Spectrum Estimation Methodology for Next Generation Wireless Systems: Introduction and Results of Application to 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 describes this new ITU method, which is based on contributions by the WINNER project to a large extent. Special emphasis is laid on describing the method for calculation of the required system capacity, which is based on a M/G/1-FCFS queue with non-preemptive priorities. Furthermore, we present the results of applying the method to an example scenario, which is derived from the scenario used for dimensioning the spectrum currently identified for IMT-2000. The comparison with the results the previously used ITU spectrum requirement estimation method delivered for this scenario leads to the conclusion that the new method delivers reasonable results in the same order of magnitude, but provides a significantly better founded estimate of spectrum requirement.**

I. Introduction

In the scope of identifying IMT-2000 radio spectrum a standardized and internationally agreed methodology, which is specified by ITU-R Recommendation M.1390 [1], was used to estimate the amount of radio spectrum needed. Due to a number of shortcomings [2], this methodology is not suitable to be applied for estimating the spectrum requirements of further developments of IMT-2000 and systems beyond IMT-2000. Therefore, in preparation for the next World Radiocommunication Conference (WRC) in 2007, and in particular in preparation of WRC-07 agenda item 1.4 "to consider frequency-related matters for the future development of IMT 2000 and systems beyond IMT 2000 [...]" [3], ITU develops a new methodology to determine the spectrum requirements of further developments of IMT-2000 and systems beyond IMT-2000. The Working Party F of ITU-R Study Group 8 (WP8F) is in charge of organizing this work. Currently the development of the methodology at ITU is almost finalized. Through the WINNER project the authors have contributed significantly to this development work, and the new draft recommendation [2] is based on these contributions to a large extent.

This paper presents the current status of the new ITU spectrum requirement estimation methodology, specifically emphasizing a new method for calculating the capacity of a cell of a wireless system that is needed to fulfill service-specific *Quality of Service* (QoS) requirements of an arbitrary number of different service classes offering packet traffic [4]. QoS requirements are considered in terms of required mean packet delay. This method is based on the concept described in [5]. Furthermore, we present a scenario and a set of input parameter values for the new methodology, which are based on the scenario previously used together with the old spectrum calculation methodology [1] at WRC-2000 for determination of the IMT-2000 spectrum requirements [6]. The results of applying the new methodology to this scenario are presented and compared to the results contained in [6].

ITU has set requirements for the spectrum requirement calculation methodology for further developments of IMT-2000 and systems beyond IMT-2000 [2]. According to the most important requirements, the methodology should accommodate a complex mixture of services requiring different bandwidths and 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 characterized 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.

The general ITU methodology flow chart is introduced in [2]. Figure 1 presents a simplified flow chart including the most important steps (source [7]).

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 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

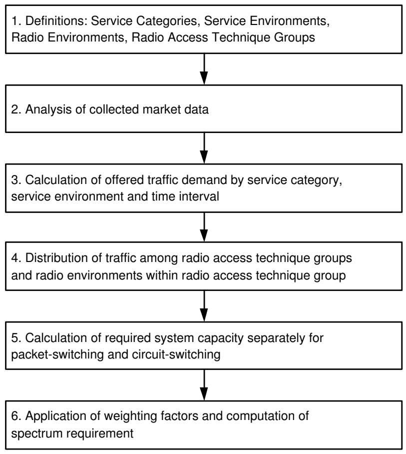

Fig. 1. Simplified Methodology Flowchart

and traffic volume conditions, as well as different types of area in terms of user density and dominant *Service Usage Pattern* (SUP). 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 characterized by the peak data rates. The traffic classes *Conversational*, *Interactive*, *Streaming* and *Background*, are mainly characterized by their QoS requirements. This traffic class concept is based on the IMT-2000 QoS classes defined by ITU-R Rec. M.1079-2 [8].

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 (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.

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 bearer type is determined by an SC's 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. 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 [9]; 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 [10] [4].

B. Service Environments

A service environment is a combination of teledensity and service usage pattern. Teledensities, such as *dense urban*, *suburban* and *rural*, describe the user density of a certain type of area. Service usage patterns, such as *home*, *office*, and *public area*, are categorized according to areas where users use similar services. 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 for the spectrum calculation.

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 represent the cell layers in a network, 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 characterized 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 type handovers.

