

RECOMMENDATION ITU-R M.1450-1<sup>\*,\*\*</sup>**Characteristics of broadband radio local  
area networks**

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

(2000-2002)

The ITU Radiocommunication Assembly,

*considering*

- a) that broadband radio local area networks (RLANs) will be widely used for semi-fixed (transportable) and portable computer equipment for a variety of broadband applications;
- b) that broadband RLAN standards currently being developed will be compatible with current wired LAN standards;
- c) that it is desirable to establish guidelines for broadband RLANs in various frequency bands;
- d) that broadband RLANs should be implemented with careful consideration to compatibility with other radio applications;
- e) that the above guidelines should not limit the effectiveness of broadband RLANs but be used to enhance their development,

*recommends*

- 1 that for guidance on preferred methods of multiple access and modulation techniques for broadband RLANs in mobile applications, Table 2 can be referred to;
- 2 that for guidance on existing broadband RLAN standards, Table 3 can be referred to;
- 3 that for guidance on the characteristics of broadband RLANs, Annex 1 can be referred to;
- 4 that for guidance on modulation schemes using orthogonal frequency division multiplexing (OFDM) for broadband RLANs, Annex 2 can be referred to;
- 5 that for detailed guidance on remote access schemes for RLANs in mobile applications, Annex 3 can be referred to;
- 6 that for other information on RLANs refer to Recommendation ITU-R F.1244.

NOTE 1 – Acronyms and terminology used in this Recommendation are given in Table 1.

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

\*\* This Recommendation should be brought to the attention of Telecommunication Standardization Study Group 7, and Radiocommunication Study Groups 3 and 4.

TABLE 1

**Acronyms and terms used in this Recommendation**

|         |  |
|---------|--|
| AFC     | Automatic frequency control                                |
| AGA     | Automatic gain amplifier                                   |
| AGC     | Automatic gain control                                     |
| AP      | Access point   |
| ARA     | Apple remote access  |
| ARP     | Authentication request packet                              |
| ATM     | Asynchronous transfer mode                                 |
| BPSK    | Binary phase shift keying                                  |
| BRAN    | Broadband radio networks                                   |
| CCK     | Complementary code keying                                  |
| CDMA    | Code division multiple access                              |
| CSMA/CA | Carrier sensing multiple access with collision avoidance   |
| DCS     | Dynamic channel selection                                  |
| DFS     | Dynamic frequency selection                                |
| DHCP    | Dynamic host configuration protocol                        |
| DQPSK   | Differential quaternary phase shift keying                 |
| DS      | Direct sequence  |
| ETSI    | European Telecommunications Standards Institute            |
| EY-NPMA | Elimination-yield non-pre-emptive priority multiple access |
| FDD     | Frequency division duplex                                  |
| FDMA    | Frequency division multiple access                         |
| FFT     | Fast Fourier transform                                     |
| FH      | Frequency hopping  |
| FSK     | Frequency shift keying                                     |
| FWA     | Fixed wireless access                                      |
| GI      | Guard interval   |
| GMSK    | Gaussian minimum shift keying                              |
| HBR     | High bit rate HIPERLAN 1 for data period only              |
| IEEE    | Institute of Electrical and Electronics Engineers          |
| IETF    | Internet Engineering Task Force                            |
| IFFT    | Inverse fast Fourier transform                             |
| IF      | Intermediate frequency                                     |
| IP      | Internet protocol  |
| ISDN    | Integrated services digital network                        |
| ISI     | Inter symbol interference                                  |
| LBR     | Low bit rate HIPERLAN 1 for signalling period only         |

TABLE 1 (*end*)

|                |   |
|----------------|---|
| LMS            | Least mean square   |
| LSIC           | Large scale integrated circuits   |
| MAC            | Medium access control   |
| OFDM           | Orthogonal frequency division multiplexing  |
| PBCC           | Packet binary convolution coding  |
| PDU            | Protocol data unit  |
| PER            | Packet error rate   |
| PPP            | Point-to-point protocol   |
| PSK            | Phase shift keying  |
| PSTN           | Public switched telephone network   |
| QAM            | Quadrature amplitude modulation   |
| QPSK           | Quaternary phase shift keying   |
| RF             | Radio frequency   |
| RLS            | Recursive least squares   |
| SOHO           | Small office home office  |
| SSMA           | Spread spectrum multiple access   |
| TCP            | Transmission control protocol   |
| TDMA           | Time division multiple access   |
| TDD            | Time division duplex  |
| TPC            | Transmit power control  |
| WATM           | Wireless asynchronous transfer mode   |
| WLAN           | Wireless local area network   |
| Access method  | Scheme used to provide multiple access to a channel   |
| Bit rate       | The rate of transfer of bit information from one network device to another                            |
| Channelization | Bandwidth of each channel and number of channels that can be contained in the RF bandwidth allocation |
| Frequency band | Nominal operating spectrum of application   |
| Modulation     | The method used to put digital information on an RF carrier   |
| Tx power       | (Transmitter power) – RF power in watts produced by the transmitter                                   |

TABLE 2

**Methods of multiple access and modulation techniques**

| Frequency band | Multiple access   | Modulation technique   |
|----------------|---|--|
| UHF            | CSMA/CA<br>FDMA<br>TDMA<br>SSMA-DS<br>SSMA-FH           | CCK<br>PBCC  |
| SHF            | CSMA/CA<br>FDMA<br>TDMA-FDD<br>TDMA-TDD<br>TDMA/EY-NPMA | GMSK/FSK<br>BPSK-OFDM<br>QPSK-OFDM<br>8-PSK-OFDM<br>16-QAM-OFDM<br>64-QAM-OFDM |

