RECOMMENDATION ITU-R M.1390

METHODOLOGY FOR THE CALCULATION OF IMT-2000 TERRESTRIAL SPECTRUM REQUIREMENTS

(1999)

Introduction

IMT-2000 are third generation mobile systems which are scheduled to start service around the year 2000 subject to market considerations. They will provide access, by means of one or more radio links, to a wide range of telecommunication services supported by the fixed telecommunication networks (e.g. public-switched telephone network (PSTN)/integrated services digital network (ISDN)), and to other services which are specific to mobile users.

A range of mobile terminal types is encompassed, linking to terrestrial and/or satellite-based networks, and the terminals may be designed for mobile or fixed use.

Key features of IMT-2000 are:

– high degree of commonality of design worldwide;

– compatibility of services within IMT-2000 and with the fixed networks;

– high quality;

– use of a small pocket-terminal with worldwide roaming capability;

– capability for multimedia applications and a wide range of services.

IMT-2000 are defined by a set of interdependent ITU Recommendations of which this one is a member.

Spectrum requirements for the terrestrial component of IMT-2000 were estimated in Report ITU-R M.1153 prior to WARC-92. Speech services were considered to be the major source of traffic at the time. As technological advancements provide additional capabilities in telecommunications users will demand more from wireless services. Future wireless services must support, not only speech but also a rich range of new services that will serve a wide range of applications. Services such as multimedia, Internet access, imaging and video conferencing will be needed in third generation wireless systems. In response to these new applications, IMT-2000 will support high rate data services. The provision of new services described in Recommendation ITU-R M.816 (Framework for services supported by IMT-2000) has an impact on the spectrum requirements for IMT-2000 systems.

There is a need to develop a new methodology for determination of spectrum requirements that can accommodate not only the new services of IMT-2000 but also the new radio transmission technologies being developed.

Scope

This Recommendation contains a methodology for the calculation of terrestrial spectrum requirement estimates for IMT-2000. This methodology could also be used for other public land mobile radio systems. It provides a systematic approach that incorporates geographic influences, market and traffic impacts, technical and system aspects and consolidation of spectrum requirement results. The methodology is applicable to both circuit switched and packet switch-based radio transmission technologies and can accommodate services that are characterized by asymmetrical traffic flows[1)].

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1) An example of the application of the methodology is provided in Appendix 1.

The ITU Radiocommunication Assembly,

considering

a) that the Radio Regulations (RR) identify the bands 1 885-2 025 MHz and 2 110-2 200 MHz as intended for use on a worldwide basis by administrations wishing to implement IMT-2000, as indicated in RR S5.388, and Resolution 212 (Rev.WRC-97);

b) that the initial implementations of IMT-2000 are expected to commence around the year 2000 subject to market considerations;

c) that the bands identified in *considering* a) are used differently in various countries;

d) that the traffic and service mix carried by IMT-2000 systems may vary from country to country, and also within countries. In some parts of the world additional spectrum may be required, whilst in other parts of the world frequency bands identified by *considering* a) could be adequate to meet IMT-2000 services present and future demands;

e) the need to support the operation of IMT-2000 terminals in different regulatory environments;

f) that the various radio access technologies that may be appropriate for IMT-2000 may have different channel bandwidth requirements, and hence varying impact on the basic frequency usage possibilities;

g) that traffic handled by mobile systems as well as the number and diversity of services will continue to grow;

h) that future systems may include the use of a range of cell types from indoor cells to satellite cells, which must be able to co-exist in a given location;

j) that IMT-2000 will offer higher data rate services than earlier systems in order to meet increasing customer demands, and this could create a demand for additional spectrum beyond that earlier estimated;

k) that efficiency of spectrum use requires consideration of the balances between IMT-2000 system costs and bandwidth needed;

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

recommends

1 that the methodology for the calculation of terrestrial IMT-2000 spectrum requirement estimates as specified in Annex 1 should be used by administrations as the basis for performing calculations involving estimates of future IMT-2000 terrestrial spectrum needs;

2 that the methodology in Annex 1 could also be considered for the calculation of terrestrial spectrum estimates for other public land mobile radio systems, and its use is highly encouraged.

ANNEX 1

IMT-2000 terrestrial spectrum requirement methodology

1 Terrestrial methodology overview

A methodology for development of a terrestrial spectrum requirement is presented below. This methodology enables the calculation of spectrum estimates to support mobile communication services of today and the future. The equation for this estimate is provided in equation 1.

This methodology is consistent with the global IMT-2000 vision and is also consistent with the services as presented in Recommendation ITU-R M.816: "Framework for services supported by IMT-2000". The methodology is flexible enough to accommodate either a global view of spectrum needed or the unique requirements of regional markets.

The basic theme of this methodology is to determine the individual spectrum requirements for all representative combinations of specific environments and services (F_{es}) in a given geographical area, and to combine the set of individual spectrum requirements F_{es} together into a total terrestrial component spectrum requirement estimate, $F_{Terrestrial}$ by employing appropriate weighting factors (α_{es}) to the summation. The factor (α_{es}) takes into account the impact of concurrent services in a given geographical area. An additional adjustment factor (β) is available to apply to the composite summation to accommodate impacts such as multiple operators, spectrum sharing, and the like.

The estimation of a spectrum requirement for many years into the future is not an exact calculation. In particular, the methodology provided in this document is not intended to include the second or third order effects, but rather the calculations capture the significant first order influences which are the primary factors for terrestrial spectrum needed.

The spectrum required ($F_{Terrestrial}$) in MHz is:

$$F_{Terrestrial} = \beta \, \Sigma \alpha_{es} F_{es} = \beta \, \Sigma \alpha_{es} T_{es}/S_{es} \quad (1)$$

where "e" and "s" are subscripts denoting dependency on environments and services respectively.