The traffic distribution follows the principle to use the radio environment with the lowest mobility support that satisfies a service category's requirements. According to this principle alone, basically all stationary/pedestrian traffic would go to pico cells, all low/high mobility to micro/macro cells (provided that the respective radio environments are available, otherwise traffic would go to the radio environment with next 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.

D. Radio Access Technology Groups

Individual radio access technologies are grouped into four RAT groups:

- Group 1: Pre-IMT systems, IMT-2000 and its enhancements. This group covers all 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 only for 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 also specify, 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 area spectral efficiency is 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 cellular radio networks.

III. Interface to Market Information and Traffic Distribution

Market studies are being conducted in different parts of the world to forecast the demand of different services in the years 2010, 2015 and 2020. By collection and analysis of their results (see Step 2 in Fig. 1) ITU will obtain a complete set of applications considered to be relevant in the future, accompanied by values for user density, session arrival rate per user, mean service bit rate, average session duration and mobility ratio (ratio of stationary, pedestrian and vehicular usage of each service category) for these services.

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. This is done by grouping the relevant applications identified by the market studies into service categories.

The fourth step is to distribute the aggregate traffic from step 3 to the different RAT groups and radio environments within a RAT group. For traffic distribution all RAT groups are considered, but the spectrum requirement is only calculated for RAT groups 1 and 2. For packet-switched traffic, the output of the traffic distribution is the aggregate bit rate matrix of a service category in a RAT group and radio environment. For circuit-switched traffic, the output is the aggregate session arrival rate matrix of a service category in a given combination of RAT group and radio environment.

The traffic distribution is done by multiplying the session arrival rate by a time-independent distribution ratio. For unicast services, the session arrival rate matrix is multiplied by the corresponding distribution ratios to yield a matrix that contains the number of sessions per service environment, RAT Group and radio environment in arrivals/s/m^2. The distribution corresponds to distributing session arrivals of different services of the same service category to different RATs and radio environments. Traffic demands in each service environment can be distributed to Radio Access Techniques groups. 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. 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 distribution ratios are determined in 3 phases. Phase 1 determines the combination of RAT groups and radio environments that cannot support a service category in a given service environment.

At this point, the session arrivals are normalized by area while we are interested in aggregate traffic per cell. In the unicast mode, the session arrival rate per cell is obtained directly by multiplying the elements of user density matrix with the corresponding cell area. 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. For circuit switched service categories, only the session duration in s/session and the matrix 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 which is calculated by multiplying the corresponding elements of the session arrival rate matrix and traffic volume matrix. The offered traffic presents the total traffic of all users of the same service category. Separate matrices of offered traffic are needed for unicast and multicast modes.

IV. Required System Capacity

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, respectively. In other words, it is assumed that packet-switched and circuit-switched traffic are served in independent subsystems.

A. System Capacity for Packet-Switched Traffic

We first recall known results for an M/G/1 non-preemptive priority queue with N different classes of customers, which have been presented by Cobham [10], Kesten and Runneberg [11]. The customer classes are distinguished by index n, where $n = 1, ..., N$. Jobs of class i have priority over jobs of class j if $i < j$. For customers of class n the mean job arrival rate is λ_n, the mean service time is β_n and the second moment of the service time is $\beta_n^{(2)}$. Considering a specific customer of class n, we denote its waiting time by $\mathcal{W}_n$, its service time by $\mathcal{T}_n$ and the customer's delay by $\mathcal{D}_n$. It is known that in an M/G/1 non-preemptive priority queue the mean waiting time of a customer of class n is

$$W_n := E[\mathcal{W}_n] = \frac{\lambda_{\leq N}\beta_{\leq N}^{(2)}}{2\left(1-\rho_{\leq n}\right)\left(1-\rho_{\leq n-1}\right)}, \qquad (1)$$

where $\lambda_{\leq k}$ denotes the aggregated job arrival rate of priority k and all higher priorities, $\beta_{\leq k}^{(2)}$ denotes the second moment of the weighted common service time *Distribution Function* (DF), and $\rho_{\leq k}$ denotes the aggregated system load of priority k and all higher priorities, i.e.,

$$\lambda_{\leq k} = \sum_{i=1}^{k} \lambda_i, \quad \beta_{\leq k}^{(2)} = \sum_{i=1}^{k} \frac{\lambda_i}{\lambda_{\leq k}} \beta_i^{(2)}, \quad \text{and} \quad \rho_{\leq k} = \sum_{i=1}^{k} \lambda_i \beta_i$$

