CHAPTER 12

WIRELESS ATM AND HIPERLAN

12.1 INTRODUCTION

In Chapter 10 we provided an overview of the wideband local access technologies and divided them into WLAN and WPAN divisions. We further divided WLAN standards into connectionless, represented by the IEEE 802.11, and connection-based represented by HIPERLAN-2. Connection-based networks are voice-oriented networks that in early 1990s were perceived to turn into the so-called end-to-end ATM solutions. This perception initiated a couple of activities related to the LANs. The first activity was the LAN emulation (LANE) using ATM that intended to integrate legacy LAN applications in an ATM setting [STA00]. The second activity was wireless ATM (WATM) that intended to design a wideband local access that integrated with the ATM backbone to provide an end-to-end ATM solution. Both these activities lost the heat of their publicity by the turn of the last century, after the success of the Internet and IP-based networks to provide a cheaper solution for the backbone connections. ATM never made it to the desktop in any case.

The WATM research activities addressed the important issue of how to implement QoS in a mobile environment. The QoS support has two features, the first providing multirate services on demand with guaranteed bandwidth, delay, and so on, and the second providing implementation of a variable user-charging mechanism according to their usage of the resources. Currently data-oriented Internet services are provided at a flat rate to the fixed users, but the voice-oriented services are charged according to the usage of the network. As was shown in Figure 10.10, the vision of the service providers for the future of the wideband local access is to provide wireless Internet access services that carry different charging mechanisms where, for example, no charge will be associated for home or office connections, but there is a tariff for public usage of the AP owned by the service provider. These public APs could be broadband WLAN APs or a GPRS BS. Therefore, the argument is that we need different charging mechanisms because we are providing different QoS to the user. To incorporate this charging mechanism into the wideband local access, service providers are keen on supporting multi-QoS operation under wideband local access. As a result, the successful EU cellular industry has supported HIPERLAN-2 to provide the transmission rate of the WLANs but incorporate a connection-based charging mechanism that is useful for variable QoS support and in particular the tariff mechanism for that support.

In this chapter first we provide an overview of the WATM activities and then we explain ETSI BRAN's initiatives in wideband local access. Symbolically one can think of the IEEE activities as the representative of successful Internet industry in the United States and HIPERLAN-2 as a representative of the European Union's successful wireless cellular telephone industry. We can then view the previous chapter as being concerned with the standards activities in the United States, and this chapter considers the standardization in the European Union's.

12.2 WHAT IS WIRELESS ATM?

Wireless ATM was first introduced in 1992 [RAY92], and it meant to provide for an integrated broadband application programming interface (API) to the ATM network for a variety of mobile terminals. In 1996, a WATM working group was formed under the ATM forum that drew around a hundred participants in their first meeting in Helsinki. Figure 12.1 illustrates the vision of the end-to-end ATM network that was used by the ATM forum. In the mid-1990s, a number of experimental projects at NEC Laboratories, Nokia, AT&T, Olivetti (now AT&T), and other research labs developed prototypes for implementation of this concept, but in the late 1990s, the heat of the WATM cooled down significantly [PAH97], [RAY99]. In the year 2000, the ATM forum regrouped to pursue this matter by cooperating with other WLAN standards activities, in particular HIPERLAN-2. However, research efforts for implementation of these testbeds discovered a number of interesting issues related to broadband wireless access that has had an impact on the development of new standards in this field. A comprehensive overview of WATM activities is available in [RAY99].

The first fundamental challenge for the implementation of a WATM system is that the ATM was designed for fast switches connecting extremely wideband and reliable fiber transmission channels. The wireless medium, however, is very unreliable and has serious limitations on wideband operations. This imposes problems in the basic transmission mechanism.

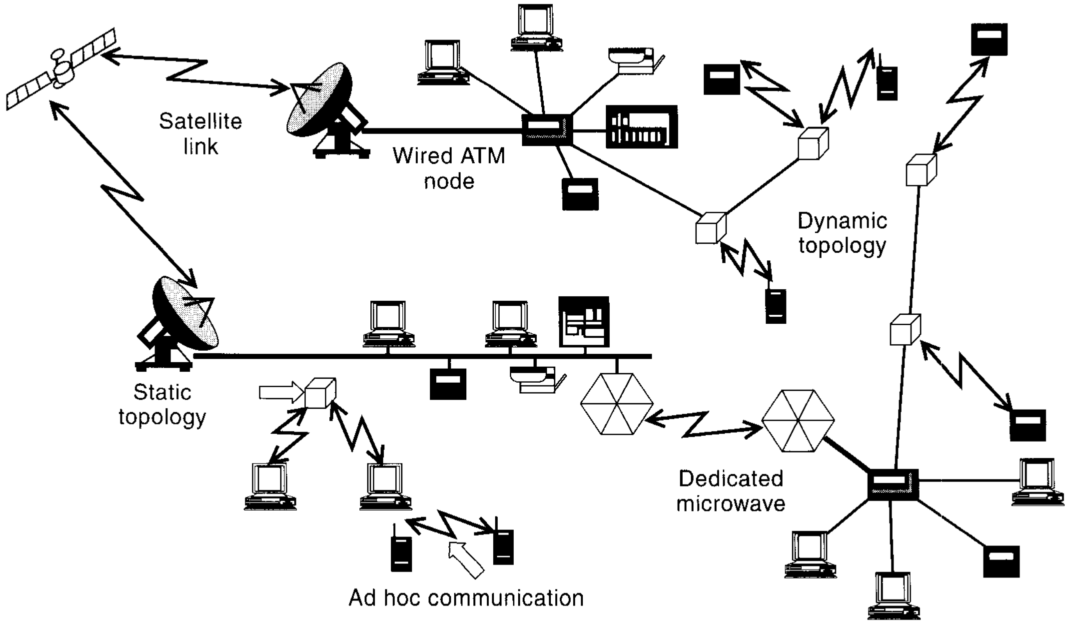

Figure 12.1 Vision of the ATM forum's Wireless ATM working group for an end-to-end ATM network [DEL96].

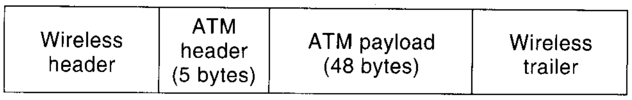

Figure 12.2 Typical packet frame format for the WATM.

Example 12.1: Format of WATM Packets

Consider the packet format for the WATM system shown in Figure 12.2. ATM packets (cells) have a fixed size of 53 bytes with a 48-byte payload. The benefit of the fixed packet size is that it facilitates fast switching in a multimedia environment. The ATM cells were considered for operation on reliable optical channels that do not need acknowledgment. When we use the same packet format in a wireless environment, for example, FHSS 802.11, we will have another additional 16 bytes for the PLCP header and a few more for a wireless MAC layer that makes the overhead so large that a 48-byte length of payload makes the transmission inefficient. On the other hand, with the unreliable fading environment in wireless channels, we need to add acknowledgment to ensure safe transmission of the packets. If we change the packet format and add acknowledgments, then it is difficult to call this protocol wireless ATM. This would be a wireless method to interact with ATM switches. So the name WATM is not really appropriate. After all we don't call 802.11 a wireless 802.3.

The second fundamental challenge is that the ATM switches are designed to support QoS based on a basic negotiation with the user terminal that is maintained throughout the session. In a wireless environment, because of the fluctuations in channel conditions, a continual support of a negotiated QoS is impossible. Besides, when a terminal roams from one AP to another, it needs to renegotiate its contract, and the new AP may not be able to honor the old contract. Therefore, the basic promise of the ATM that is honoring a negotiated service would need a new definition.

Other challenges facing WATM are to find methods to provide faster and more reliable air-interfaces, to find a method to distribute the additional complexities of the network among the network elements, and to find an efficient way to cope with IP applications developed for connectionless environments.