TABLE 3

**Technical parameters for broadband RLAN applications**

|                |                                 |  |                                       |  |
|----------------|---------------------------------|--|---------------------------------------|--|
| RLAN standard  | IEEE Std 802.11b                | IEEE Std 802.11a <sup>(1)</sup>  | ETSI BRAN HIPERLAN type 1 ETS 300-652 | ETSI BRAN HIPERLAN type 2 <sup>(1), (2)</sup>  |
| Access method  | CSMA/CA, SSMA                   | CSMA/CA  | TDMA/EY-NPMA                          | TDMA/TDD   |
| Modulation     | CCK (8-complex chip spreading)  | 64-QAM-OFDM<br>16-QAM-OFDM<br>QPSK-OFDM<br>BPSK-OFDM<br>52 subcarriers<br>(see Fig. 1) | GMSK/FSK                              | 64-QAM-OFDM<br>16-QAM-OFDM<br>QPSK-OFDM<br>BPSK-OFDM<br>52 subcarriers<br>(see Fig. 1) |
| Data rate      | 1, 2, 5.5 and 11 Mbit/s         | 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s   | 23 Mbit/s (HBR)<br>1.4 Mbit/s (LBR)   | 6, 9, 12, 18, 27, 36, 48 and 54 Mbit/s   |
| Frequency band | 2 400-2 483.5 MHz               | 5 150-5 250 MHz<br>5 725-5 825 MHz<br>5 250-5 350 MHz <sup>(3)</sup>                   | 5 150 to 5 350 MHz<br>5 470-5 725 MHz | 5 150-5 350 MHz<br>5 470-5 725 MHz <sup>(4)</sup>                                      |
| Channelization | 25/30 MHz spacing<br>3 channels | 20 MHz channel spacing<br>(8 + 4) channels   | 23.5294 MHz (HBR)<br>1.4 MHz (LBR)    | 20 MHz channel spacing<br>19 channels in the 2 bands                                   |

TABLE 3 (end)

|                              |  |  |   |  |
|------------------------------|--|--|---|--|
| Maximum Tx power             | 1 000 mW e.i.r.p. <sup>(5)</sup><br>100 mW e.i.r.p. <sup>(6)</sup><br>10 mW/MHz<br>e.i.r.p. density <sup>(7)</sup>   | 5 150 to 5 250 MHz<br>10 mW/MHz<br>200 mW e.i.r.p. in<br>20 MHz channel<br>5 250-5 350 MHz<br>1 W e.i.r.p.<br>5 725-5 825 MHz<br>4 W e.i.r.p. <sup>(8)</sup>   | 5 150-5 350 MHz<br>e.i.r.p. <sup>(4)</sup> 200 mW<br>maximum indoor<br>use only.<br>5 470-5 725 MHz<br>e.i.r.p. 1 W   | 5 150-5 350 MHz<br>e.i.r.p. <sup>(4)</sup> 200 mW<br>maximum indoor<br>use only.<br>5 470-5 725 MHz<br>e.i.r.p. 1 W  |
| Sharing considerations       | <ul style="list-style-type: none"> <li>– CDMA allows orthogonal spectrum spreading.</li> <li>– CSMA/CA provides “listen before talk” access etiquette</li> </ul> | <ul style="list-style-type: none"> <li>– OFDM provides low power spectral density.</li> <li>– CSMA/CA provides “listen before talk” access etiquette.</li> <li>– IEEE 802.11h are standardizing DCS and TPC</li> </ul> | In 5 150-5 250 MHz e.i.r.p. density limit should be subject to Recommendation ITU-R M.1454.<br>Dynamic frequency selection and transmit power control are required in the bands 5 250-5 350 MHz and 5 470-5 725 MHz | <ul style="list-style-type: none"> <li>– OFDM provides low power spectral density.</li> <li>– Dynamic frequency selection and transmit power control are required</li> </ul> |
| Minimum receiver sensitivity |  | 6 Mbit/s: –82 dBm<br>54 Mbit/s: –65 dBm<br>10% PER 1 000 Byte PDU  |   | 6 Mbit/s: –85 dBm<br>54 Mbit/s: –68 dBm<br>10% PER 54 Byte PDU   |

(1) Common parameters for the physical layer have been published in the IEEE Std 802.11a-1999 (Supplement to IEEE Std 802.11-1999) and ETSI BRAN HIPERLAN Type 2;2 ETSI TS 101 475 Physical (PHY) layer.

(2) HIPERLAN Type 2 supports cell-based (ATM) and packet-based (IP) core networks.

(3) For the band 5 150 to 5 250 MHz, No. 5.447 of the Radio Regulations (RR) applies.

(4) See ERC/DEC/(99)23.

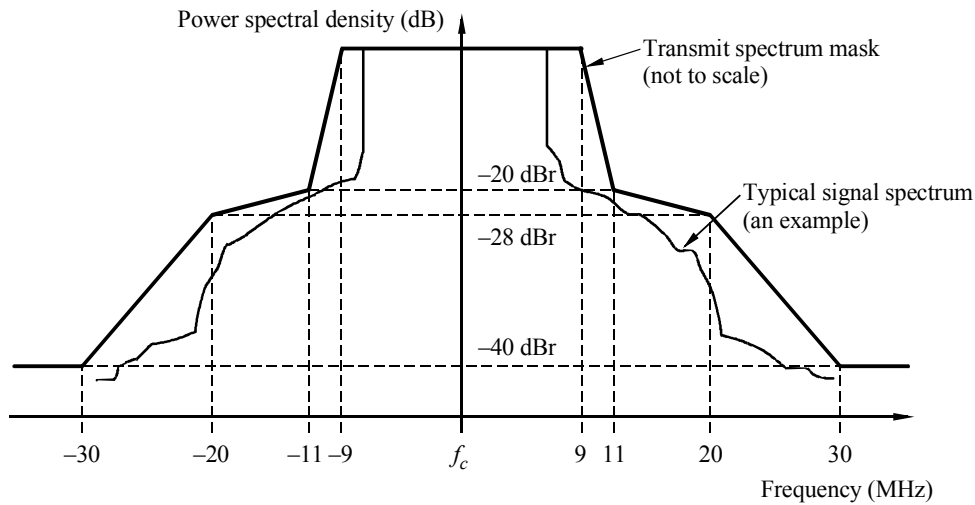
(5) This requirement refers to FCC 15.247 in the United States of America.

