

RECOMMENDATION ITU-R M.1651*

A method for assessing the required spectrum for broadband nomadic wireless access systems including radio local area networks¹ using the 5 GHz band

(Questions ITU-R 212/8 and ITU-R 142/9)

(2003)

Summary

This Recommendation provides a method for assessing the required spectrum for broadband nomadic wireless access (NWA) systems including radio local area networks (RLANs). Annex 1 gives a general description of RLANs, the deployment scenarios, an overview of the method for estimating the required spectrum as well as an example calculation in the 5 GHz band.

The ITU Radiocommunication Assembly,

considering

- a) that there is a need to estimate the actual spectrum requirement for broadband nomadic wireless access (NWA) systems, including radio local area networks (RLANs), used in various environments;
- b) that Recommendation ITU-R M.1390, which is used to calculate the spectrum requirement for the IMT-2000 terrestrial component, would be a suitable basis for the development of a new method as stated in *considering a*),

recommends

1 that the method described in Annex 1 should be used as guidance to estimate the spectrum requirement for broadband NWA systems, including RLANs, using the 5 GHz band.

NOTE 1 – Abbreviations used in this Recommendation are given in Table 1.

NOTE 2 – Reference ITU Recommendations are given in Table 2.

* This Recommendation was jointly developed by Radiocommunication Study Groups 8 and 9, and future revisions should be undertaken jointly.

¹ In this Recommendation radio local area network (RLAN) is as described in Recommendation ITU-R M.1450.

NOTE – The United States of America does not agree with this Recommendation and therefore reserves its position on it.

TABLE 1

Abbreviations used in this Recommendation

AP	Access point
BPSK	Binary phase shift keying
DLC	Data link control
HDTV	High definition television
HiMM	High speed interactive multimedia
HMM	High speed multimedia
IP	Internet protocol
LAN	Local area network
MAC	Medium access control
MiMM	Medium speed interactive multimedia
MMM	Medium speed multimedia
MT	Mobile terminal
NWA	Nomadic wireless access
PDA	Personal digital assistant
PER	Packet error rate
PHY	Physical (layer)
RLAN	Radio local area network
QAM	Quadrature amplitude modulation
QoS	Quality of service
QPSK	Quaternary phase shift keying
SDTV	Standard definition television
VCR	Video cassette recorder
WAS	Wireless access systems
VHiMM	Very high speed interactive multimedia
VHMM	Very high speed multimedia

TABLE 2

Reference ITU Recommendations

Recommendation ITU-R P.1238	Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900 MHz to 100 GHz
Recommendation ITU-R M.1390	Methodology for the calculation of IMT-2000 terrestrial spectrum requirements
Recommendation ITU-R M.1450	Characteristics of broadband radio local area networks
ITU-T Recommendation I.356	B-ISDN ATM layer cell transfer performance

Annex 1

A method for assessing the required spectrum for broadband NWA systems including RLANs using the 5 GHz band

1 Background

A key condition for market acceptance of NWA systems is the availability of a sufficient amount of spectrum to allow for a high-quality user experience in the presence of other uncoordinated users. A method for estimating the amount of spectrum required to support forecast market penetration, user densities and scenarios and the kind of traffic they generate is therefore needed.

A suitable basis for a method of estimating spectrum requirements for NWA systems is available in Recommendation ITU-R M.1390, which was developed for the calculation of IMT-2000 terrestrial spectrum requirements. In fact, the scope of this Recommendation states that the method can be used for other than public land mobile radio systems, and is applicable to both circuit-switched and packet-switch based radio technologies. An example calculation is included as Appendix 1 to illustrate how the method may be implemented. In this example, RLANs are used as a representative model of NWA systems.

Section 2 provides a short introduction of NWA systems and introduces user scenarios. Section 3 reviews the methodology. Section 4 then explains the implementation of the methodology for RLAN spectrum requirements. Finally, an example calculation is supplied in Appendix 1.

2 Introduction to NWA systems

NWA includes broadband RLANs, which are described in Recommendation ITU-R M.1450. Typical applications include public and private wireless access offered in homes, schools, hospitals, hotels, conference centres, airports, shopping centres, etc. Administrations, through national rules and policies, may either choose to license these devices or to exempt these devices from licensing.

Office or indoor environments generally have low e.i.r.p.s and very small radio cells on the order of 30 m radius or less. Outdoor environments generally use higher e.i.r.p.s and have larger radii.

Sufficient spectrum, among other factors, is a necessary condition to allow satisfactory performance in the presence of other uncoordinated users and is one of the key conditions for market acceptance for these kinds of systems.