12.2.1 Reference Model

The basic elements of the traditional ATM networks are ATM switches and ATM terminals. The ATM forum defines, among other things, two protocols, the user–network interface (UNI) protocol connecting user terminals to the switches, and the network–network interface (NNI) protocol connecting two switches together [STA98b]. The elements of a WATM network are shown in Figure 12.3. In the WATM environment, we have two new elements, the WATM-MS and the ATM-BS, and we need to upgrade the ATM switches to support mobility. The WATM environment needs to define a new UNI air-interface "W" for wireless operation and a new UNI-NNI interface protocol, "M" that connects the ATM-BS to the ATM switches. The *WATM-MS* is physically implemented on a radio NIC (net-

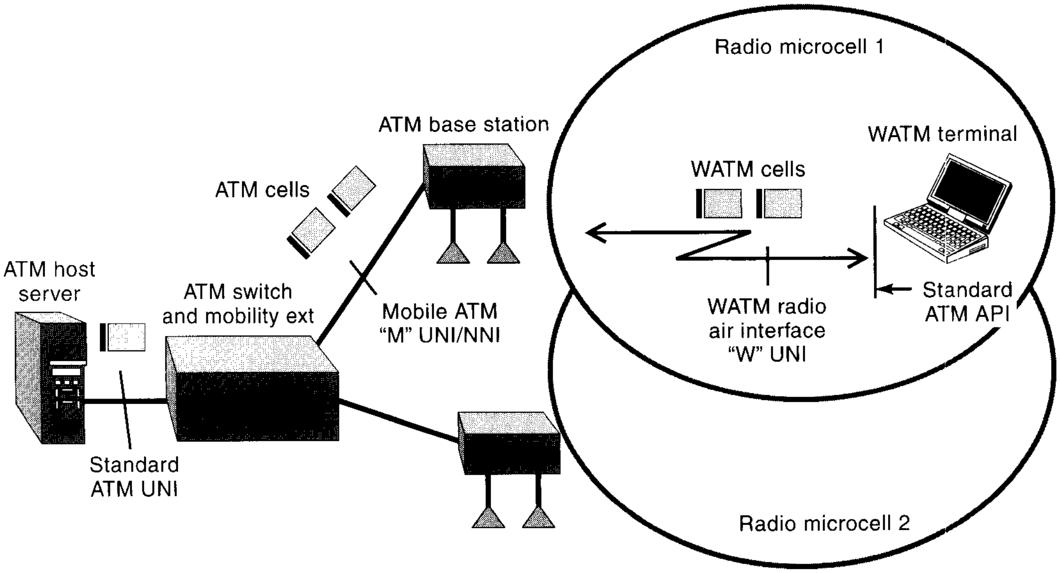

Figure 12.3 Basic architecture of a WATM network [RAY99].

work interface card) hardware and mobility or radio enhanced UNI software for handling call initiation and traffic handling. The *ATM-BS* is a new small ATM switch with ports for wireless and wired connections. This switch also needs enhanced UNI-NNI software which supports mobility in the wireless medium. The *ATM switch* with mobility software is a normal switch with upgraded UNI-NNI software that handles mobility.

12.2.2 Protocol Entities

Figure 12.4 represents a general description of the protocol entities in the ATM that includes the WATM entities. The PHY layer specifies the transmission medium and the signal encoding technique. In the wired part, the PHY layer standard specifies high-speed connection to SONET, TAXI, and UTP-3 [STA00] media for optical and wired copper media. In the wireless part, the standard has not specified anything yet, but the experimental systems use variety of technologies commonly used in WLAN standards and products. The *ATM* network layer defines transmission in fixed-size cells and the use of connections for wired parts. Additional WATM data link control (DLC) and MAC layers are needed to adapt the system to the wireless environment. The ATM adaptation layer (AAL) is a service-dependent layer that maps higher-layer protocol packets (such as AppleTalk, IP, NetWare) into ATM cells. The ATM forum defines five different AAL specifications, AAL-5 being the most popular in LAN applications that is also suitable for WATM operation. The *user plane* provides control (flow, error, etc.) over information transfer. The *control plane* provides for call establishment and control functions. The specified Q.2931 signaling for the ATM needs further modifications

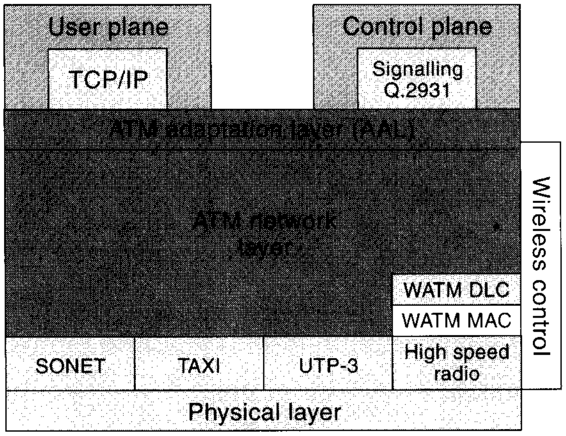

Figure 12.4 Protocol entities in an ATM environment that supports wireless mobility.

to support wireless mobile environments. In addition, a wireless control layer is needed to coordinate all the additional functionalities added to support wireless operation.

Figure 12.5 represents three possibilities for communication between a mobile terminal (MT) and a fixed terminal (FT). Figure 12.5(a) is a normal WLAN-LAN communication. Two applications in the two terminals communicate through the TCP/IP protocol. The IP packets in the wireless terminal use the MAC and PHY layer of IEEE 802.11, and the IP packets at the wired terminal use the MAC and PHY layer of the IEEE 802.3. Protocol conversion takes place at the wireless AP. This situation is the same as normal WLAN operation described earlier in Figure 11.2. Figure 12.5(b) represents a case for communication between a WLAN and an ATM environment. The wireless side is the same as before, but the wired terminal applications run on top of the ATM protocol stack. The application on the ATM terminal could be a native ATM application or IP application. The AP in this case needs LANE software to interface the AAL-5 packets to the 802.11 MAC. Figure 12.5(c) represents the third case when a WATM terminal communicates with an ATM terminal. The PHY and MAC layers of WATM are not yet specified, so the system is an experimental system using a proprietary design.

Figure 12.5 clarifies the importance of two issues. Regardless of the technology for the air-interface, a local network works to run legacy applications over available backbones. If ATM switches move inside offices or homes and native ATM applications become popular, then there is a need for a full WATM service. If LANs, already installed in all offices and penetrating all homes, become the predominant local access mechanisms, then WATM will not find any application. Today, as we discussed earlier, hopes for a WATM type of operation is in the public APs. At home and in offices, the existing legacy LANs appear to be adequate. One solution in this type of environment is to use the operation as in Figure 12.5(a) for the home and office and Figure 12.5(b) for public access.

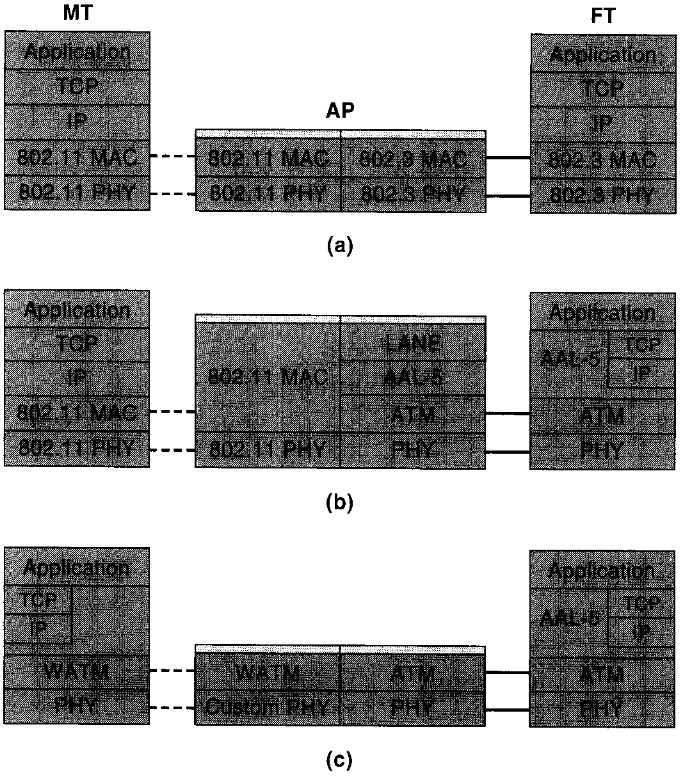

Figure 12.5 Different methods to run applications: (a) WLAN to LAN, (b) WLAN to ATM, and (c) WATM to ATM.

