Spectrum Requirements for IMT-2000 Using the New ITU Spectrum Requirement Estimation Methodology

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Abstract—**Frequency-ralated matters for IMT-2000 are on the agenda of the next World Radiocommunication Conference of the ITU-R. The results of standardized methodologies for estimating the future spectrum requirements for mobile communication provide the necessary information basis for possible additional allocation of radio spectrum for mobile services within the international spectrum regulatory process of the ITU-R. The methodology that was used by the ITU-R to estimate the spectrum requirements for IMT-2000 [1] has several shortcomings and is not suitable to be applied for estimating the spectrum requirements of further developments of IMT-2000 and systems beyond IMT-2000. Therefore the ITU-R decided to develop a new spectrum estimation methodology. Key elements of the concepts of the new methodology have been developed by the authors [3,4,6]. This paper presents a scenario and a set of input parameter values for the new methodology, which can be used as a Test Case for validation of the new methodology. Scenario and parameter values are based on the scenario used for determination of the IMT-2000 spectrum requirements considered at the WRC-2000. The results of applying the new methodology to the scenario are presented and compared to the results that were considered for the IMT-2000 spectrum identification at WRC-2000.**

Keywords— **Spectrum estimation, 4G, Next Generation Wireless Systems, M/G/1, NONPRE, priorities, mean waiting time, mean IP delay, delay percentile**

I. INTRODUCTION

The allocation of frequency bands within the international spectrum regulatory framework is under the authority of the *International Telecommunications Union* (ITU). For this purpose ITU maintains the *Radio Regulations* (RR), which document the spectrum regulation status. Changes to the RR need to be authorized by the *World Radiocommunication Conference* (WRC). The next WRC will be held in 2007. Based on the results of the study period between WRC-03 and WRC-07, WRC-07 offers possibility to identify additional spectrum for further developments of IMT-2000 and systems beyond IMT-2000.

The current ITU methodology used to estimate the spectrum requirements for IMT-2000 systems (specified by [1]) does not meet the current requirements set by ITU's framework for the future development of IMT-2000 and systems beyond IMT-2000 [2]. Since packet-based traffic is forecasted to be the dominant switching scheme in future wireless networks, the main motivation for developing a new spectrum requirement estimation methodology is that the current approach [1] does not sufficiently consider packet-based traffic. For the new methodology a reasonable compromise between accuracy of modelling, complexity of computation and transparency of the method is required. Such a compromise has been found in the form of a simple model developed by the authors [3], which has been further developed in [4] and [5].

In this paper we present a scenario and a set of input parameter values for the new methodology, which can be used as a Test Case for validation. Scenario and parameter values are based on the scenario previously used at WRC for determination of the IMT-2000 spectrum requirements [5]. The results of applying the new methodology to this scenario are presented and compared to the results in [6], which were the basis for the IMT-2000 spectrum identification at WRC-2000.

The rest of this paper is organised as follows. Sec. II introduces the new methodology's principle for calculation of the required system capacity for packet-based traffic. In Sec. III a scenario is constructed that is equivalent to the scenario used in [5], but fits into the scenario framework of the new methodology (see [7]). Sec. IV presents the input parameter values used, while in Sec. V the results of the capacity calculation are shown. Sec. VI presents the actual spectrum requirements, and Sec. VII concludes the paper.

II. KEY CONCEPTS OF THE NEW ITU METHODOLOGY

The overall flowchart of the new ITU spectrum estimation methodology is shown in Fig. 1. A complete introduction of the new methodology can be found in [7]. A key part of the methodology flow is the calculation of the required system capacity, which is performed in step 5. This step is performed separately for circuit-switched (CS) and packet-switched (PS) traffic, applying different capacity calculation algorithms. Main input parameters of both algorithms are offered traffic and required QoS.

A. System Capacity Required for Packet Traffic

The algorithm for calculation of the system capacity needed to fulfil the QoS requirements of packet-based traffic is based on an M/G/1 queue with non-preemptive priorities as a model for downlink IP packet transmission in a wireless system. Solutions for analysis of such a queue have been presented by Cobham [9], Kesten and Runneberg [10].