Most 5 GHz air interface standards have an adaptive feature whereby the physical layer (PHY) mode may automatically adapt to the radio path characteristics. Table 3 shows the PHY modes and typical throughput for each mode. This allows most efficient use of the radio channel, but has the consequence of service area differences: the highest bit rate is only available over a fraction of the total area coverage of the lowest bit rate for any specific access point (AP). Hence in the detailed calculations an averaging over the service area is applied. Spectral efficiency in bit/s/Hz as delivered to the network layer is a function of the throughput achievable in the medium access

control (MAC) layer. The different 5 GHz RLAN standards considered here employ different MAC strategies and therefore different network layer throughput. For the spectrum requirements calculation, the best achievable throughput has been assumed, as per Table 3. This gives a lower limit for the required spectrum: lower MAC throughput results in a greater amount of spectrum required in any given environment needed to support the same aggregate user traffic.

TABLE 3

Example RLAN MAC throughput with 1 500 byte packets

PHY mode (Mbit/s)	Coding rate	Maximum throughput	
		Mbit/s	Throughput (%)
6	1/2	4.6	77
9	3/4	6.9	77
12	1/2	9.2	77
18	3/4	13.9	77
27	9/16	21	77
36	3/4	28	77
54	3/4	42	77

2.1 Recommendation ITU-R M.1390 terminology in the RLAN context

RLANs can be considered a complement to IMT-2000 systems, providing higher data rates and system throughput in geographically limited areas (range of the order of 100 m). Multimedia services are defined in Recommendation ITU-R M.1390 as MMM, HMM and HiMM with user bit rates from 64 kbit/s to 384 kbit/s and up to 2 000 kbit/s. The bandwidth demands of true, high-resolution multimedia communications will require bit rates of the order of 10 Mbit/s and above. RLANs can achieve much higher data rates and system capacity. These data rates can be handled by RLAN standards in the 5 GHz band for several users simultaneously within smaller cells than IMT-2000 systems, and normally inside buildings.

RLANs are typically deployed in a cellular structure, however not with contiguous area coverage like cellular systems. Even if the RLAN coverage area is limited, the entire spectrum may be needed due to local traffic demands.

2.2 Application environments

Typical applications can be found in Recommendation ITU-R M.1450. The environments analysed here are:

- corporate office environment;
- public access environment;

- wide area access environment;
- home environment.

Each of the environments is given attributes in the sections below which should be used in the calculations.

2.2.1 Corporate office environment

RLANs can be used for the replacement or extension of wired LANs. Typical cases could be temporary office installations or installations into spaces where building characteristics or protection prohibit the extensive use of cabling. More recently the sheer convenience of untethered connection to the LAN is proving very attractive to users of laptop PCs, and RLAN products are experiencing high growth rates.

Terminals typically connected to infrastructure networks are designed for fixed use. Such a terminal could, for example, be a workstation, a PC or any other purpose-specific terminal. The applications are typically broadband applications. In this scenario the user device is mostly stationary and the main benefit derived from RLANs is the wireless convenience. Thus, it will be a most likely scenario that RLANs should provide or approximate fixed network QoS to a stationary user. The user should not be able to notice the difference between using the wireless system and a wired system.

TABLE 4

Characteristics of an office environment

Attribute	Requirement
End-user equipment	Portable PC or workstation, personal digital assistant (PDA)
Usage environment	Corporate offices, etc.
Range	Up to 50 m for indoor systems
QoS expectation	Basically same as fixed installation
Applications	Basically same as fixed installation
Mobility	Limited
Coverage	Continuous within the workspace

2.2.2 Public access environment

Typical places for using the RLAN system outside an office room would be meeting rooms, dining facilities, patient wards, classrooms and auditoria, as well as waiting rooms/halls. A user may also be able to access the public network through base stations installed in locations such as railway stations, airports and shopping centres. In some cases, connectivity has to be maintained while the user is in transit from one location to another.

The terminals in this scenario are movable. A typical terminal could be built around a laptop computer and a RLAN card. The mobile node will in many cases be a battery driven device so that an economic consumption of power is required.

Public wireless access applications are in principle similar to office environment applications. However, the users can be located in a wider variety of building types and the ranges are typically greater than in office environments. Furthermore, there may be uncoordinated networks with different owners, which can interfere with a given terminal.

The QoS expected from the RLAN system in this scenario could be somewhat lower than the QoS expected of an office or home system. The user can be assumed to accept that a small loss in QoS is the price paid for the mobility gained. For example, the connection might tolerate a short interruption because of a cell change (resulting in momentary disturbance in the video picture), and the required video picture size and definition for a person temporarily in the access area is also lower.

TABLE 5

Characteristics of a public access environment

Attribute	Requirement
End-user equipment	Portable computer, e.g. notebook or PDA
Usage environment	Offices, schools, hospitals, airports, railway stations, shopping centres, etc.
Range	Up to 50 m for indoor systems Up to 150 m for outdoor systems
QoS expectation	Somewhat lower than desktop
Applications	Similar to desktop
Mobility	Limited
Coverage	Continuous within defined area, e.g. airport hall

It is envisaged by some administrations that RLANs could be used for public access. User devices for such public access should have the same air interface as those for private access. A user device, therefore, can access both public and private networks.