The mean delay D_n of a customer of class n is

$$D_n := E[\mathcal{D}_n] = W_n + \beta_n = \frac{\lambda_{\leq N}\beta_{\leq N}^{(2)}}{2\left(1-\rho_{\leq n}\right)\left(1-\rho_{\leq n-1}\right)} + \beta_n. \qquad (2)$$

Assume the M/G/1 non-preemptive priority queue for modelling the downlink traffic in a cell of a packet-based wireless system that comprises N different classes of *Internet Protocol* (IP) based services, where each service class $n, n = 1, ..., N$ corresponds to one customer class. Each customer corresponds to one IP packet. The size [bits] of an IP packet of class n is denoted by $\mathcal{S}_n$ with moments

$$s_n := E[\mathcal{S}_n], \quad s_n^{(2)} := E[\mathcal{S}_n^2], \ ... \qquad 1 \leq n \leq N.$$

If an IP packet of class n is transmitted over a channel with capacity C [bits/s], the service time of the packet is $\mathcal{T}_n = \mathcal{S}_n/C$. Accordingly, mean and second moment of the service time *Distribution Function* (DF) are

$$\beta_n = \frac{s_n}{C} \quad \text{and} \quad \beta_n^{(2)} = \frac{s_n^{(2)}}{C^2}. \qquad (3)$$

Substituting the expressions in (3) into (2) results in an expression for the mean IP packet delay as a function of the system capacity C,

$$D_n(C) = \frac{\lambda_{\leq N} s_{\leq N}^{(2)}}{2\left(C - \sum\limits_{i=1}^{n}\lambda_i s_i\right)\left(C - \sum\limits_{i=1}^{n-1}\lambda_i s_i\right)} + \frac{s_n}{C} \qquad (4)$$

If the QoS requirement for IP packets of class n, is given in terms of a required mean delay D_n, the required system capacity C_n is defined as the capacity satisfying the condition $D(C_n) = D_n$.

Given a certain value for D_n, the system capacity C_n required to achieve D_n can be calculated by solving (4) for C.

Among the three roots of this equation there is always one that satisfies the stability condition

$$C_n > \sum_{i=1}^{n} \lambda_i s_i. \qquad (5)$$

This value is chosen as the solution to the problem of dimensioning the system capacity so that IP packets of service class n have the required mean delay D_n. The system capacity that fulfills the mean delay requirements of all classes, denoted by $\mathcal{C}$, is obtained by determining the set $\{C_1, C_2, ..., C_N\}$ of system capacity values required to fulfill the QoS requirements of classes $n = 1, ..., N$, and selecting the maximum value from this set, i.e. $\mathcal{C} = max(C_1, C_2, ..., C_N)$.

B. System Capacity for Circuit-Switched Traffic

The capacity required for circuit-switched traffic is calculated using a multi-service loss model [9], which is an extension of the well-known Erlang-B formula. This extension allows the simultaneous occupation of several channels by a session. Sessions of N_{CS} different circuit-switched service categories are assumed to share the set of available service channels with an associated service channel rate of 16 kbit/s. It is assumed that a session of service category n requires the simultaneous use of ν_n channels $(1 \leq n \leq N_{CS})$. If an arriving service request of service category n does not find ν_n empty channels, it is counted as lost (sometimes this is denoted as *blocked call*). Given the required blocking probability B_n of service category n, the required number of channels for service category n is determined as the smallest value that satisfies $B_n(\nu_n) \leq B_n$. The maximum of the set of required numbers of channels and corresponding system capacity values (determined by multiplying the number of required service channels with the service channel date rate) then defines the overall required system capacity for circuit-switched traffic. The concept was suggested for being used for the ITU spectrum requirement calculation by Japan in late 2004.

V. Application Example: Spectrum Requirements for IMT-2000

In the following an example scenario and an example set of input parameter values for the new methodology are presented, based on the scenario previously used at WRC-2000 for determination of the IMT-2000 spectrum requirements [6]. The results of applying the new methodology to this scenario are presented and compared to the results contained in [6], which were the basis for the IMT-2000 spectrum identification at WRC-2000.

