HIPERLAN type 2 for broadband wireless communication

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The aim of several standardization efforts, including GPRS, EDGE, and UMTS, is to meet the requirements being put on wireless data communication. These standards are for wide-area wireless data services with full mobility up to 2 Mbit/s. In addition, standards are being developed in Europe, Japan, and the US for wireless local area network multimedia communication in the 5 GHz band.

HIPERLAN/2, which is being specified by the ETSI *BRAN* project, will provide data rates of up to 54 Mbit/s for short-range (up to 150 m) communications in indoor and outdoor environments. Almost total harmonization was achieved between the standardization bodies in Europe (ETSI) and Japan (ARIB) when the core parts of the specification were finalized in 1999.

In this article, the authors present an overview of the HIPERLAN/2 standard and results of link and system performance.

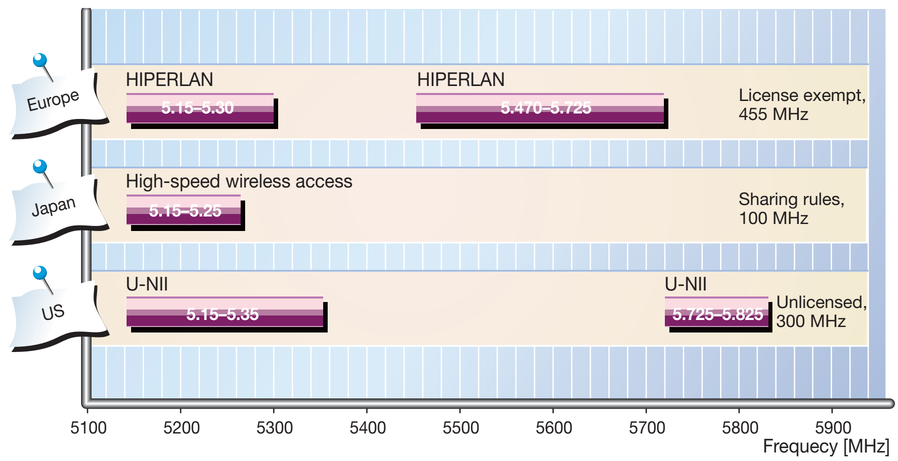
Introduction

The key drivers of demand for radio-based broadband access networks are massive growth in wireless and mobile communications, the emergence of multimedia applications, demands for high-speed Internet access, and the deregulation of the telecommunications industry. Present-day wireless telecommunications networks, which are primarily narrowband, are mostly used for circuit-switched voice services. The evolution of second-generation and the development of third-generation mobile wireless systems aim to enable networks to provide instantaneous user bit rates of up to 2 Mbit/s per radio channel. This capacity will significantly improve packet-data and mobile multimedia applications. In addition, even higher data rates can be obtained for local area networks using novel short-range wireless technologies. Bandwidth-hungry, real-time and interactive multimedia services, such as high-quality video distribution, client/server applications, and data-bank access, are typical applications for this technology. Therefore, new wireless networks with broadband capabilities are being sought to provide high-speed integrated services (data, voice, and video) with cost-effective support for quality of service (QoS).

Considerable research and standardization efforts have been expended to devise appropriate transmission and networking technologies. The Internet Engineering Task Force (IETF), the International Telecommunication Union (ITU) and the ATM Forum are defining the fixed core network. Similarly, the Broadband Radio Access Networks (BRAN) project of the European Telecommunications Standards Institute (ETSI) is working on standards for different kinds of wireless broadband access network. One of these standards, called *high-performance radio local-area network, type 2* (HIPERLAN/2) will provide high-speed communications access to different broadband core networks and moving terminals (portable as well as mobile).[1-9] In Japan, a system that is very similar to HIPERLAN/2 has also been specified. The main difference between it and HIPERLAN/2 is that the spectrum-sharing rule of the Japanese system introduces a carrier-sensing mechanism.

Before beginning standardization work on HIPERLAN/2, ETSI had developed the HIPERLAN/1 standard for *ad hoc* networking of portable devices. This standard mainly supports asynchronous data transfer and applies a multiple access mechanism—from the carrier-sense multiple access (CSMA) family—with collision avoidance (CA). Using the CSMA/CA technique for resolving contention, the scheme shares available radio capacity between active users who attempt to transmit data during an overlapping time span. Although HIPERLAN/1 provides a means of transporting time-bounded services, it does not control or guarantee QoS on the wireless link. It is thus considered a system for best-effort delivery of data. This is what motivated ETSI to develop a new generation of standards that support asynchronous data and time-critical services (for example, packetized voice and video) that are bounded by specific time delays.

Figure 1
Current spectrum allocation of HIPERLAN/2 at 5 GHz. In Europe, a 455 MHz bandwidth has been allocated (license-exempt band); in Japan, 100 MHz (with sharing rules); and in the US, 300 MHz (U-NII band).



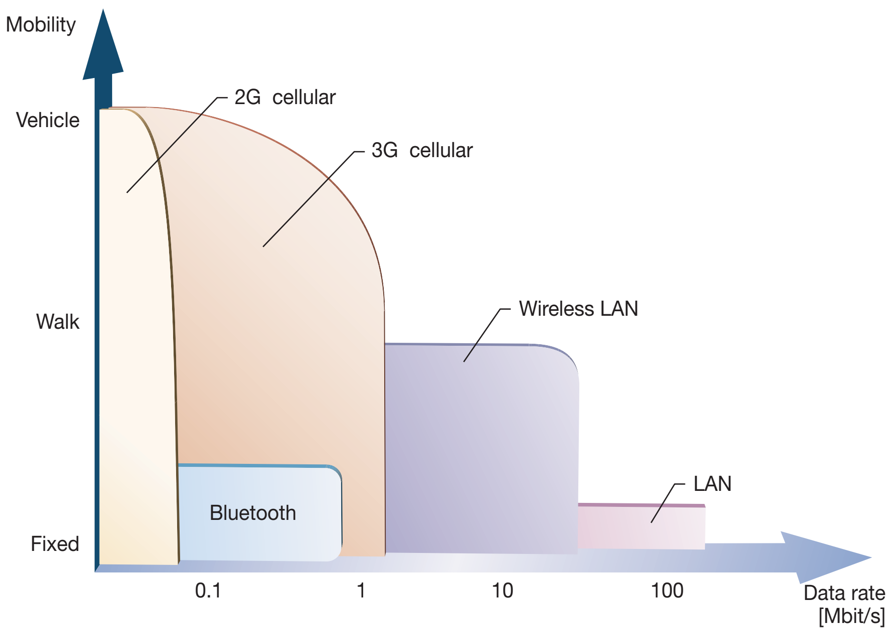


Figure 2
Mobility and data rates for communications standards.

