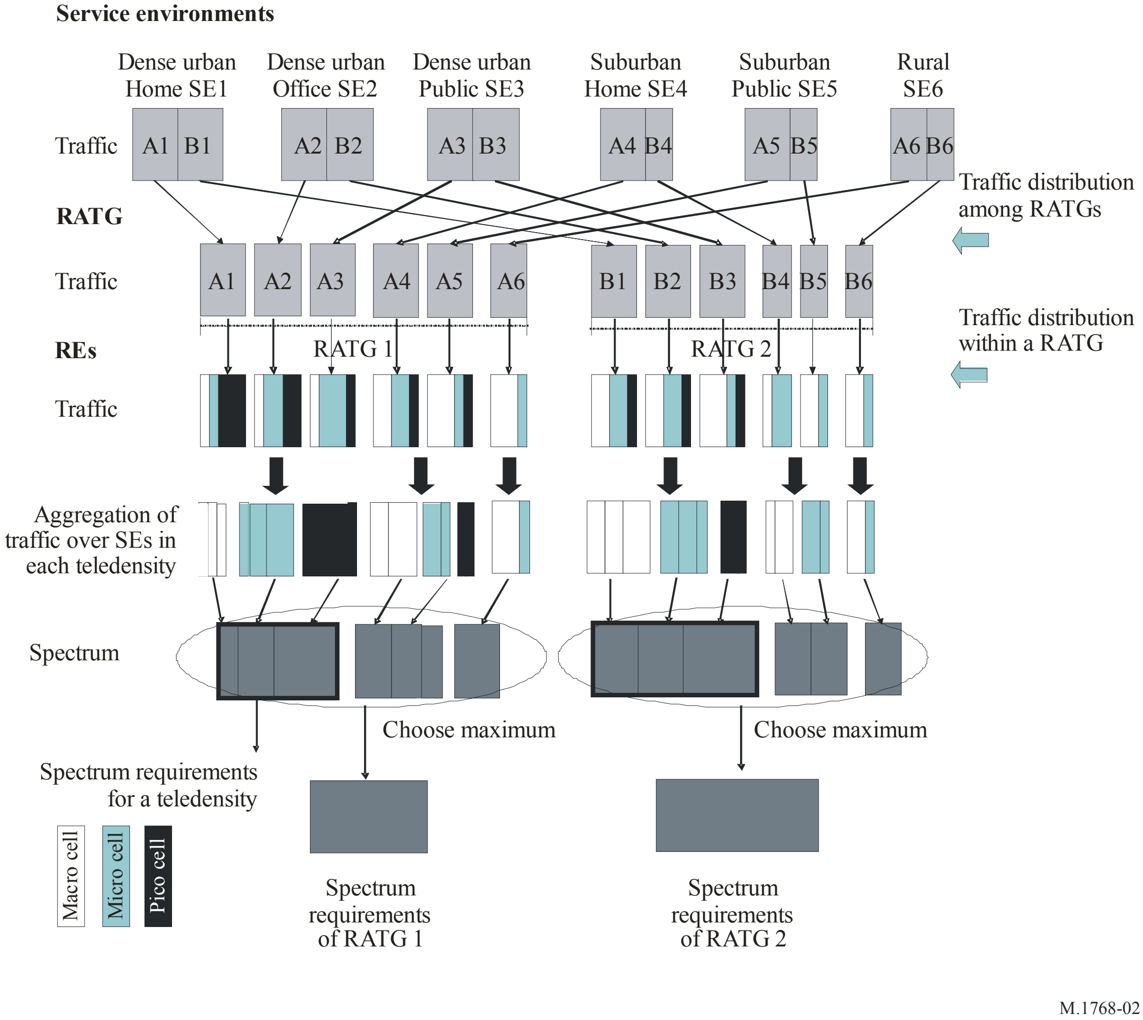
Service environments and radio environments should be separately considered in the spectrum calculation such that traffic demands are forecasted over service environments only, while total spectrum requirements are calculated with different RATGs and their possible radio environments. Spectrum requirements are calculated within each teledensity but final spectrum requirements need to be chosen as the maximum among spectrum requirements of all teledensities. Therefore, traffic in service environments should be accumulated with their corresponding teledensity first.

Figure 2 shows an example of the traffic distribution with six service environments, two RATGs and three radio environments. Traffic demands in each service environment can be distributed to RATGs. In Fig. 2, for example, the traffic of the service environment “dense urban home” has two components, which are the traffic amounts of A1 for RATG1 and B1 for RATG2. The service environments “Dense urban office”, “Dense urban public”, “Suburban home/public” and “Rural” also have the traffic amounts for each RATG as presented in Fig. 2.

Since each RATG supports one or more REs, the amount of traffic demand for each RATG at each SE can be distributed into its supported REs, as shown in the third row of Fig. 2. Distributed traffic for SEs belonging to same teledensity are accumulated in the fourth row of Fig. 2. Each RATG has its own deployment scenario for its component REs as well as its own spectrum efficiency. These deployment scenarios, e.g. cell sizes, also impact on the spectrum efficiency. Taking these into consideration, spectrum requirements can be calculated by using traffic demands and spectrum efficiency coefficients, and spectrum requirements can be separately calculated based on each instance composed of teledensity, RATG and RE. The rectangles shown in the fifth row of Fig. 2 represent spectrum requirements of RATGs in different teledensities. The spectrum requirements of a RATG will be the maximum among spectrum requirements of all teledensities for the RATG.

FIGURE 2

Traffic distributions among SEs, RATGs, and REs



3.5 Analysis of the collected market data

3.5.1 Collection of market data

The market data was collected by answering to the questionnaires in the service view document (Step 2 in Fig. 1).

The questionnaires included the following items in order to survey future market and application trends:

– services and market survey for existing mobile services;

– key market parameters;
– service and market forecast for IMT, including:
  • service issues;
  • market issues;
  • preliminary traffic forecast;
  • related information;
– service and market forecast for other radio systems;
– driving forces of the future market; and
– any other views on future services.

The responses to the questionnaires are summarized and analysed in Report ITU-R M.2072, particularly, the input values to the methodology are described in Annex 8 of the Report. Market data is provided for three points in time, years 2010, 2015 and 2020.

More recent market data is provided in Report ITU-R M.2243.

3.5.2 Data analysis

Terminology for market data analysis

Application: An application which is general and essential enough to categorize all the collected services concisely and appropriately.

Service: The service is basic element, of which an application is composed. The services composing an application have the assumption that they happen independently. For example, use of VoD service does not depend on the use of AoD service. The second assumption is that all services mapped to the same service category have identical and independent properties in market attributes.

Market attribute parameters: Related with users' perspective. These values are obtained from the market data.

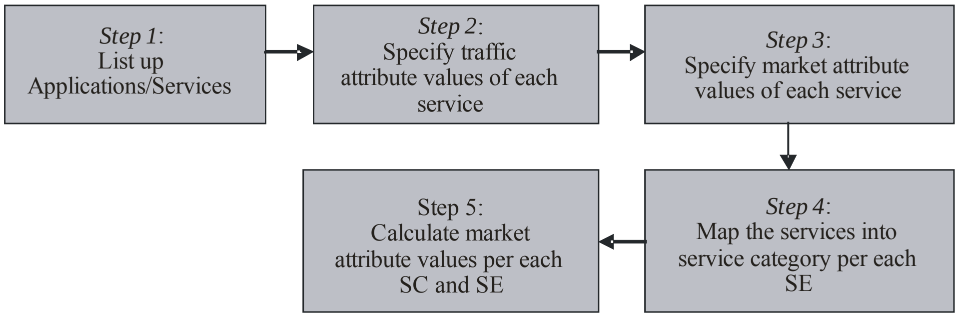
Traffic attribute parameters: Related with traffic characteristics of the service. These values are obtained by analysing technical trends.