TABLE I

MAPPING OF M.2023 ENVIRONMENTS TO SE AND RE OF IMT.METH

	IMT.Meth SE		
M.2023 Env.	**SUP**	**Teledensity**	**IMT.Meth RE**
Central Business Distr.	Office	Dense Urban	Pico cell (RE1)
Urban Pedestrian	Public Area	Dense Urban	Micro cell (RE2)
Urban Vehicular	Vehicular	Dense Urban	Macro cell (RE3)

In order to compare the results of [6] with the results of the new methodology it is necessary to construct a scenario that is equivalent to the scenario considered in [6], but uses the scenario framework of the new methodology. In the following this equivalent scenario is called the "IMT.Meth" scenario, and the original scenario considered in [6] is called the "M.2023" scenario.

A. RAT Groups and time intervals

Only one RAT group is considered, i.e., no distribution of traffic to different RAT groups is necessary. Furthermore, only one time interval (the Busy Hour) is considered.

B. Service Categories

The M.2023 scenario considers six Services, namely *High Interactive Multimedia* (HIMM), *High Multimedia* (HMM), *Medium Multimedia* (MMM), *Switched Data* (SD), *Simple Message* (SM) and *Speech* (S). HMM, MMM and SM are considered to be served by packet-switching (PS) and HIMM, SD and S are served by circuit-switching (CS). The M.1390 services are equivalent to the IMT.Meth Service Categories (SC), but in IMT.Meth each SC consists of a Service Type (ST) and a Traffic Class (TC). For the equivalent IMT.Meth scenario the Services considered in M.2023 are assumed to be STs in the IMT.Meth scenario. CS STs are associated with Conversational TC. PS STs are associated with Streaming and Background TC. This mapping results in six different SCs to be considered for the IMT.Meth scenario, which are numbered SC1,..., SC6.

C. Service Environments and Radio Environments

In IMT.Meth a combination of Service Environment (SE) and Radio Environment (RE) is equivalent to an Environment considered in [1]. In IMT.Meth a SE is a combination of *Service Usage Pattern* (SUP) and Teledensity. Table I illustrates this relation and the correspondence chosen for the IMT.Meth scenario. The resulting three SEs are denoted SE1,...,SE3 in the following.

The three different radio environments considered are pico cell (RE1), micro cell (RE2) and macro cell (RE3). In SE1 only pico cells are available, in SE2 there are only micro cells and in SE3 only macro cells are assumed to be available.

D. Input Parameter Values

Table II lists the RE parameters. An achievable cell edge user bit rate of 2 $^{Mbit}/_{s}$ is assumed in all radio environments. The assumed Cell Spectral Efficiency value is 0.125 b/s/Hz/cell.

TABLE II

RADIO ENVIRONMENT PARAMETERS

Radio Environment	Cell geometry	Cell/Sector Area (unit: m^2)
RE1	Omni	5030 (Cell)
RE2	3-sectored	312000 (Sector)
RE3	3-sectored	866000 (Sector)

TABLE III

PARAMETERS FOR PS SERVICE CATEGORIES

Parameter	SC2	SC3	SC5
Mean packet size [kbit/packet]	12	4.32	1.44
Second moment [kbit^2/packet^2]	288	37.325	4.1472
Mean delay requirement [s/packet]	0.04	0.4	2

SC1, SC4 and SC6 are considered to require a circuit-switched bearer, i.e., the required capacity for these SCs is calculated using the CS capacity calculation procedure (see Sec. IV-B, while the required capacity for SC2, SC3 and SC5 is calculated using the PS capacity calculation procedure (see Sec. IV-A. Different parameters are required for a service category depending on whether it is served in a packet-switched or in a circuit-switched manner.

For all Service Categories the Stationary Mobility Class is assumed for all Service Environments.

For packet-switched service categories values for the mean packet size, the second moment of the packet size distribution and the mean delay requirement are needed. Furthermore, the priority ranking of the service categories needs to be specified. The values assumed are given in Table III. The priority ranking is assumed to be SC2 in highest priority, SC3 in medium priority, and SC5 in lowest priority. The parameters mean packet size, second moment of the packet size distribution, mean delay requirement and priority ordering of the packet-switched service categories required by the new modelling approach for packet traffic in IMT.Meth cannot directly be derived from the information contained in [6]. Thus, the selection of these values represents a degree of freedom in the scenario definition, which of course does influences the results gained.

For circuit-switched service categories (i.e., SC1, SC4, SC6) values of the blocking probability, the service channel data rate and the channel data rate granularity are needed; the assumed values are given in Table IV.

