REPORT ITU-R M.2074

Radio aspects for the terrestrial component of IMT-2000 and systems beyond IMT-2000

(2005)

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1 Scope

This Report provides radio-related technical information which is relevant to the preparations of WRC-07 Agenda item 1.4. It describes technical matters related to radio aspects such as requirement for technical characteristics that are needed for the spectrum requirements calculations, values of the required radio parameters, spectrum efficiency values, and suitable spectrum range preference from a technical aspect. These matters are reflected in the process to calculate the required spectrum and to determine suitable frequency ranges for the future development of IMT-2000 and systems beyond IMT-2000 from the year 2010 onwards to fulfil the framework shown in Recommendation ITU-R M.1645.

2 Introduction

Recommendation ITU-R M.1645 defines the framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000. That framework is based on the global user and technology trends, including the needs of developing countries. Further ITU-R Recommendations will develop these concepts in more detail. This Report addresses technical matters related to radio aspects for the future development of IMT-2000 and systems beyond IMT-2000.

WRC-03 set an agenda item for WRC-07 to consider frequency-related matters for the future development of IMT-2000 and systems beyond IMT-2000 and invited ITU-R to report, in time for WRC-07, on the results of studies on the spectrum requirements and potential frequency ranges suitable for the future development of IMT-2000 and systems beyond IMT-2000.

Market trends in future systems such as the amount of traffic in the year 2010 onwards and predictions of the future technical characteristics, such as radio parameters, will be considered as important inputs for the calculation of required spectrum bandwidth and the determination of suitable frequency ranges for the future development of IMT-2000 and systems beyond IMT-2000. Market trends are detailed in Report ITU-R M.2072.

Studies in radio aspects are indispensable for the calculation of required spectrum bandwidth and the determination of suitable frequency ranges, taking into account technical trends in the year 2010 onwards. These studies should be technology neutral and include relevant technical factors such as radio environments, radio parameters, and spectrum efficiency.

3 The framework on IMT-2000, future developments of IMT-2000, and systems beyond IMT-2000

The high level framework of the future development of IMT-2000 and systems beyond IMT-2000 includes:

– future development of IMT-2000, new capabilities of systems beyond IMT-2000;

– relationship of IMT-2000, systems beyond IMT-2000, and other access systems, as described in Recommendation ITU-R M.1645.

The new capabilities are comprised of new mobile access capabilities and new nomadic/local area wireless access capabilities.

3.1 IMT-2000 and its enhancements

IMT-2000 and its enhancements are expected to continue supporting wide area mobility capability and will further address user needs for low and medium data rate services with increased spectrum efficiency. These include all kinds of speech services, SMS, low and medium multimedia and location-based services. Along with that, the initial enhancements of IMT-2000, for which standards are already being developed, will be followed by further enhancements that could increase the peak aggregate useful data rate up to approximately 30 Mbit/s under favourable circumstances. IMT-2000 and its enhancements should support low to high mobility since these systems would be mainly deployed in a cellular environment. In such an environment, both line-of-sight (LoS) and non line-of-sight (NLoS) should be considered.

3.2 New mobile access

A new mobile access is envisaged to handle low to high mobility applications with a wide range of supported data rates according to economic and service demands in multi-user environments with target peak data rates of up to approximately 100 Mbit/s with very high spectrum efficiency. It is expected that this new mobile access provides high bitrate applications, such as MMS, video streaming and super high multimedia, as well as various kinds of simultaneous medium even if their data rates do not require high speed. Since a new mobile access would be deployed in cellular and hotspot environments, low to high mobility should be supported. Both LoS and NLoS should be considered in new mobile access.

3.3 New nomadic/local area wireless access

A new nomadic/local area wireless access is predicted to handle low mobility applications with a wide range of data rates according to economic and service demands. Since it is expected that users would download or upload large-size data with high speed in a particular space, a new nomadic/local area wireless access should support peak data rates up to 1 Gbit/s in low mobility. It is anticipated that the new nomadic/local area wireless access would be deployed according to economic and service demands in isolated environments referred to as hot spots.

4 Radio access techniques (RATs) and RAT groups

4.1 Justification for RAT group approach for the spectrum requirements calculation methodology

WRC-07 agenda item 1.4 states: "to consider frequency related matters for the future development of IMT-2000 and systems beyond IMT-2000 taking into account the results of ITU-R studies…". According to the agreed guidelines the methodology is technology neutral and generic. This means that the calculations focus on "future development of IMT-2000" and on "Systems beyond IMT-2000" without addressing individual technologies separately. The methodology (Recommendation ITU-R M.1768) also has the "flexibility to handle both emerging technologies, and well characterized systems such as those defined in Recommendation ITU-R M.1457". This implies that the technical characteristics are defined on a generic level.

Furthermore, the methodology needs to:

– produce results in a manner that is easily understandable and credible;
– be implementable and verifiable within the available time scales;
– be no more complex than is justified by uncertainty of the input data.

The first conclusion is that a suitable, technology neutral and simplified approach would be to have the technologies grouped rather than having the need to handle all, (possibly tens of) technologies individually.

The second conclusion is that in order to cover the scope of agenda item 1.4, there is a requirement for the RAT groups on the "Future developments of IMT-2000" and "Systems beyond IMT-2000".

In addition there is a need to take other RAT groups into account as "service functionalities in fixed, mobile and broadcasting networks are increasingly converging and inter working" (Resolution 228, Rev.WRC-03). This means that such networks can increasingly cover overlapping service types. Therefore, services and traffic of other relevant converging technologies must be taken into account. However, the intention of WRC-07 agenda item 1.4 is not to calculate the spectrum requirements of the other technologies, but to focus on those mentioned in the agenda item 1.4 text.

The third conclusion is therefore, that the traffic distribution to the relevant other RAT groups must be taken into account, and to do so, the other relevant RAT groups need to be defined. This will be addressed in the next section.

Finally, the RAT grouping will ease the processing of input data. Traffic data originating from service and market predictions will be needed as inputs to the methodology. It can be assumed that the predicted traffic can be distributed with reasonable accuracy to relevant RAT groups but not realistically down to individual RATs, irrespective whether the distribution will be done in the processing of the market data or by the methodology itself.

Concerning the required radio parameters, defining the radio parameters for a few RAT groups is expected to be much more feasible than for tens of separate RATs.

4.2 RAT groups

The RAT groups are not technology specific and are defined as the following:

– *Group 1*: Pre-IMT systems, IMT-2000 and its enhancements.
  – This group covers the digital cellular mobile systems, IMT-2000 systems and their enhancements.
– *Group 2*: Systems beyond IMT-2000 as described in Fig. 2 of Recommendation ITU-R M.1645 (e.g., new mobile access and new nomadic/local area wireless access), but not including systems already described in any other RAT groups.
– *Group 3*: Existing radio LANs and their enhancements.
– *Group 4*: Digital mobile broadcasting systems and their enhancements.
  – This group covers systems aimed at broadcasting to mobile and handheld terminals.

The justifications for each group are the following:

Group 1: The need for this RAT group stems directly from agenda item 1.4 and Recommendation ITU-R M.1645. The proposal to include IMT-2000 and its future enhancements into a single RAT group is in line with the Recommendation ITU-R M.1645 expectation that "there will be a steady and continuous evolution of IMT-2000 to support new applications, products and services", which is also confirmed by ongoing standardization activities.

Pre-IMT systems are included in RAT Group 1 for the following reasons:

– Pre-IMT systems cover a subset of the IMT-2000 services and therefore the corresponding traffic can be aggregated with IMT-2000 traffic.
– Most bands for pre-IMT-2000 technologies are identified for IMT-2000, and as such those bands will be taken into account in the estimations.
– Presence of pre-IMT systems can technically be taken into account by appropriate adjustments in radio parameters of RAT Group 1, e.g. the spectral efficiency, so that the value of each radio parameter is *representative* for all RATs in the group.
– The time span for the market data is beyond 2015, when significance of the pre-IMT systems may be decreasing in some countries or Regions. However, there will be differences in different countries and Regions with respect to the licensing, market

development, migration to IMT-2000 etc. Covering such questions is not within the scope of WRC-07 agenda item 1.4.

Group 2: The need for this RAT group stems directly from agenda item 1.4 and Recommendation ITU-R M.1645. Systems beyond IMT-2000 will cover new mobile access and new nomadic/local area access capabilities. The motivation for a separate RAT group compared to Group 1 is that systems beyond IMT-2000 are expected to have significantly differing RAT characteristics and capabilities than IMT-2000 and its future developments.

Group 3: The need for taking this RAT group into account comes from Recommendation ITU-R M.1645. IMT-2000 and systems beyond IMT-2000 are identified to have a relationship with RLANs. It can be expected that existing RLANs will share a portion of the relevant total traffic. WRC-03 identified globally common spectrum for RLANs, which allows considerable capacity for such networks.

Group 4: The need for taking this RAT group into account comes also from Recommendation ITU-R M.1645 and the fact that new mobile broadcasting services based on technologies such as IP datacast are expected to emerge in the coming years. These services will provide point-to-multipoint (P-MP) services that cover part of the total mobile market.

4.3 Usage of RAT groups and radio parameters

4.3.1 Usage of RAT groups

The handling of each RAT group is identified in the spectrum calculation methodology. In the spectrum calculation methodology, there are two stages that are related to RAT groups. The first is the stage for distributing the calculated traffic amount to possible RAT groups. The second is the stage for calculating the required spectrum from amount of distributed traffic for future development of IMT-2000 and systems beyond IMT-2000. Thus, there are two types of RAT groups in the spectrum calculation methodology:

Type a): RAT group for which the spectrum requirements are to be calculated (this type of RAT group is considered through the whole stages in the spectrum calculation methodology);

Type b): RAT group which takes part of the total predicted traffic (this type of RAT group is considered only in the stage of traffic distribution among RAT groups).

RAT Groups 1 and 2 are considered as the first type in the spectrum calculation methodology. Required spectrum is calculated for RAT Groups 1 and 2. The spectrum that has already been identified at WARC-92 and WRC-2000 should be subtracted from the overall required spectrum for future development of IMT-2000 and systems beyond IMT-2000 in order to avoid a double count of the spectrum demand.

RAT Groups 3 and 4 are considered as the second type in the spectrum calculation methodology, for which only the amounts of traffic that are distributed to them are considered.

The traffic distribution to RAT groups needs to consider the availability and capabilities of the RAT groups in each service environment. Market predictions can provide a first indication which service categories each RAT group can support. The final distribution of traffic to RAT groups may be derived in the methodology by considering both market data and radio characteristics.

4.3.2 Usage of radio parameters for each RAT group

The full set of required radio parameters needs to be provided for the RAT Groups 1 and 2. For Groups 3 and 4 the parameters related to the spectrum demand calculation are not required. However, parameters needed in the distribution of traffic are required to the extent necessary to enable distribution of traffic to RAT groups.

5 Radio aspects relevant to spectrum requirements

5.1 General consideration

It is expected that IMT-2000 and its enhancements will continue to operate in the bands identified by WARC-92 and WRC-2000 by the time the systems beyond IMT-2000 are deployed. To fulfil the framework for systems beyond IMT-2000, it is envisaged that further spectrum may be needed in addition to that identified for IMT-2000 at WARC-92 and WRC-2000. The new capabilities for mobile access and nomadic/local wireless access have different objectives for mobility and bit rate, for which different frequency ranges may be appropriate. For new mobile access capability, data rates higher than IMT-2000 may result in a smaller cell size. This would increase the number of base stations required and hence the deployment cost. It would therefore be preferable for the frequency bands that support higher bit rate with the wide area mobility capability of systems beyond IMT-2000 to be reasonably close to the bands already identified for IMT-2000. There is also a need to address, in accordance with Resolution 228 (Rev.WRC-03), the usage of frequencies below those identified for IMT-2000 in RR No. 5.317A for the future development of IMT-2000 and systems beyond IMT-2000, notably assessing their advantages and disadvantages. Those studies should take into consideration, in particular, the needs of developing countries and countries having large territories and low teledensities. By including, for example, use of frequencies below those currently identified for IMT-2000 and use of the satellite component of IMT-2000 for suitable coverage of these countries.

IMT-2000 is already being enhanced (e.g., towards IP-based networks and to offer bit rates up to over 10 Mbit/s under favourable conditions). These initial enhancements, for which standards are already being developed, will be followed by further enhancements that could increase the peak aggregate useful data rate up to approximately 30 Mbit/s under favourable conditions. IMT-2000 and its enhancement should support low to high mobility since these systems are mainly to be deployed in the cellular environment. A new mobile access is envisaged to handle a wide range of supported data rates according to economic and service demands in multi-user environments, with target peak data rates of up to approximately 100 Mbit/s. Low to high mobility should be supported since a new mobile access would be deployed both in cellular and hotspot environments. A new nomadic/local area wireless access is predicted to handle wide range of supported peak data rates up to 1 Gbit/s. Low mobility should mainly be supported since the new nomadic/local area wireless access would be deployed in a hotspot environment.

In Recommendation ITU-R M.1390, radio operation environments have been defined as areas exhibiting common propagation conditions. The radio operation environments were categorized into four environments:

– rural;

– suburban;

– urban;

– dense urban.

Since the radio operation environments considered only IMT-2000, common service conditions were exhibited in each radio environments. In the future development of IMT-2000 and systems beyond IMT-2000, however, environments that are defined as areas exhibiting common service conditions would be important. Therefore, service usage patterns and teledensity were introduced for the spectrum calculation methodology.

The current terminology is briefly introduced in the following.

The service usage patterns are defined as areas representing common usage conditions and can be classified to:

– home;

– office;

– public area.

The teledensity is defined as area representing locality and population density and can be classified to:

– dense urban;

– suburban;

– and rural.

Service usage patterns and teledensity should be used as combined environments that can be redefined as service environments. Service environments can be defined as areas exhibiting common service conditions.

The number of service environments can be reduced taking into account the commonality and nature of service application usages and six classes are defined:

– dense urban/home;

– dense urban/office;

– dense urban/public area;

– suburban/home;

– suburban/office and public area;

– rural.

The radio environments defined as areas representing common propagation conditions should separately be treated from service environments since typical deployment scenario and technical requirements for radio access technique group (RAT group) may be discussed from a technical view point.

The radio environments may be categorized into:

– macro cell;

– micro cell;

– pico cell;

– hot spot.

The definition of the radio environment is the most relevant element of those described above. As such the Radio environments will be addressed in detail in § 6 of this Report.

5.2 Radio parameters

Section 5.2.1 describes the required parameters which are necessary to calculate the spectrum needs. Tables 1a to 1d show also the initial recommended values for the parameters. The justifications for the values can be found in Annexes 2, 3, 4 and 5.

Section 5.2.2 lists additional parameters which have been input by various proponents. These additional parameters provide additional radio related information. The additional parameters may provide additional assistance in calculating not only spectrum requirements, but propagation characteristics, radio characteristics related to services, and technical characteristics. Therefore they may be useful in further work on radio aspects, even though they are not needed in the current spectrum requirement calculation methodology, and thus not relevant for the WRC-07 related preparatory work.

Additional parameters may be assigned to three categories:

– Propagation (P);

– Service (S);

– Technical (T).

Rational of the categorization is given in § 5.5.

Most of the values for the additional parameters are still undefined and the values can be considered at the later stages of the work.

5.2.1 Radio parameters required for spectrum calculation methodology

These parameters are used in the spectrum requirement calculation methodology and are briefly defined in the following sub sections. The parameters and the initial recommended values for the parameters are shown in Tables 1a to 1d. The justifications for the values are shown in the Annexes to this Report. One parameter value per radio environment and RAT group is considered. The parameters should represent the RATs belonging to the group in a reasonable manner.

