WINNER Methodology for Calculating the Spectrum Requirements for Systems Beyond IMT-2000

Marja Matinmikko[1], Tim Irnich[2], Jörg Huschke[3], Antti Lappeteläinen[4], and Jussi Ojala[4]

[1]VTT Electronics, Finland; [2]ComNets, RWTH Aachen University, Germany; [3]Ericsson Research, Germany; [4]Nokia, Finland

email: Marja.Matinmikko@vtt.fi

ABSTRACT

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

I. INTRODUCTION

The allocation of frequency bands is under the authorization of the general WRC (World Radio-communication Conference) process. The process of preparation of WRC is organized by the study groups of ITU-R (International Telecommunication Union Radio-communication sector). In Europe, the preparation process is coordinated by ECC (Electronic Communication Committee) of CEPT (Conference of European Post and Telecommunications).

The leading group on IMT-2000 and systems beyond IMT-2000 at ITU is the ITU-R Working Party 8F (ITU-R WP 8F). ITU-R WP 8F has established the Working Group Future Services & Market Aspects (WG SERV), which concentrates on services, market, and spectrum calculation methodology to assist in the preparation for WRC 2007 in terms of potential spectrum requirements. Sub-Working Group Methodology of WG SERV is responsible for developing a methodology to calculate the spectrum requirements of future developments of IMT-2000 and systems beyond IMT-2000 from the year 2010 onwards. The methodology development process is contribution driven and the WINNER project has contributed actively.

The current ITU methodology used to estimate the spectrum requirements for IMT-2000 systems is presented in Rec. ITU-R M.1390 [1]. This methodology has several shortcomings and does not meet the requirements set for the methodology for systems beyond IMT-2000. Therefore, a new methodology needs to be developed. ITU-R WP 8F has decided that the new methodology is based on a deterministic approach similar to that of the old methodology but some parameters may be determined by Monte-Carlo based simulations for added accuracy.

We present an overview of the WINNER methodology for estimating the spectrum requirements of further developments of IMT-2000 and systems beyond IMT-2000 developed in the IST-WINNER project. The development of the methodology at ITU is almost finalised and the WINNER methodology presented here has been accepted for the new draft recommendation [2] to a large extent. A detailed discussion on the WINNER methodology is included in [3]. In this paper, some of the parts have been updated compared to [3]. Estimation of spectrum requirements for future systems is also considered in [4].

The 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 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.

II. WINNER METHODOLOGY TO CALCULATE SPECTRUM DEMAND

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 Technologies (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.

B. Methodology flow chart

The general ITU methodology flow chart is presented in [2]. Figure 1 presents a simplified flow chart which includes the most important steps. We describe the steps in the following sections and in Chapters III-V.

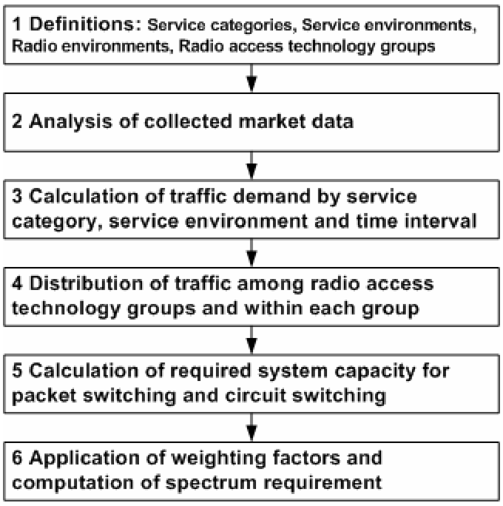

Figure 1. Methodology flow chart.

C. Definitions

The first step in the flow chart in Figure 1 is definitions needed in the methodology. The definitions include service categories, service environments, radio environments and radio access technology (RAT) groups.

Service categories

A service category is defined as a combination of a service type and an associated traffic class. Service types, such as Speech, Simple Message, Switched Data, Medium Multi-media, High Multimedia, High Interactive Multimedia and Ultra High Multimedia, are characterised by the peak data rates. Traffic classes, such as Constant Bit Rate, Variable Bit Rate, Available Bit Rate, and Unspecified Bit Rate, are characterised by data rate variations and required delay.

