Methodology for Calculating the Spectrum Requirements for the Future Development of IMT-2000 and Systems Beyond IMT-2000

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Abstract - In preparation for the next World Radiocommunication Conference (WRC) in 2007, ITU is developing a methodology for calculating the spectrum requirements of further developments of IMT-2000 and systems beyond IMT-2000. This paper presents a spectrum requirement calculation methodology that has largely been developed in the IST-WINNER project. ITU has accepted this methodology to form the new methodology recommendation to a large extent.

I. INTRODUCTION

The *International Telecommunication Union* (ITU) uses standardized and internationally agreed methodologies for the purpose of estimating the amount of radio spectrum needed for the future development of mobile communication systems. The current ITU methodology used to estimate the spectrum requirements for IMT-2000 systems for WRC.2000 is presented in Rec. ITU-R M.1390 [1].

In preparation for the next World Radiocommunication Conference (WRC) in 2007, ITU is developing a new methodology to calculate the spectrum requirements of further developments of IMT-2000 and systems beyond IMT-2000. The methodology used to estimate the additional spectrum requirements for IMT-2000 at WRC-2000 [1] is not suitable to be applied for estimating the spectrum requirements of further developments of IMT-2000 and systems beyond IMT-2000. Therefore, a new methodology needs to be developed. Currently the development of the methodology at ITU is almost finalised. The WINNER project has contributed significantly to this development work, and the new draft recommendation [2] is based on these contributions to a large extent.

Extending and updating [3], this paper presents the current status of the new ITU spectrum requirement estimation methodology, which was agreed in February 2005. In addition, it presents a number of proposals for amendments and changes to the methodology, which were recently contributed to ITU by the WINNER project. These proposals are mainly resolving issues that were discovered during the development of a software tool implementing the new methodology, which was also conducted by the WINNER project. These proposals were discussed at ITU-R WP8F in June and they were accepted to be included in the methodology.

A detailed discussion on the methodology proposed by WINNER is included in [4]. An early description of some basic concepts of the new ITU methodology is given in [5]. As companion paper to this paper, [6] compares the results delivered by the new methodology to the results of the M.1390 methodology, which are given in [7].

This paper is organised as follows. In Section II, we summarise the requirements for the methodology set by ITU, present a simplified methodology flow chart, and introduce the scenario framework and related definitions used in the methodology. In Section III, we present the calculation of traffic demand resulting from various services in different environments. In Section IV, we introduce the capacity calculation algorithms, which derive the system capacity required to carry the offered traffic. In Section V, we present the spectrum requirement calculation based on the capacity requirement, area spectral efficiency, and some network parameters. Finally, conclusions are drawn in Section VI.

A. Requirements on the methodology from ITU

ITU has set requirements for the spectrum requirement calculation methodology for further developments of IMT-2000 and systems beyond IMT-2000, see [2]. According to the most important requirements, the methodology should accommodate a complex mixture of services requiring different bandwidths and quality of services (QoS), be able to model systems consisting of multiple interworking networks, and have the flexibility to handle different combinations of Radio Access Techniques (RAT) in different environments. The methodology should also be technology neutral and generic, have the flexibility to handle both emerging technologies and well characterised systems, produce results in a credible and easily understandable manner, be suitable to be used during ITU meetings in terms of needed computing facilities and time, and finally be no more complex than is justified by the uncertainty of the input data.

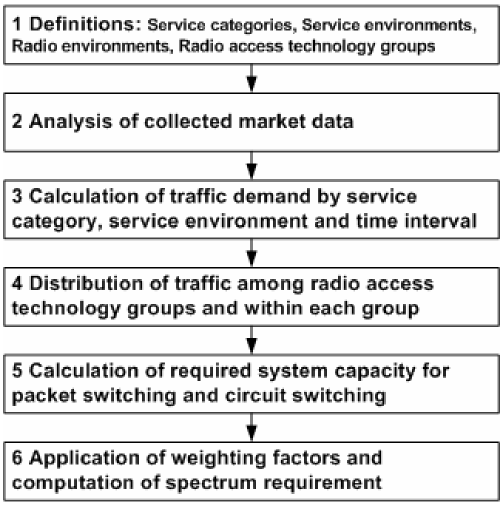

Figure 1. Methodology flow chart.

