

RECOMMENDATION ITU-R F.1244\*

**RADIO LOCAL AREA NETWORKS (RLANs)**

(Question ITU-R 142/9)

(1997)

The ITU Radiocommunication Assembly,

*considering*

- a) that radio local area networks (RLANs) will be widely used for transportable and fixed computer-based equipment and for a variety of wide band services (e.g. video distribution);
- b) that RLAN standards may be compatible with those of wired LANs;
- c) that it is desirable to establish operating guidelines for RLANs in various frequency bands;
- d) that the above guidelines should not limit the potential of RLANs but be used for promoting their development;
- e) that RLANs should be operated giving careful consideration to interference compatibility with other radio systems;
- f) that studies on RLANs within the ITU-R should give due consideration to the appropriate work carried out by the ITU-T,

*recommends*

- 1** that for guidance, some features of RLANs as described in Annex 1 should be referred to;
- 2** that for guidance on some proposed frequency bands and approximate data rates for RLANs, Table 1 should be referred to;

TABLE 1  
(Note 1)

Frequency	Frequency bands	Approximate data rates
UHF (300-3 000 MHz)	900 MHz 1 900 MHz 2 400 MHz	Up to 6 Mbit/s
SHF (3-30 GHz)	5.2 GHz 5.7-5.8 GHz 17.2 GHz 18.8 GHz 19.5 GHz	Up to 50 Mbit/s
EHF (30-300 GHz)	60 GHz (Note 2)	Under study

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\* This Recommendation should be brought to the attention of Telecommunication Standardization Study Groups 7 and 13 (JRG on GII), and Radiocommunication Study Groups 3 (WP 3K), 4 (WP 4A), 8 (WP 8A) and 11 (WP 11C).

3 that for guidance on some proposed schemes for multiple access and modulation techniques Table 2 should be referred to;

TABLE 2  
(Notes 3 and 4)

Frequency	Multiple access	Modulation
UHF	FDMA, TDMA, CDMA (direct sequence spread spectrum, frequency hopping)	FSK, QPSK
SHF	FDMA TDMA CDMA	FSK GMSK QPSK 16-QAM
EHF	Under study	Under study

4 that the topology of RLANs be further studied. Two basic topologies are presented in Figs. 1 and 2:

- non-centralized or hubless systems;
- centralized systems;

5 that for guidance on performance requirements for RLANs, § 2.4 in Annex 1 should be referred to;

6 that an RLAN which shares a frequency band with other systems in the FS or other radio services should meet certain technical requirements to enable such sharing to take place (see Note 5);

7 that for further guidance on RLAN radio equipment standards, draft Recommendation [ITU-R M.Doc. 8/60] should also be referred to.

NOTE 1 – The use of other frequency bands is not excluded. Band availability for RLANs may be different from country to country.

NOTE 2 – Development of RLANs using EHF bands is under study (see Appendix 3 of Annex 1).

NOTE 3 – Examples of typical RLANs operating in each frequency band are presented in Table 3.

NOTE 4 – It has been suggested that time division duplexing (TDD) techniques may be effectively used to simplify the hardware.

NOTE 5 – Consideration on interference compatibility is given in § 2.5 of Annex 1.

## ANNEX 1

### Radio local area networks (RLANs)

#### 1 Introduction

Local area networks (LANs) are generally considered to be networks operated by a single organization within a single facility or over a small campus. LANs have been designed and installed for the purpose of interconnecting computers and sharing computer resources. Unlike circuit switched networks, LANs are particularly suited to the efficient handling of bursty traffic typical of computer activity.

Many of the constraints associated with cable-based LANs such as cost, maintenance and installation can be solved by intelligent application of advanced radio techniques. For example, microcell radio architectures combined with highly adaptable modulation techniques could be applied to RLANs. Cells can be interconnected to the network using either cable or radio techniques.

One feature of RLANs unavailable in wired LANs is that network members are untethered, and in principle free to connect to and disconnect from a network, and to move around a network and between networks.

“Untethered” communications include private, on-premise networking, which is not covered by the traditional definitions of fixed or mobile communications. Untethered users are not bound to a large, desk-mounted personal computer. Instead they are able to take their lightweight personal computers and electronic notebooks with them wherever they go throughout their organization’s premises, and beyond, while still maintaining the ability to interact with and make use of other systems on the local network. In the future untethered communications may become a trigger for the restructuring of two well-established concepts of fixed and mobile communications.

As examples, some general features that might be provided by RLANs include:

- supporting certain data rates, protocols, standards and performance generally in common with those supported by wired LANs;
- facilitating portable applications (i.e. small, low power units), and the ability, when desirable, to transfer from one network to another;
- supporting high speed communications requirements such as computer-to-computer linkage;
- possibly supporting applications where the time taken to deliver the data is critical, for example voice and videocommunication including videoconferencing.

A wide range of data rates will be required up to more than 100 Mbit/s depending on the application.

RLANs can be used both indoors or outdoors or in combination, although interference considerations may be different in each case. It may, in some cases, be necessary to restrict operation to within buildings to meet local frequency sharing criteria.

RLAN applications within buildings are affected by the indoor propagation environment which is still not well understood. Radio link performance will depend on such factors as building dimensions and materials, exposure to adjacent buildings through windows, the furniture and their placement with respect to radio paths and dynamic variation of the path geometry.

Further studies will be necessary to better characterize the RLAN propagation environment.

## **2 RLANs characteristics**

There are a number of technologies available for RLANs, the selection of which will depend on requirements such as system architecture, frequency bands, transmission rate, error performance, security and interference compatibility.

### **2.1 Modulation, coding and diversity considerations**

For RLAN applications, radio equipment must offer high performance at low cost. Most of the data services that will be provided require the maintenance of very low bit-error ratios, for example ranging between  $1 \times 10^{-5}$  and  $1 \times 10^{-10}$ , especially if RLAN services are to compete, or interface with fibre or cable services, which currently offer performance with error ratios lower than  $1 \times 10^{-10}$ .

Error performance can be enhanced with diversity processing (in space, time, frequency, polarization or other variables) and error control coding which may allow bit-error ratios as low as the order of  $1 \times 10^{-14}$ . In the specification of such schemes, however, close attention must be paid to the trade-off between cost and performance. Signalling schemes that are tolerant of phase noise and frequency errors will probably be strong contenders, as they will allow the use of low cost oscillators and frequency synthesizers.

Applications currently in existence imply certain data rates at the application service interface, for example for integrated services digital network (ISDN) connectivity. The consideration of these existing applications should not limit the development of RLAN standards, which should also take into account emerging application proposals and be a stimulus to the development of new application areas.

In the case of ISDN, it is currently difficult to provide broadband ISDN (B-ISDN) (at or above the primary rate = 155.52 Mbit/s) over indoor radio channels. A first step can be to consider the provision of various multiples of the basic ISDN rate of 144 kbit/s or the DS-1 rate of 1.544 Mbit/s over short radio links to backbone system interface units. There, rate conversion to B-ISDN could take place before transmission over the backbone network that can be for example fibre or line-of-sight radio. Such sub-rate services could be provided at various frequencies. The choice of signalling will be frequency-dependent because of differences in propagation characteristics, component costs and spectrum availability.

At UHF, spectrum is becoming an extremely scarce resource. Consequently, signalling schemes should be spectrally efficient and tolerant of interference. Direct sequence or frequency hopping code division multiple access (CDMA) with some form of phase shift keying might be used as it satisfies these requirements, and additionally, can be implemented with built-in diversity. Properly designed receivers can discriminate among different multipath components. This could result in high order diversity with only a small number (e.g., 2) of antennas. A complication, however, is that such systems may need to employ power control to prevent capture by the strongest received signal. Power control normally requires a physically centralized control system which may be incompatible with the non-centralized control system to be used by many RLANs. CDMA also implies restrictions in the flexibility of any frequency channelling, which can mean difficulty in arriving at systems that can be used in many countries without reprogramming (a very desirable characteristic of untethered communication systems).

In addition, such systems can use convolutional, or BCH codes for error correcting coding. These types of codes are suitable for correcting random errors. To meet future demands for extremely low error ratios while maintaining high capacity under bursty fading conditions however, more powerful codes capable of correcting burst errors will be required. One approach might be to use a concatenated coding scheme with a convolutional inner code and a Reed-Solomon outer code. With such a scheme, the convolutional inner code would correct random errors, while the Reed-Solomon code would correct burst errors. Concatenated codes can achieve very low error ratios under conditions of low signal-to-noise ratios, thereby reducing transmit power requirements, interference potential and equipment costs. In addition, when these codes are not capable of correcting errors satisfactorily, they are capable of detecting the coding failure with very high probability so that path diversity, or some other form of re-routing to provide a better channel can be invoked. Concatenated coding schemes are particularly suited for use on indoor channels. They have been shown to yield robust performance under Rician fading conditions. Other signalling schemes can achieve similar results.