Therefore, $F_{Terrestrial}$ is the total required spectrum as a weighted summation of co-existing individual F_{es} in the same geographical area for all environments "e" and services "s" considered relevant, adjusted for influences such as spectrum sharing, multiple operators,

where:

$F_{Terrestrial}$	= Terrestrial Component Spectrum Requirement	Units: MHz
T_{es}	= Traffic/$Cell_{es}$	Units: Mbit/s/cell
S_{es}	= System capability	Units: Mbit/s/MHz/cell
α_{es}	= Weighting factor	Units: dimensionless
β	= Adjustment factor	Units: dimensionless

Equation 1 addresses both circuit and packet-switched services and includes consideration for traffic asymmetry in the uplink and downlink directions. Each of the factors of equation 1 will be defined further in the following subsections.

The calculations, parameters, and definition of inputs within the methodology are divided into four categories and serve to group similar aspects of the methodology into sub-units:

A geographic considerations,

B market and traffic considerations,

C technical and system consideration,

D spectrum results considerations.

An example is included in Appendix 1 that shows how the methodology is applied. This example is based on a representative subset of environments and services. The example is calculated with parameter values estimated from market research on public land mobile communications services, including IMT-2000, and with technical parameter values estimated from IMT-2000 radio transmission technologies, for the year 2010.

The results shown in this example should not be considered as providing an answer to the question of future spectrum requirements for public land mobile communications services, including IMT-2000, as all environments and services that must be considered for completeness have not been included in the example. Nonetheless, the example includes all environments and services required to sufficiently exercise all aspects of the methodology.

2 Methodology flowchart

The following material presents the methodology in "flowchart" format with a sequential listing of the steps divided among the four sub-categories. Subsequent sections of this document provide detailed information and description of the terms, parameters, calculations performed[2)].

A Geographic considerations

A1 Select "e"

"e" - environment type: selects density and mobility.

These environments are defined by a combination of a density attribute and a mobility attribute considered jointly, and are shown in the following matrix:

Mobility	In-building	Pedestrian	Vehicular
Density			
Dense Urban (CBD)			
Urban			
Suburban			
Rural			

For example, "dense urban, in-building" could be a value of "e".

A2 Select direction of calculation

Uplink (from the mobile station to the base station) or downlink (from the base station to the mobile station).

A3 Establish representative cell area and geometry Units: metres

Diameter if circular omnidirectional cell geometry; radius of vertex if sectored hexagonal cell geometry.

A4 Calculate Cell_Area A_e Units: km^2

$Cell\_Area_e$.

B Market and traffic considerations

B1 Select "s"

s – service type: selects service type and hence $Net\_User\_Bit\_Rate_s$ (kbit/s)

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2) The mathematical convention of describing a complex function as a function name and a list of input parameters is used in several places in this document. It is demonstrated as follows:

Function {parameter1, parameter2, …, parameterN}.

B2 Establish Population_Density$_e$ Units: potential users/km^2

B3 Establish penetration_rate$_{es}$ Units: %

B4 Calculate users/cell$_{es}$ Units: users

Users/Cell$_{e\ s}$ = Population_Density$_e$*Penetration_Rate$_{es}$*Cell_Area$_e$.

B5 Establish traffic parameters

Busy_Hour_Call_Attempts$_{es}$ **Units: calls in busy hour**

Effective_Call_Duration$_{es}$ **Units: seconds**

Activity_Factor$_{es}$ **Units: dimensionless**

B6 Calculate Traffic/User$_{es}$ Units: call-seconds

Traffic/User$_{es}$ = Busy_Hour_Call_Attempts$_{es}$*Call_Duration$_{es}$* Activity_Factor$_{es}$.

(NOTE – May be expressed as Erlangs, where an Erlang = call-seconds/3 600.)

B7 Calculate Offered_Traffic/Cell$_{es}$ Units: call-seconds/cell

Offered_Traffic/Cell$_{es}$ = Traffic/User$_{es}$*Users/Cell$_{es}$.

(NOTE – May be expressed as Erlangs, where an Erlang = call-seconds/3 600.)

B8 Establish Quality_of_Service_Function$_{es}$ Parameters Units: varied

Group_Size$_{es}$;

Blocking Criteria$_s$ {Formula and Grade of Service for circuit switched; Formula and Delay for packet switched}.

C Technical and system considerations

C1 Calculate number of Service_Channels/Cell$_{es}$ required to carry Offered_Traffic/Cell$_{es}$ Units: none

Service_Channels/Cell$_{es}$ =

(Quality_of_Service_Function$_s$
{Offered_Traffic/Cell$_{es}$*Group_Size$_{es}$;
Blocking Criteria$_s$})/Group_Size$_{es}$

C2 Determine Service_Channel_Bit_Rate$_{es}$ needed to carry Net_User_Bit_Rate$_{s}$ **Units: kbit/s**

C3 Calculate Traffic$_{es}$ **Units: Mbit/s/cell**

$\mathbf{T_{es}}$ = Service_Channels/Cell$_{es}$∗Service_Channel_Bit_Rate$_{es}$.

(Note conversion to Mbit/s from kbit/s.)

C4 Determine Net_System_Capability$_{es}$ Parameters **Units: varied**

System Spectral Efficiency; Coding Factor; Overhead Factor; Deployment Model; and other factors.

C5 Calculate Net_System_Capability$_{es}$ **Units: Mbit/s/MHz/cell**

S_{es} = Function of {Spectral Efficiency; Coding Factor; Overhead Factor; Deployment Model, and other factors}.

D Spectrum results considerations

D1 Calculate individual F_{es} Component

(Answer will be for direction of calculation chosen either uplink or downlink.)

$F_{es} = T_{es}/S_{es}$ (either uplink or downlink) **Units: MHz**

D2 Repeat process for calculation of other direction (either downlink or uplink as appropriate)

Repeat steps A2 through D1.