B. Methodology flow chart

The general ITU methodology flow chart is introduced in [2]. Figure 1 presents a simplified flow chart including the most important steps. The description of the methodology in this document follows this flowchart.

II. SCENARIO FRAMEWORK

The first step in Figure 1 is the definition of a scenario, which must be constructed within the scenario framework defined by the methodology. A spectrum requirement estimation scenario consists of service categories, service environments, radio environments and radio access technology (RAT) groups and the parameters that are associated with these elements.

Service categories represent the applications and services used. Service environments represent common service usage and traffic volume conditions, as well as different types of area in terms of user density and dominant service usage pattern. A RAT Group summarizes properties and capabilities of similar radio access technologies, and radio environments represent the different deployment types and cell layers in a network.

A: Service categories

A service category is defined as a combination of a service type and traffic class. Service types are primarily characterised by the peak data rates. Traffic classes, such as Conversational, Interactive, Streaming and Background, are mainly characterised by their QoS requirements. This traffic class concept is based on the IMT-2000 QoS classes defined by [10]. At the last meeting of WP8F in June, the WINNER project proposed to use this concept also in the framework of the spectrum requirement calculation methodology, and the proposal was accepted to replace the previously existing traffic classes.

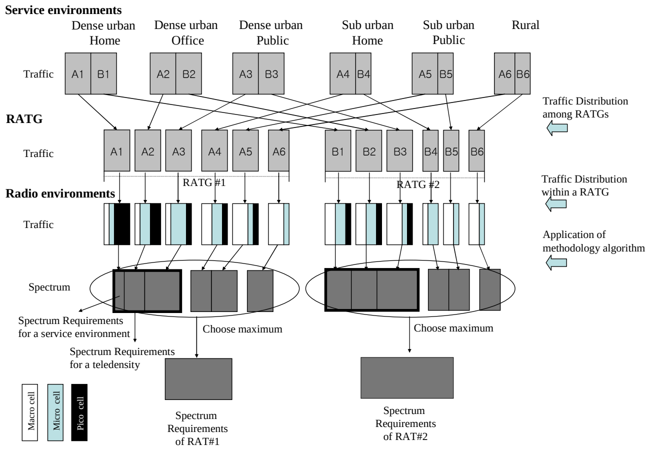

Figure 2. Methodology scenario framework and the role of the different scenario elements for traffic distribution. (source: [2])

Each service category has an associated set of parameters, which can be classified into parameters that can be different for each service category depending on the regarded service environment and time interval (i.e., user density, session arrival rate per user, mean service bit rate, mean session duration and mobility ratio), and parameters that are unique for each service category (e.g., mean and second moment of the packet size distribution for packet-switched service categories and allowed blocking probability and channel data rate granularity for circuit-switched service categories).

The applications that are considered to be relevant for the spectrum requirement calculation need to be grouped into these service categories based on commonalities in terms of the parameters associated with a service category, i.e. applications that offer a similar bitrate should be in the same service type, and applications requiring a similar QoS should reside in the same traffic class.

With respect to the calculation of required system capacity a service category is either considered to be served using a circuit-switched or a packet-switched bearer service. The corresponding capacity calculation algorithm is selected accordingly. The calculation of the required system capacity for circuit-switched traffic is performed using a multi-service loss model [11]; see Sec. IV.B, while the required capacity for packet-switched traffic is based on an M/G/1-FCFS queue with non-preemptive priorities [7],[12]. A service category's associated bearer service switching type is determined by its traffic class. Conversational and Streaming traffic class are assumed to require a circuit-switched bearer service, while Interactive and Background traffic classes require a packet-switched bearer service.

Another property associated with each service category is whether it can or cannot be provided by multicast or by unicast transmission modes, respectively. Unicast transmission modes enable communication between a single transmitter and receiver, whereas multicast transmission modes enable the transmission of the same information to multiple users, which is more efficient e.g. for services such as mobile TV and message distribution.

B. Service environments

A service environment is a combination of teledensity and service usage pattern. Teledensities, such as dense urban, sub-urban and rural, describe the user density of a certain type of area. Service usage patterns, such as home, office, and public area, describe the user behaviour and are categorized according to areas where users use similar services and expect similar quality of service. Teledensities are geographically non-overlapping areas whereas several service usage patterns can co-exist in the same geographical area within a teledensity, resulting in several service environments being possible in each teledensity. Not all possible combinations of Service usage pattern and Teledensity are considered; see Table 1.