While ETSI was working on the HIPERLAN/2 standard, the Institute of Electrical and Electronic Engineers (IEEE) began specifying a physical layer for the Unlicensed National Information Infrastructure (U-NII) band, to extend its IEEE 802.11 standard for high-speed applications. The IEEE 802.11a reuses the medium access control (MAC) protocol already specified for the Industrial Scientific Medical (ISM) band (2.4 GHz). In contrast to HIPERLAN/2, the scope of the IEEE 802.11—as a mandatory operation mode—mainly applies to asynchronous data applications.

In Japan, the Multimedia Mobile Access Communications (MMAC) promotion association within the Association of Radio Industries and Broadcasting (ARIB) had begun developing various high-speed radio-access systems for business and home applications at 5 GHz. One such system, for business applications in corporate and public networks, has been aligned with HIPERLAN/2.

The HIPERLAN/2 standard is a complement to present-day wireless access systems, giving high data rates (capacity and throughput) to end-users in hot-spot areas. Compared to other cellular systems, the outdoor mobility of HIPERLAN/2 is limited. Typical application environments are offices, homes, exhibition halls, airports, train stations, and so on (Figure 2). In these environments, HIPERLAN/2 offers wireless

BOX A, ABBREVIATIONS

16QAM	16-ary quadrature amplitude modulation
64QAM	64-ary quadrature amplitude modulation
ACH	Access feedback channel
AP	Access point
ARIB	Association of Radio Industries and Broadcasting
ARQ	Automatic repeat request
ATM	Asynchronous transfer mode
BCH	Broadcast channel
BPSK	Binary phase-shift keying
BRAN	Broadband Radio Access Networks
CA	Collision avoidance
C/I	Carrier-to-interference
CL	Convergence layer
CM	Centralized mode
CSMA	Carrier-sense multiple access
DFS	Dynamic frequency selection
DLC	Data link control
DM	Direct mode
EC	Error control
EDGE	Enhanced data rates for global evolution
EIRP	Effective isotropic radiated power
ETSI	European Telecommunications Standards Institute
FCH	Frame channel
FEC	Forward error control
GPRS	General packet radio service
H2GF	HIPERLAN/2 Global Forum
HIPERLAN/2	High-performance radio local-area network, type 2
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IFFT	Inverse fast Fourier transform
IP	Internet protocol
ISM	Industrial Scientific Medical (2.4 GHz frequency band)
ITU	International Telecommunication Union
LCH	Long transport channel
MAC	Medium access control
MMAC	Multimedia Mobile Access Communications
MT	Mobile terminal
OFDM	Orthogonal frequency-division multiplexing
PDU	Protocol data unit
PHY	Physical (layer)
PPP	Point-to-point protocol
QoS	Quality of service
QPSK	Quaternary phase-shift keying
RCH	Random access channel
RLC	Radio link control
RRC	Radio resource control
SCH	Short transport channel
SDU	Service data unit
SR	Selective repeat
SSCS	Service-specific convergence sublayer
TDD	Time-division duplex
TDMA	Time-division multiple access
UMTS	Universal mobile telecommunications system
U-NII	Unlicensed National Information Infrastructure

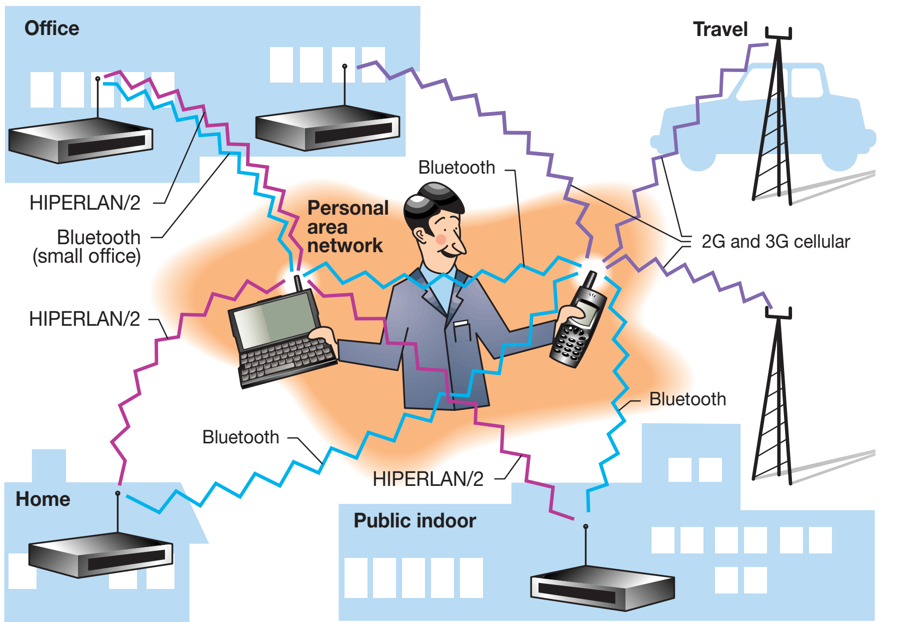


Figure 3
Typical usage of communications standards.

access to terminals (laptops, VCRs, and so on). Figure 3 illustrates the end-user's personal area network (PAN). Via HIPERLAN/2, users gain access to their network—for instance, to the Internet, an intranet, or another HIPERLAN/2-capable device. By contrast, Bluetooth technology is mainly used for linking individual communication devices within the personal area network.

System overview

The HIPERLAN/2 standard specifies a radio-access network that can be used with a variety of core networks. This is made possible thanks to

- a flexible architecture that defines core network independent physical (PHY) and data-link-control (DLC) layers; and
- a set of convergence layers that facilitate access to various core networks (Figure 4).