12.2.3 PHY and MAC Layer Alternatives

The ATM forum's WATM working group has not made any specification for a standard. To illustrate the PHY and MAC layer options for WATM, we provide a comparative overview of a few test beds used for implementation of the WATM concept. Table 12.1 summarizes various features of five major projects in this field [PAH97], [AGR96], [AYA96], [ENG95], [RAY97], [WAN96]. Of these, the SWAN and MII/BAHAMA were developed at AT&T/Lucent Research Labs, Olivetti in the United Kingdom, NEC was the leading project (in their laboratory in New Jersey), and the Magic WAND was supported by the ACTS research program in EC that involved a number of participants led by Nokia. These prototypes operated in the ISM and U-NII bands. The data rates ranged from less than 1 Mbps to 24 Mbps. Transmission techniques included FH-SS, traditional QPSK with DFE, and OFDM. The access methods were token passing, reservation-slotted ALOHA, or TDMA/TDD, all providing a controlled environment for the support of the QoS. Today, to support higher data rates of up to 54 Mbps, HIPERLAN-2 and IEEE 802.11a standards use OFDM modulation at 5 GHz. Prior to these standards, the Magic WAND and MII/BAHAMA had adopted the same solution to provide data

Table 12.1 Overview of Several WATM Experimental Projects

WATM System	SWAN	MI/BAHAMA	Olivetti	NEC	WAND
Frequency bands	2.4 GHz ISM bands	900 MHz (Proposed 5 GHz :U-NII)	2.4 GHz ISM bands	2.4 GHz ISM bands	5.2 GHz
Data rate	625 kbps	2–20 Mbps	10 Mbps	8 Mbps	24 Mbps
Modulation scheme	Frequency hopping	(suggested OFDM or GMSK with LMS/RLS)	QPSK	$\pi/4$-QPSK with DFE	16-channel OFDM
Medium access	Each mobile has a fixed channel; token passing	Distributed queue reservation updated multiple access (DQRUMA)	Reservation with Slotted Aloha and piggy-backing on data cells	TDMA/TDD with Slotted Aloha	Reservation with Slotted Aloha
Handoffs	Mobile initiated	Mobile initiated	Mobile initiated (with Mobile Manager) Infrastructure initiated (with Mobile Representative)	Mobile initiated	Mobile initiated
Techniques for reliability	FEC with (8, 4) linear codes	FEC (proposed Reed-Solomon codes for real-time traffic and FEC/retransmissions for data	16 bit CRC and ARQ	Data link control for error recovery	FEC
QoS	MAC supports QoS	Supported	Priority for certain traffic	Fixed slots available for QoS support	Worst case QoS estimate to be used

rates around 20 Mbps. The access method of HIPERLAN-2 is similar to TDMA/TDD which was experimented in NEC's WATM prototype earlier. All these testbeds have tried different approaches to ensure certain levels of QoS. These efforts have helped the understanding of the complexity of QoS in a wireless mobile environment, and have discovered partial solutions for this problem. These studies have laid a ground for the HIPERLAN-2 standard to work on implementation of QoS in a WLAN standard.

12.2.4 Mobility Support

As we saw in previous examples of connection-oriented and connectionless networks, a wireless mobile operation requires a number of functionalities. The MS needs to support location management to identify where the MS is. It needs a registration process and a handoff procedure to register the terminal to an AP each time it is turned on and manage the switching of connections to other APs. It needs authentication and ciphering to provide security and power management to save in the life of the battery. We have provided detailed examples of these functionalities in connection-oriented (GSM and CDMA systems) as well as connectionless networks (WLAN and mobile data services). The overall structure of these functionalities for WATM is very similar to the others. However, handling the connection in an environment where there is a contract for QoS is challenging. In the case of ATM, ATM cells must be received in sequence, and they all follow the same route (virtual circuit—VC). When an MS moves from one AP to another, the existing VC is broken. The VC should either be extended or reconstructed to satisfy the negotiated QoS. This problem is quite challenging.

12.3 WHAT IS HIPERLAN?

The HIPERLAN stands for HIgh PErformance Radio LAN and was initiated by the RES-10 group of the ETSI as a pan-European standard for high-speed wireless local networks. The so-called HIPERLAN-1, the first defined technology by this standard group, started in 1992 and completed in 1997. Unlike IEEE 802.11, which was based on products, HIPERLAN-1 was based on certain functional requirements specified by ETSI. In 1993, CEPT released spectrum at 5 and 17 GHz for the implementation of the HIPERLAN. The HIPERLAN 5.15–5.35 GHz band for unlicensed operation was the first band that was used by a WLAN standard at 5 GHz. These bands being assigned for HIPERLAN in the European Union was one of the motives for the FCC to release the U-NII bands in 1996, which stimulated a new wave of developments in the WLAN industry. During the standardization process, a couple of HIPERLAN-1 prototypes were developed; however, no manufacturer adopted this standard for product development. For that reason, those involved in the EU standardization process consider this effort an unsuccessful attempt. Later on HIPERLAN standardization moved under the ETSI BRAN project with a new and more structured organization. Figure 12.6 [WIL96] shows the overall format of the HIPERLAN activities after completion of the HIPERLAN-1. In addition to

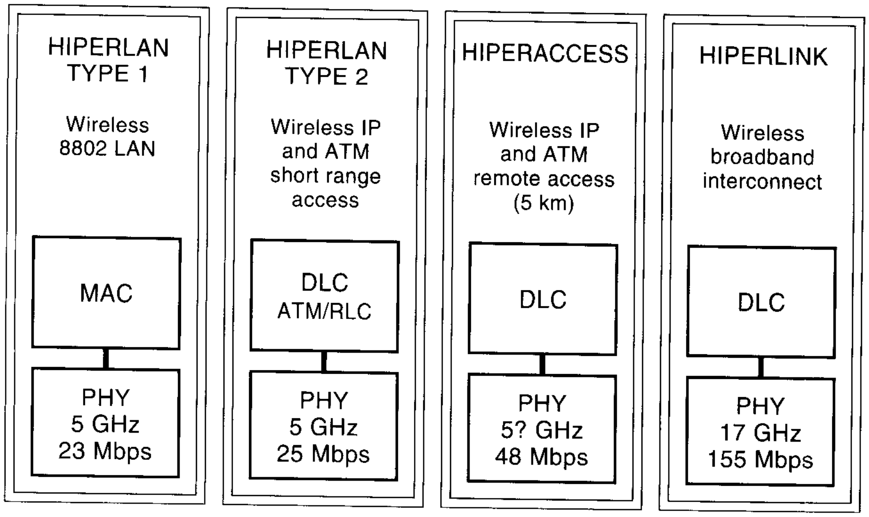

Figure 12.6 Divisions of the HIPERLAN activities.

HIPERLAN-1, we have HIPERLAN-2, which aims at higher data rates and intends to accommodate ATM as well as IP type access. This standardization process is under development. They have coordinated with the IEEE 802.11a in the PHY layer specification and current work on the MAC to support QoS is under progress. Other versions of HIPERLAN are HIPER-ACCESS for remote access and HIPER-LINK to interconnect switches in the backbone. In the United States, these activities are under IEEE 802.16 for LMDS. Only HIPERLAN-1 and -2 are considered WLANs and will be discussed in this chapter. Most of the emphasis is on HIPERLAN-2 which has attracted significant support from cellular manufacturers such as Nokia and Ericsson.

12.3.1 HIPERLAN-1 Requirements and Architecture

The original "functional requirements" for the HIPERLAN-1 were defined by ETSI. These requirements were

- Data rates of 23.529 Mbps
- Coverage of up to 100 m
- Multi-hop ad hoc networking capability
- Support of time-bounded services
- Support of power saving

The frequency of operation was 5.2 GHz unlicensed bands that were released by CEPT in 1993, several years before release of the U-NII bands. The difference between this standard and the IEEE 802.11 was perceived to be the data rate, which was an order of magnitude higher than the original 802.11 and emphasis on ad hoc networking and time-bounded services.