Table 1: Identification of service environments

Teledensity / Service usage pattern	Dense Urban	Sub-Urban	Rural
Home	SE 1	SE 4	SE6
Office	SE 2	SE 5	
Public area	SE 3		

In general spectrum requirements are calculated separately for each service environment. Then, spectrum requirements are summed up over service environments belonging to the same teledensity. The final spectrum requirements are calculated by taking the maximum value among spectrum requirements for the three Teledensity areas considered. However, for the macro and micro cell radio environments of the service environments located in the same teledensity, the offered traffic is summed up before the required system capacity is calculated. Parameters that depend on the combination of service category and service environment are user density, session arrival rate per user, mean service bit rate, mean session duration and mobility ratio.

C. Radio environments

Radio environments are defined by the cell layers in a network consisting of hierarchical cell layers, e.g. macro, micro and pico cells. In other words, radio environments comprise areas that exhibit common propagation conditions and relate to the technical way radio coverage is achieved (i.e., the deployment type). Examples of radio environments include hot spot, pico cell, micro cell, and macro cell. Each radio environment is characterised by minimum and maximum cell radii, cell geometry, typical cell area, support for outdoor-to-indoor coverage, line-of-sight requirement and whether it provides seamless coverage for intra radio deployment environments handovers.

In the traffic distribution process, traffic is distributed to radio environments according to mobility classes. The traffic distribution follows the principle to use the radio environment with the lowest mobility support that just satisfies the requirements. According to this principle alone, basically all stationary/pedestrian traffic would go to pico, all low mobility to micro and all high mobility to macro (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 this will not happen because 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, each possible combination of radio environment and service environment has an associated population coverage percentage. The population coverage percentage can be zero for certain combinations, meaning that the particular radio environment is not deployed in the particular service environment.

The coverage percentages are based on the following assumptions:

- All SEs are assumed to have 100% population coverage by macro cells. The coverage in reality may be some percent smaller, but this is negligible for the purpose of traffic distribution.
- micro cells are mainly there to cover streets and that the spill over coverage into homes and offices is negligible.
- The home service usage pattern in all teledensities is assumed to be not covered by pico cells. Hot spot coverage of homes is assumed to be high, using self provided equipment.
- The office usage is assumed to be covered only to a small percentage by pico cells since traffic requirements are expected to require the deployment of hot spots in most cases.
- In a dense urban public area environment of a mature network a high micro cell population coverage is assumed. Pico cell and hot spots are assumed to be deployed only in special locations like shopping malls or transportation stations (airports, train stations, bus stop hub). Therefore the population coverage with respect to the entire population in the public areas in the dense urban teledensity is assumed to be low.
- The Sub-urban office/public area service environment considers usage in office and public areas in sub-urban teledensity. The majority of the population is assumed to be in the office areas rather than the public area. Micro cells are assumed to cover a few major roads that are assumed to contain 20% of the overall population of this service environment. Pico and hot spot coverage

in the public areas is assumed to be very low. In the office usage their coverage is assumed to be high, however considing both the public area and the office usage together, the pico and hot spot coverage is assumed to be low.

- In the rural teledensity category, home, office and public area usage belong to the same service environment. Pico and hot spot coverage in the public areas is assumed to be very low. In the office usage their coverage is assumed to be high. In the home usage, no pico cell coverage is assumed, but a high coverage of self provided hot spot equipment. Therefore considing all 3 usage types, only very low pico cell coverage is assumed (lower than in SE5), but medium hot spot coverage (higher than in SE5) is assumed.

D. Radio access technology groups

The methodology needs to be technology neutral and generic and therefore the individual radio access technologies are grouped into four RAT groups:

- 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: Systems beyond IMT-2000 as described in figure 2 of ITU-R M-1645 (e.g., new mobile access and new nomadic/local area wireless access), but not including systems already described in any other RAT groups.
- Group 3: Existing Radio LANs and their enhancements.
- Group 4: Digital Mobile Broadcasting systems and their enhancements. This group covers systems designed for broadcasting to mobile and handheld terminals.

Traffic can be distributed to all four RAT groups but the spectrum requirement is calculated for only RAT groups 1 and 2. Each RAT group is characterized by parameters such as supported bit rates and velocities, carrier bandwidths etc. RAT group definitions show which of the service categories are served with unicast or multicast transmission.