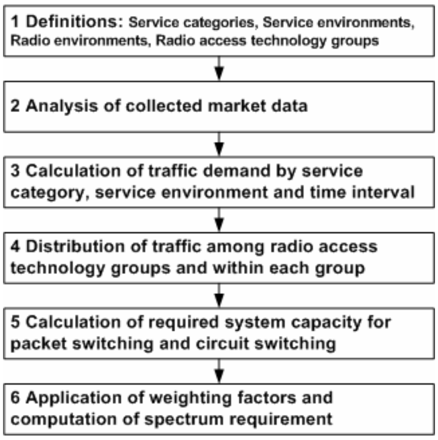

Fig. 1: Overall flowchart of the new ITU spectrum estimation methodology

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. System Capacity Required for Packet Traffic

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. 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.

III. Scenario Equivalent to ITU-R Report M.2023

The new methodology’s scenario framework includes service categories (SC), service environments (SE), radio environments (RE) and radio access technology groups (RATG) (further details are given in [7]). Offered traffic can be specified for different time intervals. In order to compare the results of [5] with the results of the new methodology it is necessary to construct a scenario that is equivalent to the scenario considered in [5], 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 [5] 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 RAT groups is necessary. Furthermore, only one time interval (the Busy Hour) is considered. For all services stationary mobility is assumed.

B. Service Categories

The M.2023 scenario considers six Services. Three of them are considered to be served packet-switched and three are circuit-switched. These Services are considered as equivalent to the IMT.Meth Service Categories (SC). In IMT.Meth each SC consists of a Service Type (ST) and a Traffic Class (TC). For the IMT.Meth scenario the Services considered in M.2023 are assumed as IMT.Meth service types. STs that are circuit-switched in M.2023 are associated with Constant Bit Rate (CBR) TC. STs treated as packet-switched in M.2023 are associated with non-realtime Variable Bit Rate (nrtVBR) and Available Bit Rate (ABR) TC, respectively. This results in six different SCs to be considered for the IMT.Meth scenario, which are numbered SC1,…, SC6; see Table 1.

Table 1: Service Categories and corresponding Service Types and Traffic Class, respectively

Traffic Class / Service Type	Conversational	Interacitve	Streaming	Background
HIMM	SC1			
HMM			SC2	
MMM				SC3
SD	SC4			
SM				SC5
S	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 [5]. An IMT.Meth Service Environment is a combination of Service Usage Pattern and Teledensity. Table 2 illustrates this relation and the correspondence chosen for the IMT.Meth scenario. The resulting three SEs are denoted SE1, …, SE3 in the following.

Table 2: Mapping of M.2023 Environments to Service and Radio Environment of IMT.Meth

Environment in M.2023	**IMT.Meth Service Environment**		**IMT.Meth Radio Environment**
	Service Usage Pattern	**Teledensity**	
CBD	Office	Dense Urban	Pico Cell (RE1)
Urban Pedestrian	Public Area	Dense Urban	Micro Cell (RE2)
Urban Vehicular	Vehicular	Dense Urban	Macro Cell (RE3)

The three different radio environments considered are pico cell (RE1), micro cell (RE2) and macro cell (RE3). Table 3 shows their availability in the service environments. In SE1 it is assumed that only pico cells are available, in SE2 there are only micro cells and in SE3 only macro cells are assumed to be available.

Table 3: Availability of radio environments in each SE.

Radio environment	**SE1**	**SE2**	**SE3**
RE1 (Pico cell)	X		
RE2 (Mirco cell)		X	
RE3 (Marco cell)			X

IV. INPUT PARAMETER VALUES

This Section described the complete set of parameter values needed for the scenario presented in the previous section.

A. *Service Category Parameter Values*

This section presents the values for the parameters that depend on the service category only. In Table 4 the type of bearer used by the Service Categories are specified.

Table 4: Specification of bearer service type assumed for Service Categories

Service Category	**Bearer service (circuit-switched = 1, packet-switched = 0)**
SC1	1
SC2	0
SC3	0
SC4	1
SC5	0
SC6	1

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 packet-switched service categories (i.e., SC2, CS3 and SC5) 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 5. 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 [5].

Table 5: Parameters for packet-switched Service Categories [Note: change to unit byte]

Parameter	**SC2**	**SC3**	**SC5**
Mean Packet Size [kbit/packet]	12	4.320	1.440
Second Moment of Packet Size [$kbit^2/packet^2$]	288	37.325	4.1472
Mean delay requirement [s/packet]	0.04	0.4	2

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 6.