TABLE 1a

Required radio parameters for RAT Group 1*

Attribute	RAT Group 1				
	Value				
	Unit	Macro cell	Micro cell	Pico cell	Hot spot[(1)]
Application data rate	Mbit/s	1	1	2.5	–
Supported mobility classes		Stationary/ pedestrian, low, high,	Stationary/ pedestrian, low	Stationary/ pedestrian	–
Carrier bandwidth (CBW)	MHz	Up to 5	Up to 5	Up to 5	–
Guardband between operators	MHz	0	0	0	–
Minimum deployment per operator per radio environment (where *n* = 1 or 2)	MHz	n*CBW	n*CBW	n*CBW	–
Number of overlapping network deployment	#	5	5	5	–
Possibility to flexible spectrum usage (FSU)	Boolean	No	No	No	–
FSU margin	Multiplier	1	1	1	
Area spectral efficiency	bit/s/Hz/ cell	0.4	0.4	0.7	–
Area spectral efficiency for multicasting	bit/s/Hz/ cell	0.2	0.2	0.4	–

TABLE 1a (*end*)

Attribute	RAT Group 1				
	Value				
	Unit	**Macro cell**	**Micro cell**	**Pico cell**	**Hot spot**(1)
Typical operating frequency	MHz	< 2 700	< 2 700	< 2 700	–
Support for multicast	Boolean	Yes	Yes	Yes	–

* The values presented in Table 1a are not applicable to the scenario at large areas with low teledensity coverage. These values should be further estimated.

(1) Hot spot radio environment is not relevant for RAT Group 1.

TABLE 1b

Required radio parameters or RAT Group 2

Attribute	RAT Group 2				
	Value				
	Unit	**Macro cell**	**Micro cell**	**Pico cell**	**Hot spot**
Application data rate	Mbit/s	50	100	1 000	1 000
Supported mobility classes		Stationary/ pedestrian, low high	Stationary/ pedestrian, low	Stationary/ pedestrian	Stationary/ pedestrian
CBW	MHz	25-50	25-100	100	100
Guardband between operators	MHz	0	0	0	0
Minimum deployment per operator per radio environment	MHz	50-100	50-100	100	100
Number of overlapping network deployment(1)	#	1-4	1-4	1-4	1-4
Possibility to FSU	Boolean	Yes	Yes	Yes	Yes
FSU margin	Multiplier	1	1	1	1
Area spectral efficiency	bit/s/Hz/cell	2-4	2-5	3-6	5-10
Area spectral efficiency for multicasting	bit/s/Hz/cell	1-1.5	1-2.5	1.5-3	2.5-5
Typical operating frequency	MHz	< 6 000	< 6 000	< 6 000	< 6 000
Support for multicast	Boolean	Yes	Yes	Yes	Yes

(1) This parameter needs to be determined during the estimation process.

TABLE 1c

Required radio parameters for RAT Group 3

Attribute	RAT Group 3				
	Value				
	Unit	Macro cell	Micro cell	Pico cell	Hot spot
Application data rate	Mbit/s	–	–	50	100
Supported mobility classes		–	–	Stationary/ pedestrian	Stationary/ pedestrian
Support for multicast (yes = 1, no = 0)		Yes			

NOTE 1 – Macro cell and micro cell are not considered for RAT Group 3.

TABLE 1d

Required radio parameters for RAT Group 4

RAT Group 4		
Attribute	Unit	Macro cell
Application data rate	Mbit/s	2
Supported mobility classes		All (Stationary/pedestrian, low and high)

NOTE 1 – Only macro cell is considered for RAT Group 4.

5.2.1.1 Application data rate

This parameter is used by methodology for distributing the traffic. It represents a bit rate which is available for applications in a particular cell type. It may be smaller than the available peak bit rate and may not be available throughout the whole cell.

5.2.1.2 Supported mobility classes

The maximum velocity is determined by Doppler frequency and handover initiation and execution times. For macro cells the Doppler frequency limits the velocity and the cell edge user data rate will decrease once the velocity exceeds a certain limit. This limit is around 120 km/h for IMT-2000.

In particular, for small cells, the minimum time a user stays in a cell between handovers needs to be significantly longer than the handover initiation and execution time. Therefore for small cells, the cell size limits the maximum supported velocity.

For Recommendation ITU-R M.1768, this parameter will affect the distribution of traffic to the radio environments and RAT groups. Traffic is classified into mobility classes.

The methodology defines the mobility classes (MC) stationary/pedestrian, low and high. These mobility classes correspond with the following velocities:

– Stationary/pedestrian (0-4 km/h)

– Low (> 4 km/h and < 50 km/h)

– High (> 50 km/h)

5.2.1.3 Carrier bandwidth (MHz)

The carrier bandwidth is used in the spectrum requirements method to adjust the final spectrum requirements. The calculated spectrum requirement for each RAT group is an integer multiple of the carrier bandwidths. The carrier bandwidth is equal to carrier separation thus it already includes a guardband between carriers inside one operator network. The carrier bit rate should support the promised achievable bit rate of the RAT group. Inside RAT group the carrier bandwidth may be different for different RATs and the parameter value should represent the largest RAT individual carrier bandwidth, in order not to under estimate the spectrum demand.

5.2.1.4 Guardband between operators (MHz)

This parameter is determined by technology specific characteristics like the filter properties and the level of tolerated adjacent channel interference. In case some techniques require guardband between the spectrum allocations of different operators this is added in the calculated spectrum requirement. Guardbands required between carriers of the same operator are assumed to be contained in the CBW parameter.

5.2.1.5 Minimum deployment per operator per cell type (MHz)

This is defined to be a minimum amount of spectrum needed for one operator to build a practical working network per radio environment, including e.g. the needed frequency reuse and guardband between carriers of one operator. Therefore this parameter is typically an integer multiple of the carrier bandwidths.

5.2.1.6 Number of overlapping network deployments

In the spectrum requirement calculation method the number of operators in the same geographical area is used to calculate the total required spectrum. The capacity requirement of one RAT group to serve the total traffic of this RAT group, calculated according the spectrum requirement method, is distributed equally to all these operators (i.e. deployments). This enables to take the minimum needed spectrum for deployments and guard spectrum bands between operators into consideration.

5.2.1.7 Possibility to FSU (Boolean)

The spectrum requirement method provides the possibility of taking into account time-sharing of spectrum by different RAT groups. A common spectrum requirement is calculated for all RAT groups that support FSU. Thus, if the characteristic RATs inside the RAT group in the spectrum allocation area can utilize FSU, this parameter is true.

5.2.1.8 FSU Margin

FSU Margin is needed to indicate the gain from the possible flexible spectrum use. It is a multiplier, and in the case of no FSU it should be 1. If the FSU is possible in the RAT group then the FSU margin is greater or equal to 1.

5.2.1.9 Area spectral efficiency

The area spectral efficiency is used in the spectrum requirement calculations to convert the capacity requirements in terms of bit/s/Hz/cell to the spectrum requirements. The area spectral efficiency factors should be measured below the IP layer and/or above L2. The spectral efficiency includes all RAT specific overheads, retransmissions load, scheduling, etc. Even though the spectral efficiency might be the same for several teledensities, it is possible that spectral efficiency may also vary between teledensities, thus the spectral efficiency for different teledensities may be needed.

5.2.1.10 Area spectral efficiency for multicasting (bit/s/Hz/cell)

The spectrum efficiency is generally different for multicasting than for "normal" point-to-point communication. If there is support for multicast, values for this parameter have to be provided.

5.2.1.11 Typical operating frequency

This parameter is not needed by the spectrum requirement method directly, but will be essential in interpreting the spectrum demands that will be the outcome of calculations, and in the process of identifying candidate frequency bands. This parameter needs to reflect the assumptions on propagations conditions that have an effect on the cell radius and spectral efficiency parameters, for example. It is suggested that the suitable frequency range should be below 6 GHz.

5.2.1.12 Support of multicast

The parameter is meant to indicate the capability of this RAT group to support P-MP mode. For this multicast mode, the methodology assumes that the capacity requirement is independent of the number of serviced users.

5.2.2 Additional parameters

The additional parameters may be utilized for spectral efficiency calculations.

5.2.2.1 Path loss factor

Mean path loss is calculated by a function of distance, d. The function is simply presented as $K + \chi_d \log(d)$, where K and χ_d are propagation law constant including dependency to carrier frequency and path-loss exponent for typical radio environments, respectively. Pathloss should be taken into account for determining cell area to be covered and suitable frequency range. Variation in received signal level should be considered in calculating the average spectrum efficiency.

5.2.2.2 Slow fading distribution

Slow fading is due to shadowing and scattering. The slow fading variation is considered to be log-normally distributed with a standard deviation of σ dB in typical radio environments. Slow fading distribution should also be taken into account to discuss cell deployment and requirement for handover.

5.2.2.3 Fast fading distribution

Fast fading is due to multipath propagation. The fast fading variation is typically Rayleigh distributed or Rice distribution. Supported maximum Doppler frequency is determined by supported terminal velocity and suitable frequency range to be operated. Requirement for radio packet size is much smaller than coherence time which is characterized by fading variation. Techniques to compensate degradation due to fading variation should be taken into account to determine supported peak bit rate and spectrum efficiency.

5.2.2.4 Service channel bit rate

Service channel bit rate is determined for each service category. Supported service channel bit rate mainly depends on propagation characteristics.

5.2.2.5 Target deployment environment

Target deployment environment of each radio environment should be discussed. Location of base station, surrounding obstacles, mobility, and etc. affect propagation characteristics. The applicability of highly efficient transmission technology depends on propagation characteristic. Cell structure (multi-cell or isolated area) may determine the requirements for handover.

Deployment scenario is considered to discuss cell area, supported bit rate and spectrum efficiency, required carrier bandwidth, required number of channels, required guardband, and traffic distribution within RAT group.

5.2.2.6 Support of horizontal and vertical handover

Requirements for handover between cells of the same RAT group and handover between different RAT groups are determined taking into account the deployment scenario.

5.2.2.7 Modulation scheme

The process of varying certain parameters of a digital code signal (carrier) may be achieved, through digital signal processing, in accordance with a digital message signal, to allow transmission of the message signal through IF and RF channels, followed by its possible detection.

Modulation can be categorized as data modulation and spreading modulation. Data modulation explains how data can be mapped to the in-phase branch and quadrature-phase branch. Spreading modulation explains how in-phase branch data and quadrature-phase branch data are spread by channelization code and scrambled by scrambling code

5.2.2.8 Multiple antennas

Applicability of multiple antenna techniques to increase capacity, bit rate and spectrum efficiency should be considered.

5.2.2.9 *C*/*N* requirement for peak bit rate

Required *C*/*N* ratio to achieve transmission with peak bit rate.

5.2.2.10 Channel coding and interleaving

Describes the requirements for channel coding and interleaving under the radio environment and spectrum efficiency and quality requirements of the various services.

5.2.2.11 Delay parameter of propagation

Delay spread and delay per path.

5.2.2.12 Doppler spectrum

Mobility characteristics and frequency define the Doppler spectrum. For example, maximum Doppler shifts range from approximately 50 Hz to 1.2 kHz when the carrier frequency is 5 GHz.

5.2.2.13 Multiple access technology

Describes the requirements for multiple access technology that has major impact on the design of the radio interface.

5.2.2.14 Network topology

Network structure (cellular, ad-hoc/multi-hop, etc.). Hexagonal cellular/circular area/irregular area.

5.2.1.15 Achievable cell edge user bit rate (bit/s)

This parameter should be given for the deployment of hot spot (isolated cells), where typically higher values are achievable, and for other, non-isolated cells, where multiple cells together provide geographical coverage. The values can be determined based on radio link and system simulations (literature/new simulations).

This parameter is defined in the network taking the propagation conditions, interference conditions and network overheads into account and is thus lower than the peak bit rate.

The peak data rate achieved in cellular systems is a function of a number of factors that include propagation conditions and interference. These two factors heavily influence the performance of any cellular system.

There are two kinds of interference in cellular systems; intracell interference and intercell interference. The former is always present, but the latter depends upon the multiple access method. Intercell interference can be reduced by sectorization and/or frequency reuse.

In a highly loaded system, the interference will reduce the peak bit rates achieved, especially at the cell edge, but the extent of this depends upon the numbers of sectors and frequency reuse scheme employed.

The available cell edge user data rate is in any event implicitly dependent on how the operator chooses to distribute the available peak sector data rate amongst users in the sector or cell and how this translates to the peak data rate achieved by individual users at any instant in time given the varying traffic conditions over time.

5.2.2.16 Spatial channel characteristics

Angle spread, angles of departure, angle of arrival, and power azimuth spectrum per path, etc.

5.2.2.17 Supported peak bit rate (Mbit/s)

From the technical point of view, the supported peak bit rate $B_{rat,\,p}$, is determined by taking into account the radio propagation characteristics and cell deployment. Applicability of highly efficient transmission techniques such as adaptive modulation or multi antenna transmission should be considered. The typical peak bit rate currently achieved in RAT Group 1 is approximately 14 Mbit/s. It should also be noted that target peak bit rates for RAT Group 2 are approximately 100 Mbit/s and 1 Gbit/s with high mobility and low mobility, respectively, as described in Recommendation ITU-R M.1645. From the service point of view, the supportable service type or application usage scenario depends on $B_{rat,\,p}$.

5.2.2.18 Radio frame size

Required radio frame size, $\beta_{rat,\,p}$, is determined by taking into account the propagation characteristic. $\beta_{rat,\,p}$ should be much shorter than the coherence time in order for the radio channel to be quasi-static within a frame. The coherence time depends on mobility and carrier frequency. Typical radio frame size in RAT Group 1 is 2 ms. Since the bit rate in RAT Group 2 is much higher than that in RAT Group 1, the radio frame size is expected to be much shorter.

5.2.2.19 One-way air interface delay (ms)

This parameter is assumed to exclude the core network delay and in packet-based systems is measured from on the IP layer to IP layer. Thus the delay includes the queuing and transmission times. For circuit switched (CS) services the air interface delay only includes delays on layer 1 and 2.

5.3 Spectrum efficiency

5.3.1 Area spectral efficiency

For each RAT group an area spectral efficiency matrix needs to be estimated. The area spectral efficiency of each RAT group in each radio environment can be estimated using average spectrum efficiency, which is determined taking into account propagation characteristics, interference considerations and typical deployment scenarios and technical requirements for technical characteristics.

In the spectrum calculation methodology, the required spectrum in each radio environment for each RAT group is calculated by using area spectrum efficiency.

The area spectral efficiency is calculated from the mean data throughput achieved over all users, which are homogeneously distributed in the area of the radio environment, on the IP layer for packet switched services, and on the application layer for circuit switched services, for fully loaded radio networks.

The recommended area spectral efficiency values for both RAT Group 1 and 2 are shown in Tables 1a and 1b.

5.3.2 Required spectrum calculation

Required unadjusted spectrum $F_{rat,p}$ in radio environment P (Re*p*) for RAT Group *rat* is calculated by dividing the required system capacity per cell area by net system capability as,

$$F_{rat,p} = C_{rat,p} / \eta_{rat,p}$$

5.3.3 Technical issues affecting spectral efficiency

Multiple antenna techniques at the base station transmitter can be used to enhance performance metrics such as throughput, peak rate, and coverage by providing for example diversity gain, spatial multiplexing (SM), and/or spatial division multiple access (SDMA) gain. Diversity provides multiple independent realizations of a fading channel to improve link performance. Under SM, parallel data streams are transmitted using the same spectral resources to a single user to improve its link rate. And under SDMA, the base station transmits simultaneously to multiple users using the same spectral resources but over separate spatial channels to increase the system throughput. For further details see Report ITU-R M.2040.

Spatial multiplexing

SM requires multiple antennas at the receiver in order to demodulate the parallel data streams. Using multiple transmit and receive antennas per terminal, higher spectral efficiencies can be achieved.

For example, by increasing spectral efficiencies from 1 to 4 bit/s/Hz/cell, a 100 Mbit/s peak data rate can be achieved in 25 MHz bandwidth or 100 MHz bandwidth can achieve a 400 Mbit/s peak rate.

Example simulation results are shown in Annex 5.

Spatial division multiple access

While SM is effective for increasing the peak data rate per user, SDMA is more effective for increasing the spectral efficiency in terms of throughput per cell. Using the same antenna resources, SDMA has a much higher system-level throughput than SM. However, the peak rate per user under SDMA does not increase compared to the single-antenna transmitter case.