At higher frequencies system design constraints can be somewhat different from those which apply at UHF. Signalling schemes that are more tolerant of phase noise and frequency offsets may be necessary here because of the current cost of obtaining stable oscillators. Faster rates of fading must also be dealt with. At these higher frequencies it is possible to use modulation schemes requiring higher bandwidth but which provide greater stability and a better error performance. Examples include  $M$ -ary frequency-shift keying ( $M$ -ary FSK) and chirp-based techniques. Diversity can also be desirable. If spread spectrum is used, either slow frequency hopping or direct sequence techniques are possible, depending on the application. It is considered that Reed-Solomon codes would be appropriate in determining hopping sequences, as well as being employed for error detection and correction coding although other solutions can be found.

One challenge to be faced in the development of certain indoor RLAN systems is to eliminate the requirement for rate conversion at backbone interfaces, if such interfaces are present. When RLANs are applied to interwork with B-ISDN, they can be designed to operate directly at B-ISDN rates, with performance comparable to that available over fibre links. The 155.52 Mbit/s data rate requires a large transmission bandwidth, which in turn suggests that such systems must operate in the higher frequency bands. In addition, because of the short duration of transmitted symbols, the transmission of such an extremely high data rate demands a higher transmit power to maintain sufficient bit energies to achieve acceptably low error ratios.

The data rate as well as multiple access strategy are heavily influenced by technology considerations. Among these is the current relative cost of generating carriers at millimetre waves (30-60 GHz), which may tend to discourage the use of frequency division multiple access (FDMA).

In one specific case, a non-power controlled version of CDMA, with low processing gain (i.e. 10 times) was found to be less efficient than time division multiple access (TDMA) based protocol.

Simulation results show that a TDMA system with reservation, in which users request transmitting slots in advance of transmission, could have an acceptable performance. Some form of reservation or adaptive allocation of time slots was required in the protocol to take advantage of the bit-rate variations exhibited by multimedia terminals and to accommodate the delay requirements.

Polling may be an attractive solution because the number of terminals within a cell is expected to be small.

Another technique which might simplify the hardware is the use of time division duplexing (TDD), rather than frequency division duplexing (FDD). In TDD, only a single carrier is needed for the inbound and outbound traffic. TDD may be attractive in the case of asymmetric traffic, where the inbound traffic is a small fraction of the outbound traffic.

At higher data rates and higher frequency bands, the inter-symbol-interference (ISI) related degradation related to multipath conditions will probably be of sufficient concern that for good performance it may be necessary to use an adaptive equalizer along with coding and diversity.

## 2.2 Examples of RLANs

A number of frequency bands are in use or under consideration for RLAN applications including the industrial, scientific and medical applications (ISM) bands. Table 1 indicates possible choices for frequency bands. Table 3 provides additional information regarding some typical RLAN frequency bands. One specific example of a standard in progress is also included, i.e. HIPERLAN. HIPERLAN is an European Telecommunication Standards Institute (ETSI) standard currently in the preparation stage for high performance radio LANs operating in frequency bands at 5.2 and 17.2 GHz. It will be compliant with ISO Standard 8802.

The Institute of Electrical and Electronics Engineers (IEEE) has prepared LAN standards, such as IEEE 802.3 CSMA/CD or "Ethernet", IEEE 802.4 Token Bus, IEEE 802.5 Token Ring and IEEE 802.6 Metropolitan access media. In addition, it is currently preparing IEEE 802.11 for wireless local area networks (WLANs) with data rates up to 2 Mbit/s including consideration of combined switching (PBX) and LAN functionalities.

In Appendix 1 to Annex 1 the characterization of RLAN applications is discussed with reference to IEEE 802.11/92-109.

In Appendix 3 some fundamental issues for indoor RLANs in the 20-60 GHz frequency range are presented and discussed.

### 2.2.1 Cordless telecommunication systems with RLAN aspects

Two additional examples of RLANs using systems initially or primarily designed for cordless telephone service include:

- the digital enhanced cordless telephone (DECT) system which operates in the 1 880-1 900 MHz band in Europe and which supports a cordless local area network (CLAN) which can communicate at bit rates up to 256 kbit/s. This system is referred to as system 5 in Recommendation ITU-R M.1033, Annex 1;
- the personal handyphone system (PHS) at 1 895-1 918 MHz which has RLAN applications in the fields of office automation and factory automation. This system is referred to as system 6 in Recommendation ITU-R M.1033, Annex 1.

### 2.2.2 Topology of RLANs

At least two types of RLAN network topology can be considered:

- employing a physically centralized;
- non-centralized control system.

These are illustrated in Fig. 1. Examples of systems using different topologies are presented in Fig. 2 (Figs. 2a to 2c).

TABLE 3

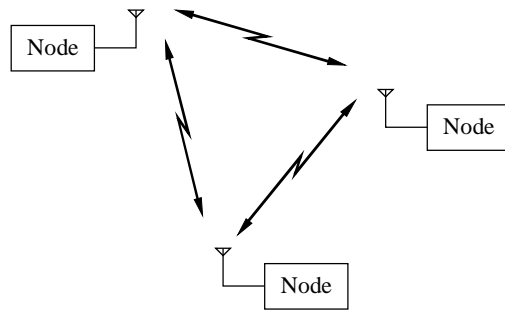
## Examples of RLAN characteristics

Frequency band	Modulation and/or access scheme	Data rate (typical)	Application	Range <sup>(1)</sup> (typical)
403-470 MHz 806-869 MHz 946 MHz	4-level FSK	19.2 kbit/s	ARDIS <sup>(2)</sup> subscriber equipment	ARDIS service area
850 MHz (cellular)	FSK	14.4 kbit/s 9.6 kbit/s (Fax)	Personal communication via cellular phone	Cellular phone service area
902-928 MHz	Frequency hopping (FSK)	64-500 kbit/s	Point-to-point data link campus and private networks	4 km
	Direct sequence	2 Mbit/s 215 kbit/s to 1.0 Mbit/s	Portable LAN Ethernet LANs	250 m 100-1 000 m
	CDMA/TDMA spread spectrum	1.536 Mbit/s line rate	Personal communication networks	450-5 000 m <sup>2</sup>
	Direct sequence with 1.5 MHz frequency channel selection	60 kbit/s	Bar-code reading	120-210 m
	Direct sequence PSK trellis code	5.7 Mbit/s	Ethernet LAN (IEEE 802.3)	80 m
2.4-2.4835 GHz 2.4-2.485 GHz (transceiver to hub) 5.745-5.830 GHz (hub to transceiver)	CDMA, direct sequence frequency hopping Direct sequence 16-PSK trellis code	1 Mbit/s (approximately) 5.7 Mbit/s	– Ethernet LAN (IEEE 802.3)	– 80 m
5.2 GHz	Gaussian minimum shift keying (GMSK) ( $BT = 0.4$ )	24 Mbit/s Raw data rate	High performance RLANs (HIPERLANs)	50 m
17.2 GHz	Specification in progress	Specification in progress	High performance RLANs (HIPERLANs)	Specification in progress

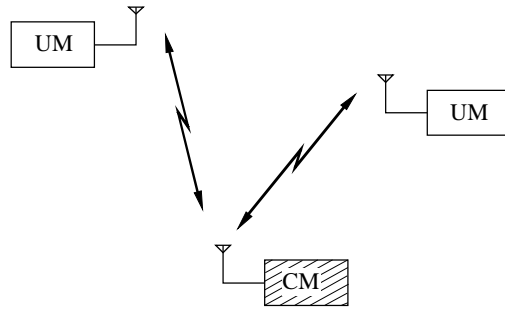
(1) The range of operation of RLAN systems may vary greatly depending on data rate, frequency, RF power, antenna and the propagation environment.

(2) ARDIS: advanced radio data information service.

FIGURE 1  
RLAN topologies



a) Non-centralized system

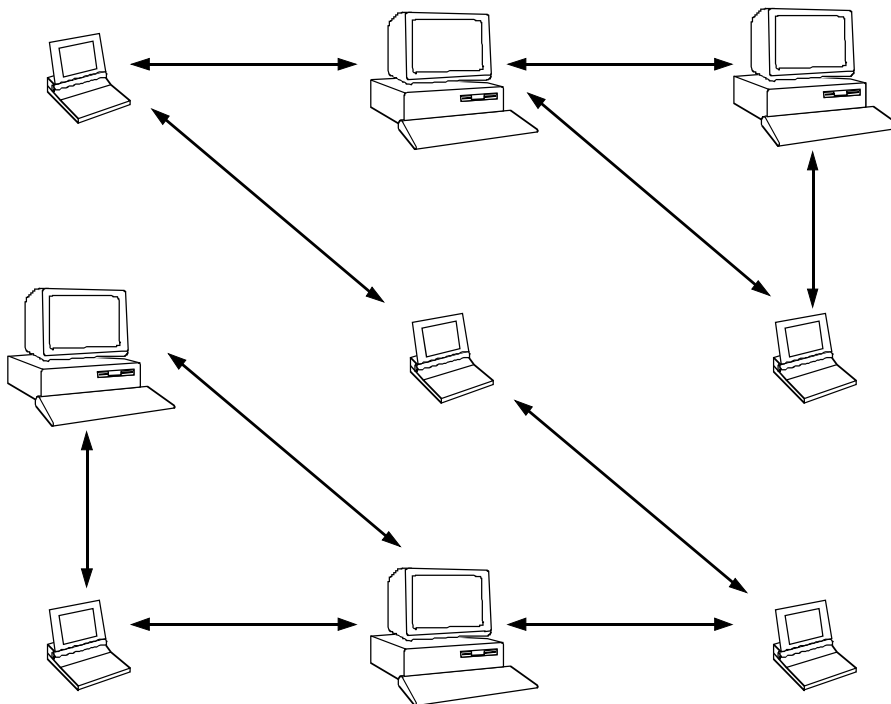


b) Centralized system

CM: control module  
UM: user module

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FIGURE 2a  
Example of a non-centralized or hubless RLAN