The parameters user density per service category n (unit: users/km^2), denoted U_n, and session arrival rate per user (unit: session arrivals/s/user), denoted Q_n, characterize the offered traffic of different service categories. They depend on the SC only (i.e., they are not dependent on SE). Based on the M.2023

TABLE IV

PARAMETERS FOR CS SERVICE CATEGORIES

Parameter	SC1	SC4	SC6
Blocking Probability [%]	12	4.32	1.44
Service channel data rate [kbit/s]	288	37.325	4.1472
Channel data rate granularity [kbit/s]	16	16	16

input parameters population density and market penetration, respectively, the elements of the user density matrix U_n are calculated from

$$U_{m,1,n} = PopulationDensity_m * Penetration_{m,n}$$

where m is the index for SE (i.e., the row index of the matrix), the second index denotes that in this particular case we only consider one time interval (i.e., denotes the first and only column of the user density matrix, the methodology in general supports considering multiple time intervals), and n is the index for the SC considered. The values for U_n are shown in Table V.

TABLE V
USER DENSITY MATRICES $U_n, n = 1, ..., 6$ (UNIT: USERS/KM^2)

	SC1	SC2	SC3	SC4	SC5	SC6
SE1	35000	21000	21000	18200	56000	102200
SE2	25000	15000	15000	13000	40000	73000
SE3	750	450	450	390	1200	2190

The elements of the session arrival rate per user matrix Q_n are determined by the M.2023 parameter *Busy Hour Call Attempts* (BHCA). They are calculated from

$$Q_{m,1,n} = {}^{BHCA_{m,n}}/_{3600}.$$

The resulting values are shown in Table VI.

The total session arrival rate per area (denoted P_n) is calculated from

$$P_{m,1,n} = U_{m,1,n} \otimes Q_{m,1,n},$$

where $\otimes$ denotes the element-wise product of two column vectors. The session arrival rate per cell is then calculated by multiplying $P_{m,1,n}$ with the cell area sizes as specified in Table II.

Packet switched SCs (i.e., SC2, SC3, and SC5) in addition require knowledge of the average session volume matrix T_n (unit: bits/session) as input parameter. The session volume in uplink or downlink direction, respectively, is calculated as follows:

$$T_{m,1,n} = CallDuration_{m,n} * ActivityFactor_{m,n} * NetBR_n.$$

Values for the parameters call duration, activity factor and net user bit rate are obtained directly from M.2023. The resulting average session volume matrices are shown in Table VII.

For the circuit-switched service categories (i.e., SC1, SC4, and SC6) the mean session duration matrix (unit: s/session),

TABLE VI
SESSION ARRIVAL RATE PER USER MATRICES $Q_n, n = 1, ..., 6$ (UNIT: $10^{-5}\cdot$ SESSION ARRIVALS/S/USER)

	SC1	SC2	SC3	SC4	SC5	SC6
SE1	3.889	4.167	13.89	5.55	16.667	83.33
SE2	1.944	1.667	11.11	5.556	8.333	22.22
SE3	30.56	22.22	22.22	55.56	5.556	11.11

TABLE VII
BASE TRAFFIC VOLUME MATRICES T_n (UNIT: $^{kbit}/_{s}$) FOR PS SCS (SAME VALUES FOR ALL SES)

	UL	DL
SC2	1094.4	90000
SC3	547.2	17280
SC5	42	42

TABLE VIII
MEAN SESSION DURATION MATRICES μ_n (UNIT: s) FOR CS SCS

	SC1	SC4	SC6
SE1	120	156	180
SE2	120	156	120
SE3	120	156	120

denoted μ_n is required; see Table VIII. The values are identical to the mean session duration figures in M.2023.

The product of session arrival rate per cell and the mean session duration denotes the offered traffic (in Erlangs) for the CS SCs. The offered traffic for the packet switched SCs is calculated by multiplying the base traffic volume per session (see Table VII) with the session arrival rate per cell.

E. Required System Capacity

From the number of required service channels determined according to the approach introduced in Sec. IV-B, the required system capacity is calculated by multiplying the ν_n with the service channel data rate (16 kbit/s in this paper). The resulting values are shown in Table IX. Since [6] foresees symmetric offered traffic in uplink and downlink for the circuit-switched services, Table IX in the first four columns only presents the required capacity for one direction (uplink or downlink). The CS capacity calculation is performed once for each combination of Service Environment, Radio Environment and Service Category, and each run of the algorithm considers the offered traffic of all service categories in the same service environment, but only the QoS requirement (in terms of the required blocking probability) of one Service Category. It is noted that due to this, the capacity requirement in each service environment is denoted by the maximum among the capacity requirements of the individual service categories present in this Service Environment, e.g., the capacity requirement for SE1 is denoted by the capacity requirement of SC1. The overall required system capacity for circuit-switched traffic is 28.44 Mbit/s (using the Multi-dimensional Erlang-B approach as defined by the latest version of [1]).