(6) This requirement refers to EUROPE ETS 300-328.

(7) This requirement refers to JAPAN MPT ordinance for Regulating Radio Equipment, Article 49-20.

(8) FCC Part 15 Subpart E – Unlicensed National Information Infrastructure Devices.

FIGURE 1  
Transmit spectrum mask



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## ANNEX 1

### General guidance for broadband RLAN system design

#### 1 Introduction

Emerging broadband RLAN standards will allow compatibility with wired LANs such as IEEE 802.3, 10BASE-T, 100BASE-T and 51.2 Mbit/s ATM at comparable data rates. Some broadband RLANs have been developed to be compatible with current wired LANs and are intended to function as a wireless extension of wired LANs using TCP/IP and ATM protocols. This will allow operation without the bottle neck that occurs with current wireless LANs. Recent bandwidth allocations by some administrations will promote development of broadband RLANs. This will allow applications such as audio/video streaming to be supported with high QoS.

A feature provided by broadband RLANs not provided by wired LANs is portability. New laptop and palmtop computers are very portable and have the ability when connected to a wired LAN to provide interactive services. However, when they are connected to wired LANs one loses the portability feature. Broadband RLANs allow portable computing devices to remain portable and operate at maximum potential.

Private on-premise, computer networks are not covered by traditional definitions of fixed and mobile wireless access and should be considered. The nomadic user of the future will no longer be bound to a desk. Instead, they will be able to carry their computing devices with them and maintain contact with the wired LAN in a facility.

Speeds of notebook computers and hand-held computing devices are increasing steadily. Many of these devices are able to provide interactive communications between users on a wired network but sacrifice portability when connected. Multimedia applications and services require broadband communications facilities not only for wired terminals but also for portable and personal communications devices. Wired local area network standards, i.e. IEEE 802.3ab 1000BASE-T, are able to transport high rate, multimedia applications. To maintain portability, future wireless LANs will need to transport higher data rates. Broadband RLANs are generally defined as those that can provide data throughput greater than 10 Mbit/s.

## **2 Mobility**

Broadband RLANs may be either pseudo fixed as in the case of a desktop computer that may be transported from place to place or portable as in the case of a laptop or palmtop devices working on batteries. Relative velocity between devices remains low. In warehousing applications, RLANs may be used to maintain contact with lift trucks at speeds of up to 6 m/s. RLAN devices are generally not designed to be used at automotive or higher speeds.

## **3 Operational environment and considerations of interface**

Broadband RLANs are predominantly deployed inside buildings, in offices, factories, warehouses, etc. For RLAN devices deployed inside buildings, emissions will be attenuated by the structure.

RLANs utilize low power levels because of the short distance nature of inside building operation. Power spectral density requirements are based on a basic service area of a single RLAN defined by a circle with a radius from 10 to 50 m. When larger networks are required, RLANs may be logically concatenated via bridge or router function to form larger networks without increasing their composite power spectral density.

One of the most useful RLAN features is the connection of mobile computer users to his own LAN network without wires. In other words, a mobile user can be connected to his own LAN subnetwork anywhere within the RLAN service area. The service area may expand to other locations under different LAN subnetworks, enhancing the mobile user's convenience.

Annex 2 describes several remote access network techniques to enable the RLAN service area to extend to other RLANs under different subnetworks. Among these techniques, the mobile VLAN (virtual LAN) technique is a most promising enhancement.

To achieve the coverage areas specified above, it is assumed that RLANs require a peak power spectral density of approximately 12.5 mW/MHz in the 5 GHz operating frequency range. For data transmission, some standards use higher power spectral density for initialization and control the transmit power according to evaluation of the RF link quality. This technique is referred to as transmit power control (TPC). The required power spectral density is proportional to the square of the operating frequency. The large scale, average power spectral density will be substantially lower than the peak value. RLAN devices share the frequency spectrum on a time basis. Activity ratio will vary depending on the usage, in terms of application and period of the day.

Broadband RLAN devices are normally deployed in high density configurations and may use an etiquette such as listen before talk and dynamic channel selection (referred to here as dynamic frequency selection, DFS), TPC to facilitate spectrum sharing between devices.

## 4 System architecture

Broadband RLANs are nearly always point-to-multipoint architecture. Point-to-multipoint applications commonly use omnidirectional, down looking antennas. The multipoint architecture employs two system configurations:

**4.1** point-to-multipoint centralized system (multiple devices connecting to a central device or access point via a radio interface);

**4.2** point-to-multipoint non-centralized system (multiple devices communicating in a small area on an ad hoc basis);

**4.3** RLAN technology is sometimes used to implement fixed point-to-point links between buildings in a campus environment. Point-to-point systems commonly use directional antennas that allow greater distance between devices with a narrow lobe angle. This allows band sharing via channel reuse with a minimum of interference with other applications.

## 5 Spectrum reuse

RLANs are generally intended to operate in unlicensed or license-exempt spectrum and must allow adjacent uncoordinated networks to coexist whilst providing high service quality to users. In the 5 GHz bands, sharing with primary services must also be possible. Whilst multiple access techniques might allow a single frequency channel to be used by several nodes, support of many users with high service quality requires that enough channels are available to ensure access to the radio resource is not limited through queuing etc. One technique that achieves a flexible sharing of the radio resource is DFS.

