# HiperLAN2: Broadband Wireless Communications at 5 GHz

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## ABSTRACT

Solutions for high data rates and local coverage have been developed over a couple of years in the area of wireless local area networking. Quality of service, security, mobility, and high throughput are key components that drive the standards for broadband wireless multimedia communications presently being developed in Europe as well as in the United States and Japan for the 5 GHz band. These technologies are well suited to complement third-generation cellular networks. HiperLAN type 2 (HiperLAN2) is one of these systems, which is being specified by the ETSI project BRAN. The core parts of the specification were finalized at the end of 1999. Almost total harmonization has been achieved between the standardization bodies in Europe and Japan (ETSI and ARIB, respectively). HiperLAN2 will provide data rates up to 54 Mb/s, and is intended for local communications in indoor and outdoor environments.

In this article, an overview of the HiperLAN2 standard is presented together with exemplary link and system performance results.

## INTRODUCTION

Massive growth in wireless and mobile communications, the emergence of multimedia applications as well as high-speed Internet access, and the advent of deregulation of the telecommunications industry are key drivers toward a new demand for wireless broadband access networks. Current wireless telecommunications networks are primarily narrowband and used for circuit-switched services, mainly voice. Evolved second- and third-generation cellular systems aim at networks being able to provide instantaneous user bit rates up to 2 Mb/s. This will result in significant improvement for packet data applications like Internet access as well as for mobile multimedia applications. Bandwidth-hungry real-time and interactive multimedia services such as high-quality video distribution, client/server applications, and database access require networks with user data rates higher than 2 Mb/s. Therefore, new broadband wireless networks are needed that can enable high-speed integrated services (data, voice, and video) with support for quality of service (QoS) in a cost-effective way. This has resulted in huge research and standardization efforts to devise appropriate transmission and networking technologies. Different fora currently work on standardization of broadband multimedia systems. Whereas the Internet Engineering Task Force (IETF), International Telecommunication Union (ITU), and ATM Forum define the fixed core network, the European Telecommunications Standards Institute (ETSI) project Broadband Radio Access Networks (BRAN) focuses on standards for different types of wireless broadband access networks. One of these standards, High Performance Radio Local Area Network type 2 (HiperLAN2), will provide high-speed communications of different broadband core networks and mobile terminals (MTs), which may be portable as well as moving. HiperLAN2 can operate in the 5 GHz band in Europe and the United States. Furthermore, a system very similar to HiperLAN2 is specified in Japan; it is called High Speed Wireless Access System (HiSWAN). The spectrum allocation at 5 GHz comprises 455 MHz in Europe (license exempt), 300 MHz in the United States (unlicensed national information infrastructure band, U-NII), and 100 MHz in Japan (with sharing rules).

Before starting the standardization work on HiperLAN2, ETSI developed the HIPERLAN1 standard for ad hoc networking of portable devices. HIPERLAN1 mainly supports asynchronous data transfer and, for this purpose, applies carrier sense multiple access (CSMA) with collision avoidance (CA). The scheme shares the available radio capacity among active users that try to transmit data during an overlapping time period by using CSMA/CA as a contention resolution technique. Although HIPERLAN1 provides a means of transporting time-bounded services,


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it is not able to control or guarantee QoS on the wireless link, and therefore can be considered a system for best effort delivery of data. This issue was the main motivation for ETSI to develop a new generation of standards that support both asynchronous data and time-critical services (e.g., packetized voice and video) that are bounded by specific time delays to achieve an acceptable QoS.

Simultaneous with the HiperLAN2 standardization work, the IEEE initiated the specification of a physical layer in the 5 GHz U-NII band, leading to IEEE 802.11a, with the aim to extend the existing IEEE 802.11 standard for applications with high data rates. It reuses the medium access control protocol already specified for the ISM band at 2.4 GHz. Moreover, an extension IEEE 802.11b with bit rates up to 11 Mb/s was developed for this ISM band. HiperLAN2 and IEEE802.11 have almost identical physical layers for the 5 GHz frequency band; however, there are major differences regarding network topology and protocol aspects. In contrast to the reservation-based time-division multiple access (TDMA) medium access control (MAC) protocol of HiperLAN2, that of IEEE 802.11 uses CSMA/CA as the basic method to access and share the physical channel. A station identifies when the medium is not busy and can transmit based on timing intervals specified. If a collision or packet error occurs, a binary exponential backoff is applied before accessing the physical channel. Hence, the degree of QoS support is the main difference between HiperLAN2 and IEEE 802.11. Whereas both systems could support best effort services (asynchronous data), it could be anticipated that HiperLAN2 is superior to IEEE 802.11 regarding support of synchronous data. Another advantage appears in terms of MAC protocol efficiency of HiperLAN2 when compared to IEEE 802.11. The result is higher useful data rates, in particular, for high-rate physical layer modes, as discussed in [1, 2].