D3 Calculate F_{es} for the Service “s” Combining uplink and downlink components

$F_{es} = (F_{es}$ uplink $+ F_{es}$ downlink$)$ **Units: MHz**

D4 Repeat process (steps A1 through D3) for All Desired “e”, “s”

D5 Determine weighting factor applicable to each individual F_{es}: α_{es} **Units: None**

D6 Determine Adjustment Factor(s): β **Units: None**

D7 Calculate Final Total $F_{Terrestrial}$ Spectrum Value **Units: MHz**

$F_{Terrestrial} = \beta\, \Sigma \alpha_{es} F_{es}$.

3 Detailed description of the methodology

A Geographic considerations

A1 Environment

The initial point for consideration of terrestrial spectrum requirements is to determine the characteristics of the cells which the system will use. The system will operate in a variety of scenarios, encompassing various combinations of density and mobility. A table of possible environments is given below, although no indication has been given of which specific environments should be considered. It is thought that the matrix below is flexible enough to cover most situations encountered in deployment of a public land mobile radio system.

The variable subscript “e” represents the environment for which the calculation is performed, and the environment is defined by a combination of a density attribute and a mobility attribute considered jointly, and are show in the following matrix:

Mobility	In-building	Pedestrian	Vehicular
Density			
Dense Urban (CBD)			
Urban			
Suburban			
Rural			

For example, “dense urban, in-building” could be a value of “e”.

Clearly some of these environments may be (geographically) overlapping, whilst others may be separate. For the calculation of the total spectrum required for IMT-2000, it will be necessary to determine the maximum spectrum which might realistically be needed in any one area. It is anticipated that not all combinations (values of “e”) will be needed and in most cases only a few combinations will need to be considered. For example, “dense-urban, vehicular” as a value of “e” may not be required in practice in some calculations. Therefore the first stage of the methodology is to determine the environments which could co-exist, and which would give rise to the greatest total spectrum demand.

In practice this will be a combination of overlapping dense urban and urban environments. The method to determine the total spectrum required is then applied to each of the members of this set of overlapping environments.

A2 Select direction of calculation

Uplink (from the mobile station to the base station) or downlink (from the base station to the mobile station).

The traffic and spectrum figures in steps A2 through D1 are calculated separately for uplink and downlink directions because of the traffic asymmetry in some services. The spectrum required for any F_{es} is the sum of the requirement for both directions.

A3 Establish representative Cell_Area and geometry

For each of the “e” environments identified in A1, the cell area and geometry has to be established. Typical examples could be a circle or hexagon, either of which could be considered as a whole or could be sectored. It is possible that, for operational reasons, different environments will use cells with differing geometry, and certainly there may be a range of cell sizes.

A4 Calculate $Cell\_Area_e$ Units: km^2

Having identified the cell geometry and dimensions for each environment, it is necessary to calculate the area of the cell.

For example:

For a circular cell, $Cell\_Area_e = \pi R^2 = \pi D^2/4$

where: R = radius of the circle

D = diameter of the circle

For a hexagonal cell, $Cell\_Area_e = (3/2) * (\sqrt{3}) * R^2$

where: R = radius (to vertex) of the hexagon.

For a cell which is a sector of a circle/hexagon, the area that should be used ($Cell\_Area_e$) is the area of the sector, and it may be sufficient to divide the area of the full circle/hexagon to obtain the sector area.

Other cell geometries and corresponding formula for calculating area may be used.

B Market and traffic considerations

B1 Select "s"

"s" – service type: selects service type and hence $Net\_User\_Bit\_Rate_s$ (kbit/s).

For a given public land mobile radio service there is a set of services that are offered. Selecting a service type "s" chooses a particular service from that set for the purpose of calculation.

As an example, in IMT-2000, a reasonable set of services (the range of "s") might be:

- Speech (circuit switched)
- Simple message (packet switched)
- Switched data (circuit switched)
- Medium multimedia (packet switched)
- High multimedia (packet switched)
- High interactive multimedia (packet switched)

B2 Establish $Population\_Density_e$ Units: potential users/km^2

For each environment considered, it is also necessary to determine a density of population. This will be a basic figure for the number of persons per unit area within the environment under consideration.

Similar geographic locations can have differing population densities as a function of the mobility component. For example, urban-pedestrian may have a population density of 100 000 users/km^2, yet the same area would not be physically able to have an urban-vehicular density of more than 3 000 users/km^2.

B3 Establish $Penetration\_Rate_{es}$ Units: %

This parameter is the ratio of the number of people subscribing to the service "s" over the total population, in environment "e".

It should be noted that the use of each service is not exclusive. Each $Penetration\_Rate_e$ refers to the penetration of that service as a proportion of the total potential user base. Since users can use more than one service it is possible for the *total* penetration in an environment (across all services) to exceed one (100%) if a high proportion of users are using more than one service.

B4 Calculate $Users/Cell_{es}$

This parameter is dependent upon the population density and the cell area for each environment "e", and on the penetration rate for the service "s" and the environment "e".

It represents the number of people actually subscribing to the service "s" in a cell of environment "e".

$Users/Cell_{es} = Population\_Density_{es} * Penetration\_Rate_{es} * Cell\_Area_{e}$.

B5 Establish traffic parameters

For each service, in each environment, the following parameters must be established:

$Busy\_Hour\_Call\_Attempts_{es}$ **Units: number of calls in busy hour**

Defined as the average number of calls attempted for the average user during the busy hour. It should be noted that these calls may originate either from the user or from the network. No distinction is made here between these two sources, the result in terms of resource needed being the same. This parameter is self explanatory for circuit-switched services, and for packet-switched services a call is understood as a session.

$Call\_Duration_{es}$ **Units: seconds**

This parameter is defined as the mean actual duration of the call or of the session during the busy hour.