Table 6: Service category parameters for circuit switched capacity calculation.

Parameter	**SC1**	**SC4**	**SC6**
Blocking probability [%]	1	1	1
Service channel data rate [kbit/s]	128	64	16
Channel data rate granularity [kbit/s]	16		

B. *Traffic parameters that depend on service environment*

The parameters user density per service category *n* (unit: users/km²), denoted $\mathbf{U}_n$ (see Table 7), and session arrival rate per user (unit: session arrivals/s/user), denoted $\mathbf{Q}_n$ (see Table 8), characterise the offered traffic of different service categories.

Based on M.2023 input parameters population density and market penetration, the elements of the user density matrix $\mathbf{U}_n$ are calculated from

$$U_{m,1,n} = Population\_density_m * Penetration_{m,n},$$

where *m* is the index for SE (i.e., the row index of the matrix), the one in the second index denotes that we consider only one time interval (i.e., denotes the first and only column of the matrix U_n), and n is the index for SC.

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:

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

Packet switched SCs (i.e., SC2, SC3, and SC5) also require the average session volume matrix $\mathbf{T}_n$ (unit: bits/session). The session volume in uplink or downlink direction, respectively, is calculated using the following formula:

$$\mathbf{T}_{m,1,n} = \mathrm{Call\_duration}_{m,n} * \mathrm{Activity\_factor}_{m,n} * \mathrm{Net\_BR}_n.$$

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 10.

For the circuit-switched service categories (i.e., SC1, SC4, and SC6) the mean session duration matrix (unit: s/session), denoted μ_n is required; see Table 9. The values are identical to the mean session duration figures in M.2023.

$\mathbf{U}_n$, $\mathbf{Q}_n$, $\boldsymbol{\mu}_n$ and $\mathbf{T}_n$ are matrices where index n denotes the service category, the row dimension corresponds to the different service environments and the column dimension denotes different time intervals. Since we consider only one time interval, the matrices reduce to column vectors.

Table 7: User density matrices $\mathbf{U}_n$, n = 1,…,6 (unit: users/km²)

	SC1 ($\mathbf{U}_1$)	**SC2 ($\mathbf{U}_2$)**	**SC3 ($\mathbf{U}_3$)**	**SC4 ($\mathbf{U}_4$)**	**SC5 ($\mathbf{U}_5$)**	**SC6 ($\mathbf{U}_6$)**
SE1	35000	21000	21000	18200	56000	102200
SE2	25000	15000	15000	13000	40000	73000
SE3	750	450	450	390	1200	2190

Table 8: Session arrival rate per user matrices Qn, n = 1,…,6 (unit: session arrivals/s/user) [Note: convert to Mbit/s]

	SC1 ($\mathbf{Q}_1$)	**SC2 ($\mathbf{Q}_2$)**	**SC3 ($\mathbf{Q}_3$)**	**SC4 ($\mathbf{Q}_4$)**	**SC5 ($\mathbf{Q}_5$)**	**SC6 ($\mathbf{Q}_6$)**
SE1	3.889E-05	4.167E-05	13.89E-05	5.55E-05	16.667E-05	83.33E-05
SE2	1.944E-05	1.667E-05	11.11E-05	5.556E-05	8.333E-05	22.22E-05
SE3	3.056E-06	2.222E-06	2.222E-06	5.556E-06	5.556E-05	11.11E-05

Table 9: Mean session duration matrices μ_n (unit : s) for circuit-switched service categories

	SC1 (μ_1)	**SC4** (μ_4)	**SC6** (μ_6)
SE1	120	156	180
SE2	120	156	120
SE3	120	156	120

Table 10: Base traffic volume matrices Tn (unit: kbits/session) for packet-switched service categories

	SC2 (i.e., T_2)		**SC3 (i.e., T_3)**		**SC5 (i.e., T_5)**	
	UL	**DL**	**UL**	**DL**	**UL**	**DL**
SE1	1094.40	90000	547.20	17280	42	42
SE2	1094.40	90000	547.20	17280	42	42
SE3	1094.40	90000	547.20	17280	42	42

For all Service Categories Stationary Mobility Class is assumed in all Service Environments.

C. *RAT group and Radio Environment parameters*

Table 11 lists the radio environment specific parameters of the REs considered.