3.5.2.1 General process

Figure 3 shows the general process for the market data analysis.

FIGURE 3

General process for the market data analysis



3.5.2.2 List up applications/services

All foreseeable applications/services of the future listed up. Since the list of applications and services is one of the important factors to calculate spectrum, the services should be chosen not to be overlapped from an application which be general and essential enough to categorize all the collected services concisely and appropriately.

In this step, the lists of applications and services must be fixed and filled up the first and second columns of Table 12. The obtained application list into application/service categories shown in Table 12 should be categorized by considering their attributions. These categories should cover all foreseeable application categories in order to make estimation reliable.

TABLE 12

Example application/service category and their traffic attributes

Applications	Services		Traffic attributes	
			Mean service bit rate	Average session duration
Existing applications	Voice (multimedia and low rate data/ conversational)		64 kbit/s	
	Video phone (medium multimedia/ conversational)		384 kbit/s	
	Packet	IM,e-mail (very low rate data/ background)	1 kbit/s	
		Video mail (medium multimedia/ background)	512 kbit/s	
		Mobile broadcasting (high multimedia/ streaming)	5 Mbit/s	
		Internet access (high multimedia/)	10 Mbit/s	
Town monitoring systems	Voice (multimedia and low rate data/ conversational)		64 kbit/s	
	Video communication (medium multimedia/conversational)		384 kbit/s	
	Medium rate data transmission for town information monitoring (medium multimedia/interactive)		384 kbit/s	
	Low rate data transmission for Reservation of restaurants, etc. (very low rate data/interactive)		1 kbit/s	
	File transfer (super-high multimedia/ background)		50 Mbit/s	

3.5.2.3 Specify traffic attribute values of each service

With the lists of applications and services developed in Step 1 of Fig. 3, the values of the traffic attributes parameters such as mean service bit rate, average session duration per each service are specified in Step 2.

By examining services developed in Step 1, the traffic attributes as shown in Table 12 are extracted. This Table gives typical values for:

– mean service bit rate;

– average session duration.

These values are used for the decomposition of the collected market data of applications, if they are not specified in the collected market data.

3.5.2.4 Specify market attribute values of each service

The time-varying and regionally-varying natures of traffic on different RATGs provide an opportunity to increase the efficiency of spectrum usage made from the use of coordinated networks and a FSU scheme. The basic idea behind this concept is to no longer have fixed and geographically equal amounts of spectrum allocated to each RATG, but to allow the RATGs to give spectrum to each other, during times when it is unused. If a perfect FSU scheme was being used then only as much spectrum as required for the traffic demand would be allocated to the RAN. These time varying patterns are seen on most RATs, as a consequence of user behavior changing depending on the time of day.

In order to calculate the dynamic spectrum requirement of a RATG, the market attribute values need to be provided for individual time interval t. The achievable spectrum savings from applying FSU will increase with the time resolution with which the market attribute values can be provided.

For analysing the market data, the values of user density and session arrival rate per user for each service in each service environment and time interval need to be specified. In addition, the mobility ratios which are defined in § 3.4.1.3 are needed in the traffic distribution. Table 13 shows an example of the expected response to Questionnaire on market and services.

3.5.2.5 Map the services into service category table per each service environment

According to Table 13, each service can be mapped into the table composed of service type and traffic class as shown in Table 1. All the services listed in Table 13 should be mapped into Table 1. This Table will be developed per each service environment so that we can establish six tables for all service environments.

3.5.2.6 Calculate market attribute values per each SC, SE and time interval

Table 13 shows the market attribute values of each service. In this step, market attribute values are calculated for each SC, SE and time interval. The results are shown in Table 14. Market attribute values are provided separately for uplink and downlink.

Required values for SE m, time interval t, and SC n are derived from the values of parameters of each service as follows:

TABLE 13

Expected response to Questionnaire on market and services

Applica-tions	**Services** ***s*: index**	**SC** ***n***	**SE** ***m***	**Market attributes**							
				User density $U_{m,t,s}$ (users/km^2)	**Session arrival rate/user $Q_{m,t,s}$ (sessions/(s · user))**	**Mean service bit rate r_s (bit/s)**	**Average session duration $\mu_{m,t,s}$ (s/session)**	**Mobility ratio (%) $MR_{m,s}$**			
								Stationary	**Low**	**High**	**Super-high**
Town monitoring systems	Town information monitoring s = 1	18	1		~	~	~				
			2		~	~	~				
			3								
					~	~	~				
					~	~	~				
	Reservation s = 2										

User density (users/km^2) of a certain service category is the summation of the user densities of each service mapped into the service category.

Mathematical expression is as follows:

$$U_{m,t,n} = \sum_{s \in n} U_{m,t,s} \tag{1}$$

where $U_{m,t,n}$ and $U_{m,t,s}$ denote the user density of service category *n* and the user density of service *s* inside service category *n*, respectively.

Session arrival rate per user (sessions/(s · user)) of a certain service category is the weighted average of session arrival rate per user of each service mapped to this service category. The weight of each service is the user density.

Mathematical expression is as follows:

$$Q_{m,t,n} = \frac{\sum_{s \in n} U_{m,t,s} Q_{m,t,s}}{U_{m,t,n}} \tag{2}$$

where $Q_{m,t,n}$ and $Q_{m,t,s}$ denote the session arrival rate per user of service category *n* and the session arrival rate per user of service *s* inside service category *n*, respectively.

Average session duration (s/session) of a certain service category is the weighted average of average session duration of each service mapped to this service category. The weight is the session arrival rate per area. We distinguish the time unit "second" for the session duration from the time unit "s" for the simple time interval.

Mathematical expression is as follows:

$$\mu_{m,t,n} = \sum_{s\in n} w_{m,t,s}\mu_{m,t,s} \tag{3}$$

where:

$$w_{m,t,s} = \frac{U_{m,t,s}Q_{m,t,s}}{U_{m,t,n}Q_{m,t,n}}$$

where $\mu_{m,t,n}$ and $\mu_{m,t,s}$ denote the average session duration of service category *n* and the average session duration of service *s* inside service category *n*, respectively.

Mean service bit rate (bit/s) of a certain service category is the weighted average of the mean service bit rates of each service mapped to this service category. The weight is the traffic volume (sum of the average durations of all sessions that arrive during a unit time) per area.

Mathematical expression is as follows:

$$r_{m,t,n} = \sum_{s\in n} \overline{w}_{m,t,s} r_{m,t,s} \tag{4}$$

where:

$$\overline{w}_{m,t,s} = \frac{U_{m,t,s}Q_{m,t,s}\mu_{m,t,s}}{U_{m,t,n}Q_{m,t,n}\mu_{m,t,n}}$$

where $r_{m,t,n}$ and $r_{m,t,s}$ denote the service data rate of service category *n* and the service data rate of service *s* inside service category *n*, respectively.

Mobility ratio of a certain service category is the weighted average of each mobility ratio for a user of a service category of each service mapped to the service category. It is assumed that the mobility ratio is not time dependent. The weighting of each service is calculated as ratio of offered traffic of a service to total offered traffic of the service category in the service environment.

Mathematical expression is as follows:

$$MR\_market_{m,t,n} = \sum_{s\in n} \overline{w}_{m,t,s} MR\_market_{m,s} \tag{5}$$

where $MR\_market_{m,t,n}$ and $MR\_market_{m,s}$ denote the mobility ratio of service category *n* and the mobility ratio of service *s* inside service category *n*, respectively. Note that this equation can be applied in all mobility cases.