In DFS all radio resources are available at all RLAN nodes. A node (usually a controller node or access point (AP)) can temporarily allocate a channel and the selection of a suitable channel is performed based on interference detected or certain quality criteria, e.g. received signal strength,  $C/I$ . To obtain relevant quality criteria both the mobile terminals and the access point make measurements at regular intervals and report this to the entity making the selection.

DFS can be implemented to ensure that all available frequency channels are utilized with equal probability. This maximizes the availability of a channel to node when it is ready to transmit, and it also ensures that the RF energy is spread uniformly over all channels when integrated over a large number of users. The latter effect facilitates sharing with other services that may be sensitive to the aggregated interference in any particular channel, such as satellite-borne receivers.

TPC is intended to reduce unnecessary device power consumption, but also aids in spectrum reuse by reducing the interference range of RLAN nodes.



## ANNEX 2

**Modulation techniques in broadband RLANs****1 Introduction**

RLAN systems are being marketed all over the world. There are several major standards for broadband RLAN systems and Table 3 provides an overview of these.

Broadband RLAN systems make it possible to move a computer within a certain area such as an office, a factory, and SOHO with high data rates of more than 20 Mbit/s. As a consequence of the great progress in this field, computer users are demanding free movement with bit rates equivalent to those of conventional wired LANs such as 10BASE-T Ethernet.

This Annex presents features of the modulation techniques used in the standards listed in Table 3.

**2 Physical layer to realize high bit rate and stable wireless networks**

The broadband radio channel is known to be frequency selective, causing ISI in the time domain and deep notches in the frequency domain. A possible method to realize a high bit rate, wireless access system under frequency selective fading channels is to shorten the symbol period. A second way is to use bandwidth efficiently by multi-level modulation. The third way is to employ multicarrier modulation. The first and second solutions show serious drawbacks in multipath environments. In the first solution, as the symbol period decreases, ISI becomes a severe problem. Therefore, equalization techniques will be necessary. The second solution reduces the symbol distance in the signal space and hence the margin for thermal noise or interference is decreased, leading to intolerable performance degradation for high bit rate, wireless access systems. The third solution, the multicarrier method, is to increase the symbol period in order to compensate for ISI resulting from multipath propagation. As promising methods for multipath countermeasures, the first solution of single carrier with equalizer and the third solution using multicarrier methods (OFDM) are discussed below.

**3 Single carrier with equalizer**

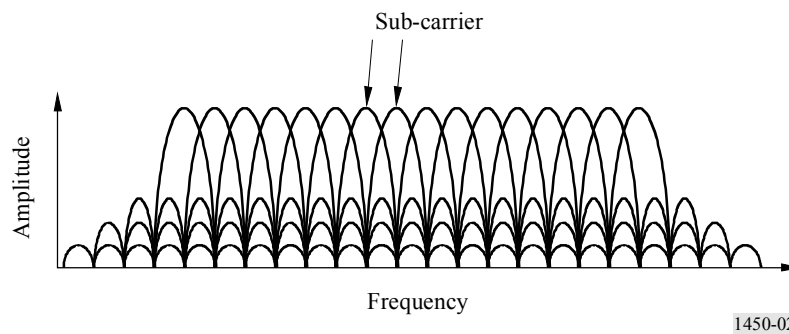
In radiocommunications, the transmission is affected by the time-varying multipath propagation characteristics of the radio channel. To compensate for these time-varying characteristics, it is necessary to use adaptive channel equalization. There are two main groups into which adaptive equalizers can be subdivided; the LMS equalizer and the RLS equalizer. The LMS algorithm is the most commonly used equalization algorithm because of its simplicity and stability. Its main disadvantage is its relatively slow convergence. LMS converges in 100-1 000 symbols. A faster equalization technique is known as an RLS method. There exist various versions of RLS with

somewhat different complexity and convergence trade-off. RLS is more difficult to implement than LMS, but converges in fewer symbols compared with LMS methods. Although much research has been conducted on RLS and LMS equalizers in the cellular systems, RLS and LMS are still a research topic in the points of fast convergence, stability and complexity for high bit rate wireless access applications.

#### 4 Multicarrier OFDM

With multicarrier transmission schemes the nominal frequency band is split up into a suitable number of sub-carriers each modulated by QPSK modulation, etc., with a low data rate. In general, when dimensioning a multicarrier system, the maximum path delay should be shorter than the symbol time. An OFDM modulation scheme is one of the promising multicarrier methods. The power spectrum of this modulation is shown in Fig. 2. The development of fast and power saving LSIC and effective algorithms, FFT for signal processing today allows a cost-effective realization of OFDM schemes. The advantages of this system are given by a satisfactory spectral efficiency and in the reduced effort for equalization of the received signal. In the case of limited delay spread ( $< \sim 300$  ns) of the multipath signals it is possible to dispense with an equalizer