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FIGURE 2b  
Example of a centralized control RLAN

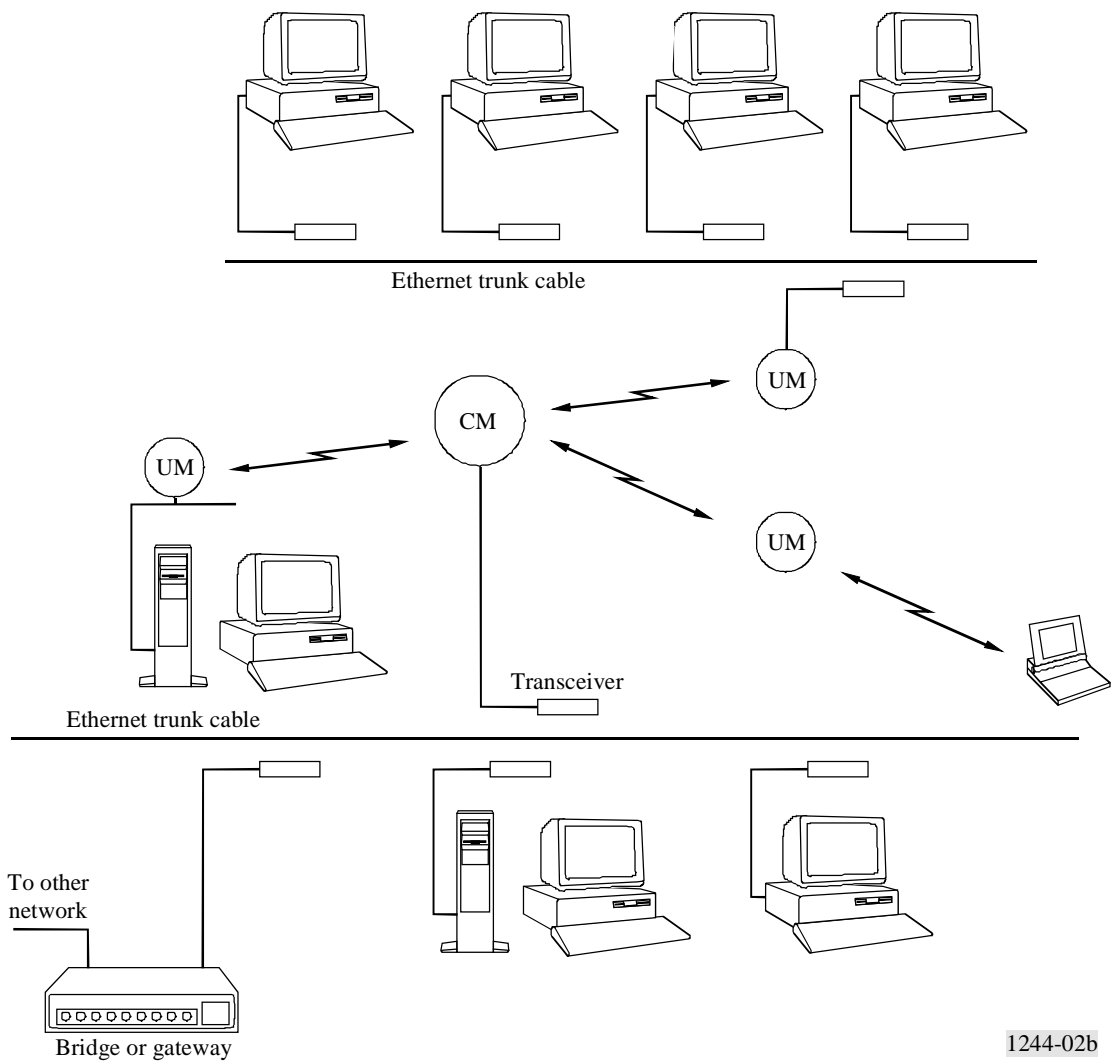
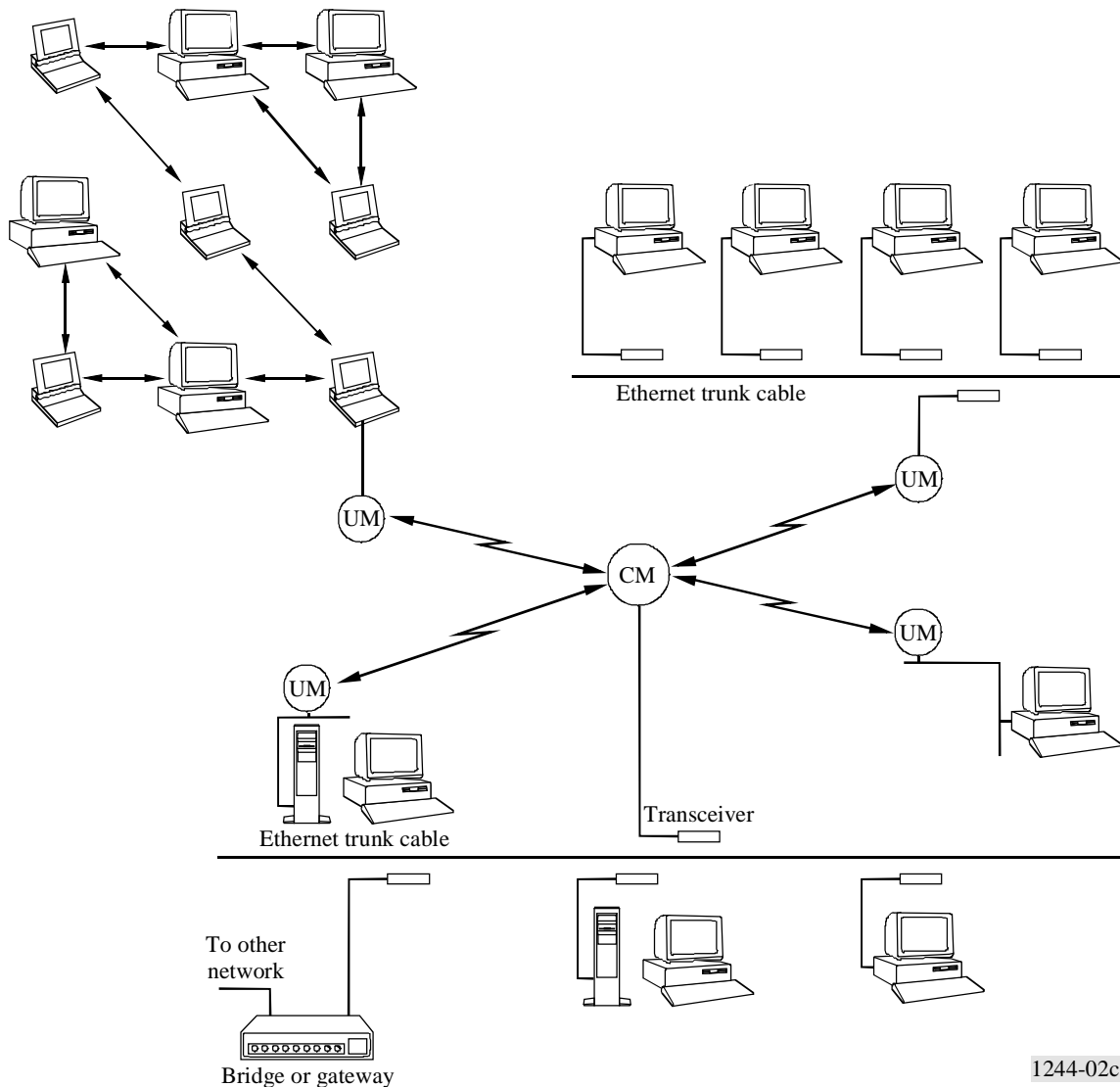




FIGURE 2c  
 Example of an RLAN comprising a centrally controlled microcell  
 with a connection to a hubless network