Table 11: Radio Environment parameters

Radio Environment	**Cell geometry**	**Cell/Sector Area [m²]**
RE1	Omni	5030 (Cell)
RE2	3-sectored	312000 (Sector)
RE3	3-sectored	866000 (Sector)

The achievable cell edge user bit rate is assumed to 2 Mbit/s in all radio environments. The assumed Cell Spectral Efficiency value is 0.125 bits/s/Hz/cell.

V. Results of Initial Calculation Steps

This section presents the results of initial calculation steps of the methodology. In Sec. V.A the number of service request per km² is calculated from user density and session arrival rate per user matrices. In Sec. V.B the ratios for distribution of traffic to RATG and Radio Environment are presented. In Sec. V.C the traffic distribution ratios derived from the parameters presented above (the corresponding procedure is described in [5]) and the cell areas from Table 11 are applied to determine the session arrival rate per cell or sector. For circuit-switched service categories (i.e., SC1, SC4 and SC6) these steps are sufficient to deliver the input parameters needed by the capacity calculation algorithm.

For packet-switched service categories as an additional step the offered base traffic per cell needs to be calculated, the results of this step are presented in Sec. V.D.

A. Service request density

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

$$\boldsymbol{P}_{m,1,n} = \boldsymbol{U}_{m,1,n} * \boldsymbol{Q}_{m,1,n.}$$

The resulting session arrival rates per area in SE1, SE2 and SE3 are presented in Table 12.

Table 12: Service request density matrices $\mathbf{P}_n$ (unit: session arrivals/s/km^2)

	SC1 ($\mathbf{P}_1$)	SC2 ($\mathbf{P}_2$)	SC3 ($\mathbf{P}_3$)	SC4 ($\mathbf{P}_4$)	SC5 ($\mathbf{P}_5$)	SC6 ($\mathbf{P}_6$)
SE1	1.36E+00	8.75E-01	2.92E+00	1.01E+00	9.33E+00	8.52E+01
SE2	4.86E-01	2.50E-01	1.67E+00	7.22E-01	3.33E+00	1.62E+01
SE3	2.29E-03	1.00E-03	1.00E-03	2.17E-03	6.67E-02	2.43E-01

B. Ratios for distribution of traffic to radio environments

The ratios for distribution of the offered traffic that result from the computation based on the input parameters should have the following result: According to the availability of radio environments specified in Table 4, in SE1 all traffic goes to RE1 (pico cell), while in SE2 the offered traffic goes to RE2 (micro cell), and in SE3 all traffic is loaded into RE3 (macro cell).

C. Session arrival rate per cell

The session arrival rate per area is multiplied with the distribution ratio and the corresponding cell area to get the session arrival rate per cell $\mathbf{P'}_{n,rat,p}$ in session arrivals/s/cell shown in Table 13.

Table 13: Session arrival rate per cell $\mathbf{P'}_{n,rat,p}$ (unit: session arrivals/s/cell).

	SC1 ($\mathbf{P'}_1$)	SC2 ($\mathbf{P'}_2$)	SC3 ($\mathbf{P'}_3$)	SC4 ($\mathbf{P'}_4$)	SC5 ($\mathbf{P'}_5$)	SC6 ($\mathbf{P'}_6$)
SE1, RE3	6.85E-03	4.40E-03	1.47E-02	5.08E-03	4.69E-02	4.28E-01
SE2, RE2	1.52E-01	7.80E-02	5.20E-01	2.25E-01	1.04E+00	5.06E+00
SE3, RE1	1.98E-03	8.66E-04	8.66E-04	1.88E-03	5.77E-02	2.11E-01

D. Offered packet-based traffic per cell

The traffic of packet switched service categories includes the aggregate offered traffic per cell $T_{n,rat,p}$ in (unit: kbits/s/cell) which is calculated from

$$\mathbf{T}_{n,rat,p} = \mathbf{T}_n \otimes \mathbf{P}'_{n,rat,p}$$

where $\otimes$ denotes element-wise product of matrices/vectors, $\mathbf{T}_n$ is session volume (kbits/s), and $\mathbf{P'}_{n,rat,p}$ is session arrival rate per cell (session arrivals/s/cell). The session volume is presented in Table 10 and the session arrival rate per cell is given in Table 13. The resulting values for the aggregate offered traffic per cell are shown in Table 14.