$Activity\_Factor_{es}$ **Units: dimensionless**

Defined as the percentage of time during which the resource is actually used during the call. For example, if voice is transmitted only if the user speaks, or if a packet transmission is bursty, the transmission is only active during a relatively small amount of time.

B6 Calculate $Traffic/User_{es}$ Units: call-seconds

This parameter is defined as the probability that the user is "offhook" and active in the busy hour for a circuit-switched call or a packet-switched session. It is clearly defined in Erlangs (call-seconds/ 3 600) for circuit-switched services and for packet-switched services has the equivalent unit of average relative activity in a period of reference of the busy hour.

$Traffic/User_{es} = Busy\_Hour\_Call\_Attempts_{es} * Call\_Duration_{es} * Activity\_Factor_{es}$.

B7 Calculate $Offered\_Traffic/Cell_{es}$ Units: call-seconds

This is the total traffic issued in a given cell of environment "e" for service "s" during the busy hour.

$Offered\_Traffic/Cell_{es} = Traffic/User_{es} * Users/Cell_{es}$.

It is clearly defined in Erlangs (call-seconds/3 600) for circuit-switched services and for packet-switched services has the equivalent unit of average relative activity in a period of reference of the busy hour.

B8 Establish $Quality\_of\_Service\_Function_{es}$ (QOS_{es}) Parameters Units: varied

Parameters required:

$Group\_Size_{es}$

Blocking $Criteria_{s}$ (Formula and Blocking for circuit switched)

or

Blocking $Criteria_{s}$ (Formula and Delay for packet switched)

Discussion of Quality Of Service Aspects:

Bearer channel capabilities are characterized in terms of parameters having Quality of Service and Grade of Service significance. Establishing $\text{Quality\_of\_Service\_Function}_{es}$ parameter values (herein $\text{Quality\_of\_Service\_Function}_{s}$ is used generically to apply to both Quality of Service specifically and also to Grade of Service) directly impacts on the number of service channel resources that are required to transport the $\text{User\_Net\_Bit\_Rate}_{s}$ streams.

These parameters are necessary to determine the actual amount of resource which is needed to carry the traffic issued from the cell. For circuit-switched services, the necessary parameter is acceptable blocking, the maximum percentage of calls which cannot be treated by the network.

For packet-switched services, the quality of service is defined in terms of maximum packet delay and packet loss probability. The acceptable values of these parameters must be established for a given Service_Type "s".

The throughput of a packet-switched system is dependent on the choice of a suitable multiple access protocol (e.g. Aloha, PMRA, etc.). Given a particular protocol, the total throughput may be determined for a particular Service_Type "s" by application of a suitable traffic model and an appropriate packet $\text{Quality\_of\_Service\_Function}_{es}$.

Traffic models for packet switched are dependent on many parameters, some of which might be included in the $\text{Net\_System\_Capability}_{es}$ variable. Some example packet-switched traffic parameters are:

– statistical arrival times of various sessions;

– numbers of packet bursts per session;

– arrival times of packet bursts within a session;

– packet size statistics.

The values of the above are also Service_Type "s" dependent. When a session consists of multiple services an aggregate traffic model should be used.

The requisite function that is used for the calculation of $\text{Quality\_of\_Service\_Function}_{es}$ relative to the number of service channels is a matter of choice of the appropriate function to match the Service_Type "s" selected. For example, Erlang B with a blocking value of some percentage (say 2% blocking) has traditionally been used for speech (circuit switched) and may be an appropriate choice to apply in the determination of spectrum associated with the speech service type. Other functions as discussed previously, which describe $\text{Quality\_of\_Service\_Function}_{es}$ appropriate to packet switched would be used in calculations of packet-based service types.

In consideration that radio transmission technologies and system deployments may provide some measure of traffic "sharing" or "redirection" among adjacent cells (perhaps in hierarchical or other arrangements) it is appropriate to consider traffic and $\text{Quality\_of\_Service\_Function}_{es}$ within a grouping of cells.

The term Group_Size_{es} is used to describe the number of cells considered to be grouped for the purpose of application of traffic and $\text{Quality\_Of\_Service\_Function}_{es}$. The Group_Size_{es} does not imply any particular geometry, although an example could be a regular hexagonal cell grid which results in a Group_Size_{es} of seven, the value arising from the cell in question and the surrounding six first tier cells.

Essentially, the Traffic/Cell_{es} is multiplied by the Group_Size_{es} and the $\text{Blocking\_Criteria}_{s}$ function applied over this grouping. Then to obtain the $\text{Service\_Channels/Cell}_{es}$ the Group_Size_{es} is divided out to restore the valuation to a per cell basis.

This calculation step has the impact of some reduction in the number of $\text{Service\_Channels/Cell}_{es}$ by considering some improvement in efficiency in the traffic spread in a geographic grouping. To the extent that grouping and/or traffic sharing across geographically grouped cells is included in the $\text{System\_Capability}_{es}$ parameter, then the Group_Size_{es} should be set to the value of one and the $\text{Blocking\_Criteria}_{s}$ function calculation performed on the traffic in a single cell.

Similarly, if the effects of a $\text{Quality\_of\_Service\_Function}_{es}$ are included in the $\text{System\_Capability}_{es}$ parameter, then the Blocking_{s} function should be set to a value of one, which should in principle, also require that the Group_Size_{es} value be set to unity.

C Technical and system considerations

C1 Calculate number of $Service\_Channels/Cell_{es}$ required to carry $Offered\_Traffic/Cell_{es}$ Units: none

The calculation of the number of $Service\_Channels/Cell_{es}$ is a complex function that involves use of the parameters discussed previously:

$$Service\_Channels/Cell_{es} = (QOS_{es}\ \{Offered\_Traffic/Cell_{es} * Group\_Size_{es};\ Blocking\ Criteria_{s}\})/Group\_Size_{es}$$

$Service\_Channels/Cell_{es}$ is the actual number of "channels" that must be provisioned to carry the intended traffic. A service channel is a channel which supports a service needing to have transported the corresponding $Net\_User\_Bit\_Rate_{s}$ for the selected service "s".