2.2.3 Wide area access environment

It is envisaged by some administrations that WAS/RLANs could be used for wireless access on a wide area coverage basis. The terminals for such access should have the same air interface as indoor WAS/RLAN devices, but would likely use modified antennas and MAC protocols that allow greater range and deal with the longer propagation and multiple access delays resulting from outdoor operation. Sectoral or high-gain omnidirectional antennas, or repeaters, could be used to create micro-cells in which operational ranges of 300 to 3 000 m are possible, depending on the outdoor propagation conditions. In such deployments, the antennas are usually highly directive and are oriented toward a central AP.

The applications are classified as nomadic since the terminals are capable of being moved from location to location. Some examples of nomadic applications are the provisioning of services to small transient businesses operating from industrial parks, or the linkage of several buildings in close proximity to each other to form a “campus” wireless network.

TABLE 6

Characteristics of wide area access environment

Attribute	Requirement
End-user equipment	Desktop and laptop computer, home entertainment centre, small office network
Usage environment	Inter-building, industrial parks (campus) and communities
Range	300 to 3 000 m
QoS expectation	Basically same as a wireline installation
Applications	Basically same as a wireline installation
Mobility	Limited
Coverage	Dependent on outdoor environment and restricted to the range of cell

2.2.4 Home environment

A home network generally covers a much smaller area than either factory or office environments. The rooms tend to be smaller when compared to work environments and have more compartmentalized structure (storage spaces and en-suites). In the home environment, many appliances, e.g. PC laptop, printer/fax machines, security systems, home appliances, digital HDTV/SDTV sets, digital video cassette recorder (VCR), speakers and more could be linked in various ways. A typical scenario would be:

- An entertainment cluster (video and sound) located in the living room transmitting to television sets located in the living room, kitchen and bedroom. The wireless link provides a “bridge” between the clusters, avoiding the use of cable.
- A music system in the living room transmitting to speakers located in the living room, bedroom or dining room.
- Security features outside the home such as wireless security camera or remote sensors. These could either be located on the external walls of the property or at the boundary wall, or a remote building such as a garage or recreation facility.
- RLAN allowing sharing of home computer resources and sharing of Internet access between several computers or PDAs for simultaneous use by several family members.

From the above, it is obvious that the domestic network should allow access to external networks, e.g. digital television or be capable of working with no external links, e.g. a music system with remote speakers.

The home network is expected to require streaming video with high QoS, thus requiring intensive use of a high bit-rate channel.

TABLE 7

Characteristics of a home environment

Attribute	Requirement
End-user equipment	Personal computer, television, entertainment cluster, security systems, PDA, etc.
Usage environment	Domestic premises, i.e. small rooms, two or several floors with high attenuation
Range	Up to 15 m
QoS expectation	Consistent with real-time multimedia services
Applications	Real-time multimedia, World Wide Web applications
Mobility	Limited
Coverage	Continuous within premises

3 Method overview

The basis of methodology is to determine the individual spectrum requirements for all representative combinations of specific environments and services, F_{es} , in a given geographical area, and to combine the set of individual spectrum requirements F_{es} together into a total spectrum requirement estimate, F_e . Hence the spectrum required, F_e (MHz) for a certain environment is:

$$F_e = \sum F_{es} = \sum T_{es}/S_{es} \quad (1)$$

where “e” and “s” are subscripts denoting dependency on environments and services respectively, and,

F_e : spectrum requirement for environment “e” (MHz)

T_{es} : traffic/cell for service “s” in environment “e” (Mbit/s/cell)

S_{es} : system capability (Mbit/s/MHz/cell).

The spectrum requirement F_e should then be rounded up to an integer multiple of the assumed channel bandwidth.

Therefore, F_e is the total required spectrum as a weighted summation of coexisting individual F_{es} for the environment “e” and its services “s” considered relevant. Equation (1) addresses packet-switched services and includes consideration for traffic asymmetry in the uplink and downlink directions. The calculations, parameters, and definition of inputs within the method are divided into four categories and serve to group similar aspects of the method into sub-units:

- A: geographic considerations;
- B: market and traffic considerations;
- C: technical and system considerations;
- D: spectrum results considerations.

In the 5 GHz band there is also a need to consider sharing with other services defined in the Radio Regulations frequency allocations. The calculation result using the method may therefore need to be augmented because of the sharing scenario.

RLANs will, for the most part, be used for Internet-type traffic except for when transmitting high quality video streams. Therefore the packet communications model is appropriate rather than the circuit-switched model, which dominates in the IMT-2000 estimate. The packet communications model will be accounted for by an activity factor (Step B5) where the fraction of the time in which the resource is used must be estimated for the service in each environment.

Note that the method assumes a centralized controller architecture; for an ad hoc network modifications to the method may be necessary.

4 Method implementation for NWA

4.1 Geographic and environment scenarios (Step A)

4.1.1 Application environments

The environments are chosen to determine spectrum requirements which are typically the most intensive in terms of data rate, user density and activity ratio. The common denominator of these environments is the need to support multimedia services.