Spatial multiplexing using MIMO systems

An explanation and schematic of a multiple input multiple output (MIMO) system is shown in [Gesbert *et al*, 2003]. MIMO systems provide a substantial increase in spectrum efficiency and hence capacity [Foschini, 1996; Foschini *et al*, 1998]. In a MIMO system a high rate data stream is converted to several low rate streams which are then transmitted over multiple transmit antennas. At the receiver the spatial interference from the received data is removed, and the bit streams are multiplexed back to the high rate stream.

Increases in spectral efficiency can be shown to be linear with respect to the number of transmit and receive antennas, e.g. if the spectrum efficiency of the coding and modulation scheme employed per stream is say 1.5 bit/s/Hz and four receive and transmit antennas are used, then the overall spectral efficiency is (4 x 1.5 bit/s/Hz =) 6 bit/s/Hz.

5.4 Technical issues influencing spectrum range preferences

Constraints to future spectrum availability are of both a technical and regulatory nature. From the technical and economical point of view, the available spectrum has to enable the future systems to reach the desired target characteristics. Currently there are research activities targeted towards defining such technologies that can fulfil the requirements of the ITU for the both new capabilities of systems beyond IMT-2000, namely the “new mobile access” and the “new nomadic/local area wireless access”, as they are presented in Recommendation ITU-R M.1645.

Technical constraints are primarily based on the requirements and target characteristics for the new system. The high level requirements result in several requirements or preferences on the possible frequency bands and spectrum range.

5.4.1 Target peak data rates

The new radio access, covering the full range of capabilities of systems beyond IMT-2000, is envisaged to support a wide range of data rates according to economic and service demands in multi-user environments. There will be target peak data rates of up to approximately 100 Mbit/s for high mobility such as mobile access and up to approximately 1 000 Mbit/s for low mobility such as nomadic/local wireless access.

The new very high bit rate requirements suggest that considerably wider bandwidths than today will be required. Thus, spectrum ranges allowing only relatively narrow bands, similar to current cellular bands should be out of prime consideration. Advanced techniques (hierarchical cell structures, adaptive antennas, MIMO) aim at increasing the spectrum efficiency. Flexibility and sharing (between user and/or systems) will be taken into account to improve spectrum efficiency. But even then, peak data rates of 100 Mbit/s and 1 000 Mbit/s require much wider bandwidths than the current systems have. It is important that sufficient spectrum is allocated.

It may be possible to reach considerably higher overall spectrum efficiency than today’s technologies, but even under the most optimistic assumptions discussed today and in favourable radio reception conditions, the 1 Gbit/s transmission rate may require bandwidth in the order of 100 MHz or more. Active research work is needed before any spectrum efficiency numbers can be defined.

5.4.2 Target grade of mobility

User equipment speed ranges, which vary from pedestrian speed for low mobility to 250 km/h for high mobility as for example high-speed trains are under discussion.

There is a trade-off between bandwidth and mobility. Due to mobility of the user and multipath propagation, fast fading phenomena are created. The radio channel remains quasi-static in a physical layer frame when the maximal frame duration time t_{frame} is much shorter then the coherence time t_c, which depends on the user equipment speed v and carrier frequency f. The channel transmission parameters are estimated once per t_{frame}.

$$t_{frame} << t_c = \frac{1}{\nu} \cdot \frac{\lambda}{2} = \frac{1}{2 \cdot \nu} \cdot \frac{c_0}{f}$$

Figure 1 illustrates the dependency of coherence time t_c on the carrier frequency f for user equipment speed v varying between 50 km/h and 250 km/h.

FIGURE 1

Dependency of coherence time t_c from the carrier frequency f for user equipment speed ν varying between 50 km/h and 250 km/h

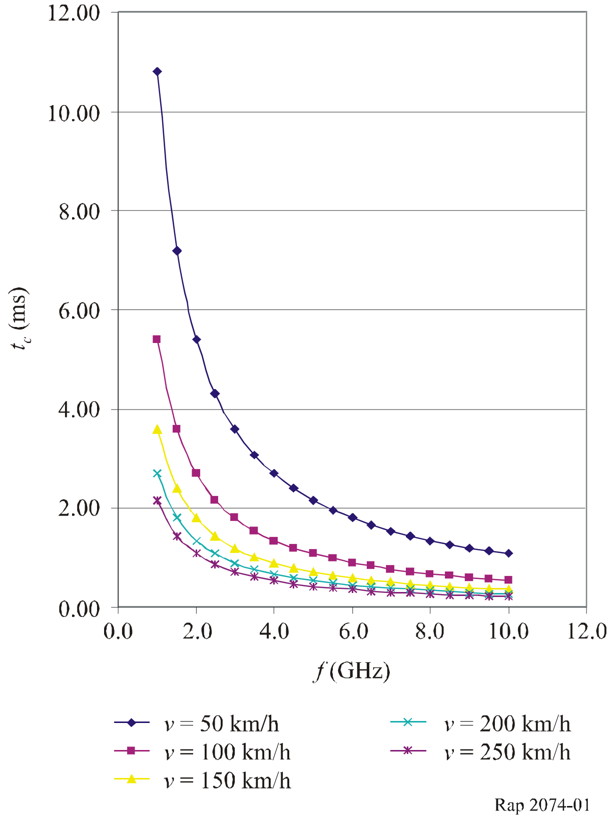


Figure 1 shows that the coherence time t_c for carrier frequency f = 2GHz varies between 5.4 ms for 50 km/h and 1.08 ms for 250 km/h. For carrier frequency f = 6GHz, the coherence time t_c varies between 1.80 ms for 50 km/h and 0.36 ms for 250 km/h.

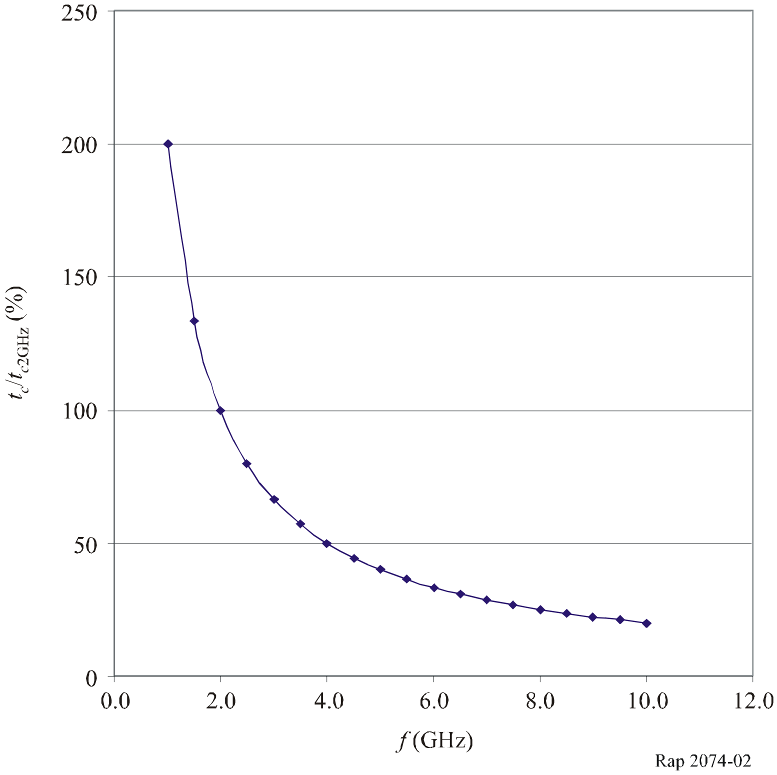
We can also compare the coherence time at different frequencies with the coherence time at carrier frequency f = 2 GHz. The frequency f = 2 GHz can be considered as reference frequency for the IMT-2000 band 1 920-1 980 MHz paired with 2 110-2 170 MHz.

Figure 2 shows the change of coherence time relative to the coherence time at carrier frequency f = 2 GHz. This relation is independent from velocity of user equipment, if the mobile speed is the same at both carrier frequencies.

We can see that the coherence time at 6 GHz is only 33% of the time at 2 GHz.

FIGURE 2

The change of coherence time relative to the coherence time at carrier frequency f = 2 GHz at the same mobile speed



As mentioned above, the radio channel remains quasi-static when the maximal frame duration time t_{frame} is much shorter than the coherence time t_c. This means, to achieve stable and reliable transmission parameters with a stable channel estimation, the frame duration must adapt to coherence time at a given carrier frequency.

The t_{frame} is considered as the time between two channel estimation points.

To fulfil the requirement that t_{frame} must be much shorter[1] than the t_c, let us assume that

$$t_{frame} = 0.1 * t_c$$

The assumption that t_{frame} is 10% of t_c is for our example calculations only – what is important are the strong dependencies. With this assumption we can say that the t_{frame} for carrier frequency f = 2 GHz varies between 0.54 ms for 50 km/h and 0.11 ms for 250 km/h. For carrier frequency f = 6 GHz, the t_{frame} varies between 0.18 ms for 50 km/h and 0.036 ms for 250 km/h.

The carrier frequency dependent frame length limits the payload size that is transportable by a frame.

The generic frame with its structure as shown in the Fig. 3 has the following tasks:

– time structuring of the radio interface;

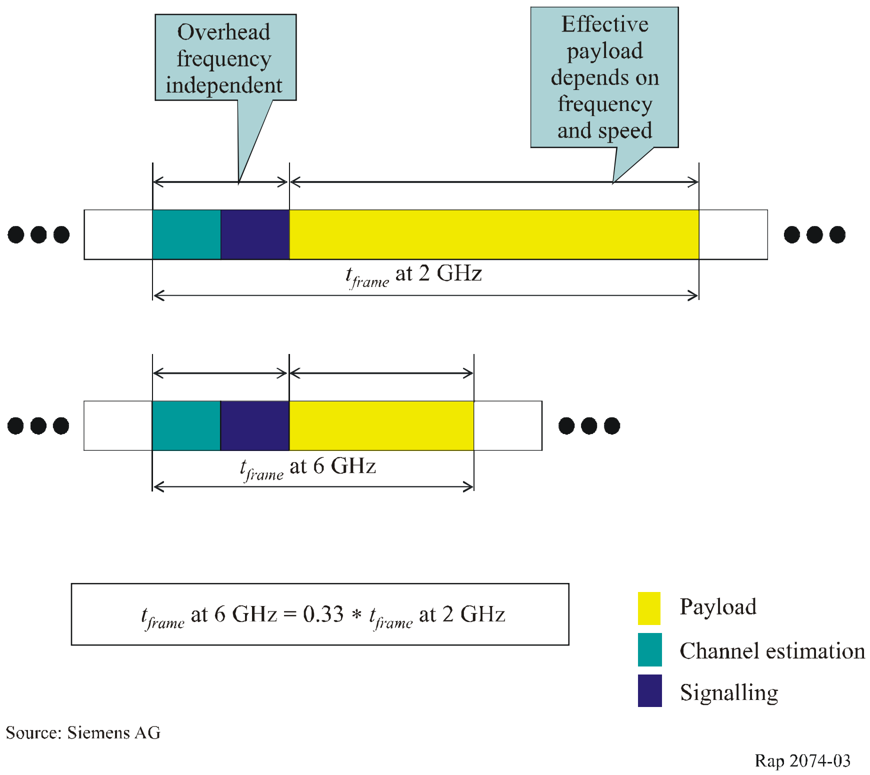
---

[1] UMTS has the slot length of 10 ms/15 = 666.7 µs, 250 km/h corresponds to 69.44 m/s, at 2 GHz the wave length is equal to 15 cm. Hence a mobile station at 250 km/h during a slot of 666.7 µs moves a distance of 4.6 cm, which corresponds to approximately 30% of a wave length. Therefore at this velocity it is not really certain that the channel estimation is still accurate enough when the channel has already evidently changed. If the channel cannot be seen as stable during the transition, tracking algorithms are necessary.

– update of channel estimation, power control and feedback information with respect to time-varying radio channel parameters;
– distinction between signalling and user date;
– synchronization purposes;
– transportation of payload.

FIGURE 3

Frame structure

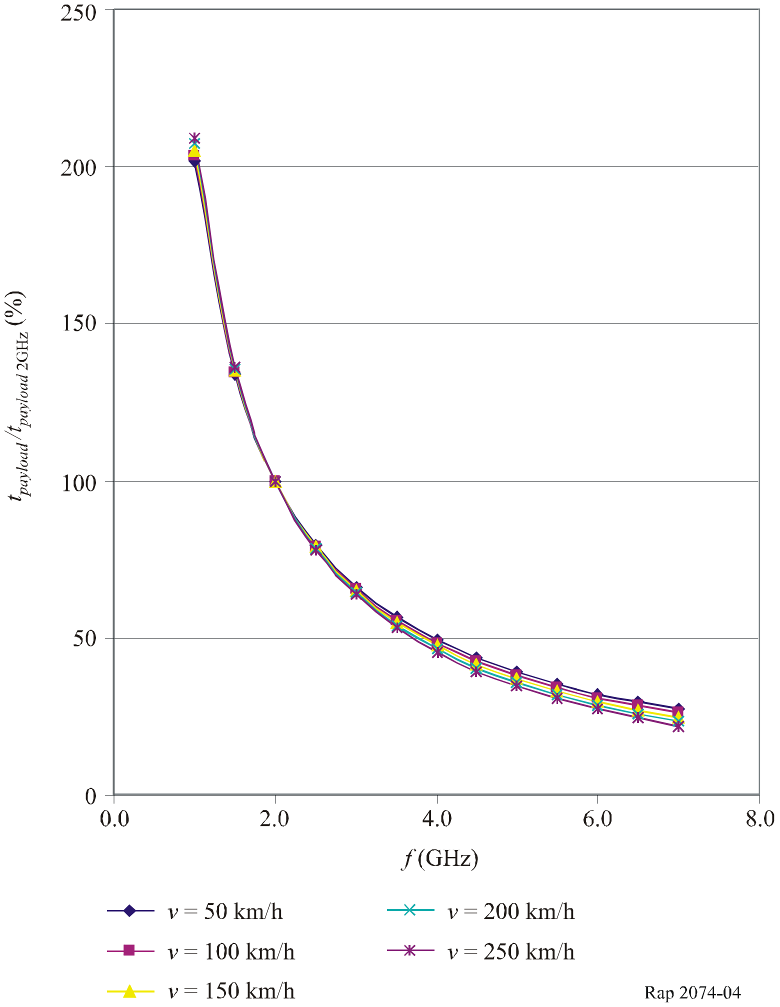


Usually the frame overhead has a constant length due to the necessary signaling overhead. Frequency and speed dependent changes of the frame length are on the expense of available time for payload. Let us assume that in the future radio interface systems the overhead time $t_{overhead}$ will vary from approximately 1/3 to 1/7 of t_{frame} dependent on frame type (similar to the range found with UMTS). In our calculations the t_c at 250 km/h and 6 GHz is equal to 0.36 ms and the resulting t_{frame} is 0.1 $*$ 0.36 = 0.036 ms. A best guess on the value of $t_{overhead}$ is ¼ of t_{frame} at 250 km/h and 6 GHz. This results in the $t_{overhead}$ = 0.009 ms, which remains constant for all frequencies and velocities in our model calculations.

Figure 4 shows the change of payload relative to carrier frequency of 2 GHz and depending on carrier frequency and user equipment speed.

FIGURE 4

Change of payload per frame relative to carrier frequency of 2 GHz

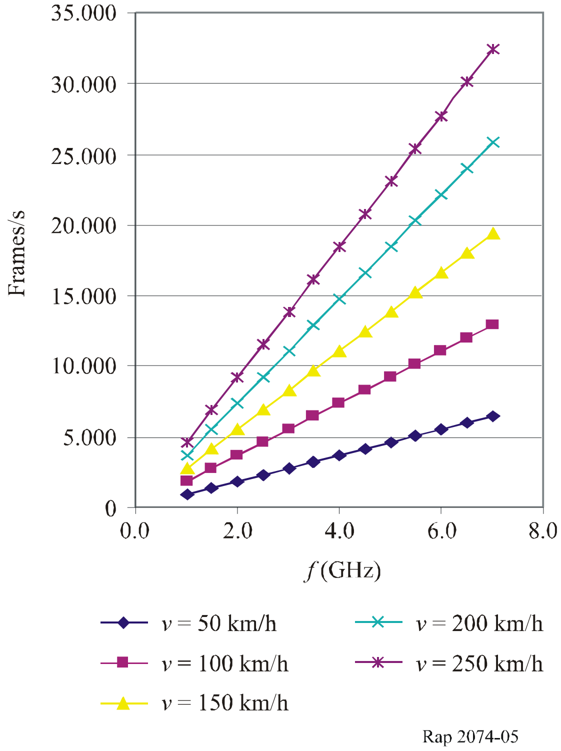


The payload per frame at carrier frequencies of 4 GHz and 6 GHz declines to approximately 45% and 30% respectively of the payload at 2 GHz.