For each RAT group an area spectral efficiency in b/s/Hz/m^2 is defined separately for each radio environment and service environment. The spectral efficiency is an important parameter in calculating the spectrum requirement. Since the spectral efficiencies of unicast and multicast modes can be significantly different, separate area spectral efficiency tables are needed for these two modes. The area spectral efficiency will be understood as being calculated from the mean data throughput achieved over all users uniformly distributed in the area of the radio deployment environment, on IP layer for packet switched services and on application layer for circuit switched services, in fully loaded radio networks. The proposed methodology considers these values as inputs for the methodology.

III. CALCULATION OF OFFERED TRAFFIC

A. Analysis of collected market data

The second step in the spectrum requirement calculation methodology flow chart in Figure 1 is the analysis of collected market data. Market studies are being conducted in different parts of the world to forecast the demand of different service categories around the year 2020. Market studies will provide the basic information required for derivation of:

- user density (users/km^2)
- session arrival rate per user (session arrivals/s/user)
- mean service bit rate (Mbit/s)
- average session duration (s/session)
- mobility ratio (ratio of stationary, pedestrian and vehicular usage of each service category).

These parameters are obtained by applying the general process shown in Fig. 3. The first step is to identify all relevant applications and services by means of market prediction and forecast. With the lists of applications and services developed in step 1, it is necessary to specify the values of the traffic attribute parameters such as mean service bit rate, average session duration per each service.

The next step is then to specify the values of service request rate (unit: session arrivals/s/km^2) and average traffic volume of a session attempt (unit: bit/session) for each service category in each service environment and time interval. In addition, the mobility ratios are needed in the traffic distribution. Service request rate and average traffic volume are presented in matrix form so that matrix $\mathbf{P}_n$ includes the session arrival rates of service category n in all service environments and time interval while matrix $\mathbf{T}_n$ presents the traffic volume per session in the same way.

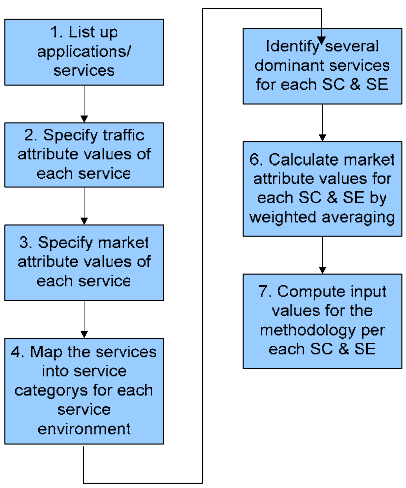

Figure 3: General process for market data analysis.

The service request density information $\mathbf{P}_n$ is determined by using the user density $\mathbf{U}_n$ (unit: users/km^2) and number of session attempts per user $\mathbf{Q}_n$ (unit: session arrivals/s/users). The average traffic volume information $\mathbf{T}_n$ is determined by using the mean service bit rate r_n (unit: bit/s) and the average session duration $\boldsymbol{\mu}_n$ (unit: s/session). It should be noted that for some services, such as file downloading, it is more meaningful to determine $\mathbf{T}_n$ directly without using the two quantities.

B. Calculation of traffic demand for service categories, service environments, and time intervals

The third step in the methodology flow chart is to compute the traffic load of different service categories in different service environments in different time intervals based on the results of the market studies. The traffic load is calculated per service environment and time interval due to the regionally varying and time varying nature of the traffic.

The traffic load information includes the traffic volume per session and service request density. The traffic volume of service category n in bits/session is collected to matrix $\mathbf{T}_n$. The service request density information includes session arrival rate per user $\mathbf{Q}_n$ (session arrivals/s/user) and user density $\mathbf{U}_n$ (users/m^2). The unicast mode uses directly session arrival rate per area $\mathbf{P}_n$. (session arrivals/s/m^2), which is obtained as element wise product of $\mathbf{Q}_n$ and $\mathbf{U}_n$. In all the matrices, the row dimension denotes the service environment and the column dimension denotes the time interval.