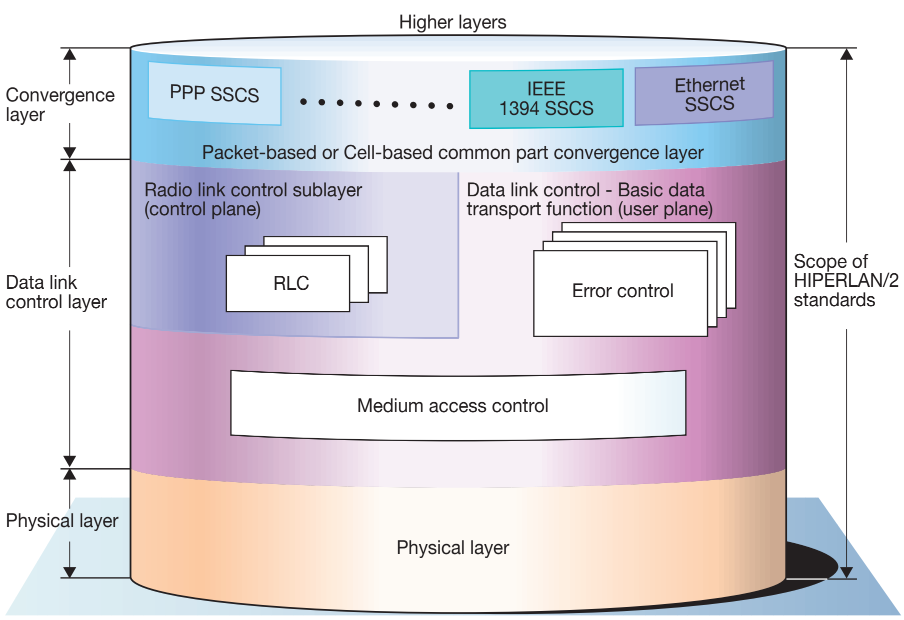
Several convergence layers have been or are currently being defined for interworking with

- Internet protocol (IP) transport networks (Ethernet and the point-to-point protocol, PPP);
- asynchronous transfer mode-based (ATM) networks;
- third-generation core networks; and
- networks that use IEEE 1394 (Firewire) protocols and applications.

The data units that are transmitted within these core networks can differ in length, type, and content. A specific convergence layer in HIPERLAN/2 segments data units into fixed-length HIPERLAN/2 DLC user service data units (U-SDU) that are transmitted to their destination by means of DLC and PHY data-transport services.

The HIPERLAN/2 standard supports ter-

Figure 4
Architecture of the HIPERLAN/2 protocols.



minal mobility at velocities of up to 10 m/s. In addition, it provides a means of handling different interference and propagation environments, with the aim of

- maintaining the communications link at low signal-to-interference ratios;
- maintaining quality of service; and
- finding a suitable trade-off between communications range and data rate.

The air interface of the HIPERLAN/2 standard is based on time-division duplex (TDD) and dynamic time-division multiple access (TDMA). HIPERLAN/2 is a flexible platform on which a variety of business and home multimedia applications can be based to provide bit rates of up to 54 Mbit/s. In a typical business application scenario, a mobile terminal receives services over a fixed corporate or public network infrastructure. In addition to quality of service, the network provides mobile terminals with security and mobility management services when they move between networks—for example, when terminals move between local area and wide area networks or between corporate and public networks. In a home application scenario, low-cost and flexible networking is supported to interconnect wireless digital consumer devices.

HIPERLAN/2 relies on cellular networking topology combined with *ad hoc* networking capability. It supports two basic modes of operation: centralized mode (CM) and direct mode (DM).

The centralized mode of operation applies to the cellular networking topology where each radio cell is controlled by an access point (AP) that covers a certain geographical area. In this mode, mobile terminals communicate with one another or with the core network through the access point. The centralized mode of operation is mainly used in indoor and outdoor business applications where the area to be covered is larger than a radio cell.

The direct mode of operation applies to the *ad hoc* networking topology of private home environments and where the entire serving area is covered by one radio cell. In this mode, mobile terminals in a single-cell home network can exchange data directly with one another. The access point controls the assignment of radio resources to the mobile terminals.

Convergence layer

The convergence layer (CL) has two main functions: it adapts service requests from higher layers to the service offered by the DLC, and it converts higher-layer packets of fixed or variable length into a fixed-length service data unit (SDU) that is used within the DLC.

The convergence layer thus maps incoming data onto different bearers of the DLC. For example, if we assume that Ethernet quality of service is supported via IEEE 802.1p, then the priority indicated in the additional tag field stipulates the type of traffic to be carried in the packet.[10] The convergence layer maps different traffic types into different classes and consequently onto different radio bearers.

There are two types of convergence layer:

- a cell-based convergence layer, which handles higher layers with fixed-length packets—for instance, ATM-based core networks; and
- a packet-based convergence layer, which handles higher layers with variable-length packets—for instance, Ethernet.

Separate service-specific convergence sublayers (SSCS) have been defined to make the appropriate service adaptation for Ethernet, IEEE 1394, PPP, and the universal mobile telecommunications system (UMTS). Figure 5 depicts the basic structure of each type of convergence layer.

The padding, segmentation and reassemble function of the fixed-length DLC service data units is a key feature that makes it pos-

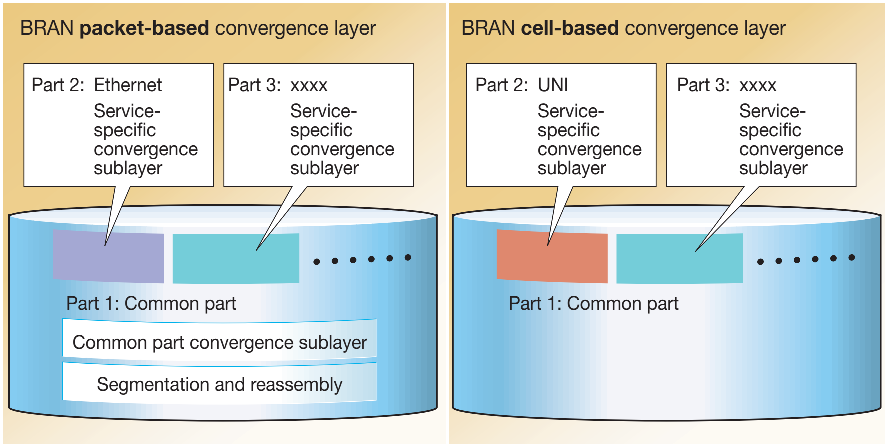


Figure 5
General structure of the convergence layer.