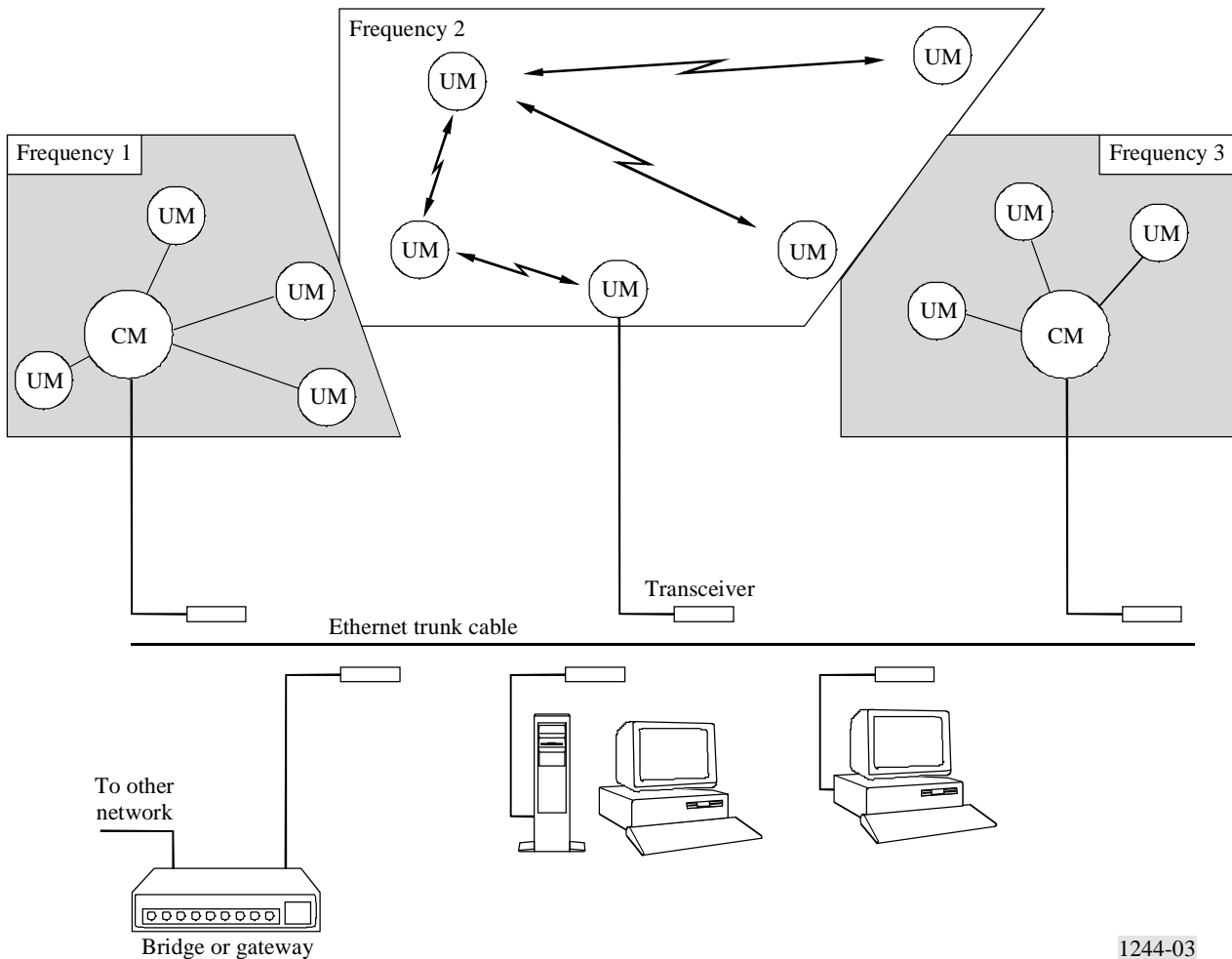


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The centralized RLAN consists of control modules (CM) and user modules (UM). The network boundaries are defined by the coverage areas (called microcells) of different CMs. The area covered by a microcell depends on the number and type of obstructions between the CM and its associated UMs and is typically between 450 and 5 000 m<sup>2</sup>. UMs do not directly communicate with one another in systems so far described, though there is no reason why the CM should not allocate a radio circuit to a number of UMs to directly intercommunicate, for instance when passing a point-to-multipoint time-bounded transmission. The CM controls the information flow between UMs, and between UMs and any outside network interface. The UMs are typically located on desktops or partitions and are connected to the end-user terminal equipment. A single UM can be capable of handling several LAN devices such as PC workstations.

If the required number of LAN devices is sufficiently large or, if for operational considerations, multiple microcells are necessary, they can be interconnected via a communication link. An example of a network of microcells is shown in Fig. 3.

FIGURE 3  
Example of systems of microcells



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For a non-adaptive TDMA system, each microcell within a network of microcells must operate on a different frequency channel unless the CMs are separated by a suitable re-use distance. The distance is dependent on the transmitted power, the number and type of obstructions in the environment, the modulation method and the required performance.

It can be seen that a centralized control RLAN system requires an infrastructure (the CMs), meaning that two UMs finding themselves within radio range of each other cannot establish a network unless they can both also access a CM. This implies network planning on an individual basis and two classes of modules (CM and UM).

An alternative is a non-centralized control RLAN system. This does not require dedicated CMs, giving advantages in reliability, lack of a need for individual network planning, and flexibility in the setting up of logical networks. Users communicate directly with each other within a given area, using a distributed communication protocol. Communication may be with one or several other nodes simultaneously, and for some networks simultaneous use of a number of channels will be possible. Networks can be created on an ad hoc basis if two users find themselves within radio range and are willing to collaborate. A node may move freely within a network or from one network to another. Certain nodes can be fitted with extra equipment to allow them to interwork with other wired or wireless networks, and to offer this facility to the rest of the wireless network.

### 2.3 Interface with wired LANs and interface with the public data network (PDN)

RLANs can interface with international standard wired LANs or other networks at defined service boundaries within the OSI protocol stack. Careful selection of the correct interface protocols at each layer of the model must be done to ensure compatibility. Individual radio units may function as bridges, routers or neither.

RLANs can also interconnect with the PDN, a subject that requires further study.

### 2.4 Performance requirements

Performance requirements for RLANs should basically be referred to the design concept of each LAN users. However, certain guidance for designers is given in the IEEE 802.11 Standard. It specifies, in the project authorization request (PAR), an objective less than  $4 \times 10^{-5}/512$  octet in terms of packet loss rate for systems up to 2 Mbit/s. Also outage time less than 0.1% is specified.

System outage in RLANs is often experienced by shadowing effects due to artificial factors. Human movement within the room may be a primary cause of shadowing. In particular in a high-frequency system shadowing of the line-of-sight path brings about sharp and deep drop of the received power. Therefore, in order to meet the above requirement, it is necessary to investigate how often such deep shadowing occurs in a given physical environment.

Further study should be made on the definition of "outage time" in RLANs. In the case of the public network represented by an hypothetical reference path (HRP) defined in ITU-T Recommendation G.826 outage time generally means severely errored seconds (SES). However, a different interpretation for "outage time" may be required for intermittent packet-based signals. Another factor to be considered in performance is quality of service (QoS). System designers should define the QoS according to the requirements of the LAN users.

In the case of ATM signals performance objectives based on cell transport parameters are being studied in Telecommunication Standardization Study Group 13. The output has been summarized in ITU-T Recommendation I.356, which may provide a reference for RLAN designers.

### 2.5 Interference compatibility

The possibility of frequency sharing between other radio systems and RLANs, including untethered nodes and a dynamic structure, is an important topic requiring much further study. Considerations include intra- and inter-network interference (inside an RLAN and among RLANs) as well as inter-system interference (between RLANs and other fixed systems or systems in other radio services sharing the frequency band on a primary basis). If RLAN spectrum is allocated on a primary basis, the interference problem reduces to the intra- and inter-network cases. Specific examples covering intercell and intersystem interference calculations are given in Appendix 2.

A further consideration when RLANs operate in an ISM band is the maximum cumulative interference from ISM equipment that the RLAN can tolerate.

One administration is considering the possible implementation of a protocol for band sharing between RLANs that requires only a minimum number of technical parameters to be specified. Each manufacturer or service provider can implement RLANs with different technology provided the protocol is followed.

## 3 Summary

This Annex provides an overview of some of the radio propagation, coding and modulation issues associated with RLANs. While some of the desired services can be provided, with transmission speeds in the 100 kbit/s range, it is expected that future demands will require transmission speeds at the application interface of up to the full B-ISDN primary rate of 155.52 Mbit/s. This is best suited to the higher frequency bands.

The indoor propagation environment, in particular, has not been well characterized until recently, especially at frequencies above 2 GHz. This has resulted in a tendency for some RLAN systems to be over-designed in terms of transmit power, thus contributing to a growing problem of interference. Certain radio interfaces which may be considered for new systems will benefit in efficiency from transmit power control administered either centrally or in a distributed way.

One of the major issues for RLAN applications is the choice of frequency band. This depends on the following:

- several emerging technologies for manufacturing low-cost compact radio equipment are becoming more economical in the higher frequency ranges;
- the control of propagation that is key to efficient spectrum utilization, depends on small directional antennas with predictable radiation patterns for fixed systems, and dynamic adaptive channelization, antennas and power control for untethered systems;
- the available channel bandwidth that is needed to handle very high instantaneous data rates on a packet basis;
- requirements for band sharing with other systems and services, if any;
- health and safety concerns requiring low radiation density.

In addition, further information and study are needed regarding possible performance requirements for:

- maximum system delay and delay variance, for time-bounded services;
- bit-error ratio, for specified propagation statistics;
- packet loss probability, for specified packet structures and protocols;
- collision processing;
- throughput;
- unsuccessful/successful call rates.