FIGURE 2  
Spectrum of OFDM



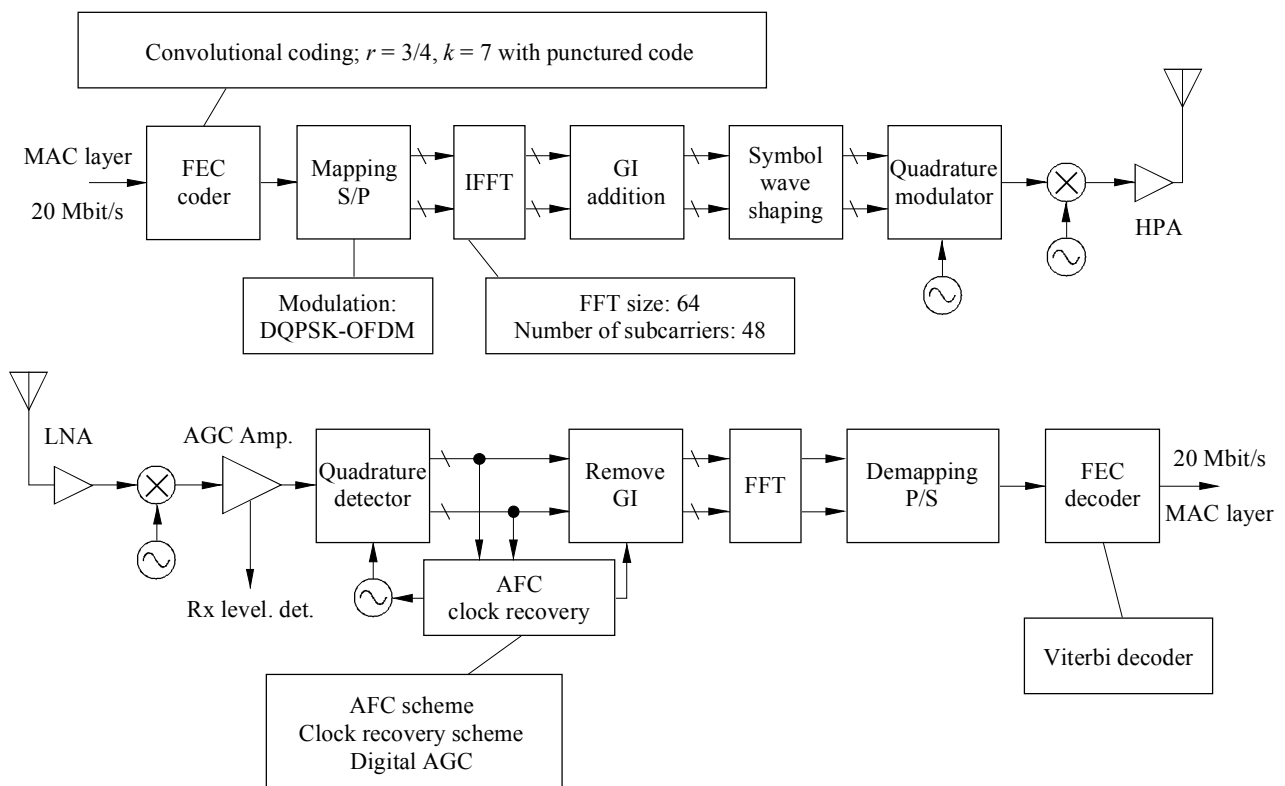
The multicarrier transmission scheme employed with OFDM causes envelope fluctuation like additive white Gaussian noise and the effect on the interference environment is negligible.

#### 5 Configuration of OFDM system

A simplified block diagram of an OFDM transmitter and receiver is shown in Fig. 3. In this example the data to be transmitted are coded by convolutional coding ( $r = 3/4$ ,  $k = 7$ ) and serial-parallel (S/P) converted and the data modulates the allocated subcarrier by DQPSK modulation. In the IEEE 802.11a and HIPERLAN/2 standards, data rates from 6 to 54 Mbit/s can be offered by using various signal alphabets for modulating the OFDM sub-carriers and by applying

different puncturing patterns to a mother convolutional code. BPSK, PSK, 16-QAM and 64-QAM modulation formats are used. An IFFT of the modulated sub-symbols generates the OFDM signals. GI signals are added to the output signals of the IFFT. The GI added OFDM signals are shaped by roll-off amplitude weighting to reduce outband emission. Finally, the OFDM signals modulate IF. At the receiver side, received signals are amplified by the AGA and converted to the baseband signals. At this stage, frequency error due to instability of the RF oscillators is compensated by AFC and the timing of packet arrival is detected. After this synchronization processing, the GI signals are removed and the OFDM signals are de-multiplexed by the FFT circuit. The output signals of the FFT circuit are fed to the de-mapping circuit and demodulated. Finally, a Viterbi decoder decodes the demodulated signals.

FIGURE 3  
Configuration of DQPSK-OFDM with convolutional coding



## 6 Computer simulation

Major simulation parameters and the OFDM symbol format are shown in Table 4 and Fig. 4, respectively. Figure 5 shows that to achieve the packet error rate of 10%, the required  $E_b/N_0$  is about 20 dB under the frequency selective fading channel with 300 ns delay spread. The proposed physical layer approach allows us to use this high bit rate RLAN system not only in indoor areas but also outdoor areas forming parts of locations such as universities, factories, and shopping malls, etc.

TABLE 4

### Major simulation parameters

|                                |                              |
|--------------------------------|------------------------------|
| Raw data rate                  | 26.6 Mbit/s                  |
| Modulation/detection           | DQPSK/differential detection |
| FFT size                       | 64 samples                   |
| Number of subcarriers          | 48                           |
| GI                             | 12 samples                   |
| Number of $T_{prefix}$ samples | 4 samples                    |
| Symbol duration ( $T_s$ )      | 84 samples (= 3.6 $\mu$ s)   |
| Carrier frequency offset       | 50 kHz (10 ppm at 5 GHz)     |