In parallel to the activities in Europe and the United States, the Multimedia Mobile Access Communications (MMAC) Promotion Association within the Association of Radio Industries and Broadcasting (ARIB) in Japan started to develop high-speed radio access systems for business and home applications at 5 GHz. One of these systems for business applications in corporate and public networks, HiSWAN, has been aligned with HiperLAN2.

HiperLAN2, as well as HiSWAN and IEEE 802.11, is a complement to other wireless communication systems like second- and third-generation cellular systems as well as Bluetooth, which is illustrated in Fig. 1 in terms of mobility and data rate. The data rate may be significantly higher, for instance, in hot spot areas that require high capacity and throughput. On the other hand, outdoor mobility is limited. Environments where these systems may typically be deployed are offices, homes, exhibition halls, airports, train stations, and so on. In these environments, HiperLAN2 with its physical layer bit rate up to 54 Mb/s offers wireless access for various kinds of terminals (e.g., laptops, PDAs, and consumer devices like VCRs).

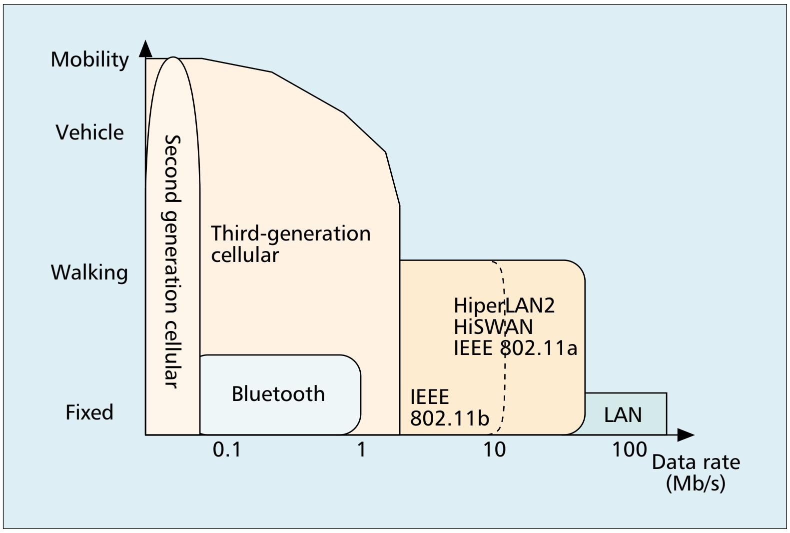


**Figure 1.** *Mobility vs. peak data rate.*

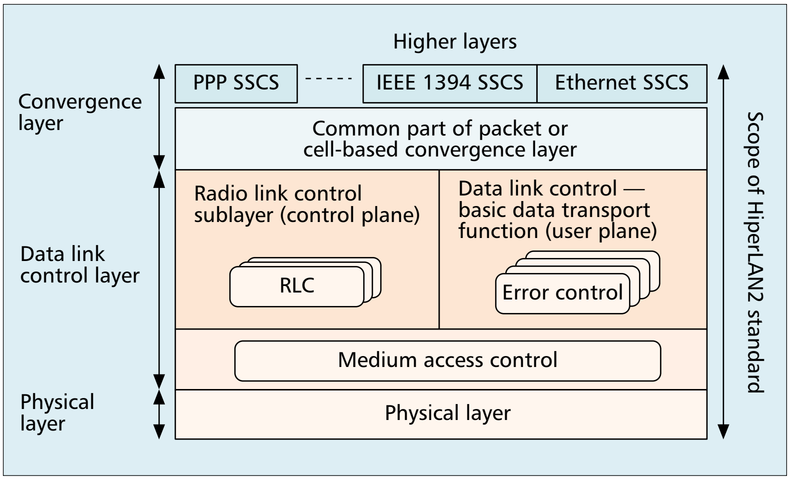


**Figure 2.** *HiperLAN2 protocol architecture.*

Bluetooth provides a physical layer bit rate of 1 Mb/s. It has been designed for very low-cost implementation, and an important application is cable replacement and universal adapter. A typical usage scenario mayå be to connect several devices within a user's personal area network. Some of these devices linked by Bluetooth may communicate by means of cellular systems with their wide-area coverage. Furthermore, a wireless broadband system like HiperLAN2 may be used to provide connections, for instance, to the network in the office, or consumer devices at home.