The environments for analysis are:

- corporate office environment;
- public access environment;
- wide area access environment;
- home environment.

Each of the environments is given attributes that are used in the calculations.

Cell geometry and size should represent typical layout installations for RLANs in each environment, where the cells (or APs) may be uncoordinated. All are assumed to be stand-alone networks under the control of one owner, but in the net system capability calculations the co-channel interference from neighbours should be taken into account (Step C). The actual area served with a given reliability appears in the system capability calculations because it is determined largely by interference, and may differ from the planned AP layout because of the propagation scenario.

A1 Environment type

Select “e” – environment type, i.e. corporate, public, wide area or home; perform a separate calculation for each environment.

A2 Select direction of propagation

The direction is either uplink (from the mobile terminal to the AP), or downlink (from the AP to the MT). The traffic and spectrum figures in Steps A2 through D1 are calculated separately for uplink and downlink directions because of the traffic asymmetry in some services. The spectrum required for any F_{es} is the sum of the requirement for both directions.

A3 Establish representative cell geometry (m)

The typical cell geometry for each environment, based on system capability.

A4 Calculate Cell_area_e (m²)

The typical cell area covered by the cell (assumed to be circular).

4.2 Market and traffic (Step B)**B1 Select “s”**

“s” – service application type: select service type (e.g. those listed in Table 8).

4.2.1 Users per cell (Steps B2-B4)

The penetration rate for the environments must be defined in order to calculate the number of users in a cell. The penetration rate could vary for each environment. A cell is considered to be the area served by one AP.

B2 Area_per_User_e (m²)

This is the area per user in the given environment “e”.

B3 Establish Penetration_Rate_{es} (%)

This is the estimated penetration in the environment.

B4 Calculate users/Cell_{es} (users)

The number of users per cell can now be obtained as:

$$\text{Users/Cell}_{es} = \text{Penetration_Rate}_{es} \cdot \text{Cell_Area}_e / \text{Area_per_User}_e$$

4.2.2 Traffic and services (Steps B5-B8)

The services that are envisaged for NWA are given in Table 8, with the parameter values that have been used in the example calculation in Appendix 1. In order to simplify the calculations, the individual services have been grouped into a reduced number of categories MiMM, HMM, HiMM, VHMM and VHiMM.

TABLE 8

Example application data rates

Application	Main link direction	Average data rate (Mbit/s)	Peak/average ratio	QoS	Peak data rate (Mbit/s)
MiMM (medium speed interactive multimedia)					
E-mail	Up or down	1.00	2,0		2.00
Videoconference	Up and down	4.00	1,0	Yes	4.00
Control	Up and down	2.00	1,5		3.00
Voice	Up and down	0.03	1,0	Yes	0.03

TABLE 8 (end)

Application	Main link direction	Average data rate (Mbit/s)	Peak/average ratio	QoS	Peak data rate (Mbit/s)
HMM (high speed multimedia)					
Web browsing	Down	2.00	3.0		6.00
File transfer	Up or down	2.00	5.0		10.00
Vidéosurveillance	Amont	2.00	1.0		2.00
HiMM (high speed interactive multimedia)					
Web hosting	Up and down	6.00	1.0		6.00
Client server	Up and down	3.00	2.7		8.00
VHMM (very high speed multimedia)					
Spooling video	Up or down	10.00	2.0		20.00
Streaming video	Up or down	6.00	2.0	Yes	12.00
VHiMM (very high speed interactive multimedia)					
Multiplayer game	Up and down	5.00	3.0	Yes	15.00

B5 Establish traffic parameters

For each service “s”, in each environment “e”, the following parameters must be established:

- Busy_Hour_Session_Attempts_{es} (sessions in busy hour): the average number of attempts during busy hour;
- Session_Duration_{es} (s): the mean actual duration of the session during the busy hour;
- Activity_Factor_{es} (dimensionless): the fraction of time a user is active *during* session.

B6 Calculate Traffic/User_{es} (session-seconds)

The traffic per user can now be calculated as:

$$\text{Traffic/User}_{es} = \text{Busy_Hour_Session_Attempts}_{es} \cdot \text{Session_Duration}_{es} \cdot \text{Activity_Factor}_{es}$$

B7 Calculate Offered_Traffic/Cell_{es} (session-seconds)

The total traffic issued in a given cell of environment “e” for service “s” during the busy hour:

$$\text{Offered_Traffic/Cell}_{es} = \text{Traffic/User}_{es} \cdot \text{Users/Cell}_{es}$$

B8 QoS factor

QoS is accounted for by the system capability (Step C), and the factor is set to one.

4.3 System capacity (Step C)

The system capacity reflects the average achievable user-data rate (excluding overhead), normalized to bandwidth and cell, over an entire RLAN deployment (a number of cells).