Table 14: Offered traffic per cell/sector $\mathbf{T}_{n,rat,p}$ for packet-switched SCs (unit: kbit/s/cell or sector)

SE	RE	SC2 (i.e., $\mathbf{T}_{1,1,p}$)		SC3 (i.e., $\mathbf{T}_{4,1,p}$)		SC5 (i.e., $\mathbf{T}_{5,1,p}$)	
		UL	DL	UL	DL	UL	DL
SE1	**Pico Cell**	4.82	396	8.03	254	1.97	1.97
SE2	**Micro Cell**	85.4	702	285	898	43.7	43.7
SE3	**Marco Cell**	0.948	77.9	0.474	15.0	2.42	2.42

VI. REQUIRED SYSTEM CAPACITY

A. Capacity Required for Circuit-switched Traffic

The resulting required system capacity (unit: Mbit/s) for circuit-switched services is shown in Table 15. Since [5] foresees the same amount of offered traffic in uplink and downlink for the circuit-switched services (i.e., the circuit-switched traffic is assumed to be symmetric), Table 15 in the first four columns only presents the required capacity for one direction (uplink or downlink). The Multi-dimensional Erlang-B capacity calculation (see [1],[5]) is executed once for each combination of Service Environment, Radio Environment and Service Category, and each execution 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.

Table 15: Required capacity in IMT.Meth approach (unit: Mbit/s)

	SC1 (uni-directional)	SC4 (uni-directional)	SC6 (uni-directional)	Max over SC (uni-directional)	Total per SE UL+DL
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

Table 16 compares the required overall capacity, including uplink and downlink for the Multidimensional Erlang-B approach with the traditional Erlang-B approach.

Table 16: Required Capacity per SE of the two IMT approaches

	Erlang-B [Mbit/s]	Multidimensional Erlang-B [Mbit/s]	Relative change Erlang-B [%]	Relative change Multidimensional Erlang-B [%]
SE1	4.51	3.52	125.6	76
SE2	33.50	23.39	66.7	16
SE3	2.30	1.53	180.9	87

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]). The relative change (i.e., {IMT.Meth value - M.2023 value} / M.2023 value * 100) compared to the values in M.2023 is given in Table 17. Note that due to the symmetry of the circuit-switched traffic the relative change is unique for each combination of SE and SC and does not depend on whether uplink, downlink or the sum of uplink and downlink is considered.

Table 17: Relative change of required system capacity for circuit-switched service categories (unit: percent)

	Total per SE UL+DL
SE1	98.40
SE2	58.09
SE3	110.73

Figure 1 compares the required system capacity per service environment and per service category according to IMT.Meth approach with the corresponding values of [5].

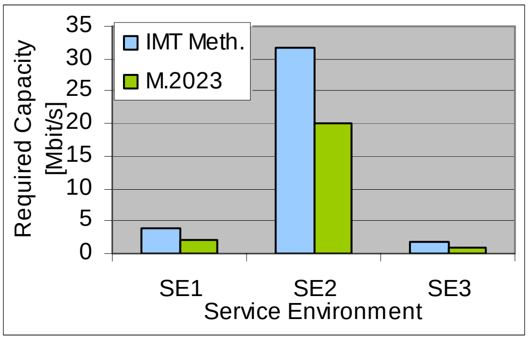

Figure1: Required sysrem capacity for circuit-switched traffic.

Figure 2 shows the relative change of required system capacity for circuit-switched service categories, compared to the values of M.2023.

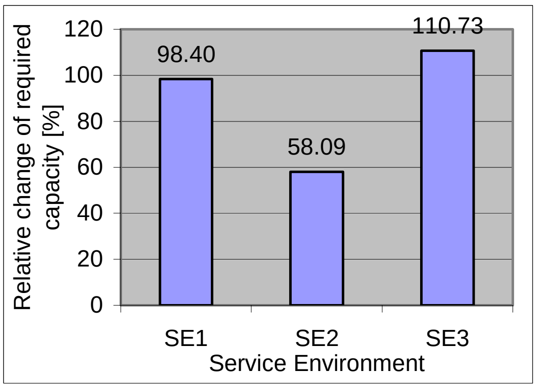

Figure 2: Relative change of required system capacity in comparison to the results of [5].