## System Overview

The HiperLAN2 standard specifies a radio access network that can be used with a variety of core networks. This is possible due to a flexible architecture based on core-network-independent physical (PHY) and data link control (DLC) layers as well as a set of core-network-specific convergence layers that enable access to different core networks as depicted in Fig. 2.

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

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Protocol (IP) transport networks (e.g., Ethernet and Point-to-Point Protocol, PPP), asynchronous transfer mode (ATM)-based networks, third-generation cellular core networks, and networks using IEEE 1394 (Firewire) protocols and applications. Data units that are transmitted within these core networks may be different in length, type, and content. A specific convergence layer in HiperLAN2 segments these data units into HiperLAN2 DLC user service data units (U-SDUs) with fixed length, which will be carried by DLC and PHY data transport services.

The HiperLAN2 standard supports MT mobility of at least 10 m/s. In addition, it includes a means to handle different interference and propagation environments with the aim to provide efficient communication at low signal-to-interference power ratios, maintain QoS, and trade off between range and data rate.

HiperLAN2 is a flexible platform for a variety of businesses and home applications that provides bit rates up to 54 Mb/s. In a typical business application scenario, an MT gets services over a corporate or public network infrastructure. In addition to QoS, the network will provide MTs with security and mobility management services when moving between different networks, for instance, between local and wide area networks, or corporate and public networks. In an exemplary home application scenario, low-cost and flexible networking is supported to interconnect wireless consumer devices.

HiperLAN2 relies on a cellular networking topology combined with an ad hoc networking capability. It supports two basic modes of operation: centralized and direct. The centralized mode is used in the cellular networking topology, where each radio cell is controlled by an access point (AP) covering a certain geographical area. In this mode, an MT communicates with other MTs or the core network through the AP. This mode of operation is mainly used in business applications, both indoor and outdoor, where an area much larger than a radio cell has to be covered. The direct mode is used in the ad hoc networking topology mainly used in typical private home environments, where a radio cell covers the whole serving area. In this mode, MTs in a single-cell home "network" can directly exchange data. In both cases, access to the medium as well as assignment of radio resources to MTs are controlled by the AP.

## The Convergence Layer

The main functions of the convergence layer are to adapt service requests from higher layers to the service offered by the DLC and to convert the higher-layer packets with fixed or variable size into a fixed-size SDU that is used within the DLC. The convergence layer thus maps the incoming data onto different bearers of the DLC. For example, assuming Ethernet QoS support via 802.1p, the priority provided in the additional tag field indicates the traffic type that is carried in the packet. In this case, the convergence layer determines the mapping of different traffic types into different classes and consequently onto the different radio bearers.

Two types of convergence layers can be distinguished, a cell-based one and a packet-based one. The packet-based convergence layer handles higher layers with variable length packets (e.g., Ethernet). For higher layers using fixed-size packets, the cell-based convergence layer is to be used. It is suited for ATM-based core networks, for example. Service-specific convergence sublayers (SSCS) are defined for Ethernet, IEEE 1394, PPP, and UMTS to perform the appropriate service adaptation.

The functionality of padding, segmentation into fixed-size DLC SDUs, and respective reassembly is one key issue that makes it possible to implement DLC and PHY layers that are core-network-independent. A higher-layer packet such as an Ethernet packet is mapped onto one or more DLC SDUs by padding and segmentation. Each SDU comprises a payload of 384 bits and 12 flag bits. It is encapsulated on the DLC layer in a DLC LCH PDU with 432 bits by adding a header and a cyclic redundancy check (CRC) checksum. LCH denotes *long transport channel*, which is used for data from higher layers. The short transport channel (SCH) PDUs, comprising 72 bits, carry control messages.