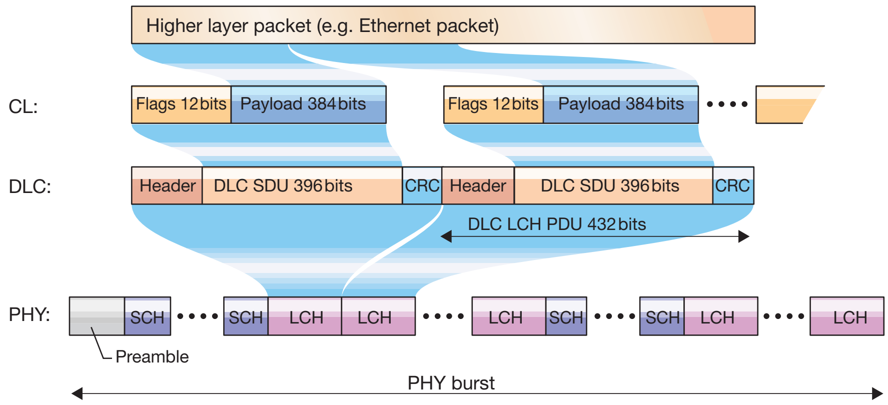


Figure 6
Mapping of higher layer packets onto the layers of HIPERLAN/2.

sible to standardize and implement the DLC and PHY layers independently of the core network. Figure 6 depicts the mapping of higher-layer data units down to PHY bursts. For transmission, the data units on the DLC layer are long transport channel (LCH) packet data units (PDU); for control messages, short transport channel (SCH) PDUs are used.

DLC layer

The DLC layer consists of a radio link control (RLC) sublayer, an error control (EC) protocol, and a MAC protocol.

RLC sublayer

The RLC handles three main control functions:

1. The association control function is used for authentication, key management, association, disassociation, and encryption seed.
2. The radio resource control (RRC) function manages handover (generic solution), dynamic frequency selection, mobile terminal alive/absent, power saving, and power control.
3. The DLC user-connection control function sets up and releases user connections, multicast and broadcast.

In summary, the RLC is used for exchanging data in the control plane between an access point and a mobile terminal—for instance, the mobile terminal forms associations with the access point via RLC signaling. After completing the association procedure, the mobile terminal can request a dedicated control channel for setting up radio bearers. Within the HIPERLAN/2 specification, radio bearers are referred to as DLC connections. The mobile terminal might even request multiple DLC connections, each offering unique support for quality of service (QoS) as determined by the access point.

Set-up of the connection does not necessarily result in immediate assignment of capacity by the access point. Instead, the mobile terminal receives a unique DLC address that corresponds to the DLC connection.

Error control

The error control modes of operation are defined to support different types of service:

1. The *acknowledged mode* uses retransmission to improve link quality and guarantee reliable transmission. The acknowledged mode is based on selective-repeat (SR) automatic repeat request (ARQ).[11] Low latency can be provided by means of a discard mechanism.
2. The *repetition mode* repeats the data-bearing DLC PDUs (LCH PDU) to provide fairly reliable transmission (Figure 4). No feedback channel is available. The transmitter can arbitrarily retransmit PDUs. The retransmission of PDUs enhances reception. However, the receiver only accepts PDUs whose sequence numbers are within its acceptance window. The repetition mode is typically used for transmitting broadcast data.
3. The *unacknowledged mode* provides unreliable, low-latency communication without retransmissions. Hence, no feedback channel is available.
4. Unicast data can be sent using either acknowledged or unacknowledged mode. Broadcast services can be supported by either repetition mode or unacknowledged mode. Multicast services can be sent in unacknowledged mode or they can be multiplexed onto existing unicast transmissions.

MAC

The basic frame structure on the air interface has a fixed duration of 2 ms and comprises fields for broadcast control, frame control, access feedback control, data transmission in the downlink and uplink, and random access (Figure 7). During direct-link communication, the frame contains an ad-

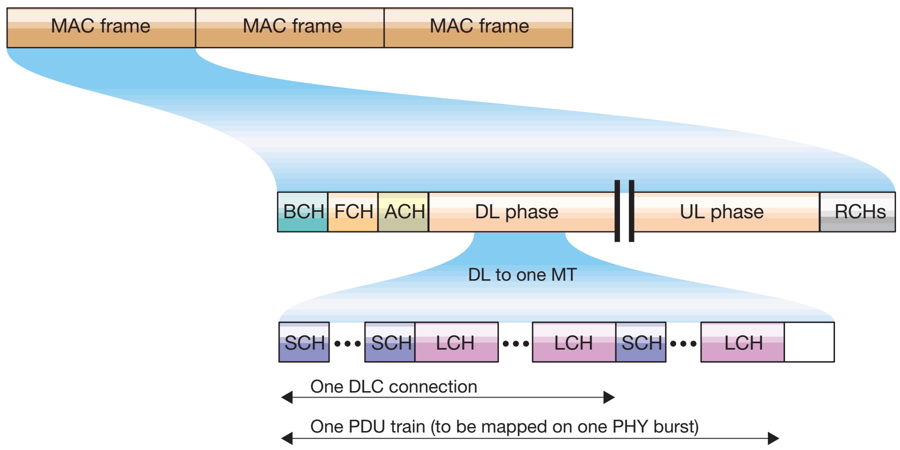


Figure 7
Basic frame structure (one-sector antenna).

ditional direct-link field (not shown in Figure 7). The duration of broadcast control is fixed, whereas the duration of other fields is dynamically adapted to the traffic situation.

The broadcast channel (BCH), which contains control information that is sent in every MAC frame, mainly enables the control of radio resources. The frame channel (FCH) contains an exact description of the allocation of resources within the current MAC frame. The access feedback channel (ACH) conveys information on previous attempts at random access. Downlink or uplink traffic consists of data to or from mobile terminals. Traffic from multiple connections to or from a mobile terminal can be multiplexed onto one PDU train, where each connection contains 54-octet LCHs for data and 9-octet SCHs for control messages.

HIPERLAN/2 supports multibeam antennas (sectors) as a means of improving the link budget and of reducing interference in the radio network. The MAC protocol and the frame structure in HIPERLAN/2 support multibeam antennas with up to eight beams (not shown in Figure 7).