In general terms, a physical transmission facility offers a corresponding physical bit rate, which may be sub-divided into several sub-rate transmission pipes, each of which can support a number of service channels.

C2 Determine $Service\_Channel\_Bit\_Rate_{es}$ needed to carry $Net\_User\_Bit\_Rate_{s}$ Units: kbit/second

Due to modularity of the bit rate of the service channel, it is possible that the $Service\_Channel\_Bit\_Rate_{es}$ might be equal to or greater than the corresponding $Net\_User\_Bit\_Rate_{es}$. An example of this would be a $Service\_Channel\_Bit\ Rate_{es}$ of 16 kbit/s to carry a 14 kbit/s $Net\_User\_Bit\_Rate_{s}$, or an 80 kbit/s $Service\_Channel\_Bit\_Rate_{es}$ to carry a 64 kbit/s $Net\_User\_Bit\_Rate_{s}$.

$Service\_Channel\_Bit\_Rate_{es}$ can also include impacts related to coding factors and channel overhead. To the extent that the actual bit rate of the service channel, coding factors and channel overhead impacts are not included in the $Net\_System\_Capability_{es.}$ they should be included here. Ignoring any factors related to $Service\_Channel\_Bit\_Rate_{es}$ that cause it to be greater than the $Net\_User\_Bit\_Rate_{s}$, the $Service\_Channel\_Bit\_Rate_{es}$ is merely equal to the $Net\_User\_Bit\_Rate_{s}$.

C3 Calculate $Traffic_{es}$ Units: Mbit/s/cell

(Note conversion to Mbit/s from kbit/s.)

$T_{es} = Service\_Channels/Cell_{es} * Service\_Channel\_Bit\_Rate_{es}$.

At this stage the traffic has been totalled for all the factors represented by the environment, service type, selected direction of transmission, cell geometry, quality of service aspects, traffic efficiencies across a group of cells, and service channel bit rate requirements.

C4 $Net\_System\_Capability_{es}$ (S_{es}) Units: Mbit/s/MHz/cell

(An equivalent expression for bits/s/Hz/cell.)

Determine Net_System_Capability Parameters **Units: varied**

S_{es} is a measure of the system capacity of a specific technology. It is related to the spectral efficiency of mobile communication systems but contains many other factors. S_{es} has the unit dimension of Mbit/s/MHz/cell. which is a direct equivalent to bits/s/Hz/cell. $Net\_System\_\ Capability_{es}$ is not the same as spectral efficiency of the radio transmission technology. It is comprised of a number of effects that are combined in a complex manner appropriate to the radio transmission technology and the service type "s" and environment "e". Often the values required to determine the $Net\_System\_Capability_{es}$ are obtained from the results of complex system simulations.

The major components of the Net_System_Capability$_{es}$ may include the following:

1) Radio transmission technology design or engineering impacts including but not limited to:
   - physical spectral efficiency of access technology used;
   - requirements of a specific E_b/N_0;
   - requirements of a specific C/I;
   - requirements for a specific frequency reuse plan;
   - coding factors used by the radio transmission technology;
   - overhead factors used by the radio transmission technology;
   - environment – indoor, outdoor, stationary, pedestrian, vehicular.
2) Deployment models and/or deployment technique including microcells, macrocells, hierarchical cells, or overlay cells, etc.

It therefore follows that there is a tradeoff between Net_System_Capability$_{es}$ and the quality or grade of service.

C5 Calculate Net_System_Capability$_{es}$

S_{es} = Function of {Spectral Efficiency, Coding Factor, Overhead Factor, Deployment Model, and other factors}.

This calculation proceeds using the values and parameters discussed previously as a function of appropriate combining functions.

D Spectrum results considerations

D1 Calculate individual F_{es} Component for a given direction

- uplink (from the mobile station to the base station); or
- downlink (from the base station to the mobile station).

The amount of spectrum required for a given service and environment, in a given direction, is determined by dividing the Traffic$_{es}$ (as determined in § C3) by the Net_System_Capability$_{es}$ (as determined in § C4).

$F_{es} = T_{es}/S_{es}$ (either uplink or downlink) **Units: MHz**

D2 Repeat process for calculation of other direction (either downlink or uplink as appropriate)

Repeat steps A2 through D1 for the other direction (if not previously calculated).

D3 Calculate F_{es} for the Service "s", combining uplink and downlink components

The total amount of spectrum required for a given service and environment is determined by directly adding the spectrum required for the uplink and downlink components.

$F_{es} = (F_{es}$ uplink + F_{es} downlink) **Units: MHz**

D4 Repeat process (steps A1 through D3) for all desired "e", "s"

Repeat steps A1 through D3 for each combination of "e" and "s" that is being considered.

D5 Determine weighting factor (α_{es}) applicable to each individual F_{es} Units: None

The weighting factor (α_{es}) provides appropriate weighting in the spectrum requirements calculations and includes the following:

– weighting to adjust for geographical offsets in overlapping environments;

– weighting to correct for non-simultaneous busy hour traffic requirements.

The value for α_{es} may range from zero up to unity, and the default value is 1.

D6 Determine adjustment factor (β) Units: None

The adjustment factor (β) provides for impacts such as:

– multiple operators (reduced trunking/spectral efficiency);

– sharing with other IMT-2000 services/systems;

– sharing with non-IMT-2000 services/systems;

– guard bands;

– technology modularity. For example, if a technology uses 10 MHz frequency division duplex (FDD) channels, then the requirements will necessarily be an integer factor of 20 MHz;

– other adjustments to be justified.