In the next step the dependency of overhead and payload on carrier frequency and velocity in the time period of 1 s can be calculated. The number of possible frames per second is illustrated in Fig. 5. Due to the fact that with increasing speed the coherence time and here from resulting maximum possible frame time decrease, the number of possible frames per second is increasing significantly with speed and frequency.

FIGURE 5

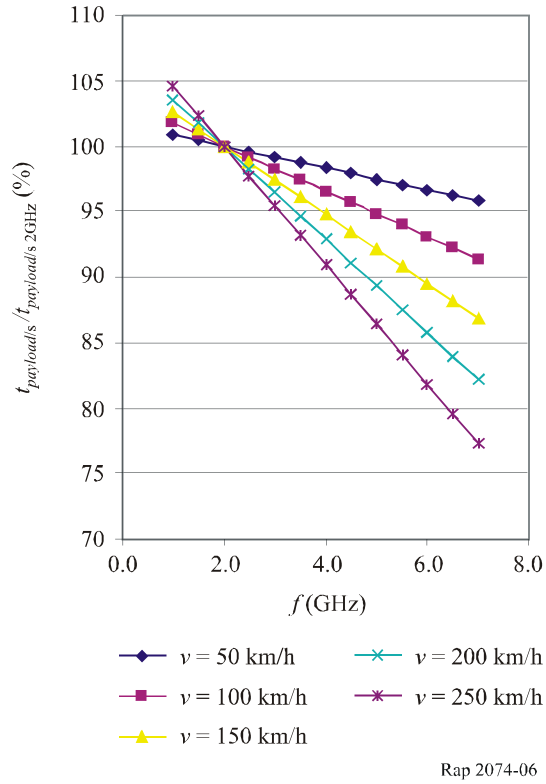
The number of possible frames per second



Since the signalling overhead per frame must remain constant and it is independent from velocity and carrier frequency, the available loads integral per second decreases. The relation of integrated (total) payload available per second at 2 GHz to the integrated available payload depending on speed and carrier frequency is illustrated in Fig. 6. The signalling overhead is increasing with increasing carrier frequency.

FIGURE 6

Available integrated payload per second in relation to 2 GHz

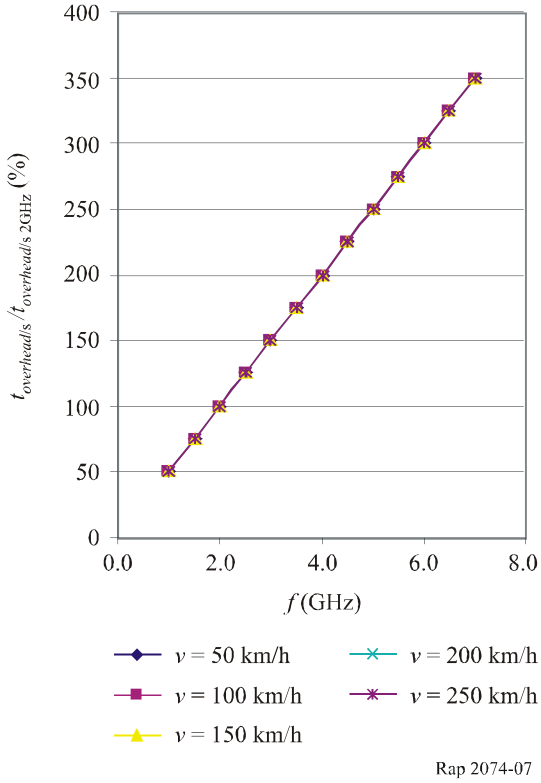


The available integrated payload per second at 250 km/h remains 91% at 4 GHz and only 82% at a 6 GHz carrier frequency compared to integrated payload per second at 2 GHz and the same speed. When the user equipment moves with the velocity of 50 km/h the available payload decreases not significantly from 98% at 4 GHz to 96% at a 6 GHz carrier frequency.

The relationships change dramatically when the overhead is discussed. Since the overhead length of every frame is constant and independent of velocity and carrier frequency, while the number of frames increases with the velocity because of decreasing coherence time, the integrated overhead time per second rises with the number of frames per second. The integrated overhead time per second rises to 200% at 4 GHz and 300% at 6 GHz in relation to that time at 2 GHz carrier frequency. This is illustrated in Fig. 7.

FIGURE 7

Integrated overhead per second in relation to integrated overhead per second at 2 GHz



5.4.3 Target coverage range with reasonable trade-off

From a coverage area point of view, the required scenarios vary from long-range, or similar to current cellular or wide-area network (WAN), to short-range systems, which correspond to WPAN/WLAN-type scenarios.

An objective of IMT-2000 is to make a wide range of telecommunication services available to mobile users, and to provide these services over a wide range of user densities (number of users per area) and geographic coverage areas. Systems beyond IMT-2000 aim at providing service bit rates up to 100 Mbit/s for full mobility, and 1 000 Mbit/s under mobility restrictions. At the same time, in order for the geographic coverage and the coverage probability of IMT-2000 to be achieved to meet the user's expectations, it is important that the coverage area of IMT-2000 networks is maintained for systems beyond IMT-2000.

A number of investigations into the multipath effects of propagation in the 3 to 6 GHz band in urban macro-cellular environments can be found in the literature. The multipath effects in the range 3 to 6 GHz are similar to those in the bands available to IMT-2000. The multipath effects therefore appear to provide no advantage of one particular frequency band over another, within the range below 6 GHz.

In contrast, the path loss shows a clear increase of with frequency. Accordingly, more base station sites need to be used per unit area, i.e. the site density needs to be increase with frequency, in order to maintain a given target coverage probability. A general propagation model is of the form:

$$\text{path loss} = k + \gamma_f \cdot 10 \cdot \log_{10}(f) + \gamma_d \cdot 10 \cdot \log_{10}(d)$$

where:

k: propagation model specific constant

γ_{f}: determines the path loss increase with frequency f

γ_{d}: determines the path loss increase with distance d.

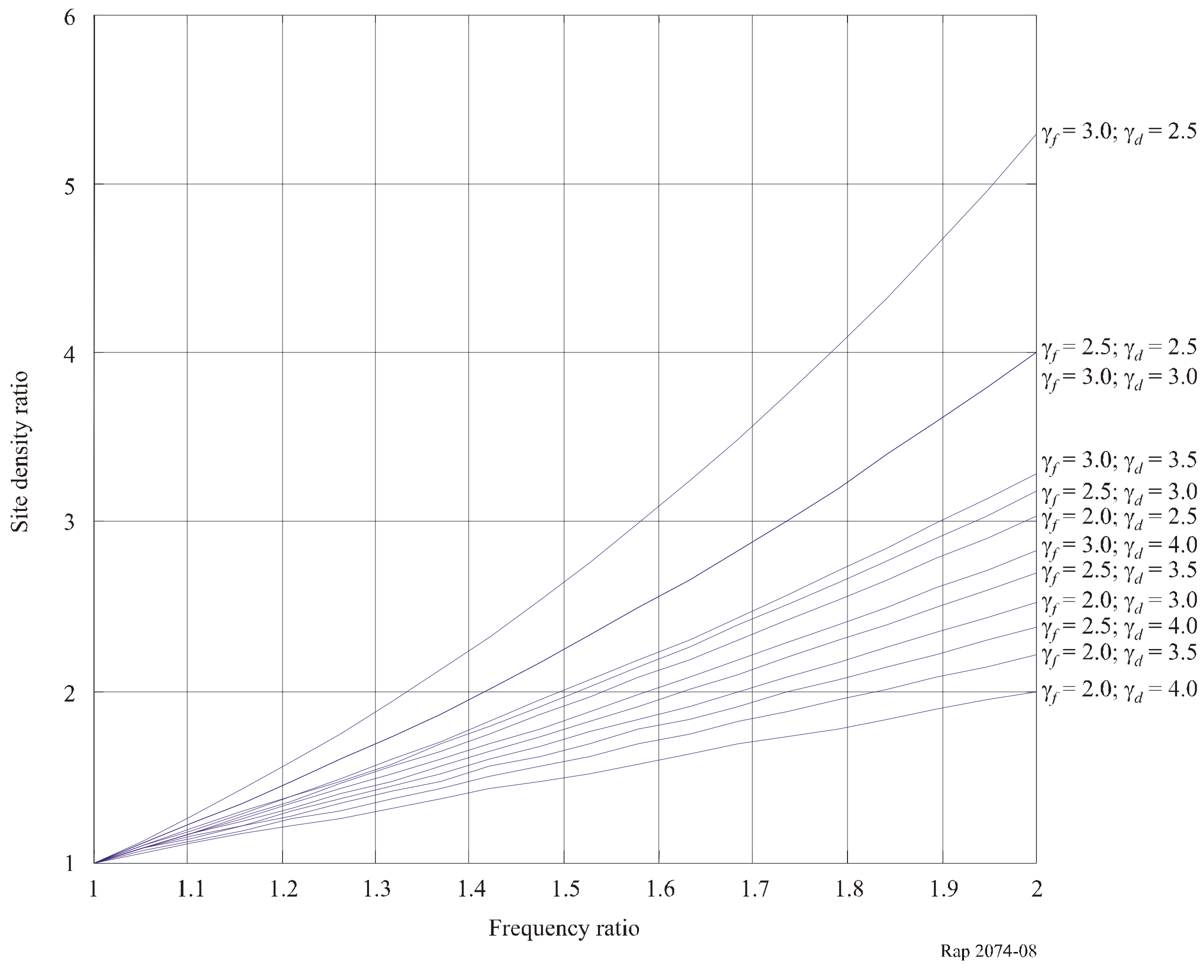
Based on this path loss model, the dependency of the site density ratio A_r on the frequency ratio f_r can be calculated as:

$$A_r = f_r^{2\gamma_f 1\gamma_d}$$

Figure 8 shows this dependency, for a number of values of the parameters γ_{f} and γ_{d}. It can be seen that even in the most optimistic propagation model with a free-space type frequency dependency of the path loss, i.e. $\gamma_{f} = 2$), and a propagation from low base station antenna heights, i.e. $\gamma_d \approx 4$, every doubling of the operating frequency would reduce the coverage area by 50%, which would require a doubling in the base station density to restore full area coverage. For typical macro base station deployment scenarios, the parameter ranges would be γ_{f} = 2…2.5 and γ_{d} = 3.5 ... 4, corresponding to a site density increase factor of 2.0 to 2.7, in the case where the frequency would be doubled. From experimental results, path loss increases proportionally to the carrier frequency to $\gamma_f = 2.5$ to 3rd power in suburban areas where a relatively large cell configuration is adopted, while in urban areas the path loss increases proportionally to the square ($\gamma_f = 2$) of the carrier frequency. Taking the reference of f_r = 3 GHz, site density for 5 GHz and 7 GHz increases by a factor of 1.7 and 2.4 in urban areas, and 2.5 and 4.5 in suburban areas, respectively.

FIGURE 8

Site density versus frequency ratio for different values of parameters γ_f and γ_d



In order to retain economical cell sizes, suitable frequency ranges for systems beyond IMT-2000 that cover the full range of capabilities of systems beyond IMT-2000 are those that are not far away from the existing frequency bands for mobile communication use. In this respect, a doubling of the frequency compared to the IMT-2000 2 500-2 690 MHz band, and the accordingly required increase in site density would be considered to be the absolute maximum, which could be economically viable. Consequently, an operating frequency of around 6 GHz is considered to be an upper limit.

As can be seen from Recommendation ITU-R P.676, atmospheric propagation attenuation also gets stronger with higher frequency. However, below the upper limit of 6 GHz that is imposed by other propagation aspects, atmospheric attenuation is negligible.

Path loss depends upon frequency, *F*, of operation. The relationship between path loss and frequency in differing radio environments is illustrated in Table 2.

TABLE 2

Comparison of path loss, frequency and cell types*

	Path loss (dB)		
Frequency (MHz)	**Macro cell**	**Small cell**	**Micro cell street canyon**
900	144.2	130.5	102.1
2 000	151.6	143.4	109.6
3 500	155.5	152.0	113.5
6 000	160.2	165.8	118.3

* These path loss values were obtained for the path loss models derived in [COST 231, 1998], by making apprioriate correction for frequency of operation. In particular the macro cell model is based on the Okamura-Hata model. The COST 231 Walfish Ikegami model was used for small cells (micro cells and micro cell street canyons).

Clearly to mitigate the impact of path loss on cell link budgets it is desirable to reduce the frequency of operation.

5.4.4 Implications of frequency range on mobile device power consumption

A reasonable degree of battery lifetime is an important characteristic for a mobile terminal. Terminal power consumption depends on various parameters like cell size, modulation order, operating frequency and frequency range, bandwidth, mobility, etc. Despite advances in battery technologies, battery capacity will continue to be a critical factor, in particular because power requirements increase roughly proportional with the terminal transmit data rate.

As the high data rates are a requirement on systems beyond IMT-2000, there is a huge challenge in keeping mobile devices size reasonable and at the same time improving available battery capacity (battery manufactures) or using it in a more efficient way (mobile system characteristics).

Therefore, power consumption of the terminals is an important issue to be considered for evaluation of potential candidate bands. Since signals at higher frequencies have higher propagation losses, consequently more RF power would be needed to meet the power budget requirements of a system. This is especially important in macro cellular scenarios.

5.4.5 Availability and feasibility of required RF components within the required time frame

Continuous evolution is foreseen in future mobile terminals, with use of new components, architectures, hardware, software platforms and improved user interfaces together providing increased performance. The key technologies that will enable the future advanced mobile terminals include:

– Smart antennas, MIMO.
– High efficiency power amplifiers.
– New filters.
– Improved RF modules, allowing higher operating frequencies and improved receiver sensitivity.
– Advances in signal processing, additional processing power.
– Improved battery technology with increased energy density.

However, these advances in technology will not completely remove frequency dependent limitations of transmitter and receiver hardware and semiconductor technology. Rather limitations will continue to exist despite the evolution. Having new spectrum ranges far from current bands would additionally increase the challenges with future RF components. This means that also from the component point of view the frequencies should be as low as possible.

Furthermore, future terminals should be capable of operating in several frequency bands and with different bandwidths (requiring improved RF modules). Terminals should have the potential of dealing with different systems (multi-mode) and they should also implement interference management to improve transmission capacity and performance (enhanced sensitivity and strategies for interference suppression).

5.4.6 Spectrum ranges influencing technology

There would be clear benefits from being able to accommodate the whole system to a single spectrum range, as the targets discussed in the beginning of § 2 may not allow usage of multiple separated, widely spread spectrum ranges for the system concept.

If it is not possible to obtain a sufficient amount of spectrum identified in the preferred single spectrum range, i.e. below 6 GHz, the result would be that the new system would need to use also other spectrum ranges in some scenarios. For example the new system might need to operate partly in higher bands, where it might be easier to get relatively wide bands identified. Due to the accompanying reduction of the coverage range and increasing mobility constraints, higher bands are only conceivable for pico-cells and short-range communication, if at all.

The propagation loss at frequencies close to 6 GHz will result in a much higher density of infrastructure relative to lower bands closer to the bands already identified for IMT-2000. Therefore it is desirable to look at flexible solutions. Thus systems are needed that can be operate using different carrier bandwidths (e.g. 25-100 MHz).

5.4.7 Spectrum range preference

The new spectrum for such new technologies that can fulfil the full range of requirements of the ITU for systems beyond IMT-2000, including both the "new mobile access" and "new nomadic/ local area wireless access", as they are presented in Recommendation ITU-R M.1645 should be identified below 6 GHz due to a number of technical reasons. Bands below 6 GHz allow sufficient mobility and there is an acceptable trade-off between cost and full area coverage. Availability of required RF hardware components is seen as feasible in the required timeframe and mobile terminal complexity and power consumption could stay at an acceptable level.