The market study mobility ratios *MR_market* obtained above for stationary (*sm*), low (*lm*), high (*hm*) and super-high mobility (*shm*) need to be mapped into the methodology mobility ratios *MR* for stationary/pedestrian (*sm*), low (*lm*) and high mobility (*hm*), which are used in the in traffic distribution in § 3.6. The mapping is done according to § 3.4.1.3 with J_m -factors given in Table 4. Mobility ratio for stationary mobility is obtained from:

$$MR\_sm_{m,t,n} = MR\_market\_sm_{m,t,n} + MR\_market\_lm_{m,t,n} \tag{6}$$

Mobility ratio for low mobility is as follows:

$$MR\_lm_{m,t,n} = J_m \cdot MR\_market\_hm_{m,t,n} \tag{7}$$

Mobility ratio for high mobility is as follows:

$$MR\_hm_{m,t,n} = (1 - J_m) \cdot MR\_market\_hm_{m,t,n} + MR\_market\_shm_{m,t,n} \tag{8}$$

TABLE 14

Market data for service category in a service environment

Service category	Service environment					
	SE1	**SE2**	**SE3**	**SE4**	**SE5**	**SE6**
SC1	$U_{1,t,1}$ $Q_{1,t,1}$ $\mu_{1,t,1}$ $r_{1,t,1}$ $MR_{1,t,1}$	$U_{2,t,1}$ $Q_{2,t,1}$ $\mu_{2,t,1}$ $r_{2,t,1}$ $MR_{2,t,1}$	...	...	...	$U_{6,t,1}$ $Q_{6,t,1}$ $\mu_{6,t,1}$ $r_{6,t,1}$ $MR_{6,t,1}$
SC2	$U_{1,t,2}$ $Q_{1,t,2}$ $\mu_{1,t,2}$ $R_{1,t,2}$ $MR_{1,t,2}$	...	...	...	...	...
SC3	...	...	...	...	...	...
...	...	...	...	...	...	...

3.6 Distribution of traffic among radio access techniques and among radio environments within each RATG

The traffic obtained for each service environment, time interval and service category will be distributed to possible RATGs and radio environments. This corresponds to the Step 4 in the generic flow chart of the methodology represented in Fig. 1.

Each service environment is supported by one or more RATGs. Therefore, traffic per SE can further be distributed to traffic per RATGs.

The following inputs are used for the traffic distribution:

– The traffic values by SC and SE that are obtained as the outcome of Step 3 of Fig. 1, see Table 14.

– Service environment definition matrix according to Step 1 of Fig. 1 including feasible REs and population coverage percentages for each SE, see Table 9.

– RATG definition matrixes according to Step 1 of Fig. 1, see Tables 10a to 10d.

– Distribution ratios among available RATGs, see Table 16.

As output the process generates offered traffic of each service category n in each SE m and time interval t divided into RATGs and REs. If the SC is served using reservation based scheduling (circuit switched), the output will be given as mean session arrival rate and mean service bit rate of SC n in SE m and time interval t per cell or sector of RATG *rat* and RE p. These values are calculated in § 3.6.3.1. If the SC is served using packet based scheduling, the output will be given as aggregate bit rate of SC n in SE m and time interval t per cell or sector of RATG *rat* and RE p. This value is calculated in § 3.6.3.2.

3.6.1 Distribution ratios

The session arrival rates are distributed into RATGs and REs with the distribution ratios $\xi_{m,t,n,rat,p}$. Distribution ratios are derived separately for different SCs in different SEs and time intervals for uplink and downlink traffic due to the different traffic values.

The following rules are used for the derivation of the $\xi_{m,t,n,rat,p}$ factors. The rules obey the inputs defined in the previous section.

The distribution ratios are determined in three phases.

Phase 1 determines which combination of RATG and RE cannot support a given service category in a given SE. The corresponding distribution ratios are set to 0 while possible combinations are set to 1. Phase 1 sets the distribution ratios to zero for:

– RATG4 for unicast service categories;

– REs that do not exist in the considered service environment from the service environment definitions in Table 9;

– REs that are not supported by the given RATG from the RATG definitions Tables 10a to 10d;

– combination of RATG and RE for which the application data rate from RATG definitions Tables 10a to 10d is smaller than the required data rate of a particular SC, which is obtained from SC definitions from Table 14;

– for macro cell RE for those RATGs that do not support the entire range of velocities associated with the high mobility class from Tables 10a to 10d.

The output of Phase 1 is a table of the combination possibilities that have been set to zero or one. Table 15 gives an example that is limited to 3 SEs and 6 SCs in one RATG and one time interval. The full table would contain all six SEs and 20 SCs.

TABLE 15

Example of possible combinations of SC, SE and RE for one RATG and time interval after Phase 1 of the traffic distribution

Service category	**SE1**				**SE2**				**SE3**			
	Macro	**Micro**	**Pico**	**Hot spot**	**Macro**	**Micro**	**Pico**	**Hot spot**	**Macro**	**Micro**	**Pico**	**Hot spot**
SC_1	1	1	1	0	1	1	1	0	1	1	1	0
SC_2	0	0	1	0	0	0	1	0	0	0	1	0
SC_3	0	0	0	0	0	0	0	0	0	0	0	0
SC_4	0	0	0	0	0	0	0	0	0	0	0	0
SC_5	0	1	1	0	0	1	1	0	0	1	1	0
SC_6	0	0	0	0	0	0	0	0	0	0	0	0

Phase 2 distributes traffic between RATGs. The RATGs distribution ratio depends on the available RATGs in each RE and SE. Phase 1 defines in Table 15 which RATGs are available in the given SE for each RE and SC. Distribution among the available RATGs is performed with distribution values presented in Table 16 which are input parameter values to the methodology. For each combination of service category, radio environment, service environment and time interval, the RATG distribution ratios are read from Table 16 from the row which corresponds to the availability of RATGs for the given combination from Table 15. The values in Table 16 are example distribution values.

TABLE 16

Example of distribution ratios among available RATGs

Available RATGs	Distribution ratio (%)			
	RATG1	RATG2	RATG3	RATG4
1	100	–	–	–
2	–	100	–	–
3	–	–	100	
4	–	–	–	100
1, 2	20	80	–	
1, 3	20	–	80	
1, 4	10	–	–	90
2, 3	–	20	80	
2, 4	–	10	–	90
3, 4	–	–	10	90
1, 2, 3	20	20	60	
1, 2, 4	10	10	–	80
1, 3, 4	10	–	10	80
2, 3, 4	–	10	10	80
1, 2, 3, 4	10	10	10	70

Phase 3 distributes the traffic among the radio environments based on mobility ratios and coverage percentages.

The methodology defines the mobility classes stationary/pedestrian, low and high. The mapping of mobility classes to radio environments is as follows:

High mobility: Macro only

Low mobility: Micro and macro

Stationary/pedestrian: All radio environment.

This mapping of mobility classes to radio environments is assumed to be the same for all RATGs. The velocity ranges for the mobility classes and the parameter maximum supported velocity of each radio environment are chosen accordingly.

The traffic distribution follows the principle to use the radio environment with the lowest mobility support that just satisfies the requirements. The reason is that hot-spot cells and pico cells are generally offering higher capacity and are spectrally more efficient than micro cell and the same applies to the relation between micro cell and macro cells. According to this principle alone, basically all stationary/pedestrian traffic would go to hot-spot and pico cells, all low mobility to micro cells and all high mobility to macro cells (always provided that the respective radio environments are available, otherwise traffic would go to the next radio environment with higher mobility support). However, in practice the total area of a particular service environment is only covered to a certain percentage X by each radio environment, e.g. by pico cells.

Table 9 defines the population coverage percentage of each radio environment in each service environment. The population coverage percentages are independent of the RATG. However, if a particular RATG does not support a particular radio environment at all, then the corresponding cell edge data rate of this RATG/radio environment combination shall be set to zero, so that the Phase 1 of the traffic distribution will force the corresponding distribution ratio to zero.