FIGURE 4  
OFDM symbol format

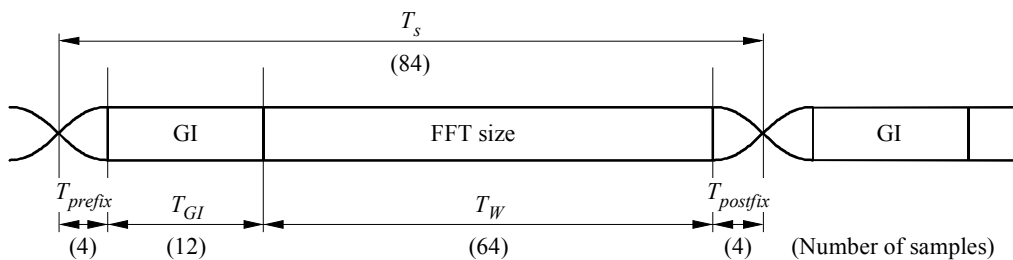
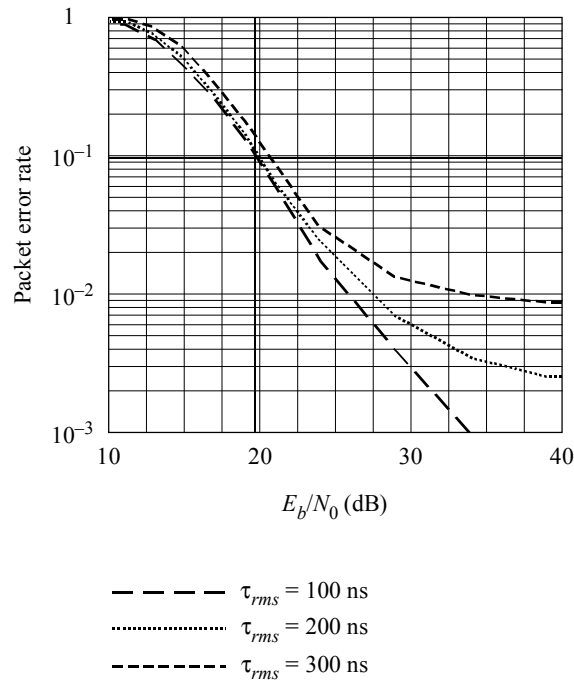


FIGURE 5  
 Packet error rate vs  $E_b/N_0$



Packet length = 1 000 byte with ideal AGC  
 3-bit soft decision  
 Output backoff = 5 dB

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## ANNEX 3

### Remote access techniques in RLANs

#### 1 Introduction

One of the most beneficial usages of RLANs is that the RLAN terminals can be used without any additional operation at other company offices where they move. In order to realize such usage, it is very important to establish network techniques to virtually connect the RLAN terminals that are in other offices (other subnetworks) to their own subnetwork.

There are several approaches to support such remote access for RLAN terminals.

In the following sections, these techniques will be explained, and compared in the aspects of service performance and system composition.

## 2 Remote access techniques

### 2.1 Dial-up connection

Currently, the simplest way to connect a terminal from a remote place is a dial-up method. It does not need a LAN environment, but it is possible wherever the telephone network is available, using a modem or an ISDN adapter. Normally, the user sets up a telephone line in his home office, and connects a modem to a dial-up server. A mobile PC with a modem card can be connected to the home network server by a public wired or wireless telephone. In this connection PPP [IETF, 1994a], or ARA is mainly used.

On the other hand, the dial-up method has the following restrictions:

- additional software is necessary on mobile terminals;
- the network interface changes;
- communication bit rate is low;
- connection fee is generally expensive.

### 2.2 Dynamic Host Configuration Protocol (DHCP)

DHCP [IETF, 1993] is a technique using a new network address at a remote network. DHCP is originally a protocol for the auto-configuration of terminal network interfaces. It enables mobile RLAN terminals to connect to the home network via the Internet by searching for a DHCP server and obtaining a new address.

For DHCP, the following restrictions exist:

- additional software is necessary on mobile RLAN terminals;
- only TCP/IP is available;
- it is unavailable for networks with private IP addresses.

### 2.3 Mobile IP

Mobile IP [IETF, 1996] is a technique that supports terminal mobility in networks. In mobile IP, IP packets transmitted to a mobile RLAN terminal are encapsulated by a home agent into other IP packets, and are forwarded to the foreign agent. In this way, the mobile RLAN terminal can be used at the home network. Because mobile IP works on the Internet, communication cost is low even for international communication.

However, the following are its restrictions:

- additional software is necessary on mobile RLAN terminals;
- only TCP/IP is available;
- it is unavailable for networks with private IP addresses.

### 2.4 VLAN

Recent advances in VLAN allow us to construct subnetworks or LAN segments independent of physical network topology, by using switching hubs, ATM switches, or routers. The main purpose of VLAN is to adopt the following independently of the physical locations:

- unified administration;
- security;

- private IP address or multi-protocol;
- broadcast.

Some of them allow us to construct wide area VLANs, which are also called Internet VPNs [IETF, 1994b]. The wide area VLAN is a very recent technique and the standardization works are now under study in the IETF. In this technique, VLAN functions are necessary on remote network routers, or mobile RLAN terminals themselves.

When the function is on a router, advance registration is necessary. This means that access to Intranet is available only in limited remote networks. When the function is on a mobile RLAN terminal, additional software is necessary.

## **2.5 Mobile VLAN**

Among the various mobile environment requirements, the mobile VLAN technique was developed to support the following features:

- low-cost communication;
- no operation for connection at the RLAN terminal;
- multi-protocol, private IP address;
- ubiquitous communication;
- high security.

In mobile VLAN, the MAC frame transmitted by a mobile RLAN terminal moves to a remote network. Next, it is encapsulated into an IP packet by the server at the remote network. The IP packet is then transferred to its home network (MAC over IP). Then the server at the home network de-encapsulates the received IP packet to the original MAC frame. Therefore, the mobile RLAN terminal can use the home network environment at the remote network.

Mobile VLAN has such functions as terminal location registration, address resolution, authentication, and recognition of disconnection. In order to connect with no operation at the RLAN terminal, all of these functions are performed on the network side.

## **3 Evaluation**

Table 5 summarizes the serviceability of the techniques mentioned above. The mobile VLAN realizes low-cost communication, connection with no operation at a RLAN terminal, support for multi-protocols, and ubiquitous communication without losing other technical advantages.