The spectrum resources and efficiency mainly determine the capacity in terms of bit/s/deployment of a RLAN. As previously noted, a system with central controller is assumed in this study. The dominant factors are the number of available RF channels, the bit rate per RF channel, the frequency reuse factor and the loading of the channels from other networks operating at the same channels within the radio range.

The actual capacity of a system further depends on the protocol overhead, on the ratio between protocol overhead and traffic payload size and on the effective channel isolation. Note that the net system capability (given as Mbit/s/MHz/cell) reflects the estimated average user-data rate attainable over a deployment within a given geographical area.

Throughput relative to PHY mode for the example calculation in Appendix 1

Table 3 gives the throughput above the data link control (DLC) using a link with the different PHY modes. The effective total user data rate on top of the DLC varies from 4.6 Mbit/s to 27.7 Mbit/s (excluding the optional 54 Mbit/s mode) per link when $C/(N + I)$ goes from some 8 dB to above 21 dB, depending on the actual radio propagation and interference situation.

In the example calculation of net system capability in Appendix 1 the throughput value 70% is used to include margins when more MTs are used. Clearly the use of a system with lower MAC efficiency would lead to an increase in spectrum requirements.

Frequency reuse and interference

The C/I requirement for each PHY mode and PER limits the frequency reuse in a high capacity environment. The link adaptation increases the average bit rate in a cell, since a relevant PHY mode can be selected depending on path loss to the wanted MT, i.e. carrier power C , and the co-channel interference, I . Typically a frequency reuse factor, FR , in the range of 3 to 5, is necessary for the corporate, home and public environments when a non-continuous coverage is assumed. However, in certain circumstances a much higher reuse factor (e.g. around 12) may be necessary. Thus, we assume that the AP to co-channel AP separation, $SepAPco$, can be determined from the AP-to-AP separation, $SepAP$, in a given layout. A simplified (and optimistic) expression is then given by:

$$SepAPco = SepAP \cdot FR^{0.5} \quad \text{m}$$

Path-loss models

In the corporate environment the path-loss model in Recommendation ITU-R P.1238 is used in the example calculation. The distance dependent path loss, basic transmission loss, L_b , is expressed as:

$$L_b = -28 + N \log_{10}(d) + L_w + 20 \log_{10}(f) \quad \text{dB}$$

where:

d : distance (m)

f : carrier frequency (MHz)

N : frequency dependent distance power loss coefficient

L_w : additional wall attenuation.

For frequencies around 5 GHz, $N = 28$. The same model is used in the home environment. In the outdoor environment a path-loss model based on linear attenuation is used, which is a suitable model when no additional wall loss is considered. This model then describes the propagation situation in open halls, city squares, or within a lightly blocked (by trees) neighbourhood. The calculation is given by:

$$L_b = -28 + 20 \log_{10}(d) + \alpha \cdot d + 20 \log_{10}(f) \quad \text{dB}$$

where α is a linear attenuation factor (dB/m).

4.3.1 QoS, transfer latency and transfer delay variance

When operating in a more or less stationary environment, NWAs shall be able to maintain the values of data rate and QoS established at the connection set up. For the applicable QoS parameters, see ITU-T Recommendation I.356.

QoS parameters such as transfer delay and delay variance have an impact on the total throughput when priority and MAC scheduling is fully taken into account. However, to avoid unnecessary complications, the calculations use simple average and peak rates for the variety of applications.

4.3.2 Traffic (bit rate) per cell (Steps C1-C3)

C1 Number of Service_Channels/Cell_{es}

The number of Service_Channels/Cell_{es} required for carrying Offered_Traffic_Cell_{es}. In view of the QoS deliberations above, it is assumed that all the available (offered) traffic according to Step B7 will be carried by the network. Equating the offered traffic with the number of service channels (Step C1) would furthermore correspond to a perfect scheduling of the traffic, where all the different service types are arranged into the appropriate MAC format without any overhead. If QoS is accounted for, then the number of service channels must be increased to account for blocking and queuing, for example.

When converting the offered traffic (Step B7) into service channels (Step C1), account is taken of the fact that the traffic streams must be mapped onto integer numbers of PHY layer packets, however. This corresponds to a marginal increase in overhead. Since the packet lengths of the standards in Recommendation ITU-R M.1450 vary (54-1 500 bytes for the standards considered), a simple way of accounting for the RLAN packet transmission in general is to approximate the offered traffic to the nearest higher (first) decimal to obtain the number of serving channels. Hence the latter is almost equal to the offered traffic.

Note that increasing the number of service channels would increase the spectrum requirements.

C2 Determine Service_Channel_Bit_Rate_{es} (Mbit/s)

The Service_Channel_Bit_Rate_{es} needed to carry Net_User_Bit_Rate_{es}, i.e. the user data rate of a service “s”. Due to modularity of the bit rate of the service channel (e.g. the PHY modes in Table 3), it is possible that the Service_Channel_Bit_Rate_{es}, might be equal to or greater than the corresponding Net_User_Bit_Rate_{es} (e.g. the application data rate given for a service class in Table 8). A service characterized by a peak rate of 4 Mbit/s, for example, would require the 6 Mbit/s PHY mode.