The population coverage percentage puts a limit on the fraction of traffic in terms of traffic density that can be distributed to this radio environment. Using the population coverage percentage information X_{hs}, X_{pico}, X_{micro} and X_{macro} of the hot-spot, pico, micro and macro radio environment, the algorithm distributes the following traffic proportions to the hot-spot, pico, micro and macro radio environments:

$$\xi_{pico\&hs} = \min(X_{pico} + X_{hs}, MR\_sm) \tag{9}$$

$$\xi_{micro} = \min(X_{micro}, (MR\_sm + MR\_lm) - \xi_{pico\&hs}) \tag{10}$$

$$\xi_{macro} = 1 - \xi_{pico\&hs} - \xi_{micro} \tag{11}$$

MR_sm and MR_lm are the ratios of offered traffic in the stationary and low mobility classes, respectively. The equations assume that:

$$MR\_sm + MR\_lm + MR\_hm = 1 \tag{12}$$

Between hot-spot and pico cells the traffic is distributed according to the relation of the population coverage ratios of hot-spot and pico cells:

$$\xi_{hs} = \xi_{pico\&hs} \cdot X_{hs}/(X_{pico} + X_{hs}) \tag{13}$$

$$\xi_{pico} = \xi_{pico\&hs} \cdot X_{pico}/(X_{pico} + X_{hs}) \tag{14}$$

Service categories that can be provided by multicasting are treated differently. They are always distributed to RATGs that support multicast transmission mode and the given service category and to the radio environment with the largest available cells, i.e. the distribution ratios for the largest cell size for these RATGs are set to one. That corresponds to the case that the multicasting service is provided concurrently by all these RATGs. The population coverage ratio is not considered in the multicasting case, because the multicasting traffic does not consider the density of users. It is noted that, as a result of this rule, a service category can be distributed to multiple RATGs and the resulting sum of distribution ratios over the RATGs can exceed one.

NOTE 1 – The methodology does not take into account whether the same or different multicast data service content is delivered to the different service environments in the same cell (in the case of the same multicast data, the spectrum requirement is lower than in the case of different multicast data).

3.6.2 Distribution of session arrival rates

The session arrival rate per area (sessions/(s · km^2)) of service category n and service environment m distributed to RATG rat and radio environment p in time interval t, $P_{m,t,n,rat,p}$ is calculated from the distribution ratio $\xi_{m,t,n,rat,p}$, user density $U_{m,t,n}$ and session arrival rate per user $Q_{m,t,n}$ (given in § 3.5.2.6) by the following equation:

$$P_{m,t,n,rat,p} = \xi_{m,t,n,rat,p} \cdot U_{m,t,n} \cdot Q_{m,t,n} \tag{15}$$

The sum of the distribution ratios over the RATG index rat and the radio environment index p is equal to one, i.e. $\sum_{rat}\sum_{p}\xi_{m,t,n,rat,p} = 1$. Thus $\sum_{rat}\sum_{p}P_{m,t,n,rat,p} = U_{m,t,n} \cdot Q_{m,t,n}$.

The traffic from all users in a cell needs to be accumulated. The session arrival rate/cell (sessions/(s · cell)) is calculated as:

$$P'_{m,t,n,rat,p} = P_{m,t,n,rat,p} \cdot A_{d,p} \tag{16}$$

where $A_{d,p}$ is the cell area (km^2) of RATG *rat* in teledensity *d* and radio environment *p*, where *d* is uniquely determined by *m* (Table 6). $P'_{m,t,n,rat,p}$ represents the session arrival rate per cell of service category *n* in RATG *rat* in service environment *m* and radio environment *p* in time interval *t*.

For mobile multicast transmission mode, a separate equation is used[1].

3.6.3 Calculation of offered traffic

To calculate spectrum requirements, the offered traffic is required for each service category. The conversational and streaming class (service category 1 to 10) are served with circuit switching, while the background and interactive class (service category 11 to 20) are served with packet switching. Therefore, offered traffic is calculated according to the required input values for circuit- or packet-switched calculation method. The traffic also needs to be accumulated over the service environments which belong to the same teledensity which is seen from Table 6.

3.6.3.1 Circuit switched traffic

For circuit switching, the session arrival rate $P'_{m,t,n,rat,p}$ from the distribution functionality and the mean session duration $\mu_{m,t,n}$ is used as input to the capacity calculation. In mathematical terms this product is equivalent to the offered traffic measured in Erlangs.

The aggregate values of the product of session arrival rate per cell and average session duration for different teledensities *d* are collected to the offered traffic $\rho_{d,t,n,rat,p}$ (s/(s · cell)) which is obtained as follows:

$$\rho_{d,t,n,rat,p} = \sum_{m \in d} P'_{m,t,n,rat,p} \mu_{m,t,n} \qquad (17)$$

This represents the sum of average durations of all sessions of SC *n* that arrive per unit time in a cell with teledensity *d*, RATG *rat*, and radio environment *p* in time interval *t*. The unit of $\rho_{d,t,n,rat,p}$ is also denoted by (Erlang/cell).

The aggregate values of the mean service bit rate $r_{d,t,n,rat,p}$ (bit/s) for teledensity *d* are obtained as follows:

$$r_{d,t,n,rat,p} = \frac{\sum_{m \in d} P'_{m,t,n,rat,p} \mu_{m,t,n} r_{m,t,n}}{\rho_{d,t,n,rat,p}} \qquad (18)$$

3.6.3.2 Packet-switched traffic

For packet-switched service categories, the capacity calculation requires the offered traffic expressed in bit/(s · cell). The offered traffic is given as the aggregate offered traffic over the service environments which belong to the same teledensity. $T_{d,t,n,rat,p}$ represents the offered traffic for service category *n* for RATG *rat* in radio environment *p* for teledensity *d* and different time interval *t*. It is obtained from:

$$T_{d,t,n,rat,p} = \sum_{m \in d} P'_{m,t,n,rat,p} \mu_{m,t,n} r_{m,t,n} \qquad (19)$$

---

[1] Multicast service categories are assumed to be provided to multiple users simultaneously using a shared radio resource. Therefore, the user density is assumed to have a negligible effect. The distribution of traffic to RAT groups supporting mobile multicast and to radio environments is therefore implemented by distributing the session arrival rate $P'_{m,t,n,rat,p} = \xi_{m,n,rat,p} \cdot Q_{m,t,n}$.

This represents the sum of the number of bits included in all sessions of SC n that arrive per unit time in a cell with teledensity d, RATG rat, and radio environment p in time interval t.

4 Determination of the required system capacity and spectrum requirements

In Step 6 of Fig. 1 the required system capacity needed to serve the offered base traffic while fulfilling the QoS requirements of each service category n is determined for each RATG rat and radio environment p in each teledensity d and time interval t. The required system capacity, given in bit/s, is determined separately for circuit switched (i.e. reservation-based) and packet-switched traffic. The number of circuit-switched service categories is denoted by N_{cs}, while the number of packet based service categories is denoted by N_{ps}, where $N = N_{cs} + N_{ps}$ denotes the total number of service categories.

The results of these calculations are the required system capacity $C_{d,t,rat,p,cs}$ and $C_{d,t,rat,p,ps}$ [bit/(s · cell)] for circuit switched traffic and packet-switched traffic, respectively.

$C_{d,t,rat,p,cs}$ represents the system capacity that is required to fulfil the QoS requirements of all circuit switched (reservation based) service categories in teledensity d, time interval t, RATG rat and radio environment p, and $C_{d,t,rat,p,ps}$ is the system capacity that is required to fulfil the QoS requirements of all packet-switched service categories in teledensity d, time interval t, RATG rat and radio environment p.