## APPENDIX 1 TO ANNEX 1

### **Characterization of RLAN applications**

#### **1 Introduction**

Designing networks such as B-ISDN and PCS to support all envisioned applications requires an in-depth understanding of applications in general. An application can be characterized by the following:

##### **1.1 Information types**

In general, the information to be communicated can be classified as time-based (synchronization between various parts of the information) or non-time-based. Typical time-based information are video and audio, while non-time-based information includes still images, graphics and text. Also, an application can in general include both time-based and non-time-based information.

##### **1.2 Delivery requirements**

Applications can also be classified according to its information delivery requirements into real-time or non-real-time applications. The former requires sufficient bandwidth, while the latter requires sufficient storage. For example, videoconferencing and image browsing are typical examples of real-time applications, while downloading digitized movies and electronic mail belong to non-real-time applications. In general, the communications requirements for supporting an application depends on both the information types as well as the delivery requirement of the application.

Another kind of application to be considered is interactive broadcasting. In this application a “return” link as well as a broadcast link is required. The return channel is normally of a relatively low bit rate, say less than 64 kbit/s. The return link might be realized in a number of ways, for example as an integral part of the broadcast RLAN or delivery mechanism or as a separate link or RLAN. This matter requires further study and is also being studied by Radiocommunication Working Party 11C under Question ITU-R 232/11.

### 1.3 Symmetry of connection

The communications requirements of an application depend on the symmetry of its connections; many networks are designed to take advantage of the (a)symmetry of the applications they intend to support. For example, the cable TV network is designed as a one-way broadcast type network, generally without any switches.

### 1.4 Human versus computing device

In general, the parties involved in the application may be either a human user (through a user terminal) or an information processing device. For instance, a voice call is a user application, while a user accessing a remote database is a user-device application, and two supercomputing performing parallel computations to solve the same problem by communicating intermediate results is considered as a device-to-device application. Real-time collaboration is a user application, while non-real-time collaboration is a user-device application.

### 1.5 Access network

The location of the communicating parties; the parties are not limited to the fixed locations where the wireline access network terminate.

### 1.6 Mobility

Mobility is a means to simplify the connection process with any desired entity wherever the latter is within the network. The mobility concept can be applied to a person, a terminal and a service.

## 2 Traffic and communications characterization

An application can be described by its traffic characteristics and the corresponding communications requirements. The traffic characteristics together with the corresponding communication requirements determine the demands on network resources (bandwidth and buffer) as well as the criteria for network protocol design.

### 2.1 Traffic characteristics

The traffic characteristics of an application can be specified by its traffic generation process (or traffic pattern) as a sequence of packets generated at arbitrary instants. This generation process can be modelled as an on-off source. The traffic pattern can be characterized by two stochastic processes:

- packet generation process (or packet arrival process),
- packet length distribution process.

#### 2.1.1 Traffic patterns

- Periodic at regular intervals for real-time applications. For example, conventional 64 kbit/s PCM audio generates samples at 125  $\mu$ s intervals, each sample consists of 8 bits;
- Bursty traffic patterns generated at random time instants separated by gaps of silence of random duration. Conventional data communications are bursty because they are typically file transfer, remote logic. The unpredictability of bursty traffic, especially the instants at which packet is generated, is the main culprit that needs to be dealt with in designing the packet-switched network.

Since multimedia applications have both periodic and bursty type traffic, the need of supporting both classes of traffic with a guaranteed performance of a single integrated network has become the most important challenge.

Application classification according to IEEE P802.11/92-112 Standard (September, 1992)		
Delivery requirements	Information types	
	Time-based	Non-time-based
Real-time	Videoconferencing Video-on-demand	Image browsing Interactive Computing
Non-real-time	Videomail	E-mail File transfer

## 2.2 Communications requirements

Communications requirements fall into three categories: bandwidth, delay and error.

### 2.2.1 Bandwidth

The bandwidth requirement of an application depends on its information type and delivery requirements.

For a real-time application, the bandwidth is the amount of information generated by the application per unit time. Such bandwidth requirement may be constant or variable, referred to as constant bit rate or variable bit rate applications, respectively. Thus today, applications are encoded to satisfy the constraint of existing networks, while a more ideal case should be networks designed based on supporting current and future applications with diverse requirements.

For non-real-time applications, the bandwidth requirement is a function of the response time requirement (the total delay allowed before all the information are transferred) and the amount of information being communicated.

The bandwidth provided by the network should always exceed the bandwidth requirement of the applications. If the bandwidth is insufficient then network buffering is required to avoid dropping of information, which in turn introduces buffering delay and may introduce errors.

The network protocol can be designed to first require each new application to negotiate with the network for available bandwidth before a connection is set up by the network. Secondly, the protocol could guarantee the bandwidth for the new application once it is accepted by the network. This would imply two criteria for the protocol: it is connection-oriented and is reservation based.

In addition to the delivery requirement and information types of the application, the total bandwidth requirement on a wireless network depends on the number of users on the network, the number of parties involved in each application (point-to-point versus multipoint) as well as the connection types of each application (i.e., whether it is symmetric or asymmetric).

Bandwidth requirements according to IEEE P802.11/92-112 Standard (September, 1992)		
Real-time multimedia applications	Examples	Bandwidth (with compression)
Time-based information	Voice	8, 16, 32 kbit/s
	CD quality stereo (MPEG <sup>(1)</sup> )	256 kbit/s
	MPEG video (VCR-quality)	1.5 Mbit/s
	HDTV	20 Mbit/s
Non-time-based information (Response time = 10 to 40 ms)	Text editing (10 kbytes)	2-8 Mbit/s
	JPEG <sup>(2)</sup> colour images (1 Mbyte)	4-20 Mbit/s (40 ms) 15-75 Mbit/s (10 ms)

<sup>(1)</sup> The International Organization for Standardization (ISO) Motion Picture Expert Group (MPEG) Standard is designed as a single direction protocol providing audio/video compression, using various spatial and temporal resolution, up to a rate of 1.92 Mbit/s.

<sup>(2)</sup> The ISO's Joint Photographic Expert Group (JPEG) Standard developed jointly by ISO/former-CCITT, has been developed to support a wide range of compression ratios for still colour and greyscale images.

### 2.2.2 Delay

The issue of network delay in a packet-switched network arises from insufficient instantaneous network bandwidth. If bandwidth is insufficient in any parts of the network, buffering is required (unless information is allowed to be dropped), a process which then introduces a random amount of delay to the information being delivered.

For real-time delivery of time-based information, the delay requirements are absolute delay and delay jitter constraints. The absolute delay is important for real-time communication like videoconferencing or conventional telephone conversation because feedback is expected within a certain time period for natural conversation to take place. The delay jitter is the variance of absolute delay incurred from packet-to-packet for the same information stream.

For non-time-based information or non-real-time delivery of time-based information, the major delay requirement is the absolute delay, which must be less than the response time required by the application.

### 2.2.3 Error

Packet switching, because of its statistical nature in multiplexing and switching, can introduce a random delay when the instantaneous bandwidth is not available at parts of the network and the information needs to be stored temporarily in buffers. Two types of error may occur. First, the buffer may be insufficient and information has to be discarded. Second, in the case of real-time applications carrying time-based information, the delay introduced by buffering this information may exceed the delay jitter constraint.

In the wireless environment, an additional source of error arises from the communication channels, due to noise and propagation conditions.

### 3 Wireless protocol requirements

The traffic characteristics of many multimedia applications include both periodic and bursty types. To guarantee the quality of service (QoS) of such applications, bandwidth must be sufficient to either support the data rates or meet the response time constraints. This means a connection-oriented protocol may be required to manage connection setup and bandwidth consumption of each connection. Contention-based medium access control (MAC) protocol, such as ALOHA and CSMA types, may not themselves be inherently capable of supporting those particular applications since they do not have built-in mechanisms for bandwidth reservation.

Contention-based MAC protocols may not be universally applicable for supporting multimedia applications, but both connection-based and reservation-based MACs are fertile ground for further research. A complete mathematical description of how the traffic characteristics and associated communications requirements (bandwidth, delay and error) translate into network requirements (bandwidth and buffer) is required.

The communication requirements of an application (or each information stream within the application) can be classified into macrorequirements and microrequirements.

Macrorequirements are specified during the connection setup phase, and characterize the application's overall information transfer needs in terms of the following parameters:

- bandwidth (average, peak, etc.),
- delay (absolute delay, transmission delay),
- error rate,
- duration of session,
- transaction rate,
- information transfer per transaction,
- total information transfer.

Microrequirements which are similar to the QoS guaranteed by the network characterize the needs of individual message transaction of an application, which includes one or more of the following parameters:

- absolute delay,
- delay variances,
- error (average and burst).

Microrequirements should be implicitly guaranteed by the network once the connection is granted.

## APPENDIX 2 TO ANNEX 1

### Examples of interference calculations

The possibility of sharing between multiple RLANs and between 18 GHz RLANs and other fixed systems or fixed-satellite systems are examined.

#### 1 Coexistence of multiple RLANs

For a macrocell where there is no line-of-sight (LOS) blockage, the CMs using the same channel should be separated by at least 15 times the distance between the CM and the UM. For example, for a CM-UM radius of 12 m, this separation is at least 180 m.

In cases where there is no LOS, the co-channel CMs require a separation distance of about five times the distance from the CM to the furthest UM in either microcell.