C3 Traffic/cell T_{es} (Mbit/s/cell)

The traffic (bit rate for each service “s”) is calculated as is calculated as:

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

4.3.3 Obtaining the system capability (Steps C4-C5)**C4 Net_System_Capability (S_{es}) parameters**

S_{es} is a measure of the system capacity of a specific technology. Often the values required to determine S_{es} are obtained from the results of complex system simulations. An example calculation of the system capacity is provided in Appendix 1. The following subsections explain some of the steps of the system capacity calculation and suggest propagation models for obtaining coverage and co-channel interference estimates.

The example calculations have considered a reliability level of 90% against noise and interference on the cell border. Hence, a typical 95% area coverage reliability is achieved with the fading and interference margins applied.

C5 Calculate S_{es} (Mbit/s/MHz/cell)

The net system capability (Step C5) is used to calculate required bandwidth. By dividing traffic (Step C3) by Step C5, we can obtain required bandwidth (Steps D1, D2, and consequently D3 below). The net system capability figure is derived by system evaluations in each of the four environments. Here path loss, interference, reliability margins, throughput, etc. are taken into account. In order to follow the ITU-R method and to be able to make comparisons, well-known path-loss models should be used.

In the example calculation in Appendix 1, this value is calculated by dividing the transmission rate by the multiplication of the bandwidth per channel and the reuse factor of the radio frequency.

4.4 Spectrum calculations (Step D)

The remaining parameters of equation (1) can now be obtained in order to determine the spectrum requirement for each environment.

D1 Calculate the individual F_{es} component (MHz)

For either uplink or downlink, $F_{es} = T_{es}/S_{es}$.

D2 Repeat the process for calculation of the other direction

Repeat Steps A2 through D1.

D3 Combine uplink and downlink F_{es} components (MHz)

For each service “s” in each environment “e”:

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

D4 Determine the number of channels (n)

This is an upward rounding required to get an integer number of channels:

$$n = \text{int} \{(\sum F_{es} / \text{channel bandwidth}) + 0.5\}$$

D5 Total spectrum

The sum of the required spectrum for each environment “e” is given by in Equation (1) (combine uplink and downlink), rounded up to a multiple of the channel bandwidth.

Appendix 1 contains example calculations with all the required steps in spreadsheet format.

The total spectrum required for the environments is then calculated based on penetration rates assumed for the year 2010.

For the example calculation, it is assumed that spectrum allocations allow 20 MHz channelization in a manner that minimizes guardbands at band edges. Any requirement for larger guardbands would clearly increase the total spectrum required.

The resulting spectrum requirements in this example are 420 MHz, 340 MHz and 320 MHz for the corporate, home and public environments, respectively (see Appendix 1). These requirements are valid for each of these geographically limited environments and are mutually exclusive. The requirements can be regarded as being at the lower end since the calculation is based on the standard with the most efficient MAC protocol of the standards listed in Recommendation ITU-R M.1450.

Appendix 1 to Annex 1

Examples of the application of the methodology

Examples of the application of the methodology to the office, public and home environments are given in this Appendix (wide area access is treated in a similar way). The calculation is performed with a spreadsheet, using the parameters and system capacity figures shown. In the calculation of net system capability the throughput value 70% is used. A lower throughput MAC protocol would result in a larger spectrum need. The spectrum requirements calculated can thus be regarded as being at the low end of the range needed to support the user density and traffic parameters used. The antenna radiation pattern is taken to be nominally omnidirectional for all terminals and access points.

The spreadsheet for the calculation of the net system capability for the office environment is followed by another sheet for the subsequent estimate of spectrum need according to the steps of the method. The resulting spectrum requirement in this example is 420 MHz, 340 MHz and 320 MHz for the corporate, home and public environments, respectively.

First we consider the services. Table 8 lists the services that are envisaged with their assumed characteristics. In order to simplify the calculations, these have been grouped into a reduced number of categories and for each environment the applications have been given the attributes required for the spectrum calculations shown in Tables 9-11.

TABLE 9

Predicted traffic parameters for corporate environments

Corporate environment	Main link direction	Average data-rate (Mbit/s)	QoS	Peak data-rate (Mbit/s)	Busy hour sessions/h (average over week)	Session duration (s)	Activity factor
MiMM	Up and down	2	Yes	4	0.5	300	0.45
HMM	Up and down	2	No	10	0.5	600	0.16
HiMM	Up and down	5	No	8	0.3	1 200	0.35
VHMM	Up and down	7	Yes	20	0.1	1 800	0.5
VHiMM	Up and down	5	Yes	15	0.1	1 500	0.4