## The Data Link Control Layer

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

### Radio Link Control

The RLC comprises three main control functions:

- The association control function is used for authentication, key management, association/disassociation, and encryption seed.
- Radio resource control (RRC) handles handover (generic solution), dynamic frequency selection, MT alive/absent, power saving, and power control.
- DLC user connection control setup, and release of user connections, multicast, and broadcast.

Thus, the RLC is used for exchanging data in the control plane between an AP and an MT; for example, the MT associates to the AP via RLC signaling. After association of the MT, it can request for a dedicated control channel that is used to set up radio bearers (within HiperLAN2 a radio bearer is referred to as a DLC connection). The MT can request multiple DLC connections, and each connection has unique support for QoS that is determined by the AP.

The connection setup does not result in an immediate capacity assignment by the AP. At the connection setup the MT receives a unique DLC address corresponding to that DLC connection.

### Error Control

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

- The *acknowledged mode* provides reliable transmissions by using retransmission to improve the link quality. The acknowledged mode is based on selective-repeat automatic repeat request (ARQ) [3]. Low latency can be provided by a discard mechanism.

- The *repetition mode* provides rather reliable transmission by repeating the data-bearing DLC PDUs, the LCH PDUs. No feedback channel is available. The transmitter can arbitrarily retransmit PDUs. By retransmitting PDUs more reliable reception is obtained. The receiver will, however, only accept PDUs with sequence numbers within the receivers' acceptance window. Typically this mode is used when transmitting broadcast data information.
- The *unacknowledged mode* provides unreliable low-latency transmission. The transmitter will send the PDUs by increased sequence number, and the receiver will deliver all correctly received ones to the convergence layer. No feedback channel is available.

Unicast data can be sent using either acknowledged or unacknowledged mode. Broadcast services can be supported by either repetition or unacknowledged mode. Multicast services can be sent in unacknowledged mode or be multiplexed onto already existing unicast transmissions.

### MEDIUM-ACCESS CONTROL

The air interface is based on time-division duplex (TDD) and dynamic time-division multiple access (TDMA). The MAC 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 downlink as well as uplink, and random access, as shown in Fig. 3. In the case of direct link communications, the frame contains an additional direct link field not shown in Fig. 3. The duration of broadcast control is fixed, whereas the duration of the other fields is dynamically adapted to the actual traffic situation.

The broadcast channel (BCH) contains control information that is sent in every MAC frame, mainly to enable some RRC functions. 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 random access attempts. Downlink or uplink traffic consists of data to or from MTs, respectively. Traffic from multiple connections to/from one MT may be multiplexed onto one PDU train, where each connection contains 54-octet LCHs for data and 9-octet SCHs for control messages.

Multibeam antennas (sectors) are supported in HiperLAN2 as a means to improve the link budget and reduce interference in the radio network. The MAC protocol and the frame structure in HiperLAN2 enable multibeam antennas with up to eight beams (not shown in Fig. 3).

Whenever an MT has data to transmit on a certain DLC connection, it initially requests capacity by sending a resource request (RR) to the AP. The RR contains the number of pending LCH PDUs the MT currently has for the particular DLC connection. The MT may use contention slots to send the RR message based on a slotted ALOHA scheme. By varying the number of contention slots (random access channels, RCHs), the AP may decrease the access delay. If a collision occurs, the MT will be informed about it in the ACH in the next MAC frame.

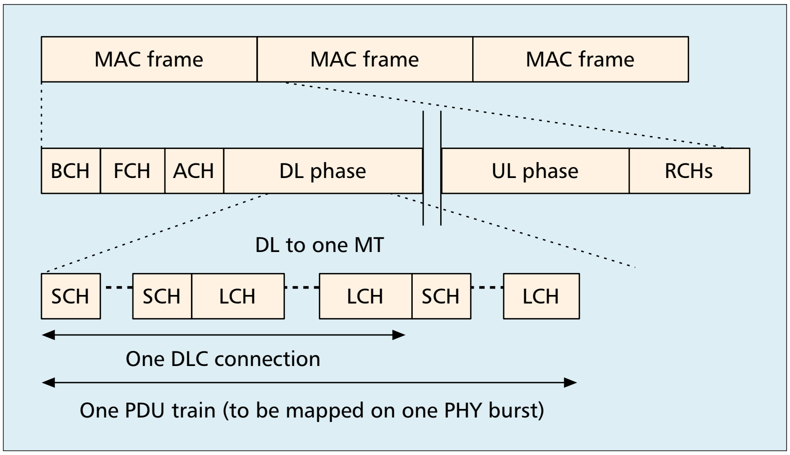


**Figure 3.** *The basic MAC frame structure of HiperLAN2 (for a one-sector antenna).*

The MT will then back off a random number of access slots.