## 2 Coexistence of RLANs with point-to-multipoint (P-MP) fixed systems

The following technical parameters were assumed in assessing compatibility between RLANs and P-MP fixed systems:

- RLANs transmit e.i.r.p. = 0 dBW;
- minimum building loss = 6 dB;
- gain of RLAN directional antennas = 10 dBi;
- gain of P-MP directional antennas = 38 dBi;
- receiver threshold = –115 dBW (RLANs and P-MP);
- interference levels below receiver threshold = 10 dB;
- P-MP user station transmit power = –13 dBW;
- P-MP nodal station transmit power = –13 dBW;
- frequency (used for path loss/distance calculations) = 18.8 GHz.

The dominating separation distance is for the case from the P-MP nodal station to the RLAN receiver. Based on the above assumptions, the free space separation distance is of the order of 115 km. The distance would be reduced in practice by taking into consideration other parameters such as curvature of the Earth, atmospheric and obstruction losses.

## 3 Coexistence of RLANs with point-to-point (P-P) fixed systems

It is generally understood that e.i.r.p.s of point-to-point fixed systems are more than 10 dB larger than those of RLANs. Therefore the coordination distance of both systems depends on the interference from a P-P system to an RLAN. Level of the interference can be expressed by the following formula.

$$E_f - \Delta G_{tf}(\theta) - L_s - L_b + \Delta G_{rl} < R_{nl} + R_{il} \quad (1)$$

where:

$E_f$ : e.i.r.p. of the P-P station  
= 28 to 37 dBW

$\Delta G_{tf}(\theta)$ : antenna directivity attenuation of the P-P station (dish antenna with 2.4 m diameter)

$\theta$ : separation angle measured from the P-P antenna main axis and the RLAN antenna main axis

$L_s$ : free-space loss

$L_b$ : shielding effect of the building  
= 6 to 40 dB

$\Delta G_{rl}$ : antenna directivity attenuation of the RLAN station  
= 5 dB

$R_{nl}$ : thermal noise level of the RLAN receiver  
= –95.8 dBm

$R_{il}$ : required I/N ratio at the RLAN receiver  
= –6 dB (see Recommendation ITU-R F.758)

Calculation results are given in Table 4 for  $E_f$  from 27 to 37 dBW (based on the maximum and minimum values in Table 8 in Recommendation ITU-R F.758) using  $\theta$  and  $L_b$  as parameters. In buildings using shielding materials in the windows and the walls attenuation effect of 20 to 40 dB can be expected in the 19 GHz frequency band. Figure 4 illustrates the variation of the coordination distance with the detailed values for  $\theta$  between 0° to 90° for  $E_f = 37$  dBW.

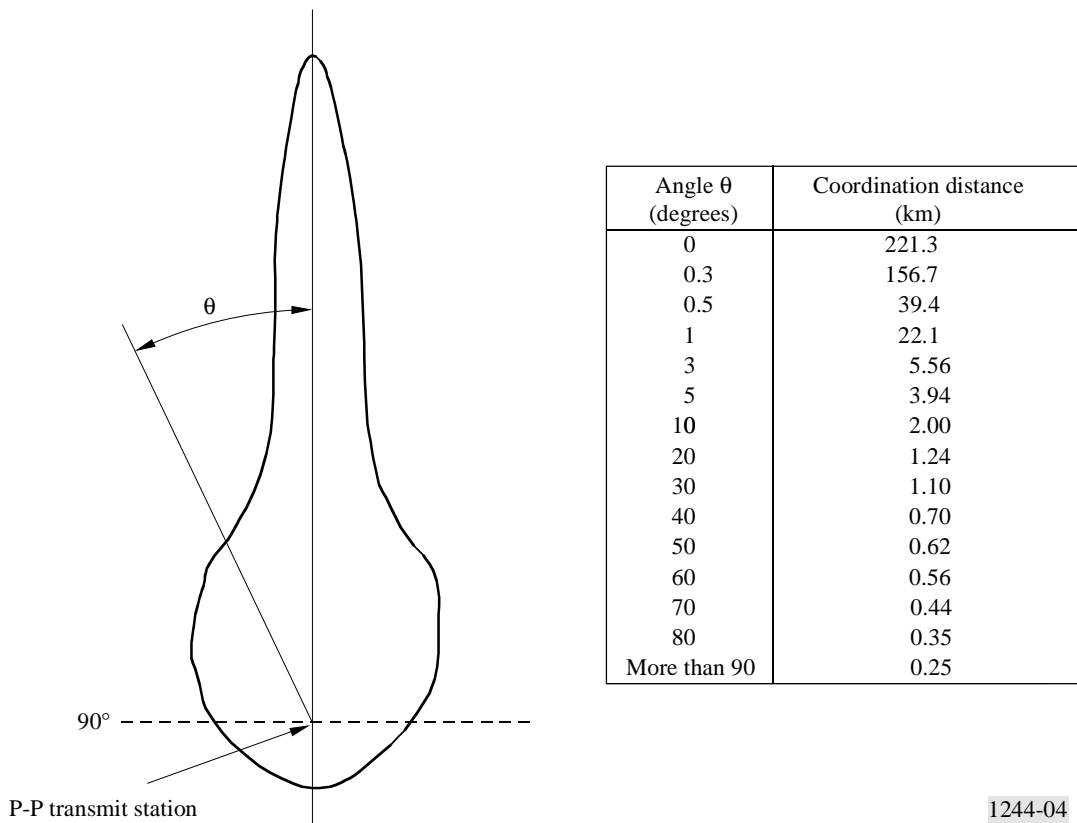
TABLE 4

Coordination distance between P-P fixed systems and an RLAN

	$L_b = 6$ dB		$L_b = 20$ dB		$L_b = 40$ dB	
	$\theta = 0^\circ$	$\theta = 90^\circ$	$\theta = 0^\circ$	$\theta = 90^\circ$	$\theta = 0^\circ$	$\theta = 90^\circ$
$E_f = 37$ dBW	229 km	25 km	46 km	52 m	4.6 km	5 m
$E_f = 27$ dBW	81 km	9 km	16 km	18 m	1.6 km	2 m

FIGURE 4

Coordination distance with P-P fixed system



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The results show that even in the case of the largest  $L_b$  coexistence of both systems requires geographical separation farther than 1 km. Considering that hop distances of many P-P systems are no longer than several kilometres, it is not feasible to realize the frequency sharing between P-P fixed systems and RLANs in the bands around 19 GHz.

## 4 Coexistence of RLANs with fixed-satellite service (FSS) systems

### 4.1 Sharing with FSS earth stations for downlinks

In this case interference from an RLAN station to the FSS earth station should be considered. Level of the interference can be expressed by the following formula:

$$E_l - \Delta G_{tl} - L_s - L_b + G_{rst}(\varphi) |_{\theta=0} - L_{fs} < R_{ns} + R_{is} \quad (2)$$

where:

$E_l$ : e.i.r.p. of the RLAN station  
= 0 to 6 dBW

$\Delta G_{tl}$ : antenna directivity attenuation of the RLAN station  
= 5 dB

$L_s$ : free-space loss

$L_b$ : shielding effect of the building  
= 6 to 40 dB

$G_{rst}(\varphi) |_{\theta=0}$ : antenna gain of the FSS earth station  
= -10 dB for  $\varphi > 36^\circ$   
=  $29 - 25 \log \varphi$  dB for  $1^\circ < \varphi < 36^\circ$

$\varphi$ : elevation angle of the FSS downlink from the direction of the RLAN station (see Fig. 5)

$\theta$ : azimuth angle of the FSS downlink from the direction of the RLAN station (see Fig. 5)

$L_{fs}$ : feeder loss of the FSS earth station  
= 2 dB

$R_{ns}$ : thermal noise level of the FSS earth station receiver  
= -99.8 dBm

$R_{is}$ : required  $I/N$  ratio at the FSS earth station receiver  
= -6 dB (see Recommendation ITU-R F.758)