For technologies aiming at covering only one of the new capabilities of the systems beyond IMT-2000, such as the "new nomadic/local area wireless access" the technical constraints may be different, possibly resulting in different preferences about the spectrum ranges.

The new technologies that can fulfil only the new nomadic/local wireless access capabilities may well need the large bandwidth (e.g. 100 MHz) carriers but systems requiring this capability are for low mobility and nomadic access. Hence frequency ranges above 6 GHz may be considered for this purpose.

As described in Recommendation ITU-R M.1645, an objective of IMT-2000 is to make a wide range of telecommunication services available to mobile users, and to provide these services over a wide range of teledensities (number of users per square kilometre) and geographic coverage areas. This continues to be a priority for the future development of IMT-2000 and systems beyond IMT-2000. Geographic coverage is especially important to developing countries because many people who do not at present have access to mobile communications live in parts of the world where the population density, teledensity, and/or income levels are low.

The increase of geographical coverage at rural areas is one important aspect of the further work. Resolution 228 (Rev.WRC-03) requests to consider advantages/disadvantages of frequency bands below those already identified for IMT-2000. Solutions for better geographical coverage are under investigation. The results of the comparison of advantages/disadvantages could show if the lower bands provide an efficient solution to increase geographical coverage.

5.5 Categorization of additional relevant radio parameters

According to Recommendation ITU-R M.1645, "optimally connected anywhere, anytime" view could be realized by a network comprising a variety of interworking access systems connected to a common packet-based core network (see Fig. 9). In this Figure, the future network of systems beyond IMT-2000 is divided into four parts:

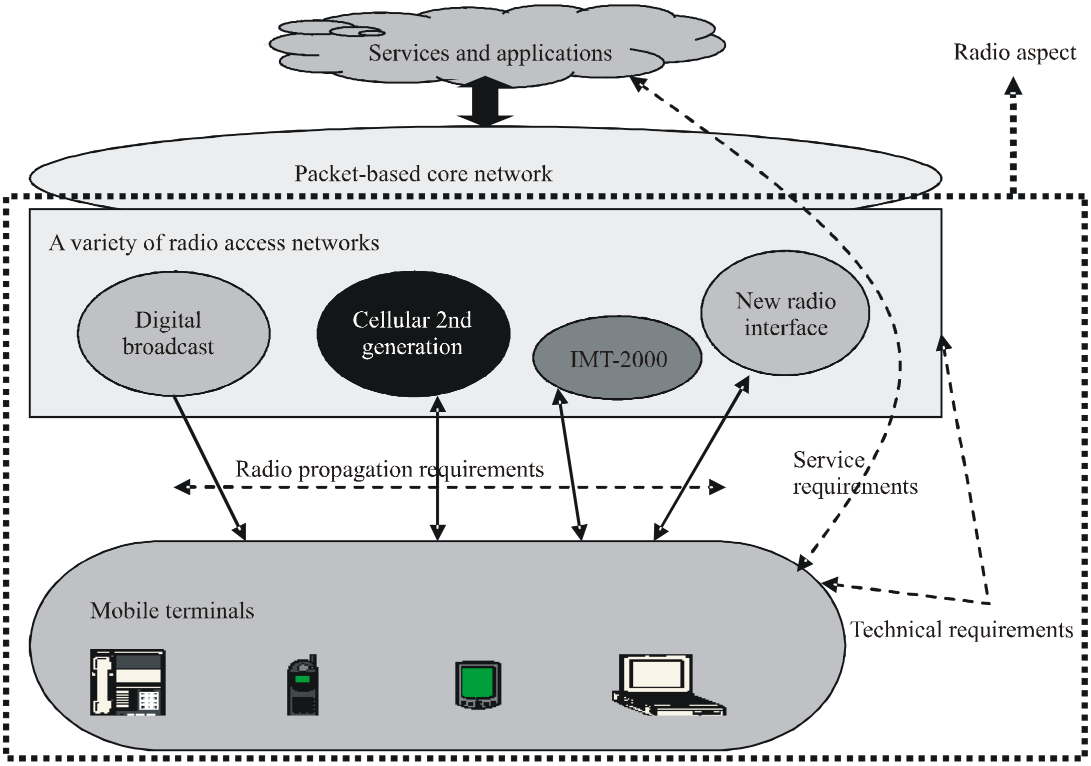
– services and applications;
– core network;
– access networks (only radio access networks are shown in the Figure);
– mobile terminals.

Obviously, radio aspects include radio access networks and mobile terminals, which are shown in Fig. 2. This Report addresses the technical matters related to the two parts. The technical matters are also impacted by the requirements of other factors such as service and radio propagation requirements. Technical matters in this Report of multiple perspectives should be considered, including:

– radio propagation requirements: horizontal impacts between radio access networks and mobile terminals;
– service requirements: vertical impacts of services and applications on mobile terminals
– technical requirements: parameters of radio aspects which are indirect relevant to spectrum requirements.

FIGURE 9

Future network of systems beyond IMT-2000 including a variety of radio access systems



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According to the above description, these technical matters are related to radio propagation requirements, service requirements, and technical requirements; thus, the additional radio parameters could be categorized as:

– parameters related to radio propagation requirements;

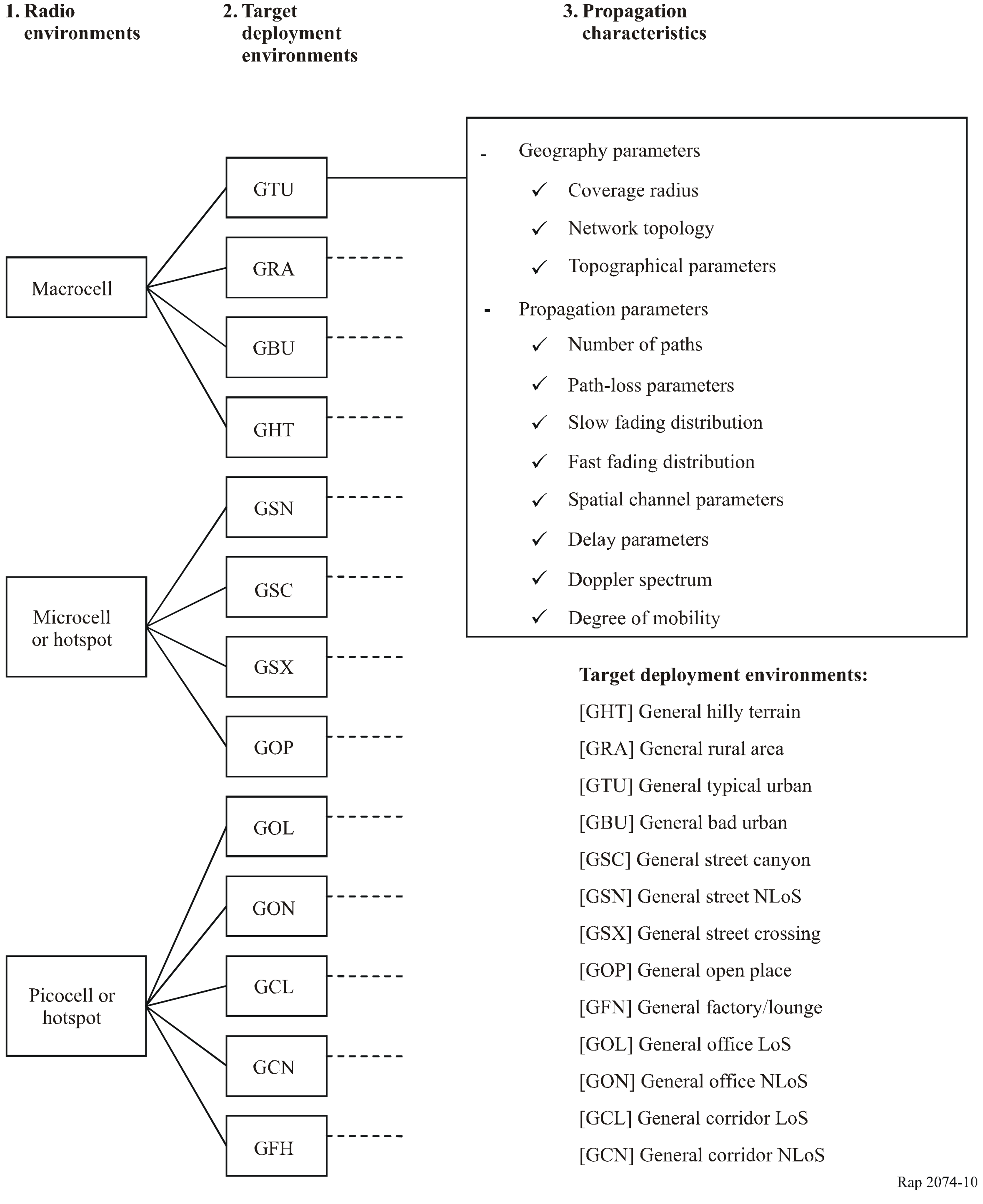
– parameters related to service requirements;

– parameters related to technical requirements.

After adopting advanced techniques such as adaptive antenna and MIMO, the conventional channel models that are only characterized by means of tap-delay line structures or discrete power delay profiles (PDPs) are not suitable. Thus, spatial channel models that include spatial channel parameters (angle spread, angle of arrival, power azimuth spectrum, etc.) should be considered. Based on the spatial channel models, a 3-level structure that includes radio environments, target deployment environment and propagation characteristics are given in Fig. 10. At the 1 st level, several radio environments have been identified as: macro-cell, micro-cell, pico-cell and hotspot. Each of radio environments has corresponding target deployment environments based on its topographical and electrical features of surroundings (see Fig. 10). Each target deployment environment can be defined by its geography and propagation parameters.

FIGURE 10

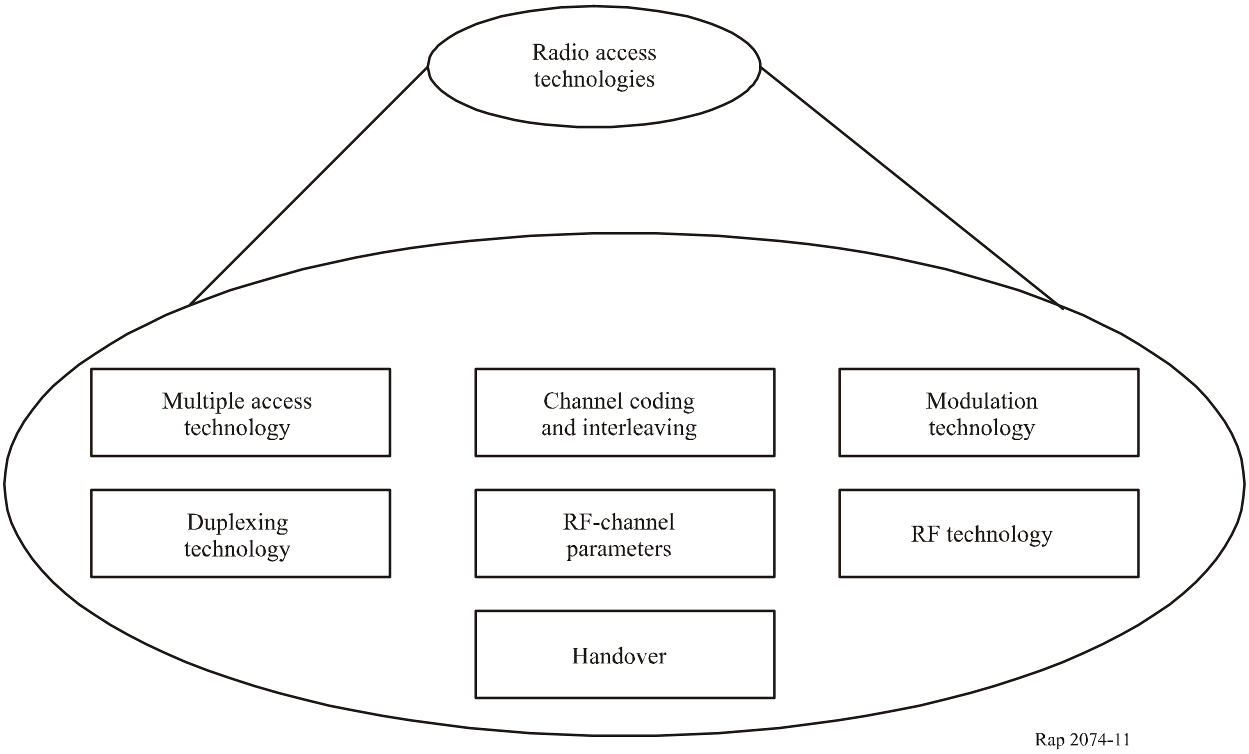
The structure of radio parameters related to radio propagation requirements



Additional radio parameters of technical categories can be identified from several key technical functions, such as multiple access technology, channel coding and modulation technology, etc. (see Fig. 11).

FIGURE 11

Key functions of radio access technologies



In summary, the additional radio parameters (see § 5.2.2) related to radio propagation requirements, service requirements, and technical requirements complement the spectrum requirements for the future development of IMT-2000 and system beyond IMT-2000. Furthermore, they are helpful to later study of the future development of IMT-2000 and systems beyond IMT-2000.

6 Radio environments

Terrestrial mobile systems generally employ a cellular architecture. Typical environments include macro, micro, and pico cells, further as a complementary hot spot. Such environments are characterized in the following sections.

In order to establish high traffic capacity in IMT-2000 and its enhancement and systems beyond IMT-2000 with minimum handovers for mobile stations at various speeds and environments, in addition to maximizing spectral efficiency, it may be beneficial for the cells of IMT-2000 and its enhancement and systems beyond IMT-2000 to have different cell types related to mobile station parameters, such as mobility characteristics, output power, and types of services utilized. A cell layer would contain cells of the same type in a service area of IMT-2000 and its enhancement and systems beyond IMT-2000. In principle, it is possible to operate these different cell types simultaneously in the same geographical area. For example, a hot spot may complementarily be deployed in the dense urban area. All cells in the cell layer are fully or partly sharing the same spectrum resource.

6.1 Macro cell

The macro cells are with a large cell radius, dependent on the teledensity or service environment. This cell radius is typically more than 1 km in urban to more than 40 km in rural. Radio propagation characteristic, typical deployment scenario, technical requirements for spectrum efficiency derivation, appropriate RAT group in macro cells are discussed in the following subsections. Additional factors such as frequency, data rate, and cell load also determine cell radius.

6.1.1 Radio propagation characteristic

As described in Recommendations ITU-R M.1034 and ITU-R M.1035, a typical macro cell may be situated in an outdoor flat terrain or rural area with lower height and density of buildings or obstacles. The base station antenna height will be above the average roof top height so that the base station can cover a wider area. The pass loss model developed by Okumura and Hata has found wide acceptance. A more accurate path loss prediction can be achieved by taking edge diffraction and scattering into account. Rough path loss estimates can also be obtained using an inverse third to fourth power law. The larger cell radius causes the larger difference in path loss depending on a location of mobile station.

In a macro cell environment, an LoS path between base and mobile stations can often be guaranteed due to the lower height and density of buildings or obstacles. The LoS path, however, may not be observed when a building blockage occurs. In such a case, shadowing effects can be adequately modelled by a log-normal distribution with a standard deviation of 10 dB.

Multi-path propagation causing fast fading and channel time dispersion is generated due to buildings and obstacles. Fast fading of the received signal envelope can be modelled by a Nakagami-m distribution in the general case, which degenerates to a Rayleigh distribution in the absence of specular paths. The Rice distribution also provides a very good fit. Fast fading is generally frequency-selective in the outdoor environment.

Typical outdoor r.m.s. delay spreads range from 1 μs for rural area. However, longer and even much longer delay spreads occur when reflections from distant hills or distant high-rise buildings are involved.

Mobility characteristic in the macro cell environment has wide range from pedestrian to vehicular speed, e.g., 0 to over 250 km/h. (For example, maximum Doppler shifts range from approximately 50 Hz to 1.2 kHz when the carrier frequency is 5 GHz.)