When a mobile terminal has data to transmit on a certain DLC connection, it must first request capacity by sending a resource request (RR) to the access point. The resource request contains the number of pending LCH PDUs in the mobile terminal for the particular DLC connection. Based on a slotted scheme, the mobile terminal can use contention slots to send the RR message. By varying the number of contention slots (random access channels, RCH), the access point can decrease access delay. If a collision occurs, the mobile terminal is informed in the ACH of the next MAC frame. The mobile terminal then backs off a random number of access slots.

After sending the resource request to the access point, the mobile terminal enters a contention-free mode where it is scheduled for transmission opportunities (uplink and downlink). The scheduling of resources is performed in the access point—a centralized controller enables efficient QoS support. From time to time the access point might poll the mobile terminal for information on pending PDUs. Similarly, the mobile terminal might inform the access point of its status by sending a resource request via the RCH.

Radio network functions and QoS support

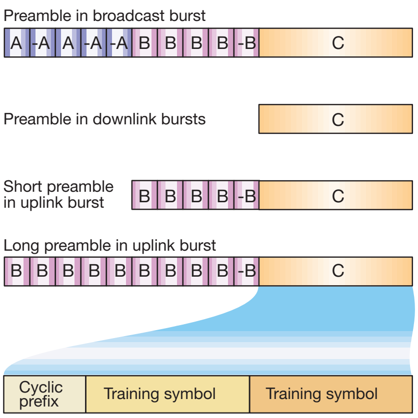
The HIPERLAN/2 standard defines measurements and signaling that support a number of radio-network functions, including dynamic frequency selection, link adaptation, handover, multibeam antennas, and power control. The algorithms are vendor-specific. The supported radio-network functions allow the cellular deployment of HIPERLAN/2 systems with full coverage and high data rates in a variety of environments. The system automatically allocates frequencies to each access point for communication—dynamic frequency selection (DFS) allows several operators to share available spectrum and avoids the use of interfered frequencies. Frequency selection is based on interference measurements performed by the access point and associated mobile terminals.[12]

The quality of the radio link, which is dependent on the radio environment, changes

TABLE 1. PHYSICAL LAYER MODES OF HIPERLAN/2

Mode	Modulation	Code rate	Physical layer bit rate
1	BPSK	1/2	6 Mbit/s
2	BPSK	3/4	9 Mbit/s
3	QPSK	1/2	12 Mbit/s
4	QPSK	3/4	18 Mbit/s
5	16QAM	9/16	27 Mbit/s
6	16QAM	3/4	36 Mbit/s
7	64QAM	3/4	54 Mbit/s

Figure 8
The preambles of HIPERLAN/2.



over time and in accordance with traffic in surrounding radio cells. To cope with variations, a link-adaptation scheme is applied: the adaption of the physical layer mode—that is, the code rate and modulation scheme—is based on measurements of link quality (Table 1). Link adaptation is used in the uplink and downlink. The access point measures link quality on the uplink and indicates, in the FCH, which PHY mode the mobile terminal should use for uplink communication. Similarly, the mobile terminal measures quality on the downlink and suggests, in each resource request signaled to the access point, a PHY mode for downlink communication. The access point selects the final PHY mode for both the uplink and downlink.

Transmitter power control is supported in the mobile terminal (uplink) and access point (downlink). Power control in the mobile terminal is used mainly to simplify the design of the access point receiver, by avoiding automatic gain control. Power control in the access point has been introduced primarily for regulatory purposes, to decrease interference to other systems on the same band.

HIPERLAN/2 supports quality of service by allowing the access point to set up and manage different radio bearers during transmission. The access point selects the appropriate error control mode (acknowledged, unacknowledged and repetition) including detailed protocol settings (for example, ARQ window size, number of retransmissions, discarding). Scheduling is performed at the MAC level, where the access point determines how much data and control signaling will be sent in the current MAC frame. For example, by regularly polling a mobile terminal for its traffic status (pending data to be transmitted), the access point provides the terminal's radio bearer with short access delay. The polling mechanism provides rapid access for real-time services. Additional QoS support includes link adaptation and internal functions (admission, congestion, and dropping mechanisms) for avoiding overload situations.

Physical layer

The data units to be transmitted via the physical layer of HIPERLAN/2 are bursts of variable length. Each burst consists of a preamble and a data field. The data field is composed of a train of SCH and LCH PDUs that are to be transmitted or received by a mobile terminal.

Orthogonal frequency-division multiplexing[13,14] (OFDM) has been selected as the modulation scheme for HIPERLAN/2, due to good performance on highly dispersive channels.[15] In terms of sensitivity and performance when subjected to co-channel interference at a bit rate of 25 Mbit/s, coherent OFDM outperforms single-carrier modulation by 2 to 3 dB. Single-carrier modulation cannot efficiently support high bit rates—this is an important factor, since HIPERLAN/2 is required to support much higher bit rates. A drawback of OFDM is power amplifier back-off, which affects coverage. For the spectrum mask that has been specified for HIPERLAN/2, the OFDM-related power amplifier back-off is 2 to 3 dB greater than that of single-carrier modulation. In terms of coverage, however, this "weakness" of OFDM is compensated for by greater sensitivity. Power consumption in mobile terminals, which is also affected by power amplifier back-off, should be considered together with

- reduced power consumption in the OFDM receiver; and
- the ratio of downlink and uplink traffic, which is expected to be highly asymmetrical.

Based on these and other arguments, OFDM is favored over single-carrier modulation.

A 20 MHz channel raster has been selected to provide a reasonable number of channels in a 100 MHz bandwidth, which might be the narrowest continuous system bandwidth available (for instance, in Japan). To avoid unwanted mixed frequencies in implementations, the sampling frequency is also 20 MHz (at the output of a 64-point inverse fast Fourier transform, IFFT, in the modulator). The obtained subcarrier spacing is 312.5 kHz. To facilitate the implementation of filters and to achieve sufficient adjacent channel suppression, 52 subcarriers are used per channel; 48 subcarriers carry data and 4 are pilots that facilitate coherent demodulation. The duration of the cyclic prefix is 800 ns, which is sufficient for enabling good performance on channels with a root-mean-square delay spread of at least 250 ns. An optional short-cyclic prefix with 400 ns can be used for short-range indoor applications.