Two kinds of service categories are considered: those that can be or cannot be more efficiently provided by point-to-multipoint rather than by point-to-point transmission modes. Point-to-point transmission modes enable communication between a single transmitter and a receiver where as point-to-multipoint 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 low data rate messaging. The approach taken here for point-to-multipoint mode assumes synchronised user arrivals, for example all users would get an MMS if they have subscribed to a news update service. The approach is not applicable to asynchronous user arrivals such as mobile TV type applications where users initiate the service independent of each other.

Service environments

Service environment is a combination of teledensity and service usage pattern. Teledensities, such as dense urban, sub-urban and rural, describe the population density. Service usage patterns, such as home, office, and public area, describe the user behaviour. Teledensities are geographically non-overlapping areas while several service usage patterns can co-exist in each teledensity, resulting in possibly several service environments in each teledensity.

Radio environments

Radio environments are areas exhibiting common propagation conditions. Radio environments are characterized by cell radius and geometry, support for outdoor-to-indoor coverage, line-of-sight requirement and provision of seamless coverage for handovers. Examples of radio environments include pico cell, micro cell, and macro cell.

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-2000, IMT-2000 and enhancements
  - e.g. WCDMA and CDMA 2000
- Group 2: Systems beyond IMT-2000 including new mobile access and new nomadic/local access
- Group 3: Existing RLAN systems and enhancements
  - e.g. IEEE802.11a and IEEE802.11g
- Group 4: Digital Mobile Broadcasting Systems and enhancements.

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 circuit switching or packet switching and with point-to-point or point-to-multipoint transmission. Point-to-multipoint transmission considered here is assumed to use only packet switching.

For each RAT group an area spectral efficiency matrix in b/s/Hz/m^2 is defined. The spectral efficiency is an important parameter in calculating the spectrum requirement. Since the spectral efficiencies of point-to-point and point-to-multipoint 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 TRAFFIC DEMAND

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 following information for the spectrum calculation methodology:

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

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 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/user) and user density $\mathbf{U}_n$ (users/m^2). Point-to-point 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 different RAT groups and radio environments inside the RAT groups in different service environments m and time intervals t. For packet-switching, the output of the distribution is the aggregate bit rate 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 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 point-to-point 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 point-to-multipoint service categories, where the service arrival information is given in terms of the matrices $\mathbf{Q}_n$ and $\mathbf{U}_n$, the session arrival rate per user $\mathbf{Q}_n$ is distributed with the corresponding distribution ratios to yield the session arrival rate per user $\mathbf{Q}_{n,rat,p}$. Here, the distribution corresponds to distributing session arrivals of different services of the same service category to different RATs and radio environments.

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. Market studies may provide an indication of the distribution ratio. In case the market studies are not able to provide the values, the distribution is proposed to be done based on data rate, mobility and loading information.

For point-to-multipoint services, that are preferably transmitted in point-to-multipoint mode it is proposed that the service category is assigned to RAT groups that support a point-to-multipoint transmission mode and supports the mobility, date rate and other requirements of the considered service category, and to radio environment providing the largest cell size and meeting the above requirements.

At this point, the session arrivals are normalised by area while we are interested in aggregate traffic per cell. In the point-to-point 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 point-to-multipoint 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 $\mathbf{Q}_{n,rat,p}$.

After distributing traffic to RAT groups and radio environments, it is now also clear for the traffic of each service category whether it will be handled as packet or circuit switched traffic. For circuit switching, only the matrix $\mathbf{P}'_{n,rat,p}$ in session arrivals/s/cell and session duration are needed for the capacity calculation. Capacity calculation for packet switching 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 point-to-point and point-to-multipoint 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 switching and circuit switching 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 for packet switched traffic is calculated separately for point-to-point and point-to-multipoint transmission modes resulting in $\mathbf{C}_{rat,p,ps,pp}$ and $\mathbf{C}_{rat,p,ps,pm}$, 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. Two different performance criteria are considered: mean delay requirement and delay percentile requirement. Capacity calculation is done separately for point-to-point and point-to-multipoint 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 and single server queue and 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.