6.1.2 Typical deployment scenario

The typical environment would include an outdoor flat terrain or rural area with lower height and density of buildings or obstacles.

In the macro cell environment, high mobility needs to be supported since usage scenarios in outdoor environments would mainly be considered. It should be noted, however, usage scenarios inside a building with low mobility may also be considered.

In the macro cell environment services may require large coverage area. In case of cellular environment, several numbers of channels are required for deployment. Guardbands have to be accommodated to reduce interference between adjacent bands. An average value for multiplier to obtain a guardband in Report ITU-R M.2023 is estimated to be 1.04.

6.1.3 Requirements for technical characteristics

Requirements for spectrum efficiency derivation taking into account the radio propagation characteristic and typical deployment scenario in the macro cell environment are addressed in the following.

In the macro cell environment, low to high mobility should be supported. This would require, for example, primarily the lower option of an adaptive modulation and coding with redundant information to cope with fast fading variation.

In support of high mobility in the macro cell environment, handover between cells is necessary to prevent the call being released when crossing cell boundaries. Handover would increase overhead factors such as additional information for control or signalling to be transmitted. In addition, handover may simultaneously require multiple channels in different cells. When a different radio environment is organized with the macro cell environment in hierarchical cell structures, support of handover to the other radio environment is also required. If a different RAT group is used in each radio environment, additional information for handover between different RAT groups may be required.

Required radio frame size should be much shorter than the coherence time in order that the radio channel remain quasi-static within a frame. The coherence time depends on mobility and carrier frequency. Thus, the radio frame size in a macro cell environment should be small enough to support high mobility. Typical radio frame size in RAT Group 1 is 2 ms. Since the bit rate in RAT Group 2 is much higher than that in RAT Group 1, the radio frame size is expected to be much shorter.

Since the radio propagation characteristic varies within a cell, average spectrum efficiency within the cell becomes smaller than peak spectrum efficiency. In [Ishii *et al*, 2004], spectrum efficiency with one of the radio access techniques in RAT Group 1 was evaluated. The average spectrum efficiency with higher mobility within the entire cell is approximately 0.1 bits/s/Hz of the peak spectrum efficiency. It is expected that RAT Group 2 can achieve similar or higher value of average spectrum efficiency compared to RAT Group 1.

6.1.4 Radio access technique groups

In the macro cell environment services may mainly be expected that require large coverage area.

Support of handover and tracking ability to fading variation would be required to support high mobility.

Both RAT Group 1 and 2 may be appropriate for macro cell environment. The typical peak bit rate currently achieved in RAT Group 1 is approximately 14 Mbit/s. Requirements for RAT Group 2 may be used to support data rates of up to 100 Mbit/s with high mobility.

6.2 Micro cell

The micro cells are with a cell radius, typically from 50 m to 1 km. Radio propagation characteristic, typical deployment scenario, technical requirements for spectrum efficiency derivation, and appropriate RAT group in micro cells are described in following subsections.

6.2.1 Radio propagation characteristic

As described in Recommendations ITU-R M.1034 and ITU-R M.1035, a typical micro cell may be situated in an outdoor urban area with moderate density of buildings. The base station antenna height in the micro cell may be lower than average rooftop height since a typical cell radius in the micro cell of up to 1 km is much smaller than that in the macro cell.

In a micro cell environment, the pass loss model used in the macro cell may be used with an additional loss called building penetration loss and defined as the difference in median signal levels between that measured immediately outside the building at 1.5 m above ground and that immediately inside the building at some reference level on the floor of interest. Median values between 10 and 18 dB with a standard deviation of about 7.5 dB are reported in the literature. An overall decrease of 1.9 dB per floor with increasing height is also reported. Signal loss within the building also increases when distance to the exterior wall increases. Measurements indicate inverse distance power law exponents between 2 and 4.

In the micro cell environment, an LoS path between base and mobile stations can seldom be guaranteed since the base station antenna is lower than the average rooftop height. Log-normal shadow fading with a standard deviation of 10 dB is reasonable for outdoors and 12 dB for indoor.

Multi-path fading environment caused by surrounding buildings may be considered. Fast fading of the received signal envelope can be modelled by Rayleigh distribution and is generally frequency-selective.

Since building attenuation tends to limit the maximum transmission range, large delay spreads are not expected in the micro cell environment.

Mobility characteristic in the micro cell environment has wide range from pedestrian to vehicular speed, e.g., 0 to over 250 km/h. (For example, maximum Doppler shifts may range from approximately 50 Hz to 1.2 kHz when the carrier frequency is 5 GHz.)

6.2.2 Typical deployment scenario

The typical environment would include an outdoor suburban or urban area with relatively higher height and high density of buildings.

In the micro cell environment, mobility from low to high should be supported since usage scenario in both outdoor and indoor would be considered.

In case of cellular environment, several numbers of channels is required for deployment. Guardbands have to be accommodated to reduce interference between adjacent bands. An average value for multiplier to obtain a guardband in Report ITU-R M.2023 is estimated to be 1.04.

Relatively high traffic requirements characterized by urban service environment are mainly expected.

6.2.3 Requirements for technical characteristics

Requirements for spectrum efficiency derivation taking into account the radio propagation characteristic and typical deployment scenario in the micro cell environment are addressed in the following.

In the micro cell environment, low to high mobility should be supported. This would require, for example, primarily the medium option of an adaptive modulation and coding with redundant information to cope with fast fading variation.

In support of high mobility in the micro cell environment, handover between other cells may frequently be required to prevent the call being released when crossing cell boundaries. Handover would increase overhead factors such as additional information for control or signalling to be transmitted. In addition, handover in the micro cell environment may simultaneously require much more channels in different cells since the number of candidate cells may increase due to small cell size. When the different radio environment is organized with the micro cell environment in hierarchical cell structures, support of handover to the other radio environment is also required. If a different RAT group is used in each radio environment, additional information for handover between different RAT groups may be required.

Required radio frame size should be much shorter than the coherence time in order that the radio channel remain quasi-static within a frame. The coherence time depends on mobility and carrier frequency. Thus, the radio frame size in a macro cell environment should be small enough to support high mobility. Typical radio frame size in RAT Group 1 is 2 ms. Since the bit rate in RAT Group 2 is much higher than that in RAT Group 1, the radio frame size is expected to be much shorter.

Since the radio propagation characteristic varies within a cell, average spectrum efficiency within the cell becomes smaller than peak spectrum efficiency. In [Ishii *et al*, 2004], spectrum efficiency with one of radio access techniques in RAT Group 1 was evaluated. The average spectrum efficiency with higher mobility within the entire cell is approximately 0.1 bits/s/Hz of the peak spectrum efficiency. It is expected that RAT Group 2 can achieve similar or higher value of average spectrum efficiency compared to RAT Group 1.

6.2.4 Radio access technique groups

Micro cells may mainly be deployed in the relatively high traffic area characterized by urban service environments.

Support of handover and tracking ability to fading variation would be required to support high mobility.

Both RAT Groups 1 and 2 may be appropriate for micro cell environment. The typical peak bit rate currently achieved in RAT Group 1 is approximately 14 Mbit/s. Requirements for RAT groups may be to support data rates of up to 100 Mbit/s with high mobility.

Typical carrier bandwidth for RAT Group 1 is 5 MHz. Taking into account the possible peak spectrum efficiency and peak bit rate to be supported, carrier bandwidth for RAT Group 2 would be approximately 100 MHz.

6.3 Pico cell

The pico cells are with a small cell radius, typically less than 50 m. Radio propagation characteristics, typical deployment scenarios, technical requirements for spectrum efficiency derivation, appropriate RAT group in pico cells are described in the following subsections.

6.3.1 Radio propagation characteristic

As described in Recommendations ITU-R M.1034 and ITU-R M.1035, a typical pico cell may be situated in a dense urban area with high density of buildings. The base station antenna height in pico cells may be much lower than average rooftop height. A typical cell radius in pico cell is up to 50 m.

In a pico cell environment, the building penetration loss should also be considered for inside the building. Inverse distance power law exponents vary due to scatter and attenuation by surrounding buildings. If the path is an LoS on a canyon-like street, for example, the inverse distance power law exponent is approximately 2.

In the pico cell environment, the LoS path between base and mobile stations can sometimes be observed on the canyon-like street. However, blockage by man-made objects may be observed. In such an environment, log-normal shadow fading with a standard deviation of 12 dB is reasonable.

Multi-path fading environment caused by surrounding objects may be considered. Fast fading ranges from Rician to Rayleigh depending on carrier bandwidth.

Since building attenuation tends to limit the maximum transmission range and the cell radius is very small, small delay spreads are expected in the pico cell. Thus, both frequency-selective and flat fading variations are considered.

Mobility characteristic in the pico cell environment is typically below pedestrian speed (for example, below 10 km/h). (For example, maximum Doppler shifts may be below approximately 50 Hz when the carrier frequency is 5 GHz.) Vehicular speed should also be considered if a main road is included in the pico cell.

6.3.2 Typical deployment scenario

The typical environment would include an outdoor street in dense urban areas with high density of buildings. Deployment in an underground complex area may also be considered.

In the pico cell environment, low mobility should mainly be supported since usage scenarios in outdoor in a city or indoor would be considered. It should be noted, however, relatively high mobility should be considered if a main street is included in the coverage area.

In case of cellular environment, several numbers of channels is required for deployment. Guardbands have to be accommodated to reduce interference between adjacent bands. An average value for multiplier to obtain a guardband in Report ITU-R M.2023 is estimated to be 1.04.

6.3.3 Requirements for technical characteristics

Requirements for spectrum efficiency derivation taking into account the radio propagation characteristic and typical deployment scenario in the pico cell environment are addressed in the following.

In the pico cell environment, low mobility should mainly be supported. This would require, for example, the higher-level option of an adaptive modulation or coding with redundant information.

Requirements for tracking ability to fading variation would be relatively low since the mobility in pico cell may be low. In support of mobility in the pico cell environment, handover between other cells may frequently be required since the cell size may be very small. Handover would increase overhead factors such as additional information for control or signalling to be transmitted. When the different radio environment is organized with the pico cell environment in hierarchical cell structures, support of handover to the other radio environment is also required If the different RAT group is used in each radio environment, additional information for handover between different RAT groups may be required. In the pico cell environment, existence of uncorrelated path may enable the application of multi-input-multi-output techniques.

Required radio frame size should be much shorter than the coherence time in order that the radio channel remain quasi-static within a frame. The coherence time depends on mobility and carrier frequency. Thus, the radio frame size in a macro cell environment should be small enough to support high mobility. Typical radio frame size in RAT Group 1 is 2 ms. Since the bit rate in RAT Group 2 is much higher than that in RAT Group 1, the radio frame size is expected to be much shorter.

Since the radio propagation characteristic varies within a cell, average spectrum efficiency within the cell becomes smaller than peak spectrum efficiency. In [Ishii *et al*, 2004], spectrum efficiency with one of radio access techniques in RAT Group 1 was evaluated. The average spectrum efficiency with higher mobility within the entire cell is approximately 0.1 bits/s/Hz of the peak spectrum efficiency. It is expected that RAT Group 2 can achieve similar or higher value of average spectrum efficiency compared to RAT Group 1.

6.3.4 Radio access technique groups

Pico cells may mainly be deployed in the high traffic area characterized by dense urban service environment.

Support of handover would be required due to small cell size; however, requirement for tracking ability to fading variation may be low since the mobility may be low in the pico cell environment.

Both RAT Group 1 and 2 may be appropriate for pico cell environment. The typical peak bit rate currently achieved in RAT Group 1 is approximately 14 Mbit/s. Requirement for RAT groups may be to support data rates of up to 100 Mbit/s or 1 Gbit/s with low mobility.

Typical carrier bandwidth for RAT Group 1 is 5 MHz. Taking into account the possible peak spectrum efficiency and peak bit rate to be supported, carrier bandwidth for RAT Group 2 would be approximately 100 MHz.

6.4 Hotspot

A hotspot is a centre (limited geographic area) of high levels of activity and/or user density using potentially high data rates, within a larger geographic area of lower activity/density generally encompassing lower data rate usage.

Hotspots are a geographic area supported by one or more cells of a small radius, typically less than several tens of metres. There may be no similar radio coverage in geographic areas between hotspots. Radio propagation characteristic, typical deployment scenario, technical requirements for spectrum efficiency derivation, appropriate RAT group in hotspots are described in the following subsections.

6.4.1 Radio propagation characteristic

A typical hotspot may be situated inside a building or semi-outdoor. The base station antenna in a hotspot may be on a ceiling in a building or much lower than average rooftop height in the semi-outdoor environment. A typical cell radius in a hotspot is up to several tens of metres.

In the hotspot, inverse distance power law exponents vary due to scatter and attenuation by surrounding objects. If the path is an LoS, for example, the inverse distance power law exponent is approximately 2. However, since the hotspot is situated in an isolated environment, interference to outside the hotspot area is significantly small.

In the hotspot environment, the LoS path between base and mobile stations can often be observed. However, blockage by man-made objects may be observed. In such an environment, log-normal shadow fading with a standard deviation of 12 dB is reasonable.

Multi-path fading environment caused by surrounding objects may be considered. Fast fading ranges from Rician to Rayleigh depending on carrier bandwidth.

Since the maximum transmission range in the hotspot is isolated or semi-outdoor with very small cell radius, small delay spreads are expected. Thus, both frequency-selective and flat fading variations are considered.

Mobility characteristic in the hotspot environment is typically quasi-static or pedestrian speed (for example, 0 to 10 km/h). (For example, maximum Doppler shifts may be below approximately 50 Hz when the carrier frequency is 5 GHz.)

6.4.2 Typical deployment scenario

The typical environment would include indoor and semi-outdoor in dense urban area with high density of buildings or objects. The hotspot may be deployed in an airport, a station, or, an underground complex area.

In the hotspot environment, low mobility should mainly be supported since usage scenario in semi-outdoor in a city or indoor would be considered.

In case of hotspot environment, the number of required channels may be smaller than that in a cellular environment since the interference from surrounding cells may less.

The hotspot is in response to the requirement for very high data rates (up to 1 Gbit/s) in quasi-static or pedestrian speed. High traffic requirements characterized by dense urban service environments are mainly expected.

6.4.3 Requirements for technical characteristics

Requirements for spectrum efficiency derivation taking into account the radio propagation characteristic and typical deployment scenario in the hotspot environment are addressed in the following.

A hotspot is in response to the requirement for very high data rates (up to 1 Gbit/s). This would require, for example, higher-level modulation or higher coding rate.

Requirements for tracking ability to fading variation would be relatively low since the mobility in hotspot may be low. Both frequency reuse and support of handover between other cells may not be required since the hotspot may mainly be isolated. In the hotspot environment, existence of uncorrelated path may enable the application of multi-input-multi-output techniques. This will increase the system capacity by maximum four fold when the four antennas are used both at the transmitter and the receiver in a typical case.

When the different radio environment is organized with the hotspot environment in hierarchical cell structures, support of handover to the other radio environment is also required If the different RAT group is used in each radio environment, additional information for handover between different RAT groups may be required.

Required radio frame size should be much shorter than the coherence time in order that the radio channel remains quasi-static within a frame. The coherence time depends on mobility and carrier frequency. Thus, the radio frame size in a macro cell environment should be small enough to support high mobility. Typical radio frame size in RAT Group 1 is 2 ms. Since the bit rate in RAT Group 2 is much higher than that in RAT Group 1, the radio frame size is expected to be much shorter.

Peak spectrum efficiency to achieve target peak bit rate in RAT Group 3 is expected to be approximately 10 bit/s/Hz since the application of multiple antenna transmission is considered. Since the radio propagation characteristic varies within a cell, average spectrum efficiency within the cell becomes smaller than peak spectrum efficiency. Taking into account the result in [Ishii *et al*, 2004], the average spectrum efficiency within the entire cell would be more than 0.21-0.47 of the peak spectrum efficiency in pedestrian speed. Average spectrum efficiency in the stationary case may be much higher.

6.4.4 Radio access technique groups

In the hotspot environment, very high data rate services may mainly be expected.