Figure 12.7 shows the overall architecture of an ad hoc network. In HIPERLAN-1's ad hoc network architecture, a multihub topology is considered that also allows overlay of two WLANs. As shown in this figure, the multihop routing extends the HIPERLAN communication beyond the radio range of a single node. Each HIPERLAN node is either a forwarder, designated by "F," or a nonforwarder. A nonforwarder node simply accepts the packet that is intended for it. A forwarder node retransmits the received packet, if the packet does not have its own node address, to other terminals in its neighborhood. Each nonforwarder node should select at least one of its neighbors as a forwarder. Inter-HIPERLAN forwarding needs bilateral cooperation and agreement between two HIPERLANs. To support routing and maintain the operation of a HIPERLAN, the forwarder and nonforwarder nodes need to periodically update several databases. In Figure 12.7, solid lines represent peer-to-peer communications between two terminals and dashed lines represent the connections for forwarding. Three of the terminals, 1, 4, and 6, are designated by letter "F" indicating that they have forwarding connections. There are two overlapping HIPERLANs, A and B, and terminal 4 is a member of both WLANs which can also act as a bridge between the two. This architecture does not have an infrastructure, and it has a large coverage through the multihop operation.

As we mentioned earlier, HIPERLAN-1 did not generate any product development, but it had some pioneering impact on other standards. The use of 5 GHz

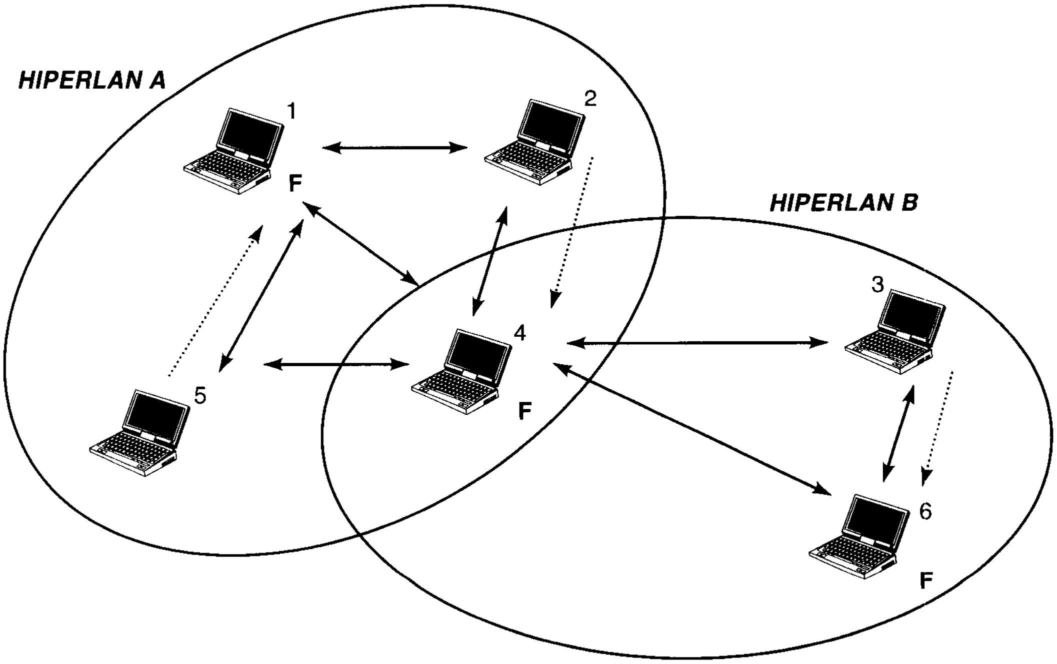

Figure 12.7 Ad hoc network architecture in the HIPERLAN-1.

unlicensed bands, first considered in HIPERLAN-1, is used by IEEE 802.11a and HIPERLAN-2. The multihop feature of the HIPERLAN-1 is considered in the HIPERLAN-2 to be used in an environment with a connection to wired infrastructure.

12.3.2 HIPERLAN-1 PHY and MAC Layers

The PHY layer of the HIPERLAN-1 uses 200 MHz at 5.15–5.35 GHz, which is divided in 5 channels (40 MHz spacing) in the European Union and 6 channels (33 MHz spacing) in the United States. In the United States, there are 3 more channels at 5.725–5.825 GHz bands. The transmission power can go as high as 1 W (30 dBm), and modulation is the single carrier GMSK that can support up to 23 Mbps. To support such high data rates receivers would include a DFE. As we discussed in Chapter 3, DFE consumes considerable electronic power. Using GMSK with the DFE is also challenging for the implementation of fallback data rates. The multisymbol QAM modulation techniques embedded in the OFDM systems allow simple implementation of fallback data rates. In QAM systems fallback is implemented by simple reduction of the number of transmitted symbols per symbol interval while the symbol interval is kept constant. The PHY layer of the HIPERLAN-1 codes each 416 bits into 496 coded bits with a maximum of 47 codewords per packet and 450 bits per packet for training the equalizer.

The nonpreemptive multiple access (NPMA) protocol used in HIPERLAN is a listen before talk protocol, similar to CSMA/CA used in 802.11, which supports both asynchronous and isochronous (voice-oriented) transmissions. Carrier sensing in HIPERLAN-1 is active, rather than passive as in 802.11, and contention resolution and ACKing is mandatory. The HIPERLAN MAC defines a priority scheme and a lifetime for each packet, which facilitates the control of QoS. In addition to the routing, the MAC layer also handles the encryption and power conservation. The MAC address of the HIPERLAN-1 uses six bytes to support IEEE 802.2 LLC and to be compatible with other 802 standards. Each packet has six address fields that identify source, destination, and immediate neighbor (for multihop implementation) transmitters and receivers. IEEE 802.11 had four address fields because it does not support the multihop operation.

Figure 12.8 shows the basic principles of the HIPERLAN-1 MAC protocol. If a terminal senses the medium to be free for at least 1,700 bit durations, it immediately transmits. If the channel is busy, the terminal access has three phases when the channel becomes available. These phases, shown in Figure 12.8, are prioritization phase, contention phase, and transmission phase. During the *prioritization* phase, competing terminals with the highest priority, among the five available priority levels, will survive, and the rest will wait for the next time that the channel is available. The combing algorithm that was described in Chapter 4 is used in five slots, each 256 bits long, to implement this phase. At the end of the prioritization period, all the terminals listen to the asserted highest priority to make sure that all terminals have understood the asserted priority level. This way MSs with the highest priority survive and contend for the next phase, and others are eliminated from the contention. This prioritization mechanism is a counterpart of the three priority level mechanism that was implemented in the 802.11 using SIFS, PIFS, and DIFS interframing intervals. The combing algorithm is more structured and active which

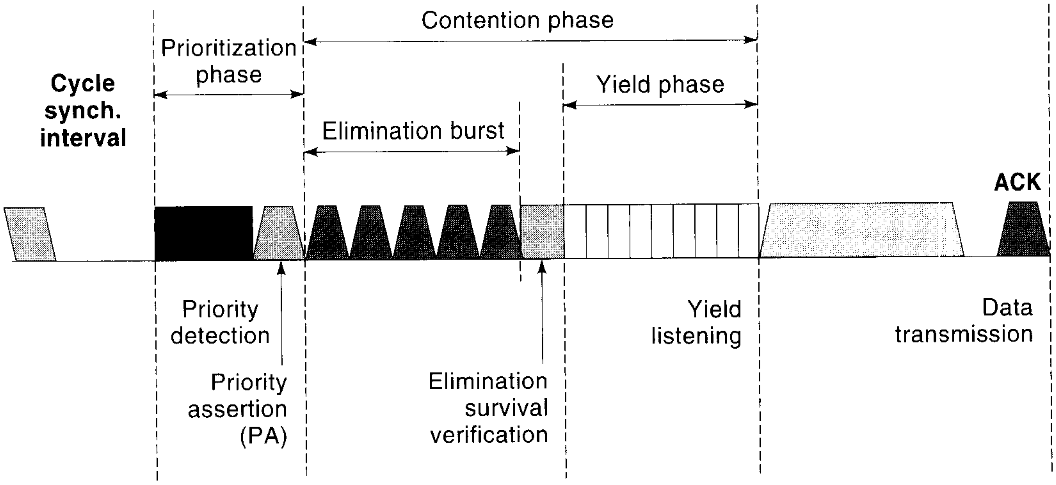

Figure 12.8 Channel access cycle in the HIPERLAN-1.

will provide for a more robust prioritization process. However, the reader should note that prioritization has not shown to be an important issue in the implementation of the WLAN products. All the existing 802.11 products don't implement PCF or any sort of prioritization.