C. Distribution of traffic to RAT groups and radio environments

The fourth step in the flow chart is to distribute the aggregate traffic from step 3 to the different RAT groups and radio environments inside a RAT group. For the traffic distribution all four RAT groups are considered, but the spectrum requirement is only calculated for RAT groups 1 and 2. For packet-switching, the output of the traffic distribution is the aggregate bit rate matrix in bits/s/cell of service category n in RAT group *rat* and radio environment p, i.e. matrix $\mathbf{T}_{n,rat,p}$. For circuit-switching, the output is the aggregate session arrival rate matrix in session arrivals/s/cell of service category n in the given RAT group and radio environment, i.e. matrix $\mathbf{P}'_{n,rat,p}$.

The distribution is done by multiplying the session arrival rate by the distribution ratio $\xi_{m,n,rat,p}$. It is assumed that the distribution ratio is the same for all time intervals t. For unicast services, the session arrivals in matrix $\mathbf{P}_n$ are multiplied by the corresponding distribution ratios to yield matrix $\mathbf{P}_{n,rat,p}$ with unit session arrivals/s/m^2. For multicast service categories, the session arrival rate per user matrix $\mathbf{Q}_n$ is distributed with the corresponding distribution ratios to yield the session arrival rate per user matrix $\mathbf{Q}_{n,rat,p}$, which is unique for each combination of Service Category, RAT Group and Radio Environment. Here, it is assumed that the arrivals of all multicast sessions of all users of a particular service coincide, as it is the case with e.g. message distribution services, so that on the radio cell level only a single multicast session needs to be serviced. The distribution corresponds to distributing session arrivals of different services of the same service category to different RATs and radio environments.

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 Radio Access Techniques groups. In Figure 2 for example, the traffic of the service environment “dense urban home” has two components, which are the traffic amounts of A1 for RATG #1 and B1 for RATG #2. The service environments “Dense urban office”, “Dense urban public”, “Sub urban home/public” and “Rural” also have the traffic amounts for each RATG as presented in Figure 2.

Since each RATG supports one or more radio environments, the amount of traffic demand for each RAT group at each service environment can be distributed into its supported radio environments, as shown in the third row of Figure 2. Each RATG has its own deployment scenario for its component radio environments 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 service environment, RAT and radio environment. A rectangle shown in the fourth row of Figure 2 represents spectrum requirements of a RAT in each service environment. Within a given RAT, spectrum requirements of each teledensity will be calculated as sum of spectrum requirements of all service environments in the teledensity and spectrum requirements of a RAT will be the maximum among spectrum requirements of all teledensities for the RAT.

The following rules are used for the derivation of the $\xi_{m,n,rat,p}$ factors. The distribution ratios are determined in 3 phases.

Phase 1 determines the combination of RAT group and radio environment that cannot support a service category in a given service environment. The corresponding distribution ratios are set to 0 while possible combinations are set to 1. In addition, Phase 1 sets the distribution ratios to zero for:

- RAT group 4 for service categories that require bidirectional communication
- radio environments that do not exist in the considered service environment as defined by the service environment definitions

- radio environments that are not supported by the given RAT group as specified by the RAT group definitions
- each combination of RAT group and radio environment for which the supported cell edge data is smaller than the required data rate of a particular service category as defined in the service category definitions and RAT group definitions.

The output of Phase 1 is a table of the combination possibilities that have been set to zero or one.

The sum of the distribution ratios $\xi_{m,n,rat,p}$ over the RAT group index *rat* and radio environment index *p* is equal to one.

At this point, the session arrivals are normalised by area while we are interested in aggregate traffic per cell. In the unicast mode, the session arrival rate per cell $\mathbf{P}'_{n,rat,p}$ is obtained directly by multiplying the elements of matrix $\mathbf{P}_{n,rat,p}$ with corresponding cell area A_p. In the multicast mode, the user density has no influence, because a RAT group would see only a single arrival event, no matter how many users there are in the cell using that service category. Therefore, the session arrival rate per cell is equal to the session arrival rate per user $\mathbf{Q}_{n,rat,p}$.

For circuit switched service categories, only the session duration in s/session and the matrix $\mathbf{P}'_{n,rat,p}$ in session arrivals/s/cell are needed for the capacity calculation. Capacity calculation for packet switched service categories requires the offered traffic in bits/s/cell in matrix $\mathbf{T}_{n,rat,p}$ which is calculated by multiplying the corresponding elements of session arrival rate matrix $\mathbf{P}'_{n,rat,p}$ and traffic volume matrix $\mathbf{T}_n$. The offered traffic presents the total traffic of all users of the same service category. Separate matrices $\mathbf{T}_{n,rat,p,pp}$ and $\mathbf{T}_{n,rat,p,pm}$ are needed for unicast and multicast modes.