This adjustment factor is an approximation across impacts of environments "e", services "s" and other influences. The default value for β is 1, and other values should be technically justified.

D7 Calculate the final total $F_{Terrestrial}$ Spectrum Value Units: MHz

For each environment and service, each F_{es} is multiplied by α_{es}, and then the individual products are added together. The result of the summation is multiplied by the adjustment factor (β) to derive the total terrestrial spectrum required $F_{Terrestrial}$.

$$F_{Terrestrial} = \beta \, \Sigma \alpha_{es} F_{es} \quad \text{MHz}$$

APPENDIX 1

Example calculations

This example provides guidance on the application of the methodology detailed in §§ 2 and 3 of Annex 1.

The example is calculated with parameter values estimated from market research on public land mobile communications services, including IMT-2000, and with technical parameter values estimated from IMT-2000 radio transmission technologies, for the year 2010 view. The results shown in this example should not be considered as providing an answer to the question of future spectrum requirements for public land mobile communications services, including IMT-2000, as all environments and services that must be considered for completeness may have not been included in the example.

Examination of environments and services reveals that there are potentially twelve values of the subscript "e" and six values for the subscript "s" that are representative major contributors to a spectrum requirement. Hence, a complete calculation of the terrestrial spectrum requirement estimate for public land mobile communications services, including IMT-2000, would require the use of 72 terms in the summation of individual F_{es} terms.

This example is based on a representative subset of environments and services as presented in the matrix below and these are sufficient to exercise all aspects of the methodology.

Representative environments "e" and services "s" (values for F_{es})

Environments "e"	High density-in building (CBD)	Urban pedestrian	Urban vehicular
Services "s"			
Speech (S)	F_{es}	F_{es}	F_{es}
Simple Message (SM)	F_{es}	F_{es}	F_{es}
Switched Data (SD)	F_{es}	F_{es}	F_{es}
Medium Multimedia (MMM)	F_{es}	F_{es}	F_{es}
High Multimedia (HMM)	F_{es}	F_{es}	F_{es}
High Interactive Multimedia (HIMM)	F_{es}	F_{es}	F_{es}

The figures presented in the tables below are often rounded figures, but the calculation is performed with more digits to provide more accurate example results.

A Example for the year 2010

A1 Environment

A subset of all environments is considered for the purpose of this example: only high density-in building also generally known as Central Business District (CBD); urban pedestrian, and urban vehicular. This subset of three environments is extracted from all possibilities because they correspond to superimposed layers in city centres.

It should be noted that no user should occupy two operational environments at a time.

A2 Direction of calculation

– uplink (from the mobile station to the base station); or

– downlink (from the base station to the mobile station).

The following calculations are detailed for each of the direction.

A3 Establish representative cell_area and geometry

The environments are defined to have the following geometry:

TABLE 1

Environment description

Environment "e"	High density-in building (CBD)	Urban pedestrian	Urban vehicular
$Geometry_e$	Circular	Hexagonal with three sectors	Hexagonal with three sectors
Cell $dimension_e$	Diameter = 100 m	Radius = 600 m	Radius = 600 m

A4 Calculate Cell_Area

Based on the cell description, the cell areas are calculated as follows:

TABLE 2

$Cell\_Area_e$

Environment "e"	High density-in building (CBD)	Urban pedestrian	Urban vehicular
$cell\_area_e$ (km^2)	7.85×10^{-3}	3.12×10^{-1}	3.12×10^{-1}

B1 Select service "s"

The services are as follows:

TABLE 3

Description of Service_Type "s" and corresponding $Net\_User\_Bit\_Rate_s$

$Net\_User\_Bit\_Rate_e$	Downlink (DL) net bit rate (kbit/s)	Uplink (UL) net bit rate (kbit/s)
Service Type "s"		
Speech (S)	16	16
Simple Message (SM)	14	14
Switched Data (SD)	64	64
Medium Multimedia (MMM)	384	64
High Multimedia (HMM)	2 000	128
High Interactive Multimedia (HIMM)	128	128

B2 Establish Population_Density

For the three environments considered, population densities can be chosen as follows:

TABLE 4

$Population\_Density_e$

Environment "e"	High density-in building (CBD)	Urban pedestrian	Urban vehicular
$Population\_Density_e$	250 000	100 000	3 000

B3 Establish Penetration_Rate$_{es}$

The following table describes the penetration rates used in this example calculation:

TABLE 5

Penetration_Rate$_{es}$ in Percent

Environments "e" / Services "s"	High density-in building (CBD)	Urban pedestrian	Urban vehicular
Speech (S)	73%	73%	73%
Simple Message (SM)	40%	40%	40%
Switched Data (SD)	13%	13%	13%
Medium Multimedia (MMM)	15%	15%	15%
High Multimedia (HMM)	15%	15%	15%
High Interactive Multimedia (HIMM)	25%	25%	25%

B4 Calculate Users/Cell$_{es}$

The table below gives the Users/Cell$_{es}$ calculated with the above assumptions:

TABLE 6

Users/Cell$_{es}$

Environments "e" / Services "s"	High density-in building (CBD) number of users	Urban pedestrian number of users	Urban vehicular number of users
Speech (S)	1 433	22 756	683
Simple Message (SM)	785	12 469	374
Switched Data (SD)	255	4 052	122
Medium Multimedia (MMM)	295	4 676	140
High Multimedia (HMM)	295	4 676	140
High Interactive Multimedia (HIMM)	491	7 793	234

B5 Establish traffic parameters

The following traffic parameters are considered representative of the average user in each of the environment for each of the services:

TABLE 7

Busy_Hour_Call_Attempt$_{es}$ expressed as calls in busy hour

Environments "e"	High density-in building (CBD) calls in busy hour		Urban pedestrian calls in busy hour		Urban vehicular calls in busy hour	
Services "s"						
Speech (S)	0.9		0.8		0.4	
Simple Message (SM)	0.06		0.03		0.02	
Switched Data (SD)	0.2		0.2		0.02	
Medium Multimedia (MMM)	0.5		0.4		0.008	
High Multimedia (HMM)	0.15		0.06		0.008	
High Interactive Multimedia (HIMM)	0.1		0.05		0.008	

TABLE 8

Call_Duration$_{es}$ in seconds

Environments "e"	High density-in building (CBD) seconds		Urban pedestrian seconds		Urban vehicular seconds	
Services "s"						
Speech (S)	120		120		120	
Simple Message (SM)	30		30		30	
Switched Data (SD)	156		156		156	
Medium Multimedia (MMM)	13.9		13.9		13.9	
High Multimedia (HMM)	53.3		53.3		53.3	
High Interactive Multimedia (HIMM)	180		180		180	

TABLE 9

Activity_Factor$_{es}$

Environments "e"	High density-in building (CBD) dimensionless		Urban pedestrian dimensionless		Urban vehicular dimensionless	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	0.5	0.5	0.5	0.5	0.5	0.5
Simple Message (SM)	1	1	1	1	1	1
Switched Data (SD)	1	1	1	1	1	1
Medium Multimedia (MMM)	1	1	1	1	1	1
High Multimedia (HMM)	1	1	1	1	1	1
High Interactive Multimedia (HIMM)	0.8	0.8	0.8	0.8	0.8	0.8

B6 Calculate Traffic/User$_{es}$

TABLE 10

Traffic/User$_{es}$ in call-seconds

Environments "e"	High density-in building (CBD) call-seconds		Urban pedestrian call-seconds		Urban vehicular call-seconds	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	54	54	48	48	24	24
Simple Message (SM)	1.8	1.8	0.9	0.9	0.6	0.6
Switched Data (SD)	31.2	31.2	31.2	31.2	3.12	3.12
Medium Multimedia (MMM)	6.95	6.95	5.56	5.56	0.111	0.111
High Multimedia (HMM)	8	8	3.2	3.2	0.427	0.427
High Interactive Multimedia (HIMM)	14.4	14.4	7.2	7.2	1.15	1.15

B7 Calculate Offered_Traffic/Cell$_{es}$

TABLE 11a

Offered_Traffic/Cell$_{es}$ in call-seconds

Environments "e"	High density-in building (CBD) call-seconds		Urban pedestrian call-seconds		Urban vehicular call-seconds	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	7.74×10^4	7.74×10^4	1.09×10^6	1.09×10^6	1.64×10^4	1.64×10^4
Simple Message (SM)	1.41×10^3	1.41×10^3	1.12×10^4	1.12×10^4	2.24×10^2	2.24×10^2
Switched Data (SD)	7.96×10^3	7.96×10^3	1.26×10^5	1.26×10^5	3.79×10^2	3.79×10^2
Medium Multimedia (MMM)	2.05×10^3	2.05×10^3	2.60×10^4	2.60×10^4	1.56×10^1	1.56×10^1
High Multimedia (HMM)	2.36×10^3	2.36×10^3	1.50×10^4	1.50×10^4	5.98×10^1	5.98×10^1
High Interactive Multimedia (HIMM)	7.07×10^3	7.07×10^3	5.61×10^4	5.61×10^4	2.69×10^2	2.69×10^2

The group size is selected to be equal to 7. The Offered Traffic/Cell shown below is the traffic across all 7 cells expressed in Erlangs.

TABLE 11b

Offered_Traffic/Cell$_{es}$ *Group_Size$_{es}$in Erlangs

Environments "e"	High density-in building (CBD) call-seconds		Urban pedestrian call-seconds		Urban vehicular call-seconds	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	150.5	150.5	2123.88	2123.88	31.86	31.86
Simple Message (SM)	2.75	2.75	21.82	21.82	0.44	0.44
Switched Data (SD)	15.49	15.49	245.85	245.85	0.74	0.74
Medium Multimedia (MMM)	3.98	3.98	50.51	50.51	0.03	0.03
High Multimedia (HMM)	4.58	4.58	29.09	29.09	0.12	0.12
High Interactive Multimedia (HIMM)	13.74	13.74	109.1	109.1	0.52	0.52

B8 Establish Quality_of_Service_Function$_{es}$ (QOS$_{es}$) parameters

The quality of service function for circuit switched is selected to be Erlang B with a blocking of 2%. For packet-switched services the Quality of service function is a rounding up to the next integer number.

C1 Calculate number of Service_Channels/Cell$_{es}$ required to carry Offered_Traffic/Cell$_{es}$

The number of traffic channels required in the group is presented below:

TABLE 12a

Service_Channels per Group

Environments "e"	High density-in building (CBD)		Urban pedestrian		Urban vehicular	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	164	164	2 137	2 137	41	41
Simple Message (SM)	3	3	22	22	1	1
Switched Data (SD)	23	23	259	259	4	4
Medium Multimedia (MMM)	4	4	51	51	1	1
High Multimedia (HMM)	5	5	30	30	1	1
High Interactive Multimedia (HIMM)	21	21	122	122	3	3

The number of traffic channels required in the cell is service channels in the group divided by the group size of 7 and then rounded up. It is presented below:

TABLE 12b

Service_Channels/Cell$_{es}$

Environments "e"	High density-in building (CBD)		Urban pedestrian		Urban vehicular	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	23.43	23.43	305.3	305.3	5.86	5.86
Simple Message (SM)	0.43	0.43	3.14	3.14	0.14	0.14
Switched Data (SD)	3.29	3.29	37.0	37.0	0.57	0.57
Medium Multimedia (MMM)	0.57	0.57	7.29	7.29	0.14	0.14
High Multimedia (HMM)	0.71	0.71	4.29	4.29	0.14	0.14
High Interactive Multimedia (HIMM)	3.0	3.0	17.43	17.43	0.43	0.43

C2 Determine Service_Channel_Bit_Rate$_{es}$ needed to carry Net_User_Bit_Rate$_{s}$

In this example, it is assumed that the Service_Channel_Bit_Rate$_{es}$ is equal to the Net_User_Bit Rate$_{s}$.