4.1 Calculation of required system capacity for circuit switched traffic

The required system capacity for circuit switched (i.e. reservation based) service categories is determined by the number of service channels needed to achieve a specified blocking probability, and the channel data rate. The well-known Erlang theory is suitable to calculate the capacity needed to obtain a blocking probability less or equal to a specified value [Kleinrock, 1975]. Input parameters for determining the required number of service channels for circuit-switched sessions are as follows:

– Offered traffic in Erlangs per cell or sector $\rho_{d,t,n,rat,p}$ (§ 3.6.3.1)

– Service channel data rate $r_{d,t,n,rat,p}$ for service category n (§ 3.6.3.1)

– Maximum allowable blocking probability π_n, whose values are given in Table 5 (§ 3.4.1.3).

In the following, $\rho_{d,t,n,rat,p}$ and $r_{d,t,n,rat,p}$ is represented by ρ_n and r_n, respectively, to improve the readability.

Taking trunking gain into account, the Erlang-B formula can be extended to the multi-dimensional case which also allows simultaneous occupation of several channels by each call as follows. We assume that calls of N_{cs} classes share the set of v channels and that each call of class n requires v_n channels simultaneously ($1 \leq n \leq N_{cs}$). If an arriving call of class n finds less than v_n idle channels then it is blocked and lost; let $v \equiv (v_1, v_2,..., v_{Ncs})$. Calls of class n arrive in a Poisson process of rate P_n independent of other classes, and they have exponentially distributed holding times with mean μ_n so that the offered traffic of class n is ρ_n. All channels used by a call are released at the end of the holding time.

Let the system state be $i \equiv (i_1, i_2,..., i_{N_{CS}})$ where i_m is the number of calls of class m currently using channels. Then the steady-state probability mass function has a simple *product-form*:

$$P(i) = G(v)^{-1} \prod_{m=1}^{N_{cs}} \frac{(\rho_m)^{i_m}}{i_m!} \tag{20}$$

with:

$$G(k) = \sum_{\{i:0 \le v \cdot i \le k\}} \prod_{m=1}^{N_{cs}} \frac{(p_m)^{i_m}}{i_m!}, \qquad 1 \le k \le v \tag{21}$$

where $v \cdot i \equiv \sum_{m=1}^{N_{cs}} v_m i_m$ is the number of channels being used when the system state is *i*.

The blocking probability for calls of class *n* is then given by:

$$B_n(v) = \sum_{\{i:v \cdot i > v - v_n\}} P(i) = 1 - \frac{G(v - v_n)}{G(v)} \tag{22}$$

Since a brute force computation of $G(k)$ by Equation (18) involves computational difficulties, several efficient algorithms have been developed. Among them the one-dimensional recursive algorithm by Kaufman [1981] and Roberts [1981] is simple and computationally preferable. Their algorithm is modified to be suitable for repetitive calculation in the inverse problem of determining the system capacity so as to satisfy the user's requirement on the blocking probabilities [Takagi *et al.*, 2005].

Namely, starting with $G(0) = 1$, we calculate $G(k)$, $k = 1,2...,v$, recursively by:

$$G(k) = \frac{1}{k}\left[\sum_{j=0}^{k-1} G(j) + \sum_{m=1}^{N_{cs}} v_m \rho_m G(k - v_m)\right] \tag{23}$$

where $G(k) = 0$ for $k < 0$. This algorithm yields the blocking probabilities for systems with up to *v* channels all at once with is $O(N_{cs}v)$ computational time and $O(v)$ memory requirement.

The above model and algorithm are used to compute the blocking probability for each of N_{cs} service categories when the total number of channels, *v*, is given. By the inverse method, the total number of channels is calculated so as to meet the condition on the blocking probability for every category required by the user. The system capacity is obtained by multiplying the required total number of channels by the bit rate per channel.

For convenience' sake, let *r* (bit/s) be the unit of service bit rate per channel. When the service bit rate for category *n* is r_n, the parameter v_n to be used in the above formula is given by:

$$v_n = \lceil r_n / r \rceil, \quad 1 \le n \le N_{cs} \tag{24}$$

where $\lceil x \rceil$ denotes the least integer greater than or equal to *x* (ceiling function). This means that the number of channels is counted using *r* as the unit data rate for each service category.

Let π_n be the blocking probability of service category *n* required by the user. Then the required number of channels per cell, κ, is obtained as the smallest *v* that satisfies the conditions:

$$B_n(v) < \pi_n, \quad 1 \le n \le N_{cs} \tag{25}$$

simultaneously. Finally, the required system capacity $C_{d,t,rat,p,cs}$ (bit/(s · cell)) for all the circuit-switched categories is given by:

$$C_{d,t,rat,p,cs} = \kappa \times r \tag{26}$$

4.2 Calculation of the required system capacity for packet-switched traffic

The system capacity needed to fulfil each service category's mean delay requirement is determined using a queuing model applicable for independent arrival times of packets and arbitrary distribution of packet size. In queuing theory the model is known as an M/G/1 queuing model with non-pre-emptive priorities or head-of-the-line queuing system [Klienrock, 1976]. Non-pre-emptive priority means that upon arrival of a job with higher priority than the current job, the service of the current job is not interrupted, but completed before the service of the newly arrived higher priority job is started. For each packet based service category one priority level is used, but it is also possible to group multiple service categories into one priority. For each priority level the incoming packets are stored in a separate queue. Inside of each priority level's queue, the first-come-first-served (FCFS) scheduling discipline is applied.

A RAT is modelled here as having a single packet channel only, independent of the number of channels used in parallel in a real RAT, since there is no trunking gain possible when multiplexing packets buffered in a queue to be transmitted via one or more parallel channels. Some minor overhead resulting from fragmentation and padding when using multiple parallel medium bit rate channels instead of one equal capacity high bit rate channel is neglected here. The service duration in the queuing system is determined by the packet size and the data transmission rate.

Determination of the required system capacity for packet traffic requires the following input parameters:

– For each service category the offered base traffic per service environment per cell $T_{d,t,n,rat,p}$ (bit/(s · cell)) from § 3.6.3.2.
– Mean s_n (bits/packet) and second moment $s_n^{(2)}$ (bits^2/packet) of the IP packet size distribution of each service category n given in Table 5.
– The required mean delay D_n of each service category given in Table 5.
– The priority ranking of all service categories n with $n = 1, 2,..., N_{ps}$. It is assumed that the service category $n = 1$ has the highest priority, i.e. IP packets of service category $n = 1$ are served first. The service category $n = N_{ps}$ has the lowest priority. The priority ordering of the service categories is equivalent to the service category numbering.

The resulting IP packet arrival rate per cell λ_n (packets/(s · cell)) of service category n is obtained by dividing the offered base traffic by the mean packet size (Table 5):

$$\lambda_{d,t,n,rat,p} = \frac{T_{d,t,n,rat,p}}{s_n} \tag{27}$$

In order to improve the readability, the indices d,t,rat and p are omitted so that $\lambda_{d,t,n,rat,p}$ is simply denoted by λ_n until the end of this section.

The aggregated arrival rate over all service categories is denoted by:

$$\lambda_{\leq N_{ps}} = \sum_{n=1}^{N_{ps}} \lambda_n \tag{28}$$

The system capacity C_n that is needed to obtain the mean delay required by service category n can be calculated in the following procedure. The priority level requiring the highest capacity denotes the total required system capacity, since for the case that the QoS requirements of the most demanding service category are fulfilled, the requirements of the other service categories are over-fulfilled. Therefore, the overall required system capacity is given by:

$$C_{d,t,rat,p,ps} = \max\,(C_1, C_1,..., C_{N_{ps}}) \tag{29}$$

One job served by the queuing system is defined as one IP packet. By using non-pre-emptive priorities it is assumed that each IP packet is completely served before the current radio resource allocation is changed. This is a valid assumption, because in many cases interrupting the service of an IP packet causes loss of the capacity already spent for that packet.