IV. CALCULATION OF CAPACITY REQUIREMENT

The fifth step in the methodology flow chart in Figure 1 is the calculation of the required system capacity. Separate capacity calculation algorithms are applied to packet-switched and circuit-switched traffic resulting in required system capacity matrices for packet and circuit switched traffic, i.e. $\mathbf{C}_{rat,p,ps}$ and $\mathbf{C}_{rat,p,cs}$, respectively. Furthermore, the capacity requirement is also calculated separately for unicast and multicast transmission modes in both circuit switching and packet switching case, resulting in $\mathbf{C}_{rat,p,cs,uc}$, $\mathbf{C}_{rat,p,cs,mc}$, $\mathbf{C}_{rat,p,ps,uc}$ and $\mathbf{C}_{rat,p,ps,mc}$, respectively.

A. Capacity calculation for packet switching

The capacity calculation for packet switched service categories is based on well established results from the queuing theory. The mean IP packet delay requirement is considered as a key QoS criterion. The capacity calculation is done separately for unicast and multicast modes assuming independent parallel servers for the two modes.

The capacity requirement is calculated based on an M/G/1-FCFS queuing model with non-preemptive priorities. M/G/1 denotes Poisson input, general service process and single server queue. FCFS denotes first-come first-serve scheduling discipline. Non-preemptive priorities mean that upon arrival of a higher priority job, the service of the current job is not interrupted, where a job corresponds to an IP packet. Solutions for analysis of such a queue have been presented by Cobham [1], Kesten and Runneberg [9].

The capacity calculation requires as input the offered traffic $\mathbf{T}_{n,rat,p}$, in bits/s/cell, mean packet delay requirement, priority ranking of service categories, and the first and second moments of the packet size distribution. The traffic is obtained from step 4 while other parameters are assumed to be input values to the methodology.

The capacity requirement is calculated separately for each priority level with its own requirement on the mean delay. Each calculation derives the capacity that is required to carry the traffic from all priority levels subject to the mean delay requirement of the current priority level. The aim is to find the priority level that requires the highest capacity to fulfil its own delay requirements and use this as the capacity requirement of all service categories. This is because when the mean delay requirement of the most demanding service category is fulfilled, the requirements of other service categories are over-fulfilled.

Consider *N* different classes of IP based services, where each service class *n* corresponds to one customer class of the queue. Each customer corresponds to one IP packet. The mean size of an IP packet of class *n* is denoted s_n, and the second moment of the IP packet size distribution function (DF) is denoted $s_n^{(2)}$. If an IP packet of class *n* is transmitted over a channel with capacity C (unit: bit/s), the service time of the packet is $T_n = S_n/C$. Accordingly, mean and second moment of the service time DF are

$$\beta_n = \frac{s_n}{C} \quad \text{and} \quad \beta_n^{(2)} = \frac{s_n^{(2)}}{C^2}$$

The required system capacity is defined as the minimum capacity that leads to a stable system (i.e., the aggregated mean packet arrival rate of all service classes must not be greater than the mean packet departure rate) and in addition achieves a mean IP packet delay that is equal or less than the service-specific mean delay requirement, which is denoted D_n.

The required system capacity is determined from the set of *mean delay bound system capacities* $\{C_n,\ldots,C_N\}$, where C_n is the system capacity that fulfils the mean delay requirement of service class *n*, considering the traffic of all service classes. Each C_n is given by the solution to the third order algebraic equation

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

that satisfies the condition $D_n(C)<=D_n$ among the three existing roots. The maximum of the set $\{C_n,\ldots,C_N\}$ determines the system capacity that is necessary to fulfil the mean delay requirements of all service classes.

B. Capacity calculation for circuit switching

The capacity required for circuit-switched traffic is calculated using a multi-service loss model, which is an extension of the well-known Erlang-B formula to the multi-dimensional case.

This extension allows the simultaneous occupation of several channels by each session. Sessions of N_{CS} circuit-switched service categories are assumed to share the set of ν service channels. It is also assumed that each session of service category n requires the simultaneous use of ν_n channels ($1<=n<=N_{CS}$). If an arriving service request of service category n does not find ν_n empty channels, it is lost (sometimes this is also denoted as *blocked call*).