A key feature of the physical layer is that it provides several physical layer modes with different coding rates and modulation schemes, which are selected by link adaptation. The physical layer supports binary and quaternary phase-shift keying (BPSK, QPSK) as well as 16-ary quadrature amplitude modulation (16QAM) for subcarrier modulation. In addition, 64QAM can be used in an optional mode.

Forward error correction (FEC) is performed by a convolutional code with rate 1/2 and constraint length 7. The 9/16 and 3/4 code rates are obtained by means of puncturing. The physical layer modes are chosen such that the number of encoder output bits matches an integer of OFDM symbols. To accommodate tail bits, appropriate dedicated puncturing is applied before the encoded bit sequence is punctured.

Seven physical layer modes have been specified (Table 1). Six of the physical layer modes are mandatory; 64QAM is optional.

Each physical layer burst includes a preamble, of which there are three kinds for:
- the broadcast control channel;
- other downlink channels; and
- the uplink and the random-access channel.

The preamble of optional direct-link bursts is identical to that of the long uplink preamble. The preamble in the broadcast control channel enables frame synchronization, automatic gain control, frequency synchronization, and channel estimation. By contrast, the preamble in downlink traffic bursts is solely used for channel estimation. The uplink traffic bursts and the random access bursts enable channel and frequency estimation. Consequently, there are several preambles with different structures and lengths (Figure 8, Box B). Depending on its receiver capabilities, the access point can choose from two uplink preambles. Each preamble is mandatory for the mobile terminal.

The performance of initial synchronization—that is, when terminals synchronize onto the BCH preamble—is characterized by detection-failure probability and false-alarm probability. Simulation results show that even in a worst-case scenario (low signal-to-noise power ratio of 5 dB, a highly-dispersive fading channel with 250 ns delay spread, and a frequency offset of 40 ppm), the probability of successful synchronization in HIPERLAN/2 is 96%.[16] Thus, HIPERLAN/2 provides a fast, efficient, and robust means of synchronization.

Performance

Link performance

The PDU error rate (PER)—which is conveniently given as a function of carrier-to-interference power ratio (C/I) in interference-limited systems—gives a suitable measure of performance for packet data communication. During standardization, channel models for simulating links have been developed from measurements in typical indoor and outdoor environments.[17-19] The power-delay profiles show exponential decay. The channel taps are statistically independent with complex Gaussian distribution and zero mean (except for the Ricean channel tap). The channel model "A" (used for the simulations discussed below) typifies large office environments with non-line-of-sight propagation.

Figure 9 shows the LCH PDU error rate for all physical layer modes. As expected, the C/I required for a certain error rate increases with bit rate. Only the 9 Mbit/s mode behaves differently.

BOX B, PREAMBLES OF HIPERLAN/2

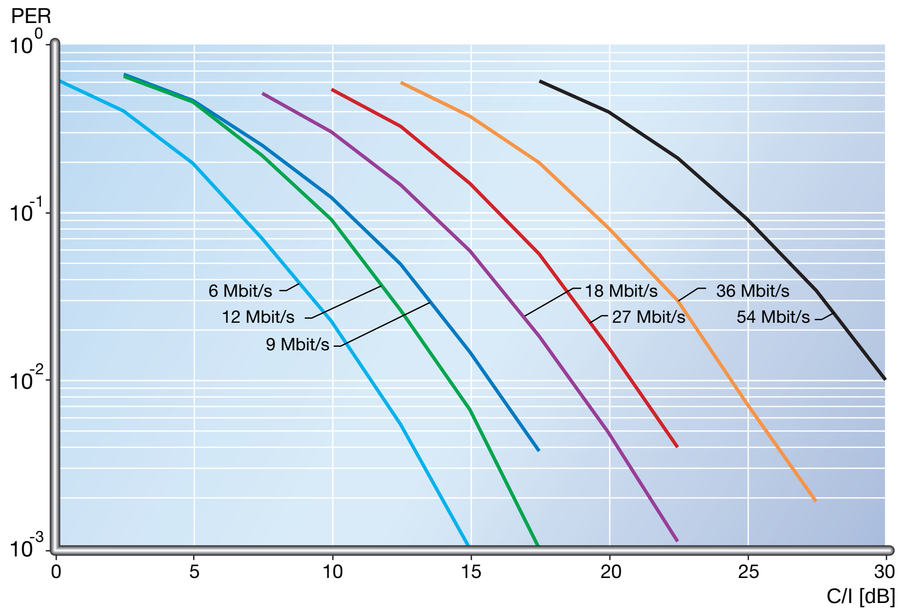
The A- and B-symbols are composed of 16 time-domain samples. The symbols denoted by -A and -B are negative replicas of A and B, respectively.

The block of four symbols A, -A, A, -A can be generated by a 64-point IFFT from a frequency-domain symbol with 12 subcarriers at the frequency indices +/-2, +/-6, and so forth. The additional -A symbol is appended by repetition in the time domain. Similarly, the B-symbols are generated from a frequency-domain symbol with the subcarriers used at the indices +/-4, +/-8, and so on.

Thanks to the time-domain structures of the A, -A, A, -A and B, B, B, B sequences, it is easy to distinguish broadcast control channels and uplink bursts. The appended -A and -B symbols improve timing estimation.

The C-part, which is included in every preamble, is composed of two training symbols that use 52 subcarriers and a cyclic prefix of 1.6 µs. The C-part is used for channel estimation, whereas the previous short symbols are used for all other purposes, such as frame synchronization, frequency estimation, and so on.

Figure 9
LCH PDU error rate versus C/I for channel model "A".