Mainly the M.2023 parameters cell grouping and activity factor are responsible for the differences between 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 [5] assumes an activity factor equal to one. The influence of cell grouping is further discussed in Section VI.A.1), and the influence of the activity factor is further explained in Section VI.A.2). Section VI.A.3) discusses means to verify the correctness of the IMT.Meth calculation by enforcing an identical scenario.

The difference in the results is partly compensated by the difference in the system model used for the capacity calculation. While in [5] for each Service an independent set of channels was assumed to be available, in [IMT.Meth] all Service Categories in the same cell share a common set of channels, which implies a significant trunking gain over the traditional Erlang-B approach. Thus, the difference in modelling approach represents a counter-tendency to the effects described above.

1) Influence of Cell Grouping

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.

It can be noticed that the cell grouping approach has a smaller impact if the number of channels required per cell is large, as it is the case for SE2. For low data rate services for which a high number available channels per cell can be assumed, the cell grouping would have negligible effect. A motivation for cell grouping may be that a user can usually be served by one of multiple cells that provide overlapping coverage. In TDMA/FDMA technology users can in fact be forced to perform handovers or be redirected at call setup if the current serving cell is fully loaded. For TDMA/FDMA technology this "directed retry" feature justifies an aggregation of traffic over multiple cells. However, technologies like UMTS and cdma2000 use soft handover and have quite limited capability of applying directed retry, which could be implemented by cutting of the power spent for a particular user that was in soft handover with an overloaded base station. On the other hand, in interference limited UMTS/cdma2000 networks the actual number of available channels is not the limiting factor. In this case the number of effectively available channels is determined by inter-cell interference, leading again to a coupling of the load of adjacent cells. It is however unclear how well this mechanism is modeled by cell grouping of [1]. In IMT.Meth it is assumed that any cell-group-like effects are collectively taken account in the area spectral efficiency.

2) Influence of Activity Factor

In M.2023 for the Speech Service (denoted SC6 here) an activity factor of 50 % was assumed, which lead to a virtual decrease of offered traffic for the Speech Service. IMT.Meth does not foresee consideration of an activity factor. This leads to an increase of required channels for speech in comparison to M.1390; see Table 17. For the required spectrum this is partly compensated by a different spectral efficiency considered for SC 6 in the equivalent IMT.Meth scenario; see SectionVII.A.

3) Validation of IMT.Meth results

The IMT.Meth algorithm for calculation of 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 5. 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 IMT.Meth approach. Another possibility of validating the IMT.Meth algorithm used here is to introduce the cell grouping for testing purposes. In this case the results of the IMT.Meth algorithm for a cell group size of seven are identical with the results of M.2023 shown in Table 17.

B. Capacity Requirement for Packet-switched Traffic

In Table 18 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 strongest QoS requirements specifies the total required capacity per direction per service environment. In SE 1 this is the case for SC2 in both directions. In Table 18 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 italics. The overall system capacity required for packet-switched traffic according to IMT.Meth is 18.4 Mbit/s.

Table 18: Required system capacity for packet-switched service categories according to IMT.Meth (unit: Mbit/s).

	SC2		SC3		SC5		Max over SC		Total per SE
	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

Figure 3 shows the overall system utilization per service environment that results from the required capacity given the offered traffic from Table 14. The low system utilization in the uplink direction of SE1 and SE3 is influenced by that fact that here 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 range the required capacity is no longer a linear function of the offered traffic, but rather a linear function of the mean packet size).

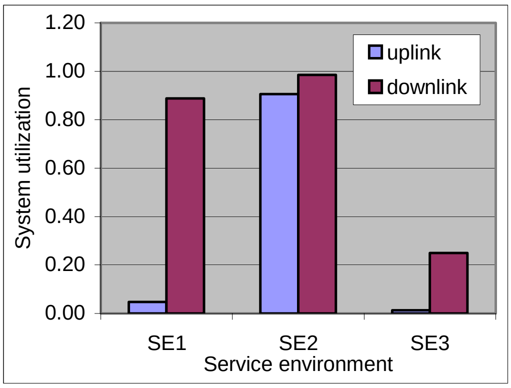

Figure 3: System utilization for the required capacity values according to Table 20.

