

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 flows³.

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.

³ An example of the application of the methodology is provided in Appendix 1.

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, $F_{\text{Terrestrial}}$ 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 ($F_{\text{Terrestrial}}$) in MHz is:

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

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

Therefore, $F_{\text{Terrestrial}}$ 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:

$F_{\text{Terrestrial}}$	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 performed⁴.

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).

⁴ 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}

A3 Establish representative cell area and geometry Units: metres

Diameter if circular omnidirectional cell geometry; radius of vertex if sectorized 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)

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_{es} = 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

$T_{es} = \text{Service_Channels/Cell}_{es} * \text{Service_Channel_Bit_Rate}_{es}$.

(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

$F_{es} = (F_{es} \text{ uplink} + F_{es} \text{ downlink})$

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 $F_{\text{Terrestrial}}$ Spectrum Value

Units: MHz

$F_{\text{Terrestrial}} = \beta \sum \alpha_{es} F_{es}$.

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 sectorized. 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: km²**

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, $\text{Cell_Area}_e = \pi R^2 = \pi D^2/4$

where: R = radius of the circle

D = diameter of the circle

For a hexagonal cell, $\text{Cell_Area}_e = (3/2) * (\sqrt{3}) * R^2$

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)