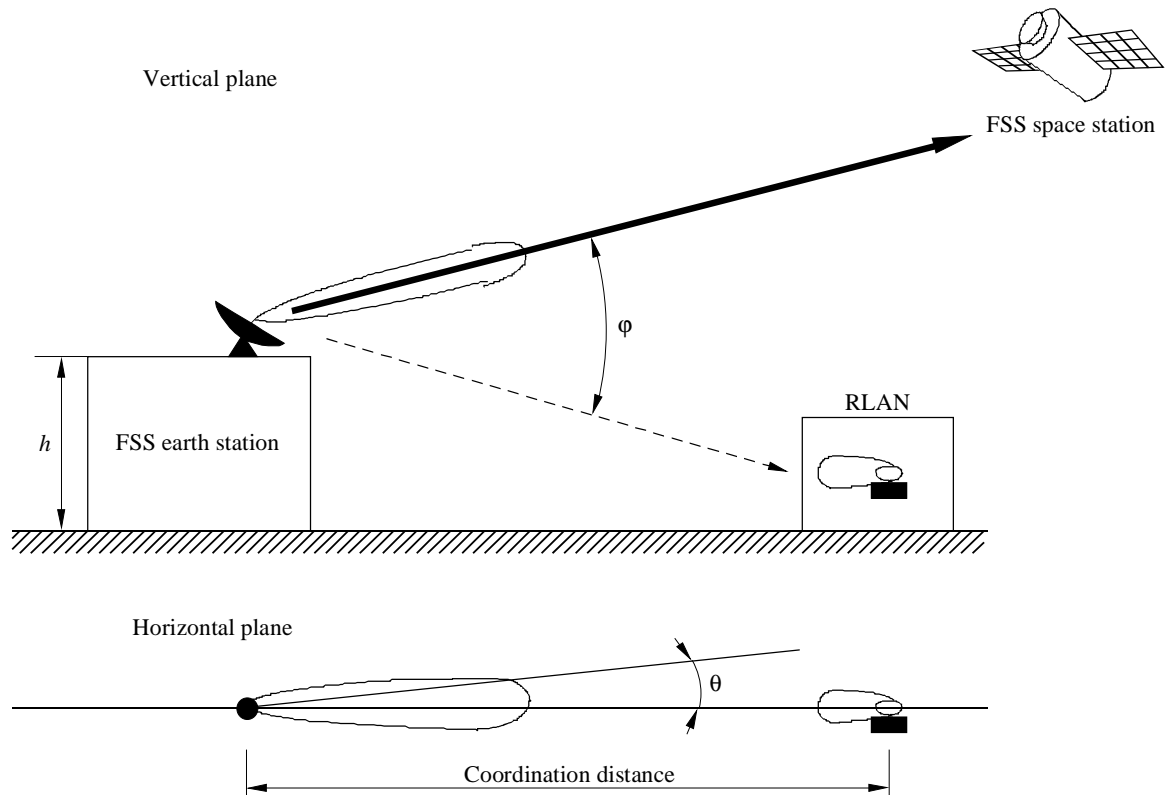
Calculation results are given in Table 5 for  $E_l = -1$  dBW and 5 dBW using  $\varphi$  and  $L_b$  as parameters.

TABLE 5

**Coordination distance between an RLAN and fixed-satellite earth station (downlink)**

	$L_b = 6$ dB		$L_b = 20$ dB		$L_b = 40$ dB	
	$\varphi = 10^\circ$	$\varphi = 36^\circ$	$\varphi = 10^\circ$	$\varphi = 36^\circ$	$\varphi = 10^\circ$	$\varphi = 36^\circ$
$E_l = 5$ dBW	4.8 km	995 m	995 m	191 m	96 m	19 m
$E_l = -1$ dBW	2.4 km	480 m	480 m	96 m	48 m	10 m

FIGURE 5  
Geographical relation of a sharing calculation model



1244-05

The values in Table 5 are derived from the assumption that the separation angle of both systems in the horizontal plane is considered to be the worst case, i.e.  $\theta = 0^\circ$ . Therefore in actual cases further reduction of the interference may be expected.

Feasibility of the sharing depends on the shielding effect of the building as well as the elevation angle of the FSS link. If RLANs are operated in a well-shielded building, sharing will be possible through case by case assessment of the interference environment.

#### 4.2 Sharing with FSS earth stations for uplinks

In this case, interference from the FSS earth station to an RLAN station should be considered.

Level of the interference can be expressed by the following formula:

$$E_{ts} + G_{ts}(\varphi) | \theta = 0 - L_s - L_b + G_{rl} - \Delta G_{rl} < R_{nl} + R_{il} \tag{3}$$

where:

$E_{ts}$ : transmit power of the FSS earth station at the antenna input  
= -4 to 20 dBW

$G_{ts}(\varphi) | \theta = 0$ : antenna gain of the FSS earth station  
= -10 dBi for  $\varphi > 36^\circ$   
=  $29 - 25 \log \varphi$  dBi for  $1^\circ < \varphi < 36^\circ$

$\varphi$ : elevation angle of the FSS uplink from the direction of the RLAN station (see Fig. 5)

$L_s$ : free-space loss

$L_b$ :	shielding effect of the building = 6 to 40 dB
$G_{rl}$ :	antenna gain of the RLAN station = 10 dB
$\Delta G_{rl}$ :	antenna directivity attenuation of the RLAN station = 5 dB
$R_{nl}$ :	thermal noise level of the RLAN station receiver = -95.8 dBm
$R_{il}$ :	required $I/N$ ratio at the RLAN station receiver = -6 dB (see Recommendation ITU-R F.758)

Calculation results are given in Table 6 for  $E_{ts} = 20$  dBW and  $-4$  dBW using  $\phi$  and  $L_b$  as parameters.

TABLE 6

**Coordination distance between an RLAN and fixed-satellite earth station (uplink)**

	$L_b = 6$ dB		$L_b = 20$ dB		$L_b = 40$ dB	
	$\phi = 10^\circ$	$\phi = 36^\circ$	$\phi = 10^\circ$	$\phi = 36^\circ$	$\phi = 10^\circ$	$\phi = 36^\circ$
$E_{ts} = 20$ dBW <sup>(1)</sup>	85 km	17 km	417 km	3.4 km	1.7 km	340 m
$E_{ts} = -4$ dBW <sup>(2)</sup>	2.2 km	441 m	442 m	88 m	44 m	9 m

<sup>(1)</sup> Typical value 20/30 GHz band earth station used in Japan.

<sup>(2)</sup> A value given in Table 7, § 2.1C in the Conference Preparatory Meeting Report to World Radiocommunication Conference (Geneva, 1995).

The values in Table 6 are also derived from the same worst assumption as the previous case of a downlink station. Considering that the number of uplink stations is rather limited and that the line-of-sight path between both stations is not always obtained, the sharing may be feasible in certain geographical conditions.

APPENDIX 3  
TO ANNEX 1

**Fundamental issues for indoor RLANs in the range 20-60 GHz**

**1 Introduction**

The 20-60 GHz range is being considered for indoor wireless communications. It is expected that a full range of communication services (voice, data, image, etc.) will be extended to wireless personal terminals both in indoor and outdoor environments. Ultimately, wireless personal communications networks will form an integral part of the emerging B-ISDN. High density of terminals in the indoor environment is expected and as such, large spectrum resources will be required. Part of the 20-60 GHz frequency range is being considered for this application.

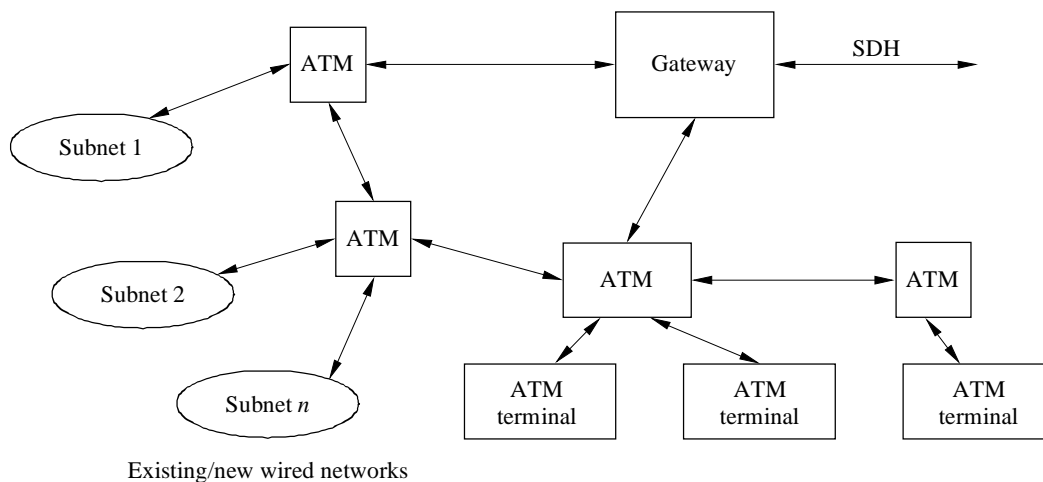
## 1.1 Design approach

Influential factors that are shaping future transport networks are the emergence of the synchronous digital hierarchy (SDH) and the asynchronous transfer mode (ATM) standards (see Recommendations ITU-R F.750 and ITU-R F.751). These and other related standards have been developed in anticipation of a quantum increase in communication traffic that will accompany the introduction of B-ISDN.

There is a considerable consensus that the ATM/SDH combination will form the foundation of B-ISDN in LANs as well as in future national and global networks. It is expected that a successful implementation of a broadband wireless network will have to be based on full compatibility with future broadband fibre-based LANs.

The ATM standard is expected to be used at all network levels. The ATM standard is a very attractive method for integrating different technologies and different forms of networks and services within a building and around the globe. Figure 6 illustrates an example configuration of future in-building LANs. The interconnections between the different components are facilitated by ATM switches with an SDH physical interface. The subnets in the figure are the present day communication facilities (e.g., Ethernet). They are connected to the ATM-based network by ATM translators. Other ATM terminals (e.g., video database, super computers, wired multimedia terminals, etc.) are connected directly to the network.

FIGURE 6  
Fibre-based ATM LAN



1244-06

## 1.2 Propagation conditions

The delay spread and the signal attenuation within a confined space are important parameters impacting on the ability of RLANs to support high data rates and low power terminals in the 20-60 GHz range.