Appendix 1 to Annex 3 outlines the mobile VLAN system, which is considered most promising to support RLAN terminal mobility.

TABLE 5

**Comparison of the mobility support techniques**

|                                 | <b>Mobile VLAN</b> | <b>Dial-up connection</b> | <b>DHCP</b> | <b>Mobile IP</b> | <b>Wide area VLAN (in router)</b> |
|---------------------------------|--------------------|---------------------------|-------------|------------------|-----------------------------------|
| Transport network               | Internet           | PSTN<br>ISDN              | Internet    | Internet         | Internet                          |
| Communication cost              | Low                | High                      | Low         | Low              | Low                               |
| Network interface modification  | No                 | Yes                       | No          | No               | No                                |
| Network address modification    | No                 | No                        | Yes         | No               | No                                |
| Additional software on terminal | No                 | Yes                       | Yes         | Yes              | No                                |
| Multi-protocol                  | Available          | Unavailable               | Unavailable | Unavailable      | Available                         |
| Private IP address              | Available          | Available                 | Unavailable | Unavailable      | Available                         |
| Ubiquitous communication        | Available          | Available                 | Available   | Available        | Unavailable                       |

**References**

- IETF [1993] Dynamic Host Configuration Protocol, RFC1541, 1531. Internet Engineering Task Force (IETF).
- IETF [1994a] The Point-to-Point Protocol, RFC1661, 1548. Internet Engineering Task Force.
- IETF [1994b] Generic Routing Encapsulation, RFC1701. Internet Engineering Task Force.
- IETF [1996] INTERNET draft. IP Mobility Support Rev.17. Internet Engineering Task Force.

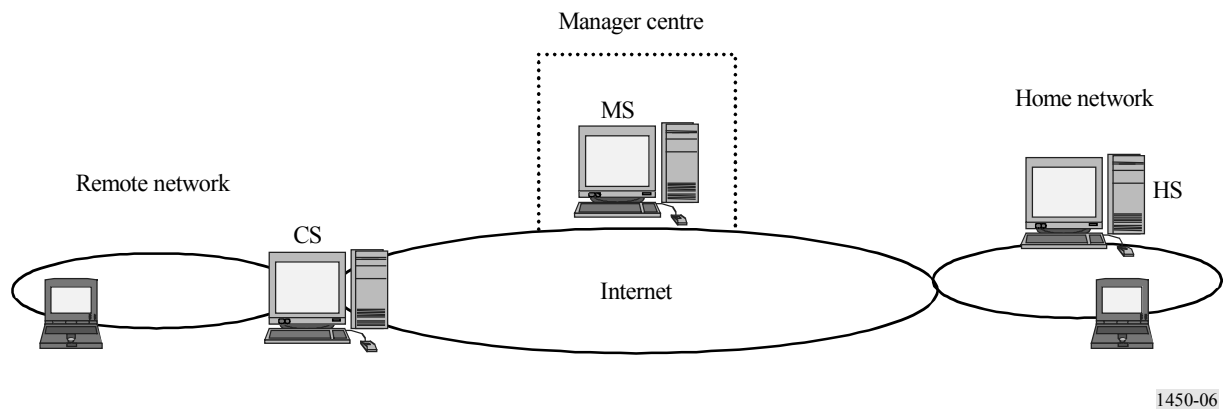
**APPENDIX 1****TO ANNEX 3****Outline of mobile VLAN system****1 System composition**

The functions needed for the mobile VLAN techniques are address resolution, terminal authentication, location registration for recognition of disconnection, and MAC frame encapsulation/de-encapsulation. The first two factors, i.e. address resolution and terminal authentication, are necessary over the entire network. The location registration function is required



only in remote networks. The MAC frame encapsulation/de-encapsulation is necessary in both home networks and remote networks. Consequently, the usage of three kinds of servers may be proposed: the management server (MS), the home server (HS), and the client server (CS), as shown in Fig. 6. One MS serves the whole network. It manages terminal authentication data and terminal location data, and resolves addresses. One HS is located in one home network, where it encapsulates and forwards MAC frames for mobile terminals. One CS is located in one remote network, where it recognizes mobile terminals, requests terminal authentication to the MS, establishes connection to the HS, and encapsulates MAC frames.

FIGURE 6  
System composition of mobile VLAN



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## 2 Major techniques of mobile VLAN

In this section, the major techniques of mobile VLAN are introduced based on sequence charts.