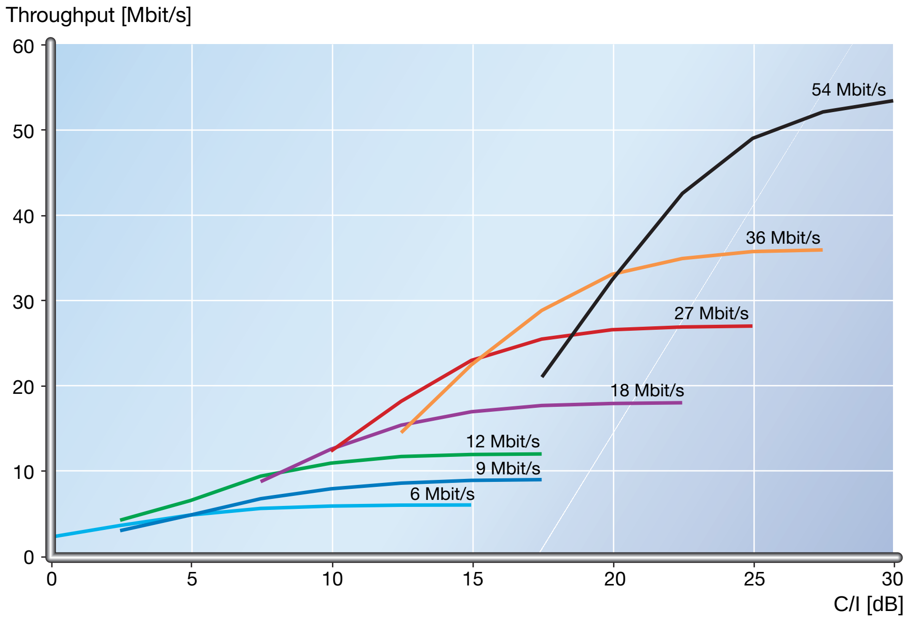


Figure 10
Link throughput versus C/I for channel model "A".

For a mode with bit rate *r(Mbit/s)*, a simple calculation of the ideal achievable link throughput is *r (1 - PER)*. Figure 10 shows the results for each mode.

Power spectrum and nonlinearities

Interference studies of cellular HIPERLAN/2 systems with high load show that the power from adjacent channel interference should be suppressed by at least 25 dB compared to the power of co-channel interference; otherwise, average system throughput in typical situations and environments degrades noticeably. This requirement affects the specification of the spectrum mask.

Based on the model of a commercially available class-AB power amplifier[17], we investigated the implications of nonlinearities on the physical layer. Figure 11 shows the spectrum of the HIPERLAN/2 transmit

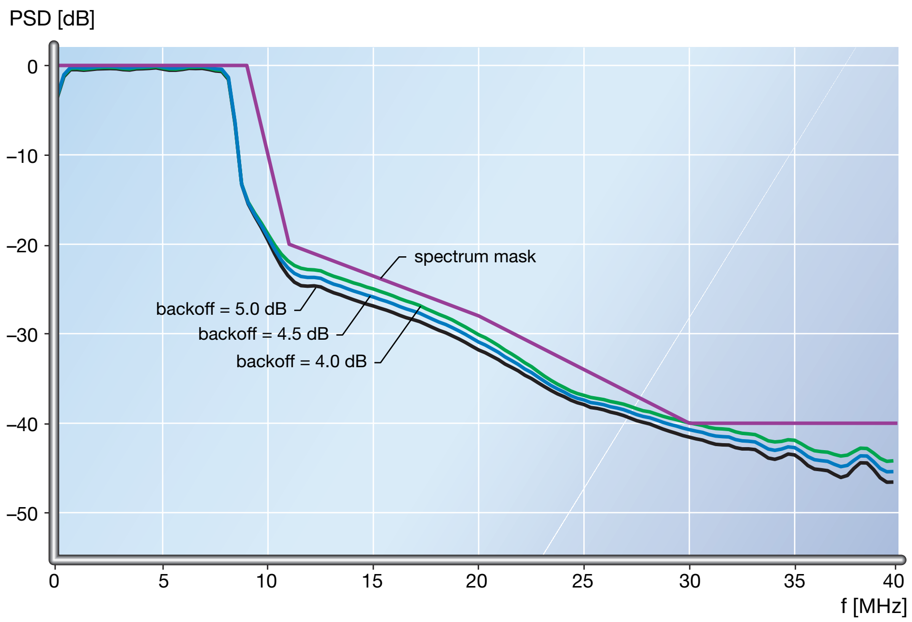


Figure 11
Power spectral density of transmitted signal and HIPERLAN/2 spectrum mask.

Figure 12
Floor of simulated office building, and position of access points (*).

signal for various back-off values. By back-off we mean the input back-off relative to the 1 dB compression point. For reference, the HIPERLAN/2 spectrum mask is also depicted. As can be seen, the spectrum requirements can be achieved by backing off 4.0 dB.

The requirement for adjacent channel suppression can be fulfilled with current requirements from the spectrum mask. That is, a back-off of 4 or 5 dB for typical power amplifier models is sufficient. Thus, this requirement is only about 2 or 3 dB greater than for typical single-carrier modulation schemes.

System performance

The performance of representative HIPERLAN/2 systems was evaluated for two indoor environments: an office building and an exhibition hall. The office scenario included a building with five floors and several mobile terminals. Eight access points per floor, located at the same position on each floor, provided coverage (Figure 12). The average path loss (that is, without fast fading) between a mobile terminal and an access point was calculated using the extended Keenan-Motley model, which includes attenuation by distance, walls, and floors in the direct propagation path.[20]

The exhibition hall scenario consisted of a large building with one floor and no interior walls. The hall was covered with 16 access points placed in a rectangular grid with a site-to-site distance of 60 m. We assumed a requirement for very high capacity in this environment, which motivated the large number of access points. We used a line-of-sight propagation model. Furthermore, we added log-normal fading with a standard deviation of 2 dB (in both scenarios) to model shadowing—for instance, due to people moving about in the buildings.

The mobile terminals were randomly placed in the buildings according to uniform distribution. The simulation technique was static: each iteration corresponded to a traffic situation that was unrelated to the previous one; that is "snapshots" were taken of the situation in the building. In each snapshot, one mobile terminal was active for each access point. Interference on a link arose from access points and mobile terminals, due to the unsynchronized TDD MAC frame. External interference was modeled by assuming that a second operator uses 11 of the 19 available carriers.

Before running the simulations, we obtained a frequency plan and a downlink power setting. The frequency plan was obtained by a distributed DFS algorithm[12], and the access point power settings were set individually, so that the received signal power of each mobile terminal exceeded the target value.