TABLE 10

Predicted traffic parameters for public environments

Public environment	Main link direction	Average data-rate (Mbit/s)	QoS	Peak data-rate (Mbits/s)	Busy hour sessions/h (average over week)	Session duration (s)	Activity factor
MiMM	Up and down	1	Yes	2	0,5	90	0.45
HMM	Up or down	2	No	10	0,2	300	0.1
HiMM	Up and down	3	No	8	0,4	90	0.3
VHMM	Up or down	6	Yes	12	0,06	600	0.5
VHiMM	Up and down	5	Yes	15	0,06	900	0.4

TABLE 11

Predicted traffic parameters rates for home environments

Home environment	Main link direction	Average data-rate (Mbit/s)	QoS	Peak data-rate (Mbits/s)	Busy hour sessions/h (average over week)	Session duration (s)	Activity factor
MiMM	Up and down	2	No	4	0.2	90	0.45
HMM	Up or down	2	No	10	0.3	600	0.12
HiMM	Up and down	4	No	8	0.3	150	0.3
VHMM	Up or down	10	Yes	20	0.1	3 600	0.5
VHiMM	Up and down	5	Yes	15	0.1	3 600	0.4

These traffic parameters are used in Steps B5-B7. Next, Table 12 shows the spreadsheet calculation of the net system capability for the corporate environment; the figures for all environments considered in this example are summarized in Table 13.

TABLE 12

Net system capability for the Corporate Environment

	Corporate environment						
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Adaptive mode
Modulation	BPSK	BPSK	QPSK	QPSK	16-QAM	16-QAM	Adaptive
Bit rate	6	9	12	18	27	36	23,37
Scenario	Office	Office	Office	Office	Office	Office	
e.i.r.p. (dBm)	23.0	23.0	23.0	23.0	23.0	23.0	
Path loss, L_b (dB)	-93.9	-92.4	-91.2	-88.5	-86.0	-84.0	
Number of walls AP-MT	1.0	1.0	1.0	1.0	1.0	1.0	
Wall attenuation, L_{wall} (dB)	8.4	8.4	8.4	8.4	8.4	8.4	
AP-MT separation (m)	18.0	17.0	16.0	14.0	13.0	12.0	15.0
Received power, P_r (dBm)	-69.4	-67.9	-66.7	-64.0	-61.5	-59.5	
Cell area (m ²)	1 017.9	907.9	804.2	615.8	530.9	452.4	1 017.9
Frequency (GHz)	5.3	5.3	5.3	5.3	5.3	5.3	
Frequency reuse	4.0	4.0	4.0	3.0	3.0	3.0	3.0
Rate/ channel (Mbit/s)	4.2	6.3	8.4	12.6	18.9	25.2	11.81
Threshold $C/(N+I)$ (dB)	9.0	11.0	13.0	15.0	19.0	21.0	
P_r specified (dBm)	-85.0	-83.0	-81.0	-79.0	-75.0	-73.0	

TABLE 12 (*end*)

	Corporate environment						
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Adaptive mode
Fade margin (dB)	15.5	15.1	14.3	14.9	13.5	13.5	
σ log-normal	6.0	6.0	6.0	6.0	6.0	6.0	
M-value	1.3	1.3	1.3	1.3	1.3	1.3	
Fade margin, (90% $M \cdot \sigma$) (dB)	7.7	7.7	7.7	7.7	7.7	7.7	
Maximum loss, L_{max} (dB)	109.5	107.5	105.5	103.5	99.5	97.5	
Number of walls AP-AP	2.0	2.0	2.0	2.0	2.0	2.0	
Number of walls APco	3.0	3.0	3.0	3.0	3.0	3.0	
L_{wall} (dB)	14.9	14.9	14.9	14.9	14.9	14.9	
Maximum AP separation (m)	50.0	50.0	50.0	50.0	50.0	50.0	50.0
APco separation (m)	87.1	87.1	87.1	77.6	77.6	77.6	
$I_{downlink}$ (dBm)	-88.5	-89.0	-89.4	-88.4	-89.0	-89.3	
System margin, 90%	2.1	1.0	0.0	0.0	7.4	6.5	2.8
Mode area (%)	11	10	19	8	8	44	100
System capacity (Mbit/s)	0.04	0.06	0.08	0.19	0,28	0.38	0.16

TABLE 13

Net system capability

	Corporate	Home	Public
Net_System_Capability (Mbit/s/MHz/cell)	0.16	0.160	0.290
Coverage area (m ²)	1 018	707	5 027

Finally, Table 14 shows the spreadsheet calculation of the spectrum requirements. These requirements are valid for each of the (geographically limited) environments, and are thus mutually exclusive.