### 1.2.1 Delay spread

There is little known information about the delay spread in indoor channels at 20-60 GHz. The results at 58 GHz are reported in a recent paper (see Table 7).

The results suggest that, in most cases, multipath rays exhibit only few reflections. This observation has implications on the design and performance of directive antennas. It appears that, in most cases, an omnidirectional antenna will exhibit a continuous power-delay profile which extends over a time comparable to the round trip propagation across the room, while a highly directive antenna may produce a clustered power-delay profile (one or two clusters), where the clusters are narrow and separated by the round trip propagation delay.

The total signal attenuation within a confined room has been measured. The results indicate that the total path loss in all cases listed in Table 7 is between 65 and 85 dB, and that the worst case difference between the absence and presence of the LOS ray is about 5 dB.

TABLE 7

**Measured delay spread data**

	Room size (m)	Delay spread (ns)	Comments
A	24.3 × 11.2	44	Wood walls
B	30 × 21	32	Acoustic soft material
C	43 × 41	58	Hall, concrete walls
D	33.5 × 32.2	55	Vax room, concrete walls
E	44.7 × 2.4	72	Corridor, concrete
F	9.9 × 8.7	40	Computer room, metal
G	12.0 × 8.9	18	Lecture room, wood walls
H	11.2 × 7.3	28	Laboratory, plastered concrete

The delay spread (i.e., the time between the first and the last detectable signal) imposes a limit to the maximum bit rate at which data can be signalled without ISI. Some typical values for the r.m.s. delay spread are given in Table 8 for the frequencies 1.7 GHz and 60 GHz.

TABLE 8

**Probability distribution for the r.m.s. delay spread**

Probability (%)	1.7 GHz	60 GHz
25	< 15 ns	< 2 ns
50	< 23 ns	< 7 ns
75	< 35 ns	< 8 ns
95	< 45 ns	< 13 ns

As shown in Table 9, the delay spread for 60 GHz is less than that for 1.7 GHz. For 60 GHz the r.m.s. delay spread will be less than 10 ns with a 90% probability.

Static measurement results reported show that, except in one small, densely furnished room, static r.m.s. delay spreads were found to be from 15 to 20% lower at 40 GHz and 60 GHz than they are at 950 MHz. Additionally, the results show that furniture has the effect of eliminating increases in multipath severity as a function of transmit-receive range.

### 1.2.2 Signal attenuation

Within a confined space, the signal will be attenuated according to the free space loss for the direct LOS ray. Other multipath rays will undergo one or more reflections, therefore, the reflectivity of the walls will affect the strength of those rays. At 60 GHz, the wall reflectivity varies over a wide range (see Table 9).

TABLE 9  
Measured wall reflectivity

Material	Reflectivity (%)
Plasterboard (1 cm)	2
Concrete	16
Aluminium	> 99
Wood (20 mm)	2
Glass (3 mm)	16

### 1.3 Antenna design

Antenna design is governed by a high gain or low gain requirement. A high gain antenna would reduce the transmitted power of the wireless terminals and reduce the delay spread but is more vulnerable to obstruction and shadowing effects.

One possible approach to the antenna design is to match the gain of antennas to the size of the room. Small rooms can be covered by low gain antennas while large rooms are covered by a set of high gain antennas.

### 1.4 Traffic requirements

There have been recent studies to forecast the data rate requirements of future indoor broadband wireless applications, IEEE P802.11/92-20 Standard. According to the IEEE 802.11 document on WLANs, the data rate of multimedia terminals could range from 16 kbit/s (compressed voice) to 20 Mbit/s (compressed real-time HDTV video). Table 10 gives a summary of some key parameters of multimedia.

The peak rate of 20 Mbit/s (2 048 octets in 11 ms) is associated with the HDTV compressed video, although the instantaneous bit rate required is variable. As indicated in Table 8, the acceptable maximum BER is  $1 \times 10^{-3}$ , and the maximum transfer delay could be less than 1 ms. These numbers pose a very challenging problem to the system designers, especially when HDTV is involved.

In wireless communications, it is more appropriate to express the traffic load in terms of data rate density,  $\rho_{data}$ , with units of bits per second per unit area ( $\text{bit/s/m}^2$ ). A recent estimate foresees a traffic average of about  $0.05 \text{ Mbit/s/m}^2$  arising in a typical office environment within the next 10 years. This estimate seems to be a lower bound on the data rate. For terminals using the HDTV mode, the upper bound on the data rate is about  $10 \text{ Mbit/s/m}^2$  (i.e.,  $0.05 < \rho_{data} < 10$ ).

### 1.5 Possible network architecture

A system architecture for a wireless network is envisaged that is fully blended with a fibre-based B-ISDN LAN as shown in Fig. 7. The total service area is divided into cells. The size and shape of cells is dictated by the building layout rather than any artificial hexagonal shaped cell. Each cell is confined by walls, and served by a wireless network (WN) which operates on a single carrier frequency in the mm-wave band. The carriers are generated at the WNs and regenerated at the portable terminals. The delay spread is to be controlled by the antenna gain. A small cell with soft material walls could be covered by a single broadbeam antenna. If the walls or the room contents have high reflectivity, the antenna gain should be increased through beam forming. Large areas would be covered by several high gain antennas, and in this case, macro-diversity signal combining will be needed and justified, where the antennas are placed just a few wavelengths away from each other.



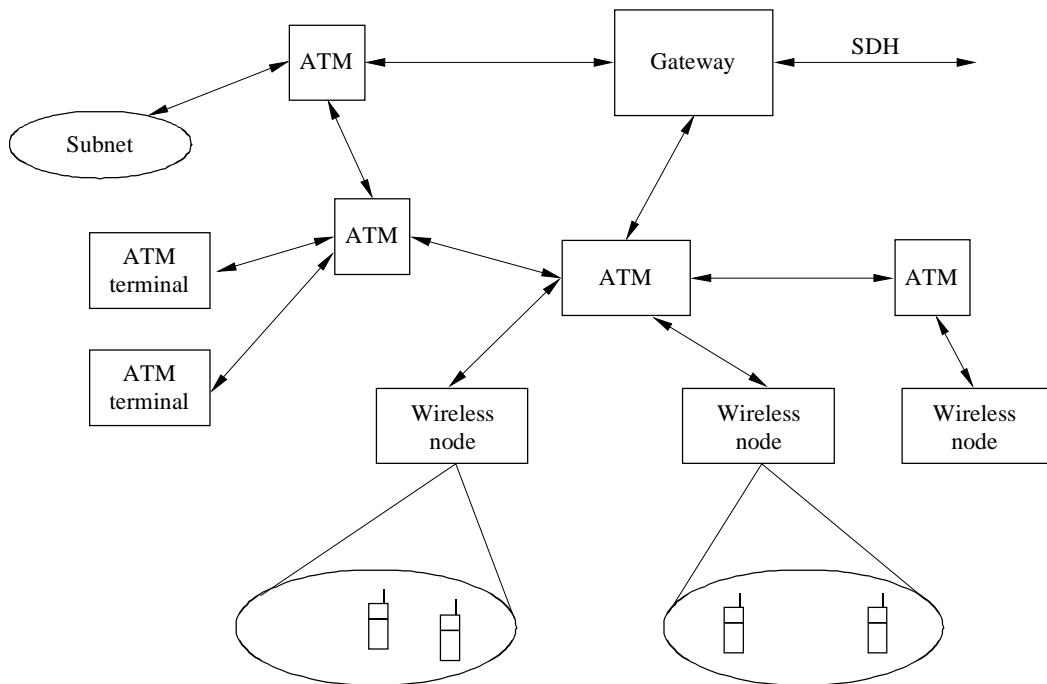
TABLE 10

Traffic parameters of multimedia terminals

	Videoconference	MPEG <sup>(1)</sup> NTSC	HDTV	Voice
Attribute	Compressed	Compressed	Compressed	Compressed
Size (octet)	2 048	2 048	2 048	512
Arrival (ms)	250 constant	11 constant	0.8 constant	250 constant
Delay (ms) (nominal)	30	5	0.8	30
Delay (ms) (standard deviation)	100	5	0.8	100
Delay (ms) (maximum)	250	11	0.8	250
BER	$1 \times 10^{-3}$	$1 \times 10^{-3}$	$1 \times 10^{-3}$	$1 \times 10^{-3}$

<sup>(1)</sup> The ISO's Motion Picture Expert Group (MPEG) Standard.

FIGURE 7  
WLAN/ATM LAN integration



The access scheme is a modified form of polling/TDD. The polling cycle consists of a sequential polling of each high data rate terminal, and a class polling of all low data terminals. Each high data terminal is allowed to empty its buffer (with some constraints imposed by the traffic conditions and priorities), while low data terminals are allowed to transmit one data unit per polling cycle. The second half of the polling cycle contains the outbound traffic.

The WN appears to the rest of the fibre-based B-ISDN network as a single ATM unit. The inbound traffic is arranged in the form of data cells, and a virtual route is established between each wireless terminal and its destination. Functions peculiar to wireless communications, such as hand-off, access control and error control will also be performed by WNs. The inter WNs communications as well as the communications between the WNs and any wireless central control unit will be conducted through the fibre LAN using ATM switching.

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