Given the required blocking probability of service category n, denoted B_n, the required number of channels for service category n is determined as the smallest ν that satisfies $B_n(\nu)<=B_n$..

The maximum of the set of required numbers of channels and corresponding system capacity values then defines the overall required system capacity for circuit-switched traffic.

The concept was originally contributed by Japan.

V. CALCULATION OF SPECTRUM REQUIREMENT

The sixth step in the methodology flow chart in Figure 1 is to calculate the spectrum requirement based on the capacity requirements, area spectral efficiency values, and some network deployment parameters. The spectrum requirement calculation is applied to RAT groups 1 and 2. The spectrum requirement in Hz is calculated as follows.

1. Combine the capacity requirements of packet switching and circuit switching for unicast and multicast modes.
2. Calculate the spectrum requirement separately for unicast and multicast transmission modes for RAT group *rat* in service environment *m*, radio environment *p* in all time intervals, by dividing the capacity requirement by the corresponding cell areas and area spectral efficiency values.
3. Sum up the spectrum requirements of unicast and multicast transmission modes.
4. Sum up the spectrum requirements of service environments which belong to the same teledensity.
5. Divide the spectrum requirements by the number of operators.
6. Round up the spectrum demand to the next multiple of the minimum amount of spectrum bandwidth required to allocate a single carrier to each cell of the considered radio environment, taking into account the frequency reuse factor.
7. Take the maximum of the spectrum requirements of pico and hot spot radio environements, as there are assumed to be non-overlapping, and add the requirements of micro and macro cell radio environments, because they are assumed to be overlapping. Currently no spectrum reuse between overlapping radio environments is considered.
8. Calculate the total spectrum requirement of RAT group *rat* in teledensity *d* for all operators.
9. Add guard bands. The guard bands between carriers of the same operator are assumed to be considered in the spectral efficiency figures. The spectrum demand is adjusted by the guard band between operators introducing additional spectrum requirements.
10. Consider the time dependency of the spectrum requirement. Assuming there is time sharing of spectrum between RAT groups, called flexible spectrum use (FSU), different calculations are applied without and with FSU. The calculation (a) without FSU possibility between any RAT groups enables the calculation of RAT group specific spectrum requirements whereas calculation (b) with FSU possibility gives the required spectrum for all RAT groups, which are enabled to utilise FSU.

    a) Spectrum for RAT group *rat* in different teledensities without FSU is taken as maximum over time.

    b) With FSU possibility, the aggregate spectrum demand for RAT groups with FSU support is calculated by summing over such RATs and applying the maximum operator over time to select the highest spectrum requirement of all times. Spectrum requirements for non-FSU RATs is calculated similarly.
11. Since the teledensities are spatially non-overlapping areas, the teledensity with the highest spectrum demand determines the spectrum requirement for a RAT group.

    a) Without FSU, the spectrum requirement for RAT group *rat* is the maximum over teledensities.

    b) If there are some FSU enabled RATs, the maximum operation is done separately for RAT groups with and without FSU.
12. Finally, the total required spectrum of all considered RAT groups is calculated. Without FSU possibility, all the RAT group spectrum demands are summed. With FSU possibility the spectrum for FSU enabled RAT

Groups and non-FSU enabled RAT groups are summed.

VI. CONCLUSIONS

In this paper, we have presented an overview of the spectrum requirement calculation methodology for further developments of IMT-2000 and systems beyond IMT-2000 largely developed in the IST-WINNER project. The proposed methodology follows the ITU flow chart and meets the requirements set by ITU. The methodology presents a novel way to calculate the capacity requirement of packet switched service categories. The main elements of the methodology presented in this paper have been contributed to ITU WP 8F as agreed European contributions by the WINNER project. The development of the methodology at ITU is almost finalised and the WINNER inputs have been accepted to a large extent to form the current working document towards the new ITU recommendation on calculation of spectrum requirements for future development of IMT-2000 and systems beyond IMT-2000 from the year 2010 onwards.

This paper presents the methodology, while results of applying the methodology will be available only later. A software implementation of the methodology is currently in preparation by the IST-WINNER project. After the tool is ready, it can be used by ITU to provide numerical results on the spectrum demand of systems beyond IMT-2000 to assist in preparation for WRC 2007.

ACKNOWLEDGEMENTS

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