Fast uplink power control was used—this aims at constant received power in the ac-

TABLE 2. IMPORTANT PARAMETERS FOR NETWORK SIMULATIONS

Simulation parameter	Value
Number of frequencies	8 and 19
Downlink traffic	75%
Adjacent channel suppression	25 dB
Handover hysteresis	5 dB
Max. AP/MT power (EIRP)	23 dBm
Noise power	-90 dBm
Antennas (omni)	0 dBi
Uplink power control target	- 55 dBm
Downlink power control target	- 55 dBm
Wall attenuation (office building)	3 dB
Floor attenuation (office building)	20 dB
Standard deviation of log-normal fading	2 dB

TABLE 3. SYSTEM THROUGHPUT FOR 19 AND 8 FREQUENCY REUSE

Exhibition hall		
PHY modes	Reuse 19	Reuse 8
1-6	36 Mbit/s	25 Mbit/s
1-7	54 Mbit/s	27 Mbit/s
Office		
PHY modes	Reuse 19	Reuse 8
1-6	36 Mbit/s	35 Mbit/s
1-7	52 Mbit/s	49 Mbit/s

cess point.[1] The link adaptation was modeled by updating the PHY mode every tenth MAC frame. The position of the receiver was fixed during the update interval, and interferers were placed randomly for each MAC frame. In each update interval, the throughput for all PHY modes was estimated (as shown in Figure 10), and the mode that achieved the highest throughput was used during the next update interval. The most important simulation parameters have been summarized in Table 2.

Figure 13 shows the downlink and uplink C/I distribution for the office building with 19 and 8 frequency reuse, which correspond to

- a single-operator; and
- a two-operator scenario.

Figure 14 shows the C/I distribution in the exhibition hall. These distributions formed the basis of estimating system throughput. It is worth noting that C/I varies greatly between the exhibition hall and the office environment.

We estimated the throughput distribution within the network by mapping the

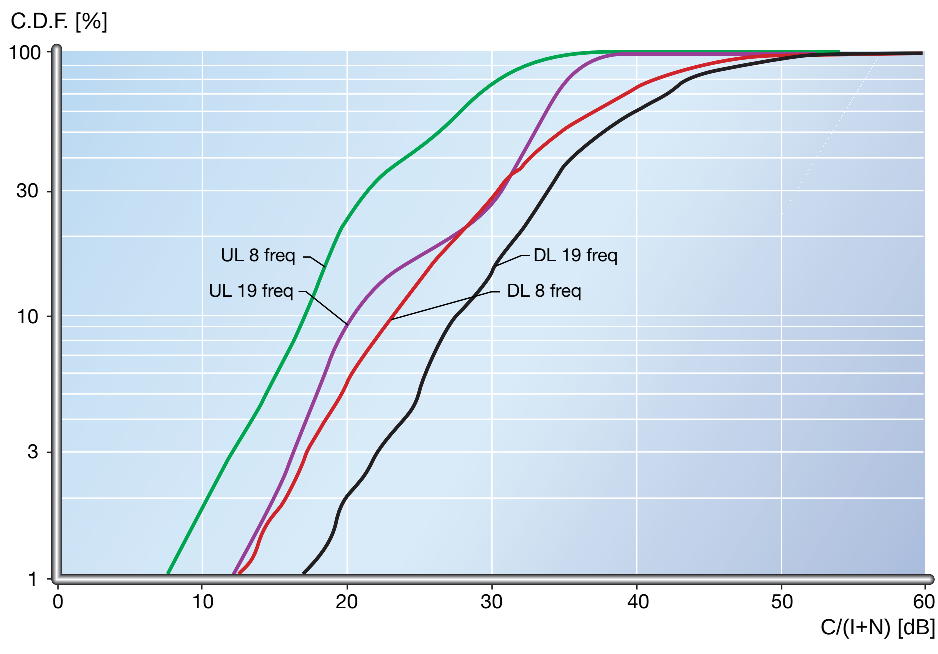


Figure 13
Downlink (DL) and uplink (UL) C/I distribution in the office building.

link throughput in Figure 10 onto the C/I distributions. We then calculated system throughput as the mean throughput for all users. This corresponds to a scheduling strategy where each user is allocated the same amount of radio resources in terms of transmitted OFDM symbols per time unit. System throughput is summarized in Table 3.

Conclusion

The HIPERLAN/2 standard specifies a short-range (150 m), high-speed (up to 54 Mbit/s) radio-access system that can be used globally in the 5 GHz band. This attractive standard enables low-cost devices in a system that yields high throughput with QoS support.

Studies show that very high performance can be achieved in most environments. To operate in environments with varying propagation conditions and severe interference, the standard features centralized control (QoS support), selective repeat ARQ, link adaptation, and dynamic frequency selection. It also supports interworking with different broadband core networks.

HIPERLAN/2 is being promoted by the HIPERLAN/2 Global Forum, H2GF (http://www.hiperlan2.com).

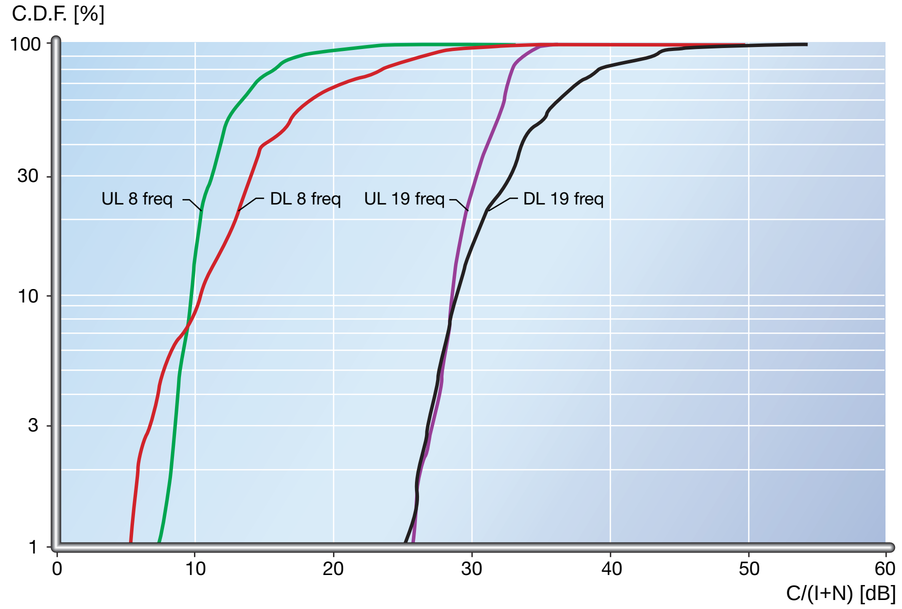


Figure 14
Downlink (DL) and uplink (UL) C/I distribution in the exhibition hall.

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