The *contention* phase of the HIPERLAN-1 has two periods, elimination and yield. During the *elimination* period each terminal runs a random number generator to select one of the 12 available slots in which it sends a continuous burst of 256 bits. After sending a burst, an MS listens to the channel for 256-bit durations. If it does not hear any other burst after its transmission, it will send another burst after the twelfth slots in the elimination survival verification interval to ensure everyone that there are survivors. The terminals that hear a burst in this period eliminate themselves. The remainder of the terminals go to the so-called yield part of the contention interval. In the *yield* period, the remaining MSs have a random yield period that is similar to the 802.11 waiting counters. Each MS will "listen" to the channel for the duration of its yield period which is determined from an exponentially distributed random variable, rather than a uniformly distributed random variable used in 802.11. The exponential distribution reduces the average waiting time for running the counter. If an MS senses the channel to be idle for the entire yield period, it has survived, and it will start transmitting data that automatically eliminates other MSs that are listening to the channel. Here the contention process is more complicated and has active as well as passive parts while contention in the 802.11 was entirely passive.

12.4 HIPERLAN-2

Today HIPERLAN-1 is not considered a successful standard by the European Union, but the HIPERLAN-2 project is very popular in and out of the European Union. The HIPERLAN-2 standardization process coordinated with IEEE 802.11 in defining the transmission technique and is working on new higher layers that facilitate the integration of WLANs into the next-generation cellular systems. Integration of WLAN into the cellular systems requires two features: (1) support for vertical roaming between local area and wide areas as well as between corporate and public environments, and (2) support for QoS control for integration into multiservice voice-oriented backbone PSTN which includes ATM switches and other facilities.

While it is still under development, HIPERLAN-2 aims at IP and ATM type services at high data rates for indoor and possibly outdoor applications. It expects to support both connectionless and connection-oriented services which will make its MAC layer far more complicated than 802.11 and HIPERLAN-1 that supports only connectionless services. Connection-based services facilitate integration into the voice-oriented networks. The HIPERLAN-2 that started as a WATM type activity now aims at connecting to IP-based as well as UMTS and ATM networks. In HIPERLAN-2 the ad hoc architecture of HIPERLAN-1 is expanded to support centralized access by using APs in a manner similar to IEEE 802.11. The TDMA/TDD-based MAC layer is similar to the PCS voice-oriented access methods that were previously used in DECT, and this provides a comfortable environment for traditional methods for support of QoS. This feature is carried from the WATM activities that we discussed earlier in this chapter. The OFDM modem operating at 5 GHz is the same as 802.11a. Support of data rates of up to 54 Mbps with this PHY layer opens an environment for innovative wireless video applications that is very crucial for development of integrated home networks. In the next few sections, we provide the details of the HIPERLAN-2 standard that are finalized by the time of this writing. The HIPERLAN-2 standard activities group has four subgroups in interoperability, regulatory, application, and marketing. For more detailed and up-to-date information, the reader can refer to [HIPweb] or [JON99].

12.4.1 Architecture and Reference Model

The overall architecture of the HIPERLAN-2 is shown in Figure 12.9. Like IEEE 802.11, HIPERLAN-2 supports centralized and ad hoc topologies. In the centralized topology of HIPERLAN, shown in Figure 12.9(a), connection between the MS and the AP is similar to that in 802.11, but communication between the APs are different. The IEEE 802.11 with IAPP protocol allows two AP connected to an IP-based subnet to communicate with one another. HIPERLAN-2 allows both handover in a subnet and IP-based handover in a nonhomogeneous network. This generic architecture allows seamless interoperation with Ethernet, point-to-point protocol connection (e.g., over dial-up modem connections), UMTS cellular networks, IEEE 1394 (e.g., Firewire, i.LINK) for entertainment systems, and ATM-based networks. These features allow manufacturers to support vertical roaming capability over a number of networks. The ad hoc networking in the HIPERLAN-2 is expected to support multihop topology that provides for a better coverage.

Features considered for HIPERLAN-2 are far more complex and detailed than the features of the data-oriented IEEE 802.11. As a result, HIPERLAN-2 uses a new protocol stack architecture that is similar to the voice-oriented cellular networks. Figure 12.10 illustrates the simplified protocol stack of the HIPERLAN-2.

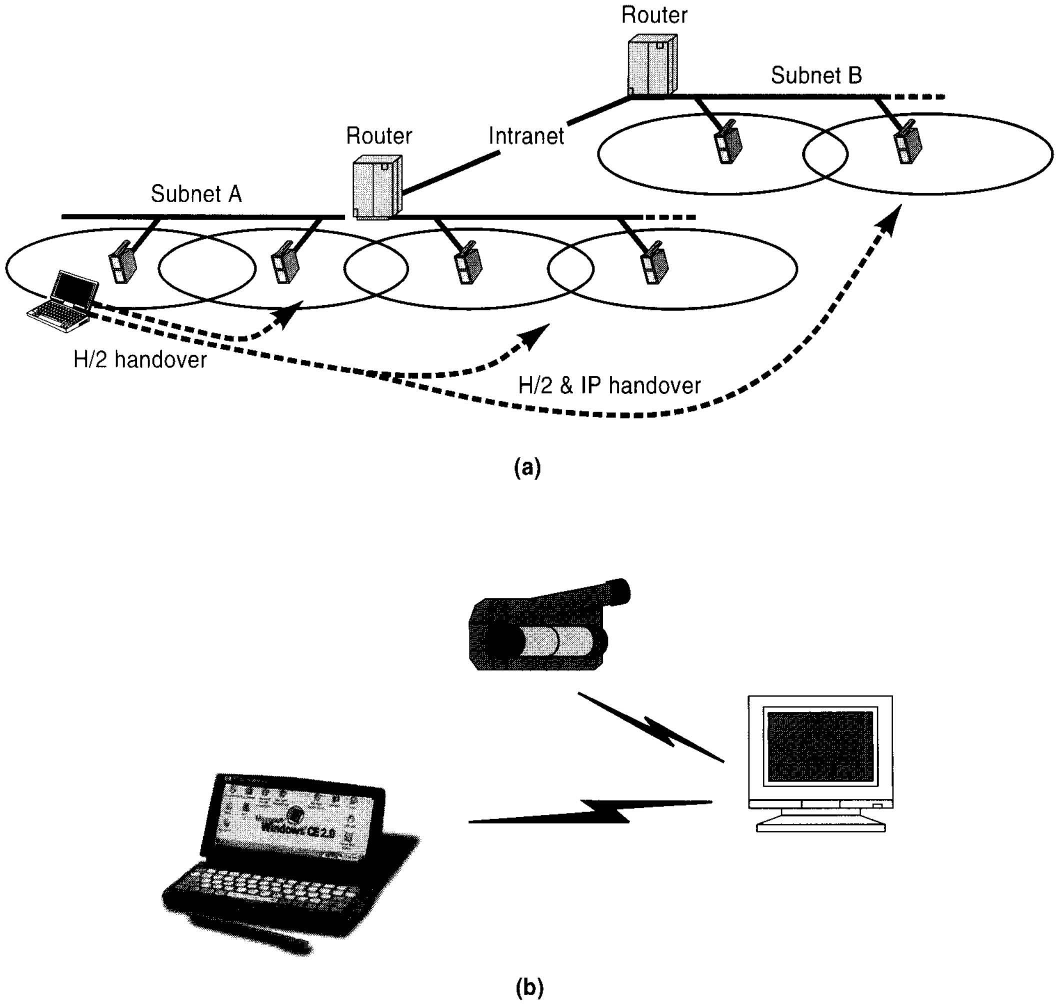

Figure 12.9 Topologies in the HIPERLAN-2: (a) infrastructure and (b) ad hoc.