Hotspot may mainly be deployed in the high traffic area characterized by dense urban service environment.

Support of handover may not be required in an isolated cell. Requirements for tracking ability to fading variation may be low since the mobility may be low in the hotspot environment.

Requirement for RAT Group 2 may be to support data rates of up to 100 Mbit/s or 1 Gbit/s with low mobility.

Taking into account the possible peak spectrum efficiency and peak bit rates to be supported, carrier bandwidth for RAT Group 2 would be approximately 100 MHz.

6.5 Metrics of radio environments

Each of these radio environments described in this section can be characterized by the following metrics (units in brackets):

– Minimum cell radius (m)
– Maximum cell radius (m)
– Typical cell radius (m)
– Cell geometry (Boolean: omni, n-sectored, link)
– Support for outdoor-to-indoor coverage (Boolean: Yes/No)

– LoS coverage (Boolean: Yes/No)
– Seamless coverage for inner radio deployment environments handovers (Boolean: Yes/No).

6.6 Radio environment parameters needed by spectrum calculation methodology

The cell area has a direct impact on the traffic volume dependent spectrum requirement, the smaller the cells size the smaller the spectrum requirement. Naturally, a trade-off has to be found between network deployment costs and the spectrum requirement. Apart from the limits on sizes that are related to these two factors, there are also technical limits.

The upper technical limit is determined by the propagation conditions, terminal transmit power limitations and to a smaller extent by the delay spread.

The lower limits for the cell sizes are determined by an increase of unfavourable interference conditions, e.g. the appearance of too frequent LoS conditions between interfering cells. The lower limit is assumed to be negligible compared to the limit imposed by deployment costs.

In methodology two parameters are used for cell areas: maximum cell area and actual cell area. The maximum cell area parameter sets the upper limit of the varying actual cell area parameter, which is the parameter used in the calculations.

Since the deployment of micro, pico and hot spot do not greatly vary between different teledensity areas, it is assumed that same "maximum" cell area for those cell layers can be utilized in the spectrum calculation method. However for macro cell the situation is different, the teledensity has impact to the targeted cell area as well as to the deployment of base stations. Thus the cell area of macro cell is made teledensity dependent in spectrum requirement calculations.

The practical cell size of the macro cell varies according the environment and base station installation opportunities. Using the propagation with the COST231 Hata Model [COST 231, 1998], for macro cells the radius of the suburban and rural macro-cells is about 1.5 and 3.5 times the radius of the dense urban macro-cells.

TABLE 3

Maximum cell area per radio environment km^{2}*

Radio environment	Teledensity		
	Dense urban	**Suburban**	**Rural**
Macro cell	0.65	1.5	8.0
Micro cell(1)	0.1	0.1	0.1
Pico cell(1)	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}
Hot spot(1)	6.5×10^{-5}	6.5×10^{-5}	6.5×10^{-5}

* Cell size is heavily influenced by frequency of operation. The maximum cell sizes designated in the table are derived from assumption that a significant amount of spectrum likely to be required can only be satisfied using frequencies towards the 6 GHz area. Other approaches that could lead to higher maximum cell sizes, e.g. the scenario at large areas with low teledensity coverage, have not been considered.

(1) It is assumed that the cell size of these environments is not teledensity dependent.

Within the spectrum calculation process, the actual cell size can be varied manually below the maximum size. The values of actual cell sizes will be defined during the estimation process and will input directly to spectrum requirement calculation.

7 Conclusions

This Report presents radio aspects related to WRC-07 agenda item 1.4. They include the overall technical approach by defining the RAT groups, definition of radio parameters required by the spectrum requirements calculation methodology and determination of their initial recommended values, addressing the preferred spectrum range from technical viewpoint and determination of area spectral efficiency for RAT groups. This Report provides all the required information except for the data related to the scenario of large areas with low teledensity coverage.

Later, the work on radio aspects will be extended to issues and items outside the relevance of the WRC-07 preparations.

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Annex 1

Spectral efficiency calculation for new capabilities of systems beyond IMT-2000

1 Background

This Report defines two kinds of parameters, denominated as required parameters and additional parameters. Required parameters are parameters necessary to perform spectrum requirement calculations, whereas additional parameters are defined to be used for spectral efficiency calculation or estimation.

Since spectral efficiency depends on technical specifications of the systems beyond IMT-2000 as well as channel modelling in frequency bands to be implemented by the systems, system level simulation is required for spectral efficiency estimation.

2 Generic procedure for spectral efficiency calculation

In this section, we will explain a generic procedure for the spectral efficiency calculation.

The basic formula for spectral efficiency is defined as:

Spectral efficiency (bit/s/Hz/Cell) = Peak data rate*AMC (adaptive modulation and coding) average factor*Sectorization gain in a cell*other gain from advanced technologies/channel bandwidth

From this formula, spectral efficiency of a system is calculated by simple product of each parameter, which is assumed to be separately estimated on an average basis. The main advantage of such a modular formulation is that we can calculate each value in a simple way and also we reuse some values from statistical information of past experience.

The peak data rate in the formula is target data rate of new capabilities of systems beyond IMT-2000. 100 Mbit/s under mobile environment and 1Gbit/s under stationary environment are regarded as such target data rate as shown in Recommendation ITU-R M.1645.

AMC averaging factor is defined as the normalized average achievable data rate of a user in a cell compared to the peak rate. Where AMC is applied, the data rate can be adjusted in coincidence with channel condition which is quantized by received CIR of a user. Usually, since this channel condition depends on operating frequency bands, mobility of a user and distance between a user and base station, CIR distribution, which implies channel condition of a user, could be obtained only if parameters described above are given. Sectorization gain is defined as the increasing rate of system throughput compared to throughput without sectorization. Conceptually, it can be expressed as the number of sectors multiplyed by the performance degradation caused by interference between sectors.

Other gains include throughput gains achieved by advanced technologies such as advanced antenna techniques.

In fact, all of the parameters shown in the formula are closely related to each other. For example, peak data rate is defined as the product of the highest order of modulation and coding, the number of symbols which a user can have in a frame and frame length. Furthermore, the number of symbols in a frame depends on the modulation technique, channel bandwidth and multiple access schemes. The formula described above can be an alternative.

For calculation of spectrum efficiency in practice, the following assumptions are necessary prior to the calculation procedure:

– possible frequency bands and channel model in the frequency bands with different mobility;
– frequency reuse factor;
– cell radius;
– table of modulation order and coding rate with CIR values for a specific FER rates which are system design parameters to be collected in the estimation phase;
– channel bandwidth, denoted by BW, which is the most important system design parameter to be collected in the estimation phase.

Under the assumptions, we can calculate each value of the above formula as follows:

1) peak data rate P is given by the maximum target data rate, for example (100 Mbit/s) for new mobile capability of systems beyond IMT-2000.

2) If the modulation orders with coding rate are denoted as r_1, r_2, ...r_n where r_1 is the highest modulation order with coding rate, then the data rate for a user with modulation order r_i can be calculated as r_i/r_1*Peak data rate. In addition, the required CIR value is denoted as cir_i corresponding to a modulation order with coding rate $\mathrm{r}_{\mathrm{i},}$ while keeping the FER value as below a predefined threshold. Table 3 shows an example of a modulation table with various channel models. In this Table, required CIR values for each modulation order with coding rate are given for each channel model.

3) CIR distribution can be obtained from channel models considering different frequency bands, user mobility, frequency reuse factor, and cell radius assuming a uniform distribution of users in a cell. It can be provided by numerical calculation or computer simulation.

4) AMC average factor taking into account user distribution and channel condition within a cell needs to be estimated from computer simulation. But usually such simulation method requires technical details. If technical details are not available then it can be alternatively calculated as:

$$\sum_i \frac{r_i}{r_1} \cdot p(cir_i < CIR < cir_{i-1})$$

5) Sectorization gain, denoted by *S*, can be obtained from statistical information of practical mobile systems where sectorization is applied.

6) For application of advanced antenna technologies such as MIMO technologies, spectral efficiency will be increased proportionally to the number of antennas used but it may not necessarily be linear. Thus, we also evaluate the gain of MIMO technology on an average basis. Assuming the gain obtained from MIMO techniques, G at a certain channel condition, the AMC averaging factor with MIMO consideration is given by:

$$R_{av} = \sum_i \frac{r_i}{r_1} \cdot p(cir_i < CIR < cir_{i-1}) \cdot G$$

7) Final spectral efficiency is obtained as follows

$$\eta = P \cdot R_{av} \cdot S / BW$$

Table 3 shows an illustrative example of such a generic procedure with maximum data rate of *P*.

TABLE 3

Calculation of parameters for spectral efficiency calculation

CIR distribution (A) $P(cir_i < CIR < cir_{i-1})$	**Modulation order and coding (B)**		**Data rate per symbol (C) (modulation order*coding rate)**	**Achievable rate (D) (*P**data rate per symbol/maximum data rate per symbol)**
$P(cir_9 < CIR < cir_8)$	QPSK,1/12	r_9	1/6	*P**1/30
$P(cir_8 < CIR < cir_7)$	QPSK, 1/6	r_8	1/3	*P**1/15
$P(cir_7 < CIR < cir_6)$	QPSK, 1/3	r_7	2/3	*P**2/15
$P(cir_6 < CIR < cir_5)$	QPSK, 2/3	r_6	4/3	*P**4/15
$P(cir_5 < CIR < cir_4)$	16-QAM, 1/2	r_5	2	*P**2/5
$P(cir_4 < CIR < cir_3)$	16-QAM, 2/3	r_4	8/3	*P**8/15
$P(cir_3 < CIR < cir_2)$	16-QAM, 3/4	r_3	3	*P**3/5
$P(cir_2 < CIR < cir_1)$	64-QAM, 2/3	r_2	4	*P**4/5
$P(cir_i < CIR)$	64-QAM, 5/6	r_1	5	*P*

NOTE 1 – Average achievable data rate comparing to peak data rate is given by sum of A product D for each user.

3 Concluding remarks

The generic procedure proposed in this contribution is designed to obtain spectral efficiency with as few technical parameters as possible. Therefore, it can provide a rough estimation of spectral efficiency in a simple manner without consideration of technical details. Furthermore, since this formula cannot reflect performance degradation caused by channel variation for a user due to slow and fast fading, it can be inferred that the spectral efficiency value calculated from the basic formula is a very optimistic value, so that we can estimate spectrum requirements conservatively.

Annex 2

Justifications for parameters for RAT Group 1

1 Application data rate

This parameter is used by methodology for distributing the traffic. It represents a bit rate which is available for applications in a particular cell type. It may be smaller than the available peak bit rate and may not be available throughout the whole cell.

2 Mobility classes supported (was: Maximum velocity supported (km/h))

The maximum velocity is determined by Doppler frequency and handover initiation and execution times. For macro cells the Doppler frequency limits the velocity and the cell edge user data rate will decrease once the velocity exceeds a certain limit. This limit is around 120 km/h for IMT-2000.

In particular for small cells the minimum time a user stay in a cell between handovers needs to be significantly longer than the handover initiation and execution time. Therefore for small cells the cell size limits the maximum supported velocity.

For Recommendation ITU-R M.1768, this parameter is proposed to affect the distribution of traffic to the radio environments. Traffic is classified into mobility classes.

The methodology defines the mobility classes (MC) stationary, low, high and super high. The following mapping between a mobility classes and the radio environments that can support the mobility classes are proposed:

High and super high mobility:	Macro only
Low mobility:	Micro and macro
Stationary:	All radio environment

With this proposal, the absolute values of the maximum velocity are not directly used in Recommendation ITU-R M.1768. Instead of being “Maximum supported velocity (km/h)”, this parameter should be changed to “Mobility classes supported (stationary, low, high and super high)”.

3 Carrier bandwidth – CBW (MHz)

Suggested value = 5 MHz, because it is the maximum carrier bandwidth used by any IMT-2000 terrestrial radio interfaces as defined in Report ITU-R M.2039 – Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses.

4 Guardband between operators (MHz)

For systems of RAT Group 1 this is usually included in CBW. Therefore the suggested value = 0.

5 Minimum deployment per operator (MHz)

Minimum deployment per operator per cell type may be 1 or 2 × CBW.

However, the total spectrum needed for a network is typically this figure multiplied by an integer.

6 Number of overlapping network deployments

Typically there are 2 to 4 overlapping digital cellular networks and 2 to 4 overlapping IMT-2000 networks. By 2015 the number of cellular networks may have decreased, and the number of IMT-2000 networks may have increased. Therefore the suggested value is 5.

7 Possibility to flexible spectrum use (FSU) (Boolean)

FSU is not available for networks of RAT Group 1. Suggested value is “No”.

8 FSU Margin

As the value suggested for the previous parameter is “No” the value for FSU margin is 1.

9 Area spectral efficiency (Bits/s/Hz/cell)

Same area spectral efficiency is assumed for all teledensities in each radio deployment environment. The suggested values are:

Macro cell: 0.4 bits/s/Hz/cell

Micro cell: 0.4 bits/s/Hz/cell

Pico cell: 0.7 bits/s/Hz/cell

These values are assumed as an average over evolved IMT-2000 systems and (pre-) IMT-2000 systems.

10 Area spectral efficiency for multicasting (Bits/s/Hz/cell)

For multicasting the spectrum efficiency is generally lower, because the transmission benefits from multiuser diversity to a smaller extent. The radio resource usage is determined by the user of a multicast group that has the worst reception conditions. Although, in the cell of multi-cell multicasting, the multicast transmission frequently can benefit from soft combining of the signals received from adjacent transmitters, this does not fully compensate for the low multiuser diversity. Therefore a lower spectral efficiency is assumed for multicast transmissions, on the order of 50% of the unicast case.

11 Typical operating frequency range (primary centre frequency)

Networks of RAT Group 1 use spectrum bands below 2 690 MHz.

12 Support of multicast

Suggested value = yes.

Annex 3

Justifications for proposed parameters for RAT2

1 Application data rate

This parameter is used by methodology for distributing the traffic. It represents a bit rate which is available for applications in a particular cell type.

1.1 Macro cell

In this section the bit rates expected to attain in macro cells under different conditions.

It is assumed that a consistent and ubiquitous data rate per link of 5 Mbit/s above layer 2 is a minimum requirement. That rate should thus be achievable at the cell edge of a macro cell. The instantaneous peak data rate is assumed to be higher, however, for use in the methodology, sustainable data rates available above layer 2 need to be considered here:

	Macro cell
Application data rate (Mbit/s) [UL]	5

For downlink (DL) the larger transmit power of the base station will typically enable higher bit rates.

	Macro cell
Application data rate (Mbit/s) [DL]	50

Note that these results apply at the cell border; most users in the cell will have higher data rates, often 100 Mbit/s or more on DL.

1.2 Micro and pico cells, hot spots

For small enough cells in a system with low load (no interference), the peak bit rate of the system will be achievable all the way to the cell border. For a micro cell, which may vary very much in size, an intermediate value is assumed:

	Micro cell	**Pico cell**	**Hot spot**
Application data rate (Mbit/s)(1)	100	1 000	1 000

(1) Values primarily refer to DL. For UL they would likely be somewhat lower.

In a highly loaded system, the interference will reduce the bit rates, but to what extent depends on what frequency reuse is used. Assuming a typical deployment scenario of 1-reuse and a signal-to-interference ratio of 0 dB at the cell edge, a bit rate of roughly 20 Mbit/s is expected (assuming symmetric half-duplex).

2 Supported peak bit rate

No value is given for that parameter, because it is not necessary any more for the spectrum estimation methodology.

3 Maximum supported velocity

High speeds affect performance negatively. It is required to specify the velocity up to which the cell edge user bit rates listed above can be maintained without significant degradation. The calculation indicate that the throughput with adaptive transmission will not decrease significantly up to 50 km/h terminal velocity (at 5 GHz), but drops off more rapidly above that speed (which depends on the receiver SINR). At 2.5 GHz carrier, the corresponding limit would be 100 km/h.

Even at higher velocities, one should be able to have substantial throughput. A crude guess would be that at least about 50% of the throughput could be maintained up to 120-150 km/h, but further studies would be required to confirm this statement. Some throughput should be possible to obtain up to 250 km/h or more, but would be more expensive in terms of radio resources.