The capacity calculation with the mean delay requirement requires as input the offered traffic in bits/s/cell), i.e. $\mathbf{T}_{n,rat,p}$, 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 delay percentile requirement approach requires also third moment of the packet size distribution, typical packet sizes for short and long packets, required delay percentile and probability associated with the delay percentile.

Mean delay requirement

The capacity requirement for the mean packet delay criterion is calculated from the equation for the mean waiting time in M/G/1-FCFS queue with non-preemptive priorities. 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 fullfil 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.

Delay percentile requirement

The user QoS experience is usually more concerned with the maximum delay rather than the mean delay. Therefore, the delay percentile requirement, i.e. the requirement that a certain percentage of packets has a delay below a threshold, is important. Usually, the delay percentile requirement results in higher capacity requirement than the mean delay requirement. The capacity requirement based on the delay percentile requirement uses the capacity requirement derived from the mean delay requirement as an initial value and adjusts this capacity to meet the delay percentile criterion. The approach calculates the probability that the delay is below the threshold using the system capacity computed for the mean delay requirement.

The delay percentile for a given capacity is estimated from the sum of the waiting time and service time of packets. A model for waiting time distribution is used and the mean and the second moment of it are calculated from the capacity using Cobham's equations and from the service time distribution, which follows from the packet size distribution and the capacity. If the probability that the delay is below the percentile value is lower than the given percentile probability requirement, e.g. 95%, the capacity is increased by a predetermined amount. The procedure is repeated until the delay percentile is met.

B. Capacity calculation for circuit switching

The capacity requirement for circuit switched service categories is calculated based on the traditional Erlang-B theory. The number of required service channels is calculated from the mean session arrival rate per cell $\mathbf{P}'_{n,rat,p}$, mean session duration and maximum allowed blocking probability. The capacity requirement of each circuit switched service category is obtained by multiplying the number of channels by the service channel data rate. The capacity requirements of all circuit switched service categories are then summed up.

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 in Hz is calculated along the following steps:

1. Combine the capacity requirements of packet switching and circuit switching for point-to-point modes.
2. Calculate the spectrum requirement separately for point-to-point and point-to-multipoint 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 point-to-point and point-to-multipoint transmission modes.
4. Sum up the spectrum requirements of service environments which belong to the same teledensity.
5. 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, taking into account the frequency reuse factor.
6. Sum up the spectrum requirements of RAT group *rat* in each teledensity over all radio environments, since the radio environments are spatially coexisting.
7. Calculate the total spectrum requirement of RAT group *rat* in teledensity *d* for all operators taking into account the minimum spectrum granularity per RAT group.
8. Next, the guard bands are considered. 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.
9. Next, the time dependency of the spectrum requirement is considered. 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 the 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.
10. 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) With FSU, the maximum operation is done separately for RAT groups with and without FSU.
11. If the calculation inside a spectrum allocation region has been done from different market studies in different geographical regions, then the maximum over the market studies is taken.
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 developed in the IST-WINNER project. The proposed methodology follows the ITU accepted 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 methodology presented in this paper has been contributed to ITU WP 8F. The development of the methodology at ITU is almost finalised and the WINNER methodology has 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. 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

This work has been performed in the framework of the IST project IST-2003-507581 WINNER, which is partly funded by the European Union. The authors would like to acknowledge the contributions of their colleagues, especially Pekka Ojanen from Nokia, Finland.

REFERENCES

[1] Recommendation ITU-R M.1390. Methodology for the calculation of IMT-2000 terrestrial spectrum requirements.

[2] ITU-R WP 8F Attachment 4.6 to Document 8F/427: Working document towards methodology for calculation of spectrum requirements for the future developments of IMT-2000 and systems beyond IMT-2000 from the year 2010 onwards.

[3] IST-WINNER Deliverable D6.2. Methodology for estimating the spectrum requirements for “further developments of IMT-2000 and systems beyond IMT-2000”. 2004. 67 p.

[4] T. Irnich & B. Walke, Spectrum estimation methodology for next generation wireless systems. Proc. of IEEE PIMRC 2004, Barcelona, Spain, 5-8 Sept. 2004.