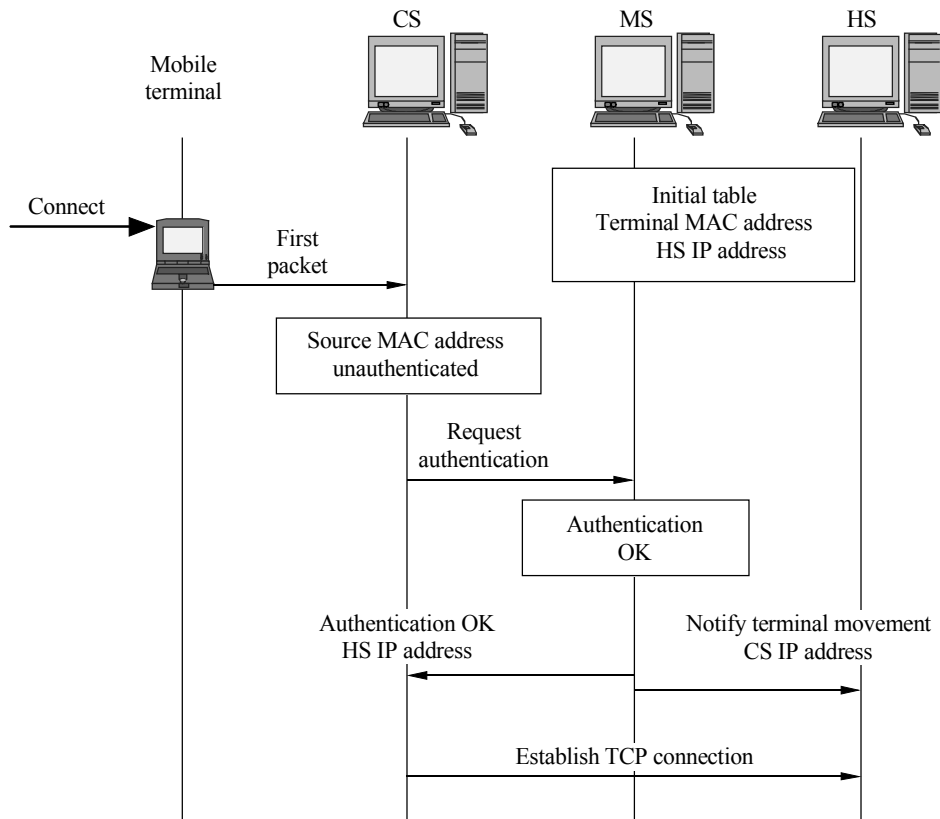
### 2.1 Terminal authentication, location registration, connection

MAC addresses and the corresponding HS IP addresses have to be registered in advance in the MS. IP addresses of all HSs and CSs are also registered. TCP connections to all HSs and CSs are established. The mobile terminal can be connected to remote networks that are connected to the CSs. After connection, when the terminal sends a packet, e.g. an ARP, the CS captures the packet as a MAC frame. The CS sends the source MAC address to the MS, and the MS authenticates that the terminal is from the corresponding home network.

Upon authentication, the MS registers the terminal location to itself, and notifies the CS and corresponding HS of terminal movement. Then, the CS establishes a TCP connection for MAC frame forwarding to the HS.

Because the destination HS differs depending on the source address of the MAC frame, a CS can belong to many HSs.

FIGURE 7  
Sequence chart for terminal authentication, location registration, and connection

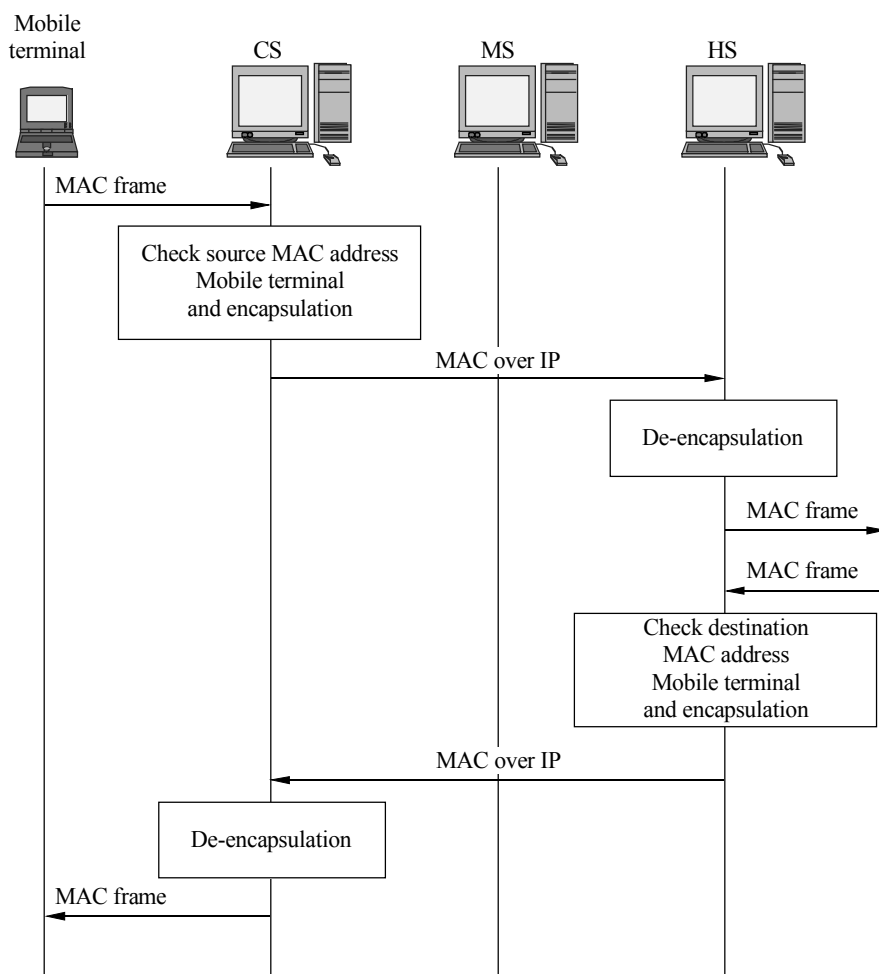


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## 2.2 Encapsulation/de-encapsulation

After TCP connection is established, the CS captures MAC frames with source MAC address of the mobile terminal, and the HS captures MAC frames with destination MAC address of the mobile terminal. Then they encapsulate MAC frames into IP packets. If they receive encapsulated MAC frames via the TCP connection, they de-encapsulate them and transmit extracted MAC frames to the LAN. If a MAC frame for another mobile terminal is captured, they encapsulate it again and send it to the corresponding CS. In this way, many CSs can belong to one HS.

FIGURE 8  
Sequence chart for encapsulation/de-encapsulation



### 2.3 Recognition of terminal disconnection

The CS has a timer, and if reception of MAC frames from the mobile terminal stops for a certain period, it recognizes this as disconnection.

FIGURE 9  
Sequence chart for terminal disconnection