After sending the RR to the AP, the MT enters a contention-free mode where the AP schedules the MT for transmission opportunities (both uplink and downlink). The scheduling of resources is performed in the AP, that is, a centralized controller is used, enabling efficient QoS support. From time to time the AP may poll the MT for more information concerning the MT's current pending PDUs. The MT may also inform the AP about the new status by sending an RR via the RCH.

### RADIO NETWORK FUNCTIONS AND QOS SUPPORT

The HiperLAN2 standard defines measurements and signaling to support a number of radio network functions (e.g., dynamic frequency selection, link adaptation, handover, multibeam antennas, and power control). The algorithms are vendor-specific. The supported radio network functions allow cellular deployment of HiperLAN2 systems with full coverage and high data rates in a wide range of environments. The system shall automatically allocate frequencies to each AP for communication. This is performed by dynamic frequency selection (DFS), which allows several operators to share the available spectrum and avoids the use of interfered frequencies. The frequency selection is based on interference measurements performed by the AP and its associated MTs [4].

The radio link quality is highly dependent on the radio environment. It also changes with time and depending on the traffic in surrounding radio cells. To cope with the varying radio link quality, a link adaptation scheme is used. Based on link quality measurements, the physical layer mode (i.e., code rate and modulation scheme) is adapted to the current link quality (Table 1). This link adaptation is used in both uplink and downlink. The AP measures the link quality on the uplink and indicates in the FCH which PHY mode the MT shall use for uplink communication. In a similar way, the MT measures the link quality on the downlink and signals a PHY mode suggestion to the AP for downlink communica-

The units to be transmitted via the physical layer of HiperLAN2 are bursts with variable length. Each burst consists of a preamble and a data field. The latter comprises a train of SCH and LCH PDUs to be transmitted or received by one MT.

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

**Table 1.** *Physical layer modes of HiperLAN2.*

tion in each RR. However, the AP is responsible for the final PHY mode selection for both uplink and downlink.

Transmitter power control is supported in both MT (uplink) and AP (downlink). MT power control simplifies the design of the AP receiver by avoiding automatic gain control. AP power control is mainly used for regulatory reasons to decrease interference to other systems in the same band.

HiperLAN2 supports QoS by allowing different radio bearers to be set up and treated differently by the AP during transmission. The AP can select an appropriate error control mode including detailed protocol settings like ARQ window size, number of retransmissions, and discarding. On the MAC layer, scheduling is performed such that the AP determines the radio bearers to access the medium as well as the amount of data and control signaling in the MAC frame. As an example, the AP can provide a certain MT's radio bearer with very short access delay by regularly polling the MT for its traffic status (i.e., pending data to be transmitted). By such a mechanism fast access for real-time services can be accomplished. Link adaptation and internal functions to avoid overload situations (admission, congestion, and dropping mechanisms) are further means to support QoS.

## Physical Layer

The units to be transmitted via the physical layer of HiperLAN2 are bursts with variable length. Each burst consists of a preamble and a data field. The latter comprises a train of SCH and LCH PDUs to be transmitted or received by one MT as depicted in Fig. 3.

Orthogonal frequency-division multiplexing (OFDM) [5, 6] has been selected as the modulation scheme for HiperLAN2 due to its good performance on highly dispersive channels. A comparison with single-carrier modulation was presented in [7] for parameters typical for HiperLAN2. Some selected issues are as follows. For a bit rate of 25 Mb/s, coherent OFDM outperforms single-carrier modulation by 2–3 dB in terms of sensitivity and co-channel interference performance. Higher bit rates may hardly be supported as efficiently by single-carrier modulation. This was an important criterion since HiperLAN2 has been required to support much higher bit rates, too. A drawback of OFDM often seen as important is the power amplifier backoff. For the spectrum mask specified for HiperLAN2, OFDM requires 2–3 dB higher backoff than single-carrier modulation. This affects coverage, which is compensated by the better sensitivity of OFDM, and power consumption in the MT. The latter, however, should be considered together with the lower power consumption for the OFDM receiver and the downlink/uplink traffic that is expected to be highly asymmetric. Based on these and further arguments, it could be concluded that OFDM is superior to single-carrier modulation for the given assumptions.