Furthermore, for small cells the minimum time a user stay in a cell between handovers needs to be significantly shorter than the handover initiation and execution time. Therefore for small cells the cell size limits the maximum supported velocity. Given the cell sizes of § 2.2, the following maximum velocities are assumed:

	Macro cell	Micro cell	Pico cell	Hot spot
Maximum velocity (km/h)	150	50	5	5

4 One way air interface delay

No value is given for that parameter, because it is not necessary any more for the spectrum estimation methodology.

5 Carrier bandwidth (CBW)

It is assumed that the future systems should be able to operate at different carrier bandwidths. From a theoretical point of view, a wider bandwidth has performance advantages, but implementation considerations and the availability of spectrum impose limitations. Assuming spectral efficiencies of radiocommunication systems to be in the order of 1-10 bit/s/Hz , one may calculate roughly what bandwidth is required for a certain target average throughput. The simple assumption of bit rates in the order of 100 Mbit/s to be achievable for most users leads to conclusion that the bandwidth will typically need to be in the order of 100 MHz. The following carrier bandwidths are examples from current research, where the spectrum efficiency is expected to be in the range what is explained in § 1.9.

	Macro cell	Micro cell	Pico cell	Hot spot
Carrier bandwidth (MHz)(1)	25-50	25-100	100	100

(1) Most probably, as in the case of RAT Group 1, not all cell types need the spectrum in parallel.

6 Guardbands

The carrier bandwidths given above include guardbands. The guardbands are assumed to constitute roughly 20% of the carrier, leaving roughly 80% for data transfer. These values are based on the assumption that FDD and TDD carriers are not adjacent, in which case much larger guardbands would be required (about same size as useful part of band).

Between carriers of different operators, additional guardbands may be needed. One reason for extra guard band between operators may be that they do not perfectly synchronize their systems with each other (applies to TDD). Another reason may be that sites of different operators are not colocated, leading to timing problems (TDD) and near-far effects. As a base line case we assume colocation:

	Macro cell	Micro cell	Pico cell	Hot spot
Guardband between operators (MHz)(1)	0	0	0	0

(1) Assuming that operators synchronize their networks and colocate sites. Without colocation, guardbands of up to 20-30% of total bandwidth might be needed under strict requirements.

It may be noted that spectrum assignment to 3G operators does typically not include room for extra guard band between operators.

7 Minimum deployment per operator

The system is intended to work with 1-reuse and based on the example bandwidths in §1.5 (CBW) the minimum deployment per operator is found to be as follows:

	Macro cell	Micro cell	Pico cell	Hot spot
Minimum deployment per operator (MHz)	50-100	50-100	100	100

Most probably, as in the case of RAT Group 1, not all cell types need the spectrum in parallel. Pico cells and hotspots may be geographically not overlapping and therefore may use the same spectrum; also those indoor cell layers may potentially share the spectrum with the outdoor cell layers like, e.g. micro cells.

8 Possibility for flexible spectrum usage and FSU margin

Flexible spectrum usage (FSU) is currently being investigated as a possible feature of the future system concept.

	Macro cell	Micro cell	Pico cell	Hot spot
Possibility to flexible spectrum usage	Yes	Yes	Yes	Yes

The current research work in the future communication is in the stage that FSU margin can not be specified and thus it is assumed to be equal to 1.

	Macro cell	Micro cell	Pico cell	Hot spot
FSU marging (multiplier)	1	1	1	1

9 Area spectral efficiency

Accurate estimation of spectral efficiency of a radio system is inherently difficult – interference, scheduling, protocol effects etc.; all come into play and interact in a complicated manner. Also, the results are heavily dependent on a number of assumptions such as site density, the number of sectors per site, the number of transmit and receive antennas, the complexity of the signal processing in the receiver (which is related to terminal price), etc.

Furthermore, the spectral efficiency can be specified for each teledensity separately in Recommendation ITU-R M.1768. It is, however proposed to assume the same spectral efficiency in all teledensities.

9.1 Macro cell

Without advanced antenna systems, spectral efficiencies in the order of 1-2 bit/s/Hz/cell seem to be a reasonable baseline assumption.

It is expected that an important feature of systems beyond IMT-2000 will be the integration of more advanced antenna systems, e.g. beam forming and MIMO. Also simpler solutions that go beyond SISO are possible, e.g. receive or transmit diversity.

A conservative estimation of 2-3 bit/s/Hz/cell is proposed.

Results indicate that spectral efficiencies of 1-2 bit/s/Hz/cell can be obtained with SISO transmission. Additional gain due to spatial processing with advanced antenna systems will be obtained. A conservative initial assumption for the overall spectral efficiency in the order of 2-3 bit/s/Hz/cell for macro cellular deployments is adopted.

9.2 Micro, pico cells, and hot spots

The micro and pico cell spectral efficiencies are estimated somewhat higher than for macro cell: 2-5 bit/s/Hz/cell for micro cell and 3-6 bit/s/Hz/cell for pico cell. Better efficiency for smaller cells is also motivated by the fact that they will likely have users with lower mobility, and that coverage limitation is less likely an issue than for macro cell. This trend is continued for hot spot scenarios, where we additionally do not suffer from interference limitation. Therefore spectral efficiencies in the range of 5-10 bit/s/Hz/cell seem to be reasonable for hot spot scenarios.

9.3 Area spectral efficiency for multicasting

For multicasting the spectrum efficiency is generally lower, because the transmission benefits from multi user diversity to a smaller extent. The radio resource usage is determined by the user of a multicast group that has the worst reception conditions. Although, in the cell of multi-cell multicasting, the multicast transmission frequently can benefit from soft combining of the signals received from adjacent transmitters, this does not fully compensate for the low multi user diversity. Therefore a lower spectral efficiency is assumed for multicast transmissions, on the order of 50% of the unicast case.

	Macro cell	Micro cell	Pico cell	Hot spot
Area spectral efficiency (bit/s/Hz/cell)	1-1.5	1–2.5	1.5–3	2.5–5

9.4 Conclusions for spectrum efficiency

The argumentation and estimations of above sections can be summarized as follows:

	Macro cell	Micro cell	Pico cell	Hot spot
Area spectral efficiency (bit/s/Hz/cell)	2-4	2-5	3-6	5-10

10 Typical operating frequency

In § 5.4.7 it is stated that:

"The new spectrum for such new technologies that can fulfil the full range of requirements of the ITU for systems beyond IMT-2000, including both the "new mobile access" and "new nomadic/local area wireless access", as they are presented in Recommendation ITU-R M.1645 should be identified below 6 GHz due to a number of technical reasons. Bands below 6 GHz allow sufficient mobility and there is an acceptable trade-off between cost and full area coverage. Availability of required RF hardware components is seen as feasible in the required timeframe and mobile terminal complexity and power consumption could stay at an acceptable level."

Therefore the following values have been chosen and other parameters have been calculated based on these values.

	Macro cell	Micro cell	Pico cell	Hot spot
Typical operating frequency (MHz)	<6 000	<6 000	<6 000	<6 000

11 Support multicast

The RAT Group 2 should support multicast:

	Macro cell	Micro cell	Pico cell	Hot spot
Support for broadcast/ multicast	Yes	Yes	Yes	Yes

Annex 4

Justifications for proposed parameters for RAT Group 3

1 RAT Group 3 parameter values

The following table contains references to notes below that explain the choice of the values.

Required radio parameters for RAT Group 3

Attribute	Unit	Value			
		Macro cell	Micro cell	Pico cell	Hot spot
Application data rate	kbit/s	(1)	(1)	(2)	(2)
Supported mobility classes				(3)	(3)
Support for multicast (yes = 1, no = 0)		(4)			

(1) The RAT group 3 is not supposed to support macro cell or micro cell type of deployment.

(2) Theoretical physical layer peak data rates of 100 Mbit/s are available on of-the-shelf WLAN cards. Peak user data rates are only about 50 Mbit/s, but with some enhancements 100 Mbit/s should be achievable

(3) The following mobility classes are used in the spectrum estimation methodology Recommendation ITU-R M.1768:

– Stationary/Pedestrian (0-4 km/h)
– Low (> 4 km/h and < 50 km/h)
– High (> 50 km/h-250 km/h)

RAT Group 3 contains nomadic systems with limited mobility support. It is assumed that on average the maximum velocity support is limited to pedestrian in the pico cell or hot spot.

(4) Similarly as for the other RAT groups, RAT Group 3 is assumed to be multicast capable.

Annex 5

Justifications for proposed parameters for RAT Group 4

1 RAT Group 4 parameter values

RAT Group 4 consists of several digital broadcasting systems for mobile reception[2]. There exist several DVB-H test networks in different continents, whereas other techniques are at the moment a bit more country specific. Thus the DVB-H has been taken as a basis for parameters presented in this Annex.

[2] ISDB-T one segment, ISDB-TSB, Digital system E, T-DMB, DVB-H, FLO.

Typical parameters for DVB-H can be found in the Physical layer specification ETSI EN300 744 V1.5.1 and in the implementation guideline ETSI TR 102 377 v1.2.1.

RAT Group 4

Attribute	Unit	Macro cell
Application data rate(1)	Mbit/s	2
Supported mobility classes(2)		All (stationary/pedestrian, low and high)

(1) The example values come from DVB-H.

(2) Could vary between about 120 km/h (8k mode, UHF) to more than 250 km/h (2k mode, UHF).

2 Application data rate

This parameter is used by methodology for distributing the traffic. It represents a bit rate which is available for applications in a particular cell type. It may be smaller than the available peak bit rate and may not be available throughout the whole cell.

The DVB-H is a flexible standard which e.g. includes three different carrier bandwidth options with different mode options from 2k to 8k. Assuming the largest 8 MHz carrier the practical throughput of the carrier is around 10 Mbit/s. In one carrier several broadcast services are multiplexed together. The typical service bit rate is less than 400 kbit/s. Depending on how many broadcast services are multiplexed to same carrier the service bit rate can be up to 10 Mbit/s, which is not seen as a practical alternative.

For the other options rough figures are that the ISDB-T throughput is less than 1 Mbit/s and T-DMB throughput is less than 2 Mbit/s. From these figures the practical upper limit for service is estimated to be 2 Mbit/s.

3 Mobility classes supported

In the DVB-H there exist different modes possibilities and the mobility support can vary between about 120km/h (8k mode, UHF) to greater than 250 km/h (2k mode, UHF). Thus using DVB-H as a reference all the mobility classes are supported by the broadcast RAT group. The mobility support of the other example radio access techniques is similar.

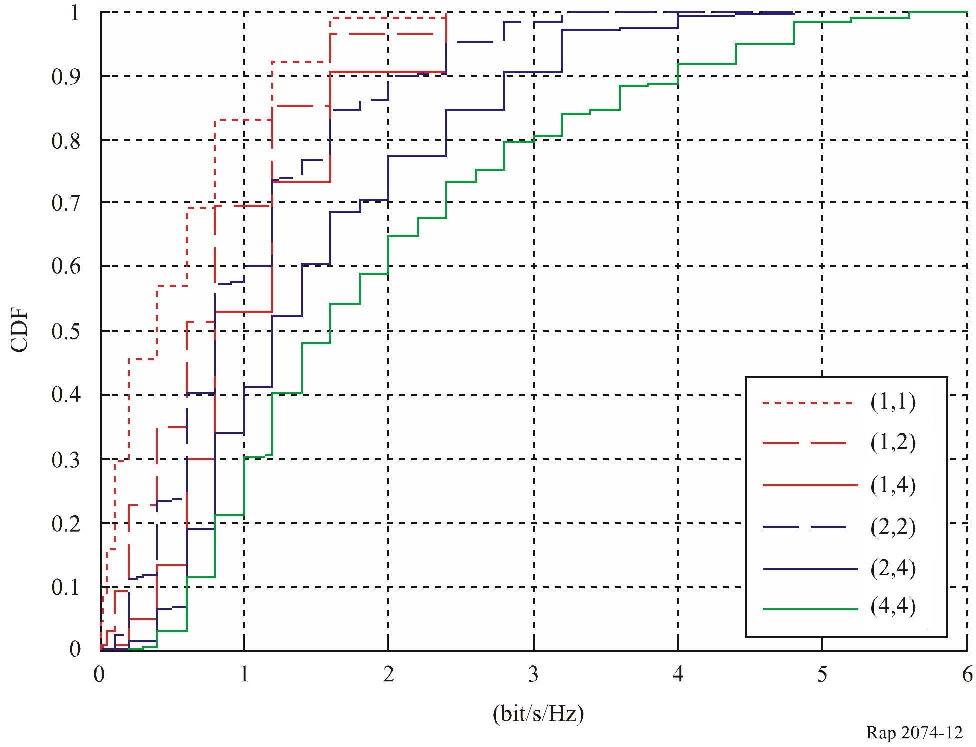
Annex 6

Example of spectrum efficiency using (4,4) MIMO

This Annex describes spectrum efficiency achievable via using a (4,4) MIMO system and examining the impact of other cell interference. This is done via simulations, see [Huang and Valenzuela, 2005]. The goal of the simulations is to generate a CDF of achievable rates for various MIMO antenna configurations in a typical cellular environment. To generate the CDF of rates, we first generate a CDF of geometry for random user locations in a cellular system consisting of a typical 19 cell cluster. The geometry is defined as the ratio of the desired signal power to the interference and background noise power. A given realization of the geometry is interpreted as an average over the fast Rayleigh fading. By generating a realization of the fast fading channel for a given geometry, we can determine the achievable rate based on link-level performance tables. This procedure is repeated to generate the CDF of rates. The CDF is shown in Fig. 12.

FIGURE 12

CDF of achievable rate

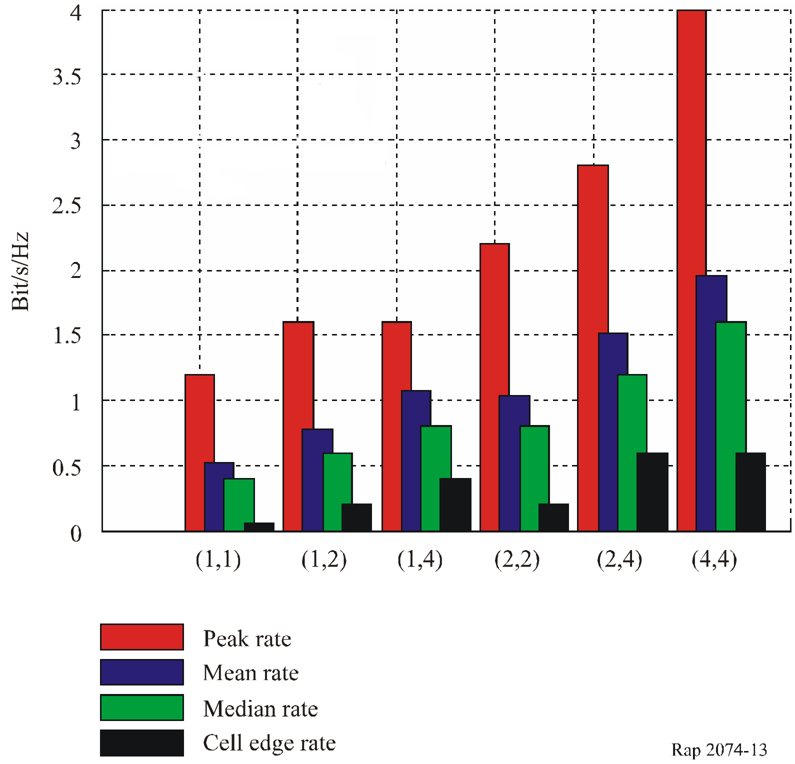


The peak data rate is defined as the rate at which the probability of achieving a lower rate is 0.9. The spectrum efficiency values for the mean rates, peak rates, and median rates are shown as bar graphs in Fig. 13.

It is clear from a consideration of Figs. 12 and 13 that data rates at the cell edge will be lower than the peak rates under interference conditions.

FIGURE 13

Peak, mean, and median achievable rates



References

HUANG, H. and VALENZUELA, R. [2005] Fundamental Simulated Performance of Downlink Fixed Wireless Cellular Networks with Multiple Antennas. PIMRC 2005, Berlin, Germany.