TABLE 14

5 GHz RLAN spectrum requirement and calculation for the year 2010

Step	Parameter	Corporate	Home	Public	Comments
A3	Cell geometry (m)	18	15	40	Defined by AP separation distance
A4	Cell area circular (m ²)	1 018	707	5 027	

TABLE 14 (continued)

Step	Parameter	Corporate	Home	Public	Comments
B2	Area per user (m ²)	14	100	10	
B3	Penetration_Rate (%)	30	30	20	
B4	Users/Cell				= B3 · A4/B2
	MiMM	22	3	101	
	HMM	22	3	101	
	HiMM	22	3	101	
	VHMM	22	3	101	
	VHiMM	22	3	101	
B5	Busy_Hour_Session_Attempts (/busy hour) average over typical week				Averages over large user population
	MiMM	0.5	0.2	0.5	
	HMM	0.5	0.3	0.2	
	HiMM	0.3	0.4	0.4	
	VHMM	0.1	0.3	0.06	
	VHiMM	0.1	0.3	0.06	
B5	Session duration (s)				
	MiMM	300	90	90	
	HMM	600	600	300	
	HiMM	1 200	150	90	
	VHMM	1 800	3 600	600	
	VHiMM	1 500	3 600	900	
B5	Activity_Factor packet communications				Defined as the fraction of the time the resource is used
	MiMM	0.45	0.45	0.45	
	HMM	0.16	0.12	0.1	
	HiMM	0.35	0.3	0.3	
	VHMM	0.5	0.5	0.5	
	VHiMM	0.4	0.4	0.4	
B6	Traffic/User (session-seconds)				
	MiMM	67.5	8.1	20.25	
	HMM	48	21.6	6	
	HiMM	126	18	10.8	
	VHMM	90	540	18	
	VHiMM	60	432	21.6	

TABLE 14 (continued)

Step	Parameter	Corporate	Home	Public	Comments
B7	Offered_Traffic/Cell (relative busy hour activity/cell)				
	MiMM	0.412	0.007	0.568	
	HMM	0.293	0.018	0.168	
	HiMM	0.77	0.015	0.303	
	VHMM	0.55	0.450	0.505	
	VHiMM	0.366	0.360	0.606	
B8	QoS				QoS is accounted for within the system capability (Step C) hence the factor is set to 1 here
	MiMM	1	1	1	
	HMM	1	1	1	
	HiMM	1	1	1	
	VHMM	1	1	1	
	VHiMM	1	1	1	
C1	Number of Service_Channels/cell required to carry Offered_Traffic/Cell				Round up according to Step C1
	MiMM	0.5	0.1	0.6	
	HMM	0.3	0.1	0.2	
	HiMM	0.8	0.1	0.4	
	VHMM	0.6	0.5	0.6	
	VHiMM	0.4	0.4	0.7	
C2	Service_Channel_Bit_Rate needed to carry Net_User_Bit_Rate (Mbit/s)				These figures are set by the PHY modes in Table 3
	MiMM	6	6	6	
	HMM	12	12	12	
	HiMM	12	12	12	
	VHMM	27	36	36	
	VHiMM	27	36	36	
C3	Traffic (Mbit/s/cell)				This is the actual traffic transmitted
	MiMM	3	0.6	3.6	
	HMM	3.6	1.2	2.4	
	HiMM	9.6	1.2	4.8	
	VHMM	16.2	18	21.6	
	VHiMM	10.8	14.4	25.2	

TABLE 14 (continued)

Step	Parameter	Corporate	Home	Public	Comments
C4	Net_System_Capability parameters				Parameters were set and a spreadsheet simulation used to obtain the capability in C5
C5	Net_System_Capability (Mbit/s/MHz/cell)				This represents the average of all modes due to rate adaptation, obtained from the simulation
	MiMM	0.16	0.16	0.29	
	HMM	0.16	0.16	0.29	
	HiMM	0.16	0.16	0.29	
	VHMM	0.16	0.16	0.29	
	VHiMM	0.16	0.16	0.29	
D1	F_{es} component $F_{es} = T_{es}/S_{es}$ (uplink/downlink)				
	MiMM	18.75	3.8	12.4	
	HMM	22.5	7.5	8.3	
	HiMM	60.0	7.5	16.6	
	VHMM	101.250	112.5	74.5	
	VHiMM	67.5	90.0	86.9	
D2	Repeat the process for calculation of the other direction (downlink/uplink)				
	MiMM	18.75	3.8	12.4	
	HMM	0	0	0	
	HiMM	60.0	7.5	16.6	
	VHMM	0	0	0	
	VHiMM	67.5	90.0	86.9	

TABLE 14 (*end*)

Step	Parameter	Corporate	Home	Public	Comments
D3	F_{es} for the service "s" combining uplink and downlink components				
	MiMM	37.5	7.5	24.8	
	HMM	22.5	7.5	8.3	
	HiMM	120	15.0	33.1	
	VHMM	101.25	112.5	74.5	
	VHiMM	135.0	180.0	173.8	
D4	Integer multiple, n , of channel bandwidth	21	17	16	20 MHz channels are assumed
D5	Sum F_e for all services in environment, upward rounding according to Step D4 (MHz)	420	340	320	This is the resultant (example) total required spectrum for each environment ($\Sigma F_{es} \cdot n$)