Basically there are three layers: PHY, DLC, and convergence. Multiple convergence layers, operating one at a time, map a number of higher layer protocol (PPP/IP, ATM, UMTS, Firewire, Ethernet) packets to DLC. The DLC layer provides for the logical link between an AP and the MTs and includes functions for both medium access and communication management for connection handling. The DLC provides for a logical structure to map the convergence layer packets carrying a number of different application protocols onto a single PHY layer.

12.4.2 PHY Layer

The PHY layer of the HIPERLAN-2 uses OFDM modulation that was described in Chapter 3. The specific details of the 802.11a/HIPERLAN-2 transmission system were illustrated in Example 3.12. The PHY layer of the HIPERLAN-2 standard

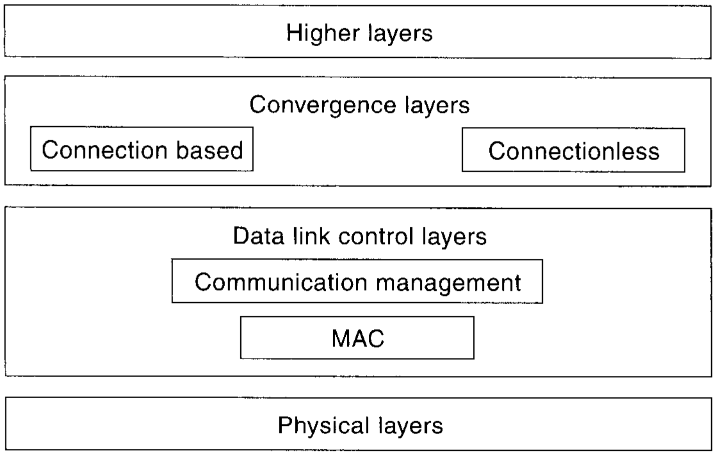

Figure 12.10 Protocol stack of the HIPERLAN-2.

adds the preamble of the DSSS IEEE 802.11, described in the previous chapter, to its own DLC packets. Then by defining a number of logical channels, similar to GSM or TDMA systems, transmits the packet as OFDM modulated bursts.

Figure 12.11 shows the detailed block diagram of the modem. Like IEEE 802.11 FH-SS standard, the received data in HIPERLAN-2 is first scrambled for the whitening process. It is important to remind the reader that IEEE 802.11 DSSS does not go through the whitening process because the DS-SS process whitens the transmitted symbols when it turns the bits to chips. Like IEEE 802.11a, the scrambled data in the HIPERLAN-2 is then passed through a convolutional coder that uses one of the rates—$1/2$, $9/16$, or $3/4$ that are used for different modulation techniques. The coded data is then interleaved to improve the reliability over temporal fading. The interleaved data is then modulated using BPSK, QPSK, 16-QAM, or 64-QAM,

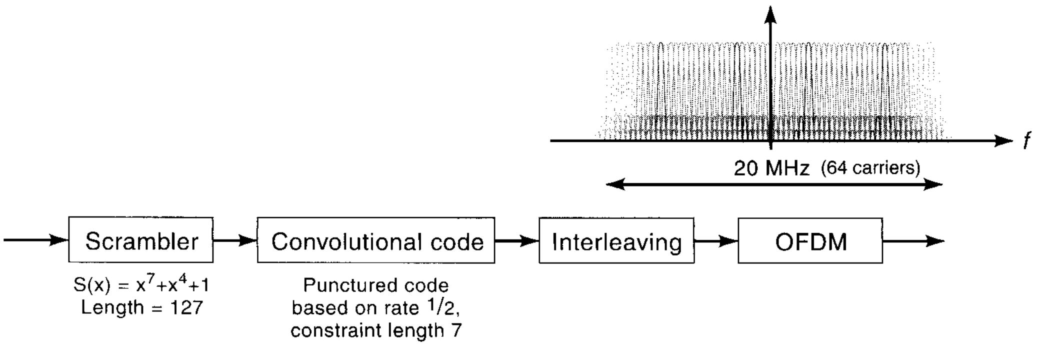

Figure 12.11 Block diagram of the OFDM modem.

to support a variety of data rates. Figure 12.12 shows all the data rates and corresponding modulation and coding schemes that are adopted by the IEEE 802.11a and HIPERLAN-2 standards. As we explained in Example 3.8, there are 64 subcarriers in the OFDM modem of the IEEE 802.11/HIPERLAN-2 of which 48 are used for user data. To support multiple user data rates, modulation and coding in the subcarriers are changed, but the symbol transmission rate is kept at 250 kSps. By keeping the same symbol transmission rate for all data rates, the sampling rate of the signal and other signal processing filters at the receiver remain the same for all rates, but the coding of the bits and number of bits per symbol are changed digitally.

Example 12.2: Data Rates in HIPERLAN-2

For the 6 Mbps user data rate, each carrier carries 6 Mbps/48 = 125 kbps of data using rate ½ convolutional encoder. The rate ½ convolutional encoder requires a 250 kbps transmission rate to support 125 kbps user data. The 250 kSps user data is modulated over a BPSK modem that transmits one symbol per each coded bit. Therefore, the symbol or pulse transmission rate of the system is 250 kSps.

Example 12.3: QAM and Rate ¾ Convolutional Coding

When we use 64-QAM modulation (six bits per symbol) with a rate ¾ convolutional coder the effective data rate will be 250 kbps/carrier × 4/3 × 6 bits/symbols × 48 carriers = 54 Mbps.

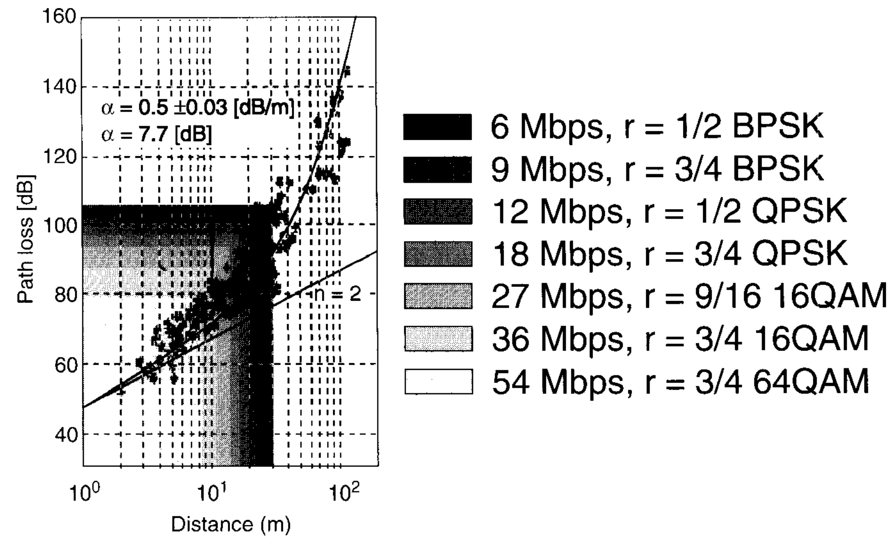

Figure 12.12 Data rates and corresponding tone modulation.

The symbol transmission rate of 250 kSps has a symbol transmission duration of 1/250 kSps = 4,000 ns. Therefore, each symbol is sent like a pulse of duration 4,000 ns with 800 ns time guard between two symbols. This time-gating process improves the resistance to multipath delay spread by preventing the intersymbol interference. The standard also allows an optional 400 ns guard time for shorter distances where delay spread is smaller. Providing for a multirate transmission is a key feature of the 802.11a/HIPERLAN-2 transmissions. Multirate transmission provides for adaptation to the radio link quality and support of different DLC requests for transportation rates.