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 19 the change of the required capacity per service environment according to IMT.Meth approach relative to the capacity requirement per service environment of M.2023 is shown.

Table 19: Relative change of required capacity per service environment for packet-switched traffic; uplink (UL), downlink (DL) and sum of uplink and downlink (UL+DL) direction.

	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%

It is important to note that due to the different type of QoS requirements considered in IMT.Meth and M.1390 approaches, respectively, and due to the unknown relation of the assumed values for required mean delay to the QoS requirements considered in M.2023 it is unknown if the values assumed here represent a stronger or a weaker QoS requirement compared to the requirements considered for 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.

VII. REQUIRED SPECTRUM

A. *Circuit-switched Traffic*

The required spectrum bandwidth for circuit-switched services is shown in Table 20. Note that for SC6 (Speech) a spectral efficiency of 125 kbit/s/MHz was assumed here, 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 Tables 15 and 20 occurs for SC6.

Table 20: Required spectrum for circuit-switched traffic (unit: MHz)

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

The relative change of the required spectrum for circuit-switched services is given in Table 21.

Table 21: Relative change of required spectrum for circuit-switched services according to new methodology.

	Total per SE UL+DL
SE1	29.992
SE2	14.189
SE3	43.402

Figure 4 compares the required spectrum bandwidth for circuit-switched service categories according to IMT.Meth and M.1390 approaches, respectively.

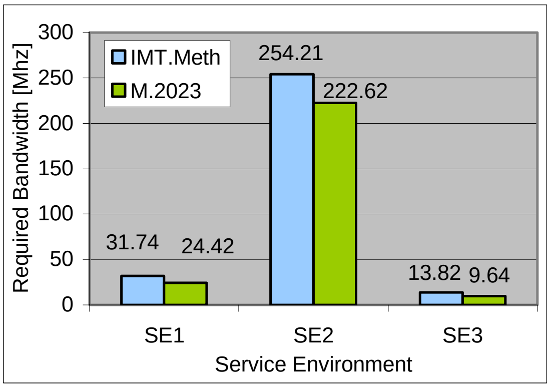

Figure 4: Required spectrum for circuit-switched traffic, IMT.Meth vs. M.2023

In addition to the influences described above, in Fig. 4 the influence of the higher spectral efficiency value for SC6 is visible. Otherwise the values in Figure 4 would be equal to the values shown in Figure 1.

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.

B. *Packet-switched Traffic*

Table 22 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; see Table 17

Table 22: Required spectrum bandwidth per service environment for packet-switched traffic according to [IMT.METH] approach (unit: MHz).

	[IMT.METH]			Relative change [%]		
	UL	DL	DL+UL	UL	DL	DL+UL
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%	-62.80%	-37.61%
Sum	8.52	139.04	147.56	44.36%	-18.47%	-16.37%

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.

C. *Aggregate Spectrum Requirements*

In Table 23 the total spectrum requirement per service environment for all service categories being summed up is compared with the values of M.2023.

Table 23: Total required spectrum bandwidth per service environment according to IMT.Meth (unit: MHz).

Service environment	UL	DL	UL+DL
SE1	18.332	21.742	40.074
SE2	130.754	257.224	387.978
SE3	9.332	9.772	19.304
Sum	154.418	288.738	**447.356**

The relative change of required spectrum bandwidth per service environment compared to M.2023 values is shown in Table 24.

Table 24: Relative change of required spectrum bandwidth for packet-switched and circuit-switched service categories (unit: percent)

Service environment	UL	DL	UL+DL
SE1	40.91	-21.37	-1.44
SE2	12.85	-0.37	3.72
SE3	73.79	-23.55	4.81
Sum	18.00	-3.33	3.28

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 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.

VIII. Conclusions

In order to produce results of the new methodology IMT.Meth that can be compared to the results 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 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 here, 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 the IMT.Meth results shown above. 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 strength of the QoS requirements considered here and considered 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 intermediate results shows that this observation cannot be generalized, especially facing the fact that the scenario considered here is not representative for the expected application scenarios in the scope of the spectrum requirement estimation in preparation of WRC-07.

However, by modeling data transmission in a significantly more realistic manner than 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 in M.1390. This tendency is compensated by removing unrealistic or not generally valid aspects of modeling, which lead to a decrease of spectrum requirements in M.1390.

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