TABLE IX
REQUIRED CAPACITY FOR CS SCS IN IMT.METH APPROACH

	SC1 (uni-directional)	SC4 (uni-directional)	SC6 (uni-directional)	Max over SC (uni-directional)	Total per SE
SE1	1.984	1.872	1.696	1.984	3.968
SE2	15.888	15.536	14.704	15.888	31.776
SE3	0.864	0.784	0.672	0.864	1.728

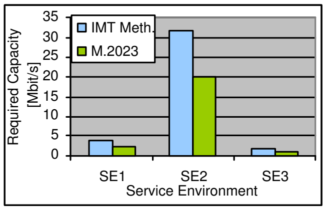

Fig. 2. Required system capacity for CS traffic, IMT.Meth vs. M.2023

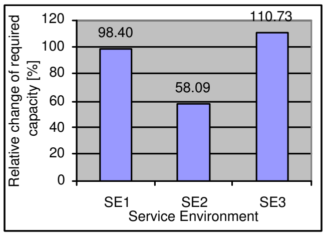

Fig. 3. Relative change of required system capacity for CS SCs (100% = Capacity in M.2023)

Figure 2 compares the required system capacity per service environment and per service category according to IMT.Meth approach with the corresponding values given in [6]. Figure 3 shows the relative change of the system capacity required for circuit-switched service categories, compared to the values given in M.2023.

The M.2023 parameters ”cell grouping” and ”activity factor” are mainly responsible for the differences between the required system capacity for circuit-switched traffic in M.2023 and IMT.Meth. The activity factor only causes a difference for SC6 (Speech), because for SC1 and SC4 an activity factor equal to one is assumed in [6].

In M.1390 the traffic of a number of cells was pooled together, the number of required channels was calculated for the whole group and then divided by the number of cells per group in order to determine the number of required channels per cell. Hence, the result of M.2023 is not an integer number of channels. The M.1390 parameter specifying the number of cells in a group is called ”Cells/Group”. The results in M.2023 are calculated using a cell group size of seven cells. In IMT.Meth it is assumed that any cell-group-like effects are collectively taken into account in the area spectral efficiency.

In M.2023 for the Speech Service (denoted SC6 here) an activity factor of 50% was assumed, which leads to a virtual decrease of offered traffic for the Speech Service. IMT.Meth does not consider an activity factor. For the required spectrum this is partly compensated by a different spectral efficiency considered for SC 6 in the equivalent IMT.Meth scenario.

The difference in the results shown in Fig. 2 is partly compensated by the difference in the system model used for the capacity calculation. Whilst in [6] for each Service an independent set of channels was assumed available, in IMT.Meth all Service Categories in the same cell share a common set of channels, which implies a significant trunking gain.

TABLE X
REQUIRED SYSTEM CAPACITY FOR PS SCs IN IMT.METH (MBIT/S)

	SC2		SC3		SC5		Max over SC		Total
	UL	DL	UL	DL	UL	DL	UL	DL	
SE1	**0.31**	**0.73**	0.03	0.7	0.02	0.7	0.31	0.73	1.04
SE2	**0.46**	7.45	0.39	16.0	0.43	**16.3**	0.46	16.3	16.7
SE3	**0.3**	**0.38**	0.01	0.14	0.006	0.12	0.3	0.38	0.68

The IMT.Meth algorithm for calculating the capacity required for circuit-switched traffic can be validated by setting the number of cells in a group to one in the M.1390 spreadsheets and setting the mean session duration for the Speech Service (i.e., SC6) to 50% of the values given in Table III. For this case the number of required channels per cell predicted by M.1390 approach is identical to the number of channels required according to the IMT.Meth approach.