12.4.3 DLC Layer

The DLC layer provides for a logical link between an AP and the MTs over the OFDM PHY layer. Figure 12.13 illustrates the details of the DLC layer in the HIPERLAN-2. The MAC protocol and frame format for logical and transport channels are the major elements of the DLC layer. Using MAC protocol multiple users share the medium for information transmission and control signaling using transport channels. Using logical channels, similar to those used in voice-oriented networks, HIPERLAN-2 implements four protocols for proper operation of the network. These protocols are radio link control (RLC) protocol, DLC connection control (DCC), radio resource control (RRC), and association control function (ACF). DLC also supports the error control (EC) mechanism over logical channels to improve the reliability of the link.

The MAC layer protocol is dynamic TDMA/TDD, which was described in Chapter 4 under the voice-oriented fixed assignment access method, and it is similar to the access method used in DECT. This protocol supports AP to MT unicast and multicast communication, as well as MT-MT peer-to-peer transmissions. The

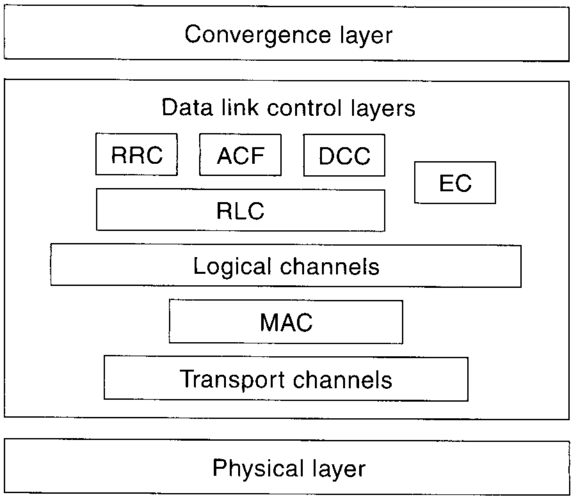

Figure 12.13 Relation between logical and transport channels in HIPERLAN-2.

centralized AP scheduling is expected to provide for dynamic resource distribution, QoS support, and collision-free transmission. Compared with IEEE 802.11, the first two are available only in HIPERLAN-2, and the third one is similar to the PCF in 802.11. Random access for reservation has a specific channel, similar to GSM, and uses slotted ALOHA with exponential backoff and ACKs.

Figure 12.14 represents the overall format of the MAC protocol. Communication between the AP and the MT is based on 2-ms MAC frames. Each frame is divided into broadcast control (BCH), frame control (FCH), access control (ACH), down link data, uplink data, and random access (RCH) time slots. The uplink and downlink are also divided into short and long channels (SCH/LCH) that are used for data transportation of lengths 9 and 54 bytes. The BCH contains broadcast control information for all the MTs. It provides for general information such as the network and AP identifiers, transmission power levels, and FCH and RCH length and wake-up indicator. The FCH contains details of distribution of resources among the fields of each packet. The ACH conveys information on previous access attempts made in the RCH. The RCH is commonly shared among all MTs for random access and contention. If collisions occur the results from RCH access are reported back to the MTs in ACH. Except for the RCH, all other slots are dedicated to specific users. Except for BCH, the duration of the other slots is dynamically adapted to the current traffic situation. BCH, FCH, and ACH are down link channels, RCH is an uplink channel, and SCH/LCH are used in both directions. The HIPERLAN-2 standard refers to all channels shown in Figure 12.14 as *transport channels*.

Like other voice-oriented networks, HIPERLAN-2 defines a set of logical channels for signaling, control, and information transfer. Logical channels in the

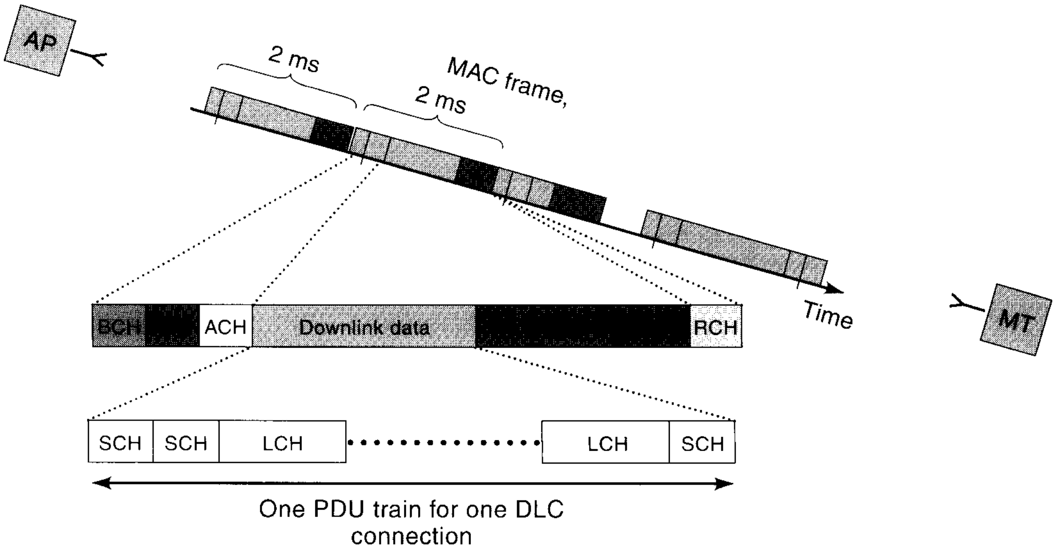

Figure 12.14 The TDMA/TDD MAC structure of the HIPERLAN-2.

HIPERLAN-2 are mapped on to the SCH, LCH, and RCH transport channels. Figure 12.15 illustrates the relation between the logical and transport channels in HIPERLAN-2 standard. The SBCH is used only in downlink to broadcast control information related to the cell, whenever needed. It assists in handover, security, association, and radio link control functions. The DCCH conveys RLC sublayer signals between an MT and the AP. The UDCH carries DLC PDU for convergence layer data. The LCCH is used for error control functions for a specific UDCH. The ASCH is used for association request and reassociation request messages.

Using the logical channels, HIPERLAN-2 implements the protocols for the proper operation of the network, shown in Figure 12.13. The RLC protocol gives a transport service for the signaling entities of the three other algorithms. These four entities provide for the DLC control plane to implement signaling messages. The ACF protocol handles association and dissociation to the network. To *associate* with the network, the MT listens to the BCH from different APs and selects the AP with the best radio link quality. The MT then continues with listening to the broadcast of a globally unique network operator in the SBCH as to avoid association to a network, which is not able or allowed to offer services to the user of the MT. If the MT decides to continue the association, the MT will request and be given a MAC-ID from the AP. This is followed by an exchange of link capabilities using the ASCH and establishing the PHY and convergence layer connection, as well as authentication and encryption procedures. After association, the MT can request for

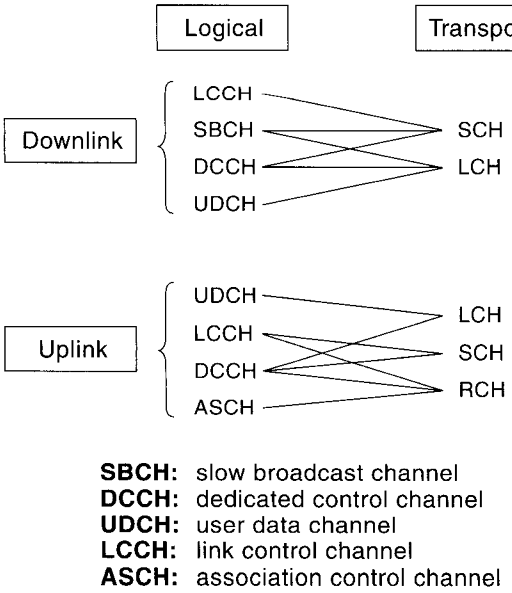

Figure 12.15 Relation between logical and transport channels in HIPERLAN-2.

a DCCH that it uses to set up a DLC user connection with a unique support for QoS. For *disassociation* from the network, either MT notifies the AP that it no longer wants to communicate or AP realizes that the MT is no more active and it is out of the network. In either case, the AP will release all resources allocated for that MT. To implement the DCC algorithm, terminals request a DLC user connection by transmitting signaling messages over the DCCH. The resource for the connection gets allocated, and after an ACK signal, the DLC connection is ready for traffic. The DCCH controls the resources for specific MAC entities. The algorithm also supports procedure for ending the connection or defining a new connection.