The mean IP packet delay D_n, i.e. the sum of mean waiting time and mean service duration, for service category n over a system with capacity C is given by:

$$D_n(C) = \frac{\sum_{i=1}^{N_{ps}} \lambda_i s_i^{(2)}}{2\left(C - \sum_{i=1}^{n} \lambda_i s_i\right)\left(C - \sum_{i=1}^{n-1} \lambda_i s_i\right)} + \frac{s_n}{C} \tag{30}$$

This equation has been derived from Cobham's formula for the mean waiting time in a single arrival M/G/1 non-pre-emptive priority queue [Cobham, 1954; Irnich and Walke, 2004].

This expression is used for determining the system capacity C_n required to satisfy the QoS condition $D_n(C_n) = D_n$. Then, C_n is given as a solution to the cubic equation:

$$a_n x^3 + b_n x^2 + c_n x + d_n = 0 \tag{31}$$

with coefficients a_n, b_n, c_n and d_n according to:

$$\begin{aligned}
a_n &= 2D_n \\
b_n &- 2\left(D_n\left(\sum_{i=1}^{n} \lambda_i s_i + \sum_{i=1}^{n-1} \lambda_i s_i\right) + s_n\right) \\
c_n &= 2\left(D_n\left(\sum_{i=1}^{n} \lambda_i s_i\right)\left(\sum_{i=1}^{n-1} \lambda_i s_i\right) + s_n\left(\sum_{i=1}^{n} \lambda_i s_i + \sum_{i=1}^{n-1} \lambda_i s_i\right)\right) - \sum_{i=1}^{N_{ps}} \lambda_i s_i^{(2)} \\
d_n &= -2s_n\left(\sum_{i=1}^{n} \lambda_i s_i\right)\left(\sum_{i=1}^{n-1} \lambda_i s_i\right)
\end{aligned} \tag{32}$$

For the solution of cubic equations good symbolic solution is available by using for example Cardano's formula. Mathematically, Equation (31) has three solutions. To determine the correct solution among these three solutions the stability border of the queuing system has to be considered, i.e.:

$$\sum_{i=1}^{n} \lambda_i s_i < C_n \tag{33}$$

In order to deliver the packets with finite packet delay, the system capacity cannot be smaller than the aggregate arrival rate.

4.3 Determination of the spectrum requirements

The procedure for calculating the spectrum requirement is outlined in the following steps:

Step 1: The capacity calculation so far has been separately for uplink and downlink. The capacity requirements for uplink and downlink are combined, separately for packet and circuit switched capacity requirements:

$$C_{d,t,rat,p,cs} = C_{d,t,rat,p,cs,UL} + C_{d,t,rat,p,cs,DL} \tag{34}$$

$$C_{d,t,rat,p,pcs} = C_{d,t,rat,p,ps,UL} + C_{d,t,rat,p,ps,DL} \tag{35}$$

Step 2: The capacity requirements of circuit switched and packet switched traffic are combined, i.e.:

$$C_{d,t,rat,p} = C_{d,t,rat,p,cs} + C_{d,t,rat,p,ps} \tag{36}$$

where $C_{d,t,rat,p,cs}$ (bit/(s · cell)) represents the capacity requirement for circuit switched traffic in teledensity *d*, time interval *t*, RATG *rat* and radio environment *p*, and $C_{d,t,rat,p,ps}$ (bit/(s · cell)) represents the corresponding capacity requirement for packet-switched traffic.

In the case of mobile multicast capacity requirements, this is calculated similarly as the sum of packet and circuit switched multicast capacity requirements.

Step 3: The spectrum requirement for RATG *rat* in teledensity *d,* time interval *t* and radio environment *p* are calculated by applying the area spectral efficiency factors from Table 11. The spectrum requirement is obtained from:

$$F_{d,t,rat,p} = \frac{C_{d,t,rat,p}}{\eta_{d,rat,p}} \tag{37}$$

where $\eta_{d,rat,p}$ (bit/(s · Hz · cell)) is the area spectral efficiency in teledensity *d,* RATG *rat* and radio environment *p* from Table 11.

In the case of mobile multicast capacity requirements, the corresponding spectrum requirement $F_{d,rat,p,mm}$ is calculated separately, using the appropriate spectral efficiency $\eta_{d,rat,p}$ value from Table 11. This spectrum requirement is then added to the spectrum requirement of user individual communication:

$$F_{d,t,rat,p} = F_{d,t,rat,p} + F_{d,t,rat,p,mm} \tag{38}$$

5 Applying necessary adjustments

In Step 7 in Fig. 1, spectrum requirements are aggregated over radio environments. Adjustments are made taking into account the minimum spectrum requirement for a network deployment, necessary guardbands and the impact of the number of operators.

The procedure for applying the necessary adjustments goes along the following steps:

Step 1: It is assumed that there is not time sharing of spectrum, called FSU within one RATG between operators, because within one RAT the traffic load is not expected to vary a lot between operators, unless operators are going to address significantly differing market segments. Consequently we assume the spectrum distribution among operators within one RATG is fixed. Furthermore we assume each operator has available the same share of the total spectrum. Then the unadjusted spectrum per operator is:

$$F_{d,t,rat,p} = F_{d,t,rat,p}/N_o \tag{39}$$

where N_o is the number of operators from Tables 10a and 10b.

Step 2: Spectrum can in general only be used with granularity $\text{GrnSpec}_{rat,p}$ and the minimum bandwidth $\text{MinSpec}_{rat,p}$ required for being able to allocate a single carrier to each cell in a wide area network, taking into account the frequency reuse factor. The spectrum requirement needs to be adjusted accordingly:

$$F_{d,t,rat,p} = 0 \quad \text{if } F_{d,t,rat,p} = 0$$

$$F_{d,t,rat,p} = \text{MinSpec}_{rat,p} \qquad \text{if } 0 < F_{d,t,rat,p} \le \text{MinSpec}_{rat,p}$$

$$F_{d,t,rat,p} = \text{MinSpec}_{rat,p} + \text{GrnSpec}_{rat,p} \cdot \lceil (F_{d,t,rat,p} - \text{MinSpec}_{rat,p}) \ / \text{GrnSpec}_{rat,p} \rceil \ \text{if } \text{MinSpec}_{rat,p} < F_{d,t,rat,p} \tag{40}$$

where ⌈⌉ means rounding to the next largest integer and $\text{MinSpec}_{rat,p}$ and $\text{GrnSpec}_{rat,p}$ are obtained from Tables 10a and 10b. Note that also for future RATGs, there will be a minimum on carrier bandwidth that is determined by the requirement to support the targeted peak user data rate.

NOTE 1 – Caution should be exercised in selecting the input parameters to be used with this methodology, noting that the calculated spectrum estimate can be particularly sensitive to certain parameters. In particular the impact of the minimum spectrum deployment per operator of RATG2 must be considered carefully since a large value for this parameter, could result in total spectrum requirement estimate that is higher than would be required on the basis of the market traffic volume if narrower channel bandwidths were selected. The choice of cell size also should be consistent with the data rate, channel bandwidth and other parameters which affect the link budget. Furthermore, the minimum spectrum deployment per operator also needs to be appropriate for the average service bit rates used in the calculation.