In Tab. X the required capacity for packet switched traffic according to IMT.Meth is shown (values for uplink and downlink denoted UL or DL). Since each value considers the offered traffic of all service categories in one service environment, but the QoS requirements of only one SC, the total required capacity per service environment is given by the maximum of the capacity requirements for the different service categories. Consider for example SE1. Fulfilling the QoS demand of SC2 given the traffic of SC2, SC3 and SC5 requires an uplink capacity of 308 kbit/s, while fulfilling the QoS demand of SC3 under the given offered traffic of SC2, SC3 and SC5 only would require 28.8 kbit/s of uplink capacity. Hence, the service category that has the most ambitious QoS requirements specifies the total required capacity per transmit direction and service environment. In SE 1 this is the case for SC2 in both directions. In Table X the largest values for each SE considering separately the UL, DL or DL+UL columns of all SCs , i.e., the values for the SC that defines the overall required capacity per direction per service environment are marked in bold face. The overall system capacity required for packet-switched traffic according to IMT.Meth is 18.4 Mbit/s.

Figure 4 shows the overall system utilization per service environment that results from the required capacity and the offered traffic. The low system utilization in the uplink direction of SE1 and SE3 is resulting from that fact that the offered traffic is very low compared to the mean packet size, resulting in very low packet arrival rates. Thus, the required capacity in these cases is dominated by the transmission time needed to fulfill the mean delay requirements (i.e., in this case the required capacity is no longer a linear function of the offered traffic, but rather a linear function of the mean packet size).

Comparison with M.2023 values on the level of single service categories does not make sense, because in M.1390 each value only considers the offered traffic of one service category, and the capacity per service environment is the sum over all service types. In Table XI the required capacity per service environment according to IMT.Meth approach is compared to

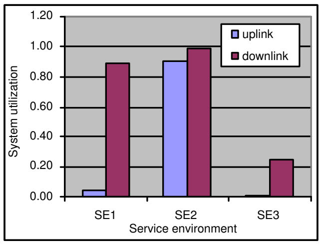

Fig. 4. System utilization for required capacity according to Table X

TABLE XI
RELATIVE CHANGE OF REQUIRED CAPACITY PER SE FOR PS TRAFFIC; UPLINK (UL), DOWNLINK (DL) AND SUM OF UL AND DL (UL+DL)

	UL	DL	UL+DL
SE1	207.86%	-62.01%	-48.71%
SE2	-19.99%	-11.41%	-11.67%
SE3	343.25%	-62.80%	-37.61%
Total	44.36%	-18.47%	-16.37%

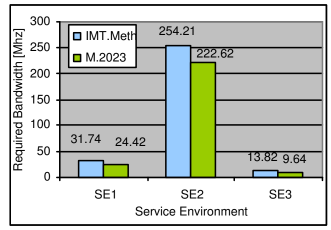

Fig. 5. Required spectrum for CS traffic, IMT.Meth vs. M.2023

TABLE XIII
REQUIRED SPECTRUM FOR PS SCS IN IMT.METH (MHZ)

	IMT.Meth			Relative change [%]		
	UL	DL	UL+UL	UL	DL	UL+DL
SE1	2.46	5.87	8.33	207.86	-62.01	-48.71
SE2	3.65	130.12	133.77	-19.99	-11.41	-11.67
SE3	2.41	3.06	5.47	343.25	-62.8	-37.61
Sum	8.52	139.04	147.56	44.36	-18.47	-16.37

the capacity requirement per service environment of M.2023. It is worth noting that due to the different definitions of QoS requirements IMT.Meth and M.1390, respectively, it is unknown if the values values applied for the mean delay requirements represent a stronger or a weaker QoS requirement compared to the QoS requirements and related values considered in M.2023. Ways to determine values for the required mean delay that represent an equally strong QoS requirement compared to the QoS criterion considered in M.2023 are currently under investigation.

F. Required Spectrum Bandwidth

The required spectrum bandwidth for circuit-switched services is shown in Table XII. Note that for SC6 (Speech) a spectral efficiency of 125 kb/s/MHz was assumed, because the IMT.Meth approach does not allow considering service-specific spectral efficiency values. In M.2023 a system capability (i.e., spectral efficiency) of 70 kbit/s/MHz was assumed for the speech service. Thus, the only difference between Tab. IX and XII occurs for SC6. The relative change of the required spectrum for circuit-switched traffic is +29.992% for SE1, +14.189% for SE2 and 43.402% for SE3. The overall spectrum requirement for circuit-switched traffic predicted by IMT.Meth for the scenario considered here is 299.78 MHz, which is equivalent to an increase of 25.67% compared to M.2023. Figure 5 compares the required spectrum bandwidth for circuit-switched service categories according to IMT.Meth and M.1390 approaches, respectively.