TABLE 13

Service_Channel_Bit_Rate$_{es}$

Environments "e"	High density-in building (CBD) (kbit/s)		Urban pedestrian (kbit/s)		Urban vehicular (kbit/s)	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	16	16	16	16	16	16
Simple Message (SM)	14	14	14	14	14	14
Switched Data (SD)	64	64	64	64	64	64
Medium Multimedia (MMM)	64	384	64	384	64	384
High Multimedia (HMM)	128	2 000	128	2 000	128	2 000
High Interactive Multimedia (HIMM)	128	128	128	128	128	128

C3 Calculate Traffic$_{es}$

Based on the number of channels needed and on the service channel bit rate, the traffic in each cell can be derived.

TABLE 14

Traffic$_{es}$

Environments "e"	High density-in building (CBD) (Mbit/s/cell)		Urban pedestrian (Mbit/s/cell)		Urban vehicular (Mbit/s/cell)	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	0.37	0.37	4.88	4.88	0.09	0.09
Simple Message (SM)	0.01	0.01	0.04	0.04	0.002	0.002
Switched Data (SD)	0.21	0.21	2.37	2.37	0.04	0.04
Medium Multimedia (MMM)	0.04	0.22	0.47	2.80	0.01	0.05
High Multimedia (HMM)	0.09	1.43	0.55	8.57	0.02	0.29
High Interactive Multimedia (HIMM)	0.38	0.38	2.23	2.23	0.05	0.05

C4 Net_System_Capabiliy_ Parameters$_{es}$ (S$_{es}$)

A number of parameters must considered in determining key elements that influence the value of Net_System_Capability$_{es}$.

C5 Calculate Net_System_Capability$_{es}$

For the purpose of this example, an improvement factor that is the expected improvement of system capabilities in the year 2010 relative to current systems is applied to current generation capabilities to obtain Net_System_Capability$_{es}$.

In this example, the following net system capabilities have been used:

TABLE 15

Net_System_Capability$_{es}$ (S_{es})

Environments "e"	High density-in building (CBD) (kbit/s/MHz/cell)		Urban pedestrian (kbit/s/MHz/cell)		Urban vehicular (kbit/s/MHz/cell)	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	67	67	67	67	67	67
Simple Message (SM)	73	73	73	73	73	73
Switched Data (SD)	73	73	73	73	73	73
Medium Multimedia (MMM)	73	73	73	73	73	73
High Multimedia (HMM)	73	73	73	73	73	73
High Interactive Multimedia (HIMM)	73	73	73	73	73	73

D1 Calculate individual F$_{es}$ component for a given direction (either uplink or downlink)

D2 Repeat process for calculation of other direction (either downlink or uplink as appropriate)

Using the traffic calculated above and the example net system capability, the F_{es} components for each direction, each environment and each direction can be derived as follows:

TABLE 16

Individual spectrum requirements (F_{es})

Environments "e"	High density-in building (CBD) (MHz)		Urban pedestrian (MHz)		Urban vehicular (MHz)	
Services "s"	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
Speech (S)	5.6	5.6	72.9	72.9	1.4	1.4
Simple Message (SM)	0.08	0.08	0.6	0.6	0.03	0.03
Switched Data (SD)	2.9	2.9	32.4	32.4	0.5	0.5
Medium Multimedia (MMM)	0.5	3.0	6.4	38.3	0.1	0.8
High Multimedia (HMM)	1.3	19.6	7.5	117.4	0.3	3.9
High Interactive Multimedia (HIMM)	5.3	5.3	30.6	30.6	0.8	0.8

D3 Calculate F_{es} for the service "s", combining uplink and downlink components

The summation gives the following results:

TABLE 17

F_{es} combining the uplink and downlink components

Environments "e"	High density-in building (CBD) (MHz)	Urban pedestrian (MHz)	Urban vehicular (MHz)
Services "s"			
Speech (S)	11.2	145.8	2.8
Simple Message (SM)	0.2	1.2	0.05
Switched Data (SD)	5.8	64.9	1.0
Medium Multimedia (MMM)	3.5	44.7	0.9
High Multimedia (HMM)	20.8	124.9	4.2
High Interactive Multimedia (HIMM)	10.5	61.1	1.5

D4 Repeat process (steps A1 through D3) for all desired F_{es}

The results have been presented in tables that show the values for all services "s" and all environments "e".

D5 Determine weighting factor (α_{es}) applicable to each individual F_{es}

If all services are assumed to have coincident busy hours, and the three environments are collocated in the same geographical area, the weighting factors are assumed to be one:

$$\alpha_{es} = 1 \text{ for all "e" and "s"}$$

D6 Determine adjustment factor (β)

To take account of the trunking inefficiency and the guard bands, an adjustment factor of 5% can be taken.

$$\beta = 1.05$$

D7 Calculate the final total $F_{Terrestrial}$ spectrum value

For this example, the summation of the components with the adjustment factor gives:

$$F_{Terrestrial} = 530.3 \text{ MHz}$$

In this example, the result shown for $F_{Terrestrial}$ is the spectrum requirement estimate for public land mobile radio service, including IMT-2000, in the year 2010 because of assumptions made in the traffic and market forecasts, (namely, that the forecasts included first and second generation public land mobile radio services, and future expected IMT-2000 services).

In must be restated that, the results shown in this example should not be considered as providing an answer to the question of future spectrum requirements for public land mobile communications services, including IMT-2000, as all figures given in this example are still under study and all environments and services that must be considered for completeness may have not been included in the example.