The carrier frequency spacing has been selected as 20 MHz to provide a reasonable number of channels in 100 MHz bandwidth, which may be the narrowest continuous system bandwidth available, for instance, in Japan. In order to avoid unwanted frequency products in implementations the sampling frequency is also chosen equal to 20 MHz at the output of a typically used 64-point inverse fast Fourier transform. The obtained subcarrier spacing is 312.5 kHz. In order to facilitate implementation of filters and to achieve sufficient adjacent channel suppression, 52 subcarriers are used per channel. 48 subcarriers carry actual data and 4 subcarriers are pilots, which facilitate coherent demodulation. The duration of the cyclic prefix is equal to 800 ns, which is sufficient to enable good performance on channels with (r.m.s.) delay spread up to at least 250 ns. An optional short cyclic prefix with 400 ns may be used for short-range indoor applications.

A key feature of the physical layer is to provide several physical layer modes with different code rates and modulation schemes, which are selected by link adaptation. Binary phase shift keying (BPSK), quaternary PSK (QPSK), and 16-quadrature amplitude modulation (QAM) are the supported subcarrier modulation schemes. Furthermore, 64-QAM can be used in an optional mode.

Forward error control is performed by a convolutional code with rate 1/2 and constraint length seven. The further code rates 9/16 and 3/4 are obtained by puncturing. The modes are chosen such that the number of encoder output bits fits to an integer number of OFDM symbols.

Seven physical layer modes listed in Table 1 are specified. The first six are mandatory, and the last one, based on 64-QAM, is optional.

Each physical layer burst includes a preamble, of which three different types are used for:
- The broadcast control channel
- Other downlink channels
- The uplink and random access channel

There are a short and a long preamble for the uplink channel. The preamble of the optional direct link bursts is identical to the long uplink preamble.

The preamble in the broadcast control channel enables frame synchronization, automatic gain control, and frequency synchronization as well as channel estimation. In contrast, the preamble in the downlink traffic bursts is designed for channel estimation only. The uplink traffic bursts and random access bursts enable channel estimation and frequency estimation. Consequently, there are several preambles with different structures and lengths. A detailed description can be found in [8].

## Performance

A suitable measure of link performance is the packet error rate (PER). It is conveniently given as a function of carrier-to-interference power ratio (C/I) in interference-limited systems. Channel models for link simulations have been developed from measurements in typical indoor and outdoor environments during standardization [9, 10]. Channel model A with a delay spread of 50 ns, which has been used for the simulations discussed in the following, can be viewed as typical for large office environments with non-line-of-sight propagation.

A simple calculation of the link throughput achievable with selective-repeat ARQ in terms of megabits per second for a mode with bit rate $r$ is given by $r$ (1 – PER). The respective results for all modes are depicted in Fig. 4. The maximum throughput of each mode is given by the physical layer bit rate; it decreases with decreasing C/I due to the increasing number of PDU retransmissions. Link adaptation enables the selection of the physical layer mode that gives maximum throughput for the complete range of interference situations.

The system performance of representative HiperLAN2 systems was estimated for two indoor environments, an office building and an exhibition hall. The office scenario included a building with five floors and eight access points on each floor. An indoor propagation model was used in the office scenario that takes account of attenuation by walls and floors. The bandwidth available was assumed equal to 455 MHz, which is valid in Europe.

The exhibition hall scenario consisted of a large open building with one floor without inner walls. The hall was covered with 16 access points placed in a rectangular grid with a site-to-site distance of 60 m. It was assumed that very high capacity is needed in this environment, which motivates the large number of installed access points. A line-of-sight propagation model was used in this scenario.

The performance was determined by estimating the C/I distribution in the buildings at high traffic load, which were mapped onto the link throughput results depicted in Fig. 4. The system throughput is calculated as the mean throughput for all users. Results were obtained for a single operator and a two-operator scenario with frequency reuse 19 and 8, respectively. A distributed DFS algorithm [4] obtained the frequency plan. More details about system performance investigations can be found in [11].

The obtained system throughput is depicted in Fig. 5. The results are given for the two cases that the six mandatory PHY modes (1–6) and all seven specified PHY modes (1–7) are used. It turns out that almost all users get the maximum bit rate if there is a single operator. With a second operator present (i.e., with fewer frequencies available for each operator), the average throughput is still 25 or 27 Mb/s in the difficult exhibition hall environment. The throughput is again almost at its maximum for the office scenario. The main reason for these very good results is the high number of frequencies available in Europe.