Table XIII shows the required spectrum bandwidth per service environment for packet-switched service categories and compares the values to the results of [5]. Since there are no service-specific differences in the spectral efficiency assumed in M.2023 (which would have been to be neglected here according to the procedure defined by IMT.Meth), the relative change of required spectrum is equal to the relative change of required system capacity.

The overall spectrum requirement for packet traffic (i.e. the sum over the spectrum requirement per service environment) predicted by IMT.Meth for the scenario considered here is 147.56 MHz, which is equivalent to a relative change of -16.37% compared to M.2023 results.

In Table XIV the total spectrum requirement and the relative change per service environment for all service categories being summed up is compared with the values of M.2023. The overall spectrum requirement predicted by IMT.Meth is 447.356 MHz, which is equivalent to 3.28% more spectrum requirement predicted by IMT.Meth than predicted by M.2023. It must be noted that this relatively small difference between old and new approaches is mainly created by the fact that the overall tendencies implied by the difference in modeling approaches partly compensate each other. The difference between M.1390 and IMT.Meth concerning the modeling of packet oriented services implies a reduction in

TABLE XII
REQUIRED SPECTRUM FOR CS TRAFFIC (MHZ)

	SC1 (uni-directional)	SC4 (uni-directional)	SC6 (uni-directional)	Max over SC (uni-directional)	Total per SE
SE1	15.872	14.976	13.568	15.872	31.744
SE2	127.104	124.288	117.632	127.104	254.208
SE3	6.012	6.272	5.376	6.912	13.824

TABLE XIV
OVERALL SPECTRUM REQUIREMENT AND ITS RELATIVE CHANGE (MHZ)

	IMT.Meth			Relative change [%]		
	UL	DL	UL+UL	UL	DL	UL+DL
SE1	18.332	21.742	40.074	40.91	-21.37	-1.44
SE2	130.754	257.224	387.978	12.85	-0.37	3.72
SE3	9.332	9.772	19.304	73.79	-23.55	4.81
Sum	154.418	288.738	447.356	18.00	-3.33	3.28

spectrum requirement, while the difference concerning the circuit-switched services implies an increase in spectrum requirement predicted by IMT.Meth in comparison to the results of M.2023. Thus, for a different relation between offered traffic for circuit-switched and packet-switched services, the results would be different. Increasing the fraction of traffic being considered as packet-switched would decrease the spectrum requirement predicted by IMT.Meth, and vice versa.

VI. Conclusion

In this paper, we have presented an overview of the new ITU spectrum requirement calculation methodology for further developments of IMT-2000 and systems beyond IMT-2000. The proposed methodology meets the requirements set by ITU, and it presents a novel way to calculate the capacity requirement of packet switched services. 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.

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.

In order to produce results of the new methodology IMT.Meth that can be compared to the results presented in M.2023, it is necessary to derive an equivalent scenario from M.2023, because the scenario structure is different in IMT.Meth and M.1390, respectively. For packet-switched traffic, values for mean and second moment of the packet size and the required mean delay need to be assumed, because these parameters cannot be directly derived from M.2023.

For circuit-switched services IMT.Meth predicts more spectrum needed, mainly due to cell grouping not being considered. For the Speech service category this tendency is partly compensated, because in IMT.Meth a service-specific spectral efficiency is not allowed, so that the Speech service category's spectrum requirement resulting from IMT.Meth is lower that in M.2023. In M.2023 the spectral efficiency for the speech service type was considered to be significantly lower than for the other service types.

For the parameters chosen in this paper, IMT.Meth predicts less spectrum being required for packet switched service categories. However, it is not directly possible to determine whether the QoS requirements assumed in M.2023 are stronger or weaker than the requirements considered for IMT.Meth. Especially with respect to the different nature of QoS requirements considered (session waiting time and blocking probability in M.1390 and mean IP packet delay in IMT.Meth, respectively) the relation of the QoS requirements considered here and in M.2023 is unknown.

The overall results of IMT.Meth and M.1390 methodologies for the scenario considered in this paper are very similar, but a detailed look to the results shows that this cannot be generalized, especially facing that the scenario considered here is not representative for the expected scenarios in the spectrum requirement estimation for WRC-07.

However, by modeling data transmission in a significantly more realistic manner than it was done in M.1390, IMT.Meth is expected to be significantly more accurate in predicting the required system capacity, which was basically over-estimated by the underlying modeling approaches used in M.1390.

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