Step 3: For RATG1, it is assumed that pico cell and hot-spot radio environments are not spatially coexisting. Therefore, the maximum of both radio environments needs to be taken. The macro and micro cell radio environments are assumed to spatially coexist with the pico cell and hot-spot radio environment, respectively. Therefore, for RATG1, the spectrum requirements of macro and micro environment need to be added to the maximum of the pico and hot-spot radio environment:

$$F_{d,t,rat} = F_{d,rat,macro} + F_{d,t,rat,micro} + \max(F_{d,t,rat,pico}, F_{d,t,rat,hotspot}) \qquad (41a)$$

For RATG2, the recent development of heterogeneous networks is leading to the direction that the different cell types are capable of being deployed on the same spectrum more efficiently than previously anticipated. Therefore, for RATG2, the spectrum requirements of maximum of macro and micro environment need to be added to the maximum of the pico and hot-spot radio environment:

$$F_{d,t,rat} = \max(F_{d,t,rat,macro}, F_{d,t,rat,micro}) + \max(F_{d,t,rat,pico}, F_{d,t,rat,hotspot}) \qquad (41b)$$

Then, the total required spectrum for all operators is:

$$F_{d,t,rat} = F_{d,t,rat} \cdot N_o \qquad (42)$$

Step 4: In the next step, guardbands are considered. It is assumed that the spectral efficiency figures already take into account a guardband that is required between carriers of the same operator. This means that the spectral efficiency figures also are based on the assumption that either an adjacent carrier has no influence, or the influence is already included in the spectral efficiency figure. The guardband *between* operators introduces additional spectrum requirements:

$$F_{d,t,rat} = F_{d,t,rat} + (N_o - 1) \cdot G_{rat} \qquad (43)$$

where the values of guardband between operators G_{rat} are input values given by Tables 10a and 10b.

6 Calculate aggregate spectrum requirements

In the final calculation block, spectrum requirements are aggregated over time intervals and teledensities.

Step 1: The time dependency of the spectrum requirement is considered. The two options below, i.e. a) and b), are to calculate the spectrum requirements without or with FSU possibility. The calculation without FSU possibility a) between any RATGs enables the calculation of RATG specific spectrum requirements whereas calculation with FSU possibility b) gives the required spectrum for all RATGs, which are enabled to utilize FSU.

a) It is reminded that at this point the spectrum requirements are still time dependent. Without FSU the spectrum need for RATG *rat* in the teledensity *d* is the maximum over time:

$$F_{d,rat} = \max_t (F_{d,t,rat}) \tag{44}$$

The largest value is taken from all time intervals *t*.

b) With FSU possibility between RATGs, the aggregate spectrum demand for those RATGs that support FSU is calculated by summing up the spectrum demands of each such RAT, separately for each teledensity. An FSU imperfection factor from Tables 10a and 10b is also included, to take into account any imperfections in the FSU scheme that will increase the spectrum demand:

$$F_{d,t,FSU} = FSU_{marg} \cdot \sum_{rat \in \{FSU \ \ RATs\}} F_{d,t,rat} \tag{45}$$

Then, the maximum operator is used to select the highest spectrum requirement of all times. Spectrum requirement for FSU RATGs is:

$$F_{d,FSU} = \max_t (F_{d,t,FSU}) \tag{46}$$

Spectrum requirements for non-FSU RATs is obtained from:

$$F_{d,rat,nonFSU} = \max_t (F_{d,t,rat}) \,; \quad rat \notin \{FSU \quad RATs\} \tag{47}$$

Step 2: Teledensity environments are spatially non-overlapping areas, thus the teledensity environment having the highest spectrum demand determines the spectrum requirement for a RATG.

a) Without FSU, the spectrum requirement for RATG *rat* is:

$$F_{rat} \max_d = (F_{d,rat}) \tag{48}$$

b) With FSU, the spectrum requirement is:

$$F_{rat,nonFSU} = \max_d (F_{d,rat,nonFSU}), \quad \text{and} \quad F_{FSU} = \max_d (F_{d,FSU}) \tag{49}$$

Step 3: It is reminded that the calculation inside spectrum allocation region might have been done from different market studies in different geographical regions. Where a common estimation is required for a group of countries, the maximum of the market study individual spectrum requirements should be taken.

a) Without FSU, the required spectrum for RATG *rat* is the maximum over all different regions/market studies:

$$F_{rat} = \max(F_{rat}) \tag{50}$$

b) With FSU, the required spectrum for RATG rat is the maximum over all different regions/market studies:

$$F_{rat,nonFSU} = \max(F_{rat,nonFSU}) \text{ and } F_{FSU} = \max(F_{FSU}) \tag{51}$$

Step 4: Optionally, as a final step, the total required spectrum is the Step 8 in Fig. 1.

a) Without FSU possibility all the RATG demands are summed:

$$F = \sum_{rat} F_{rat} \tag{52}$$

b) With FSU possibility the spectrum for FSU enabled RATGs and non-FSU enabled RATGs are added together

$$F = F_{FSU} + \sum_{rat \notin \{FSU \quad RATs\}} F_{rat,nonFSU} \tag{53}$$

7 Summary

This Recommendation presents the methodology for calculating the spectrum requirements for the further development of IMT. The methodology accommodates a complex mixture of services from market studies with service categories having different traffic volumes and QoS constraints. The methodology takes into account the time-varying and regionally-varying nature of traffic. The methodology applies a technology neutral approach to handle emerging as well as established systems using the RATG approach with a limited set of radio parameters. The four RATGs considered cover all relevant radio access technologies. The methodology distributes traffic to different RATGs and radio environments using technical and market related information. For RATG3 and RATG4 no spectrum requirements are calculated. For the traffic distributed to RATG1 and RATG2 the methodology transforms the traffic volumes from market studies into capacity requirements using separate algorithms for packet-switched and circuit switched (reservation based) service categories and takes into account the gain in multiplexing packet services with different QoS characteristics. The methodology transforms capacity requirements into spectrum requirements using spectral efficiency values. The methodology considers practical network deployments to adjust the spectrum requirements and calculates the aggregate spectrum requirements for further development of IMT.

References

KLEINROCK, L. [1975] *Queueing Systems*. Volume 1: *Theory*. John Wiley & Sons, New York, United States of America.

KAUFMAN, J.S. [October 1981] Blocking in a shared resource environment. *IEEE Trans. Commun.*, Vol. COM-29, **10**, p. 1474-1481.

ROBERTS, J.W. [1981] A service system with heterogeneous user requirements. *Perf. of Data Commun. Sys. and their Applications*, G. Pujolle (Ed.), p. 423-431, North-Holland.

TAKAGI, H., YOSHINO, H., MATOBA, N. and AZUMA, M. [2005] Methodology for calculation of spectrum requirements for the next generation mobile communication systems. Submitted to the *IEICE Trans*. (in Japanese).

KLEINROCK, L. [1976] *Queueing Systems*. Volume 2*: Computer Applications*. John Wiley and Sons, New York, United States of America.

COBHAM, A. [1954] Priority assignments in waiting line problems. *Operations Research*, Vol. 2, **1** (February) p. 70-76.

IRNICH, T. and WALKE, B. [5-8 September 2004] *Spectrum estimation methodology for next generation wireless systems.* PIMRC Barcelona, Spain.

Appendix 1
to Annex 1

List of abbreviations and symbols

Abbreviation	Description
2G	Second generation
AoD	Audio on demand
BER	Bit error ratio
CS	Circuit switching
FCFS	First come first served
FSU	Flexible spectrum usage
FTTH	Fibre-to-the-home
IMT-2000	International Mobile Telecommunications-2000
IP	Internet protocol
LAN	Local area network
M/G/1	Poisson input general service single server queue
PAN	Personal area network
PS	Packet switching
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technique
RATG	Radio access technique group
RE	Radio environment
SC	Service category
SE	Service environment
VoD	Video on demand
VoIP	Voice over Internet Protocol
xDSL	*x*-digital subscriber line