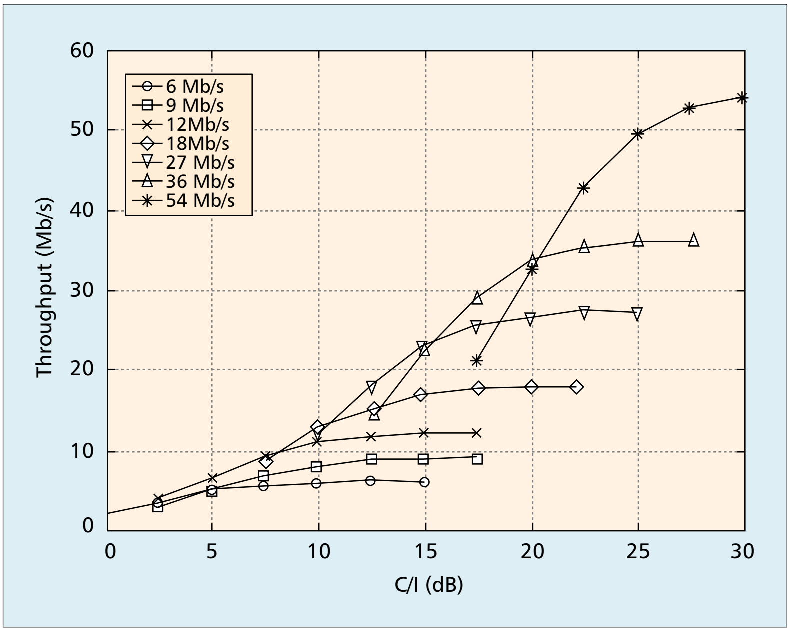


**Figure 4.** *Link throughput vs. C/I for channel model A.*

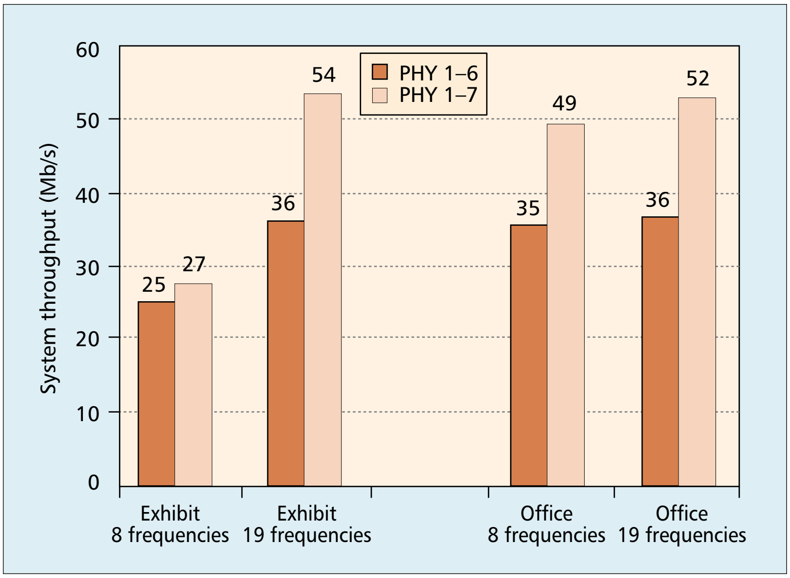


**Figure 5.** *System throughput for the exhibition hall and the office environment with frequency reuse 8 and 19.*

## Conclusions

The HiperLAN2 standard specifies a broadband radio access system in the 5 GHz band. The standard is attractive since low-cost devices can be developed for a system that enables high throughput with QoS support. The amount of available spectrum is quite large (e.g., 455 MHz in Europe), which is a further key to success.

Studies show that very good performance can be achieved in most environments. To be able to operate in environments with varying propagation

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conditions and severe interference, the standard has some key features like centralized control with QoS support, selective repeat ARQ, link adaptation, and dynamic frequency selection. HiperLAN2 can interwork with different broadband core networks. The HiperLAN2 standard is promoted by an industry forum called HiperLAN2 Global Forum, H2GF (http://www.hiperlan2.com).

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## BIOGRAPHIES


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