Symbol:	Description:	Unit:
a_n	Coefficient	–
$A_{d,p}$	Cell area of radio environment *p* in teledensity *d*	km^2
b_n	Coefficient	–
B_n	Blocking probability for circuit switched (reservation based) service category *n*	–
c_n	Coefficient	–
$C_{d,t,rat,p}$	Capacity requirement in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	bit/s/cell
$C_{d,t,rat,p,cs}$	Capacity requirement for circuit switching in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	bit/s/cell
$C_{d,t,rat,p,cs,DL}$	Capacity requirement for circuit switching in downlink in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	bit/s/cell
$C_{d,t,rat,p,cs,UL}$	Capacity requirement for circuit switching in uplink in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	bit/s/cell
$C_{d,t,rat,p,ps}$	Capacity requirement for packet switching in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	bit/s/cell
$C_{d,t,rat,p,ps,DL}$	Capacity requirement for packet switching in downlink in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	bit/s/cell
$C_{d,t,rat,p,ps,UL}$	Capacity requirement for packet switching in uplink in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	bit/s/cell
d	Index for teledensity	–
d_n	Coefficient	–
D_n	Required mean delay of service category *n*	s/packet
$F_{d,rat}$	Aggregate spectrum requirement for RATG *rat* in teledensity *d*	Hz
$F_{d,FSU}$	Aggregate spectrum requirement for RATGs with FSU in teledensity *d*	Hz
$F_{d,rat,nonFSU}$	Aggregate spectrum requirement for RATG *rat* without FSU in teledensity *d*	Hz
$F_{d,t,FSU}$	Aggregate spectrum requirement for RATGs with FSU in teledensity *d* and time interval *t*	Hz
$F_{d,t,rat}$	Aggregate spectrum requirement for RATG *rat* in teledensity *d* and time interval *t*	Hz
$F_{d,t,rat,p}$	Spectrum requirement for RATG *rat* in teledensity *d*, time interval *t* and radio environment *p*	Hz

$F_{d,t,rat,p,mm}$	Spectrum requirement for mobile multicast in RATG *rat* in teledensity *d*, time interval *t* and radio environment *p*	Hz
F	Total spectrum requirement for all RATGs	Hz
F_{FSU}	Spectrum requirement for RATGs with FSU	Hz
F_{rat}	Spectrum requirement for RATG *rat* without FSU	Hz
$F_{rat,nonFSU}$	Spectrum requirement for RATG *rat* without FSU	Hz
FSU_{marg}	FSU imperfection margin (multiplier)	–
G	Intermediate function to calculate blocking probability	
G_{rat}	Guardband between operators for RATG *rat*	Hz
$\mathrm{GrnSpec}_{rat,p}$	Granularity per operator for RATG *rat* in radio environment *p*	Hz
i_m	Number of calls of class *m* currently using channels in circuit switched capacity calculation	–
$\boldsymbol{i}$	System state vector in circuit switched capacity calculation	–
J_m	Parameter for mapping of mobility classes	–
k	Channel index in circuit switched capacity calculation	–
m	Index for service environment	–
$MR\_sm_{m,t,n}$	Methodology stationary/pedestrian mobility ratio for service category *n* in service environment *m* in time interval *t*	%
$MR\_lm_{m,t,n}$	Methodology low mobility ratio for service category *n* in service environment *m* in time interval *t*	%
$MR\_hm_{m,t,n}$	Methodology high mobility ratio for service category *n* in service environment *m* in time interval *t*	%
$MR\_market_{m,s}$	Market study mobility ratio for service *s* in service environment *m*	%
$MR\_market_{m,t,n}$	Market study mobility ratio for service category *n* in service environment *m* in time interval *t*	%
$MR\_market\_sm_{m,t,n}$	Market study stationary mobility ratio for service category *n* in service environment *m* in time interval *t*	%
$MR\_market\_lm_{m,t,n}$	Market study low mobility ratio for service category *n* in service environment *m* in time interval *t*	%
$MR\_market\_hm_{m,t,n}$	Market study high mobility ratio for service category *n* in service environment *m* in time interval *t*	%
$MR\_market\_shm_{m,t,n}$	Market study super-high mobility ratio for service category *n* in service environment *m* in time interval *t*	%
$MinSpec_{rat,p}$	Minimum per operator for RATG *rat* in radio environment *p*	Hz
n	Index for service category	–

N	Total number of service categories	–
N_{cs}	Number of circuit switched (reservation based) service categories	–
N_o	Number of operators	–
$N_{ps'}$	Number of packet-switched service categories	–
p	Index for radio environment	–
P	Intermediate function to calculate blocking probability	
$P_{m,t,n,rat,p}$	Session arrival rate per area for service category *n*, in service environment *m* and time interval *t* for RATG *rat* in radio environment *p*	Session arrivals/s/km^2
$P'_{m,t,n,rat,p}$	Session arrival rate per cell for service category *n*, in service environment *m* and time interval *t* for RATG *rat* in radio environment *p*	Session arrivals/s/cell
$Q_{m,t,s}$	Session arrival rate per user for service *s* in service environment *m* and time interval *t*	Session arrivals/s/user
$Q_{m,t,n}$	Session arrival rate per user for service category *n* in service environment *m* and time interval *t*	Session arrivals/s/user
r	Unit data rate in capacity calculation for circuit switched traffic	bit/s
$r_{d,t,n,rat,p}$	Mean service bit rate for service category *n* in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	bit/s
$r_{m,t,n}$	Mean service bit rate for service category *n* in service environment *m* and time interval *t*	bit/s
$r_{m,t,s}$	Mean service bit rate for service *n* in service environment *m*	bit/s
rat	Index for radio access technique group	–
s	Index for service	–
s_n	Mean of packet size distribution for service category *n*	bit/packet
$s_n^{(2)}$	Second moment of packet size distribution for service category *n*	(bit/packet)^2
t	Index for time interval	–
$T_{d,t,n,rat,p}$	Aggregate traffic volume for service category *n* in teledensity *d* and time interval *t* for RATG *rat* and radio environment *p*	bit/s/cell
$U_{m,t,s}$	User density for service *s* in service environment *m* and time interval *t*	users/km^2
$U_{m,t,n}$	User density for service category *n* in service environment *m* and time interval *t*	users/km^2
$w_{m,t,s}$	Weight for average session duration for service *s* in service environment *m* and time interval *t*	–

$\overline{w}_{m,t,s}$	Weight for mean service bit rate or mobility ratio for service *s* in service environment *m* and time interval *t*	–
X_{hs}	Coverage percentage for hot-spot cell	%
X_{macro}	Coverage percentage for macro cell	%
X_{micro}	Coverage percentage for micro cell	%
X_{pico}	Coverage percentage for pico cell	%
$\eta_{d,rat,p}$	Spectral efficiency of RATG *rat* in teledensity *d* and radio environment *p*	bit/s/Hz/cell
k	Required number of channels per cell	
$\lambda_{d,t,n,rat,p}$	Packet arrival rate of service category *n* in teledensity *d* and time interval *t* for RATG *rat* in radio environment *p*	Packet/s
λ_n	Packet arrival rate of service category *n*	Packets/s
$\lambda_{\leq N_{ps}}$	Aggregate packet arrival rate of all service categories	Packets/s
$\mu_{m,t,s}$	Average session duration of service *s* in service environment *m* and time interval *t*	s/session
$\mu_{m,t,n}$	Average session duration of service category *n* in service environment *m* and time interval *t*	s/session
ν_n	Number of channels required for circuit switched (reservation based) service category *n*	–
ν	Vector with numbers of channels required for circuit switched (reservation based) service categories	–
ξ_{hs}	Intermediate distribution ratio for hot-spot cell	–
ξ_{macro}	Intermediate distribution ratio for macro cell	–
ξ_{micro}	Intermediate distribution ratio for micro cell	–
ξ_{pico}	Intermediate distribution ratio for pico cell	–
$\xi_{pico\&hs}$	Intermediate distribution ratio for pico and hot-spot cells	–
$\xi_{m,t,n,rat,p}$	Distribution ratio for service category *n* in service environment *m* and time interval *t* for RATG *rat* in radio environment *p*	–
π_n	Maximum allowed blocking probability for circuit switched (reservation based) service category *n*	–
$\rho_{d,t,n,rat,p}$	Offered traffic per cell for service category *n* in teledensity *d* and time interval *t* for RATG *rat* and radio environment *p*	Erlang/cell