The RRC protocol handles handover, dynamic frequency selection, and sleeping mode and power saving operation. Like 802.11, the *handover* in HIPERLAN-2 starts with passive scanning that can be followed by an active request for handover. The difference between the 802.11 and HIPERLAN-2 is that HIPERLAN-2 provides two alternatives for passing the information for handover to the new AP. In the first approach, similar to 802.11, the new AP retrieves connection status and association information from the MT. In the second approach, MT provides the old AP address to the new AP, and the information is exchanged over the wire between the old and new APs. The second approach is faster, because the backbones always have higher bandwidth and capacity, and it does not add to the air traffic that is always desirable. The RRC in HIPERLAN-2 supports mechanism to measure the power and communicate with neighboring APs that allows *dynamic frequency selection* (DFS). Similar to 802.11, the RRC of the HIPERLAN-2 supports mechanisms for the AP to allow the MTs to go to sleeping mode to save in power consumption. The DLC layer of the HIPERLAN-2 also supports the error control mechanism to detect the errors in the arriving packets and arrange the retransmission through ACK/NACK signaling.

To support QoS HIPERLAN-2 recommends changing the periodicity of the transmitted messages that are illustrated in Figure 12.16. There are three periodic operations shown in this figure, the longest belonging to the broadcast period, the medium to Terminal A, and the shortest to Terminal B. Apparently, the delay associated with the packets from Terminal B is the shortest and packets from Terminal A have medium delay as they are compared with the normal broadcast messages. This mechanism allows a delay-controlled environment that is fertile for the implementation of the QoS control.

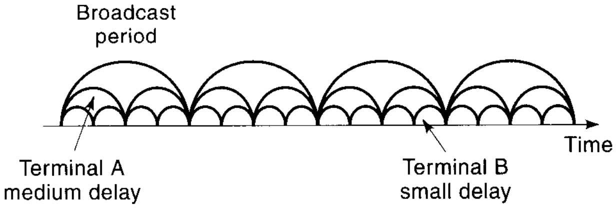

Figure 12.16 Delay control mechanism in HIPERLAN-2 for QoS support [HIPweb].

12.4.4 Convergence Layer

The main two responsibilities of the CL are adapting the service request from a higher layer to the DLC capabilities and to perform fragmentation and reassembly of different size packets from a variety of application protocols to HIPERLAN-2 packet format. Multiple convergence layers operate one at a time to map connection-based and connectionless higher layers such as PPP/IP, ATM, UMTS, Firewire, and Ethernet packets to HIPERLAN-2 DLC packets. To implement all these features, the CL of the HIPERLAN-2 provides a number of services. These services include segmentation and reassembly, priority mapping from 802.1p, address mapping from 802, multicast/broadcast handling, and flexible QoS classes [KHA00].

12.4.5 Security

Comprehensive security mechanisms are seen for the first time in the HIPERLAN-2 system compared with other wireless standards. When contacted by an MT, the AP will respond with a subset of supported PHY modes, a selected convergence layer (only one), and a selected authentication and encryption procedure. As always, there is an option not to use any authentication or encryption. If encryption is agreed upon, the MT will initiate the Diffie-Hellman key exchange to negotiate the secret session key for all unicast traffic between the MT and the AP. The Diffie-Hellman key exchange is discussed in Appendix 6A. In all other wireless systems, key management is a big issue. It is, however, not clear what the computational burden of the Diffie-Hellman key exchange is on wireless devices. Encryption is based on stream ciphers generated using a mechanism similar to the output feedback mode of DES [STI95].

HIPERLAN-2 supports both the use of DES and triple-DES (that is the de facto standard, while AES is in the standardization process) algorithms for strong encryption. Broadcast and multicast traffic can also be protected by encryption through the use of common keys distributed in an encrypted manner through the use of a unicast encryption key. All encryption keys must be periodically refreshed to avoid flaws in the security as discussed in Chapter 6.

Secret and public key algorithms can be employed for authentication. Authentication is possible using message authentication codes based on MD5, HMAC, and digital signatures based on RSA. Mutual authentication is supported for authentication of both the AP and the MT. HIPERLAN-2 supports a variety of identifiers for identification of the MS, via the network access identifier, IEEE address, and X.509 certificates. Challenge response mechanisms are also employed for identification.

12.4.6 Overall Comparison with 802.11

There are several hundreds MHz bands that are available for the 802.11a/HIPERLAN-2 networks which can provide a comfortable multichannel operation for these standards. Availability of these bands and licensing conditions, however, is different in the United States, Europe, and Japan. Figure 12.17 shows the available spectrum for the operation of the 802.11a/HIPERLAN-2 networks in typical

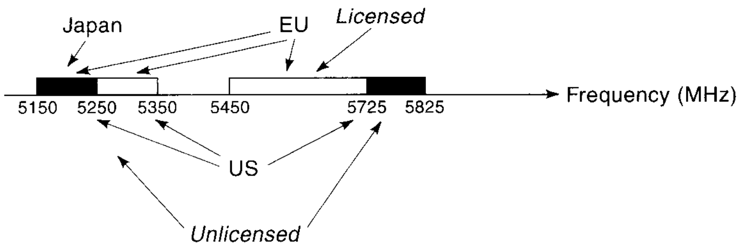

Figure 12.17 Frequency bands for HIPERLAN-2/802.11a.

countries around the world. There are 100 MHz unlicensed bands at 5,150–5,250 MHz that are available in the United States, Europe, and Japan. Another 100 MHz of unlicensed bands at 5,250–5,350 MHz are also available in Europe and the United States. In the United States only, there is another 100 MHz of unlicensed bands at 5.725–5.825 MHz. Finally, there is 255 MHz of licensed bands at 5,470–5,725 MHz in Europe that are assigned for outdoor operation. As we discussed in Chapter 11, the ISM bands in 2.4 GHz are only 84 MHz wide. For this reason, recently 5 GHz developments have dominated the attention of the wideband wireless local access industry. However, the reader must note that the penetration and consequently coverage at 2.4 GHz are better than at 5 GHz.

Table 12.2 provides an overall comparison between all aspects of the 802.11 and HIPERLAN-2 standards [JOH99]. The physical characteristics of HIPERLAN-2 and 802.11a are the same. The access method in HIPERLAN-2 is a voice-oriented access method that allows for better integration into voice-oriented backbones such as UMTS and ATM networks. Connection-orientation, compulsory authentication, link adaptation, dynamic frequency selection, and support of QoS make

Table 12.2 Detailed Comparison of 802.11 and HIPERLAN-2

	802.11	**802.11b**	**802.11a**	**HIPERLAN-2**
Frequency	2.4 GHz	2.4 GHz	5 GHz	5 GHz
Max trans. rate	2 Mbps	11 Mpbs	54 Mbps	54 Mbps
Max throughput	1.2 Mbps	5 Mbps	32 Mbps	32 Mbps
Freq. management	None			Dynamic selection
Medium access	Through sensing			Centralized scheduling
Authentication	None			NAI/IEEE Add/X.509
Encryption	40-bit RC4			DES, 3DES
QoS Support	PCF			ATM/802.1p/RSVP
Wired backbone	Ethernet			Ethernet/ATM/UMTS/ FireWire/PPP/IP
Connectivity	Connectionless			Connection-oriented
Link quality control	None			Link adaptation

HIPERLAN-2 look like a next-generation cellular network that supports high data rates and provides IP services. The main distinction with a cellular system would be the use of unlicensed bands for which a service provider cannot predict the interference. The IEEE 802.11a is an IP-based network that draws from LAN backbone.

QUESTIONS

12.1 What are the differences between the 802.11a and HIPERLAN-2 ?

12.2 Why can't cellular service providers incorporate existing IEEE 802.11 LANs into their networks?

12.3 Explain the general differences between the packet format of the ATM and WATM.

12.4 Explain the general difference between the packet format of the WATM and IEEE 802.11.

12.5 What are the major challenges in implementing WATM that did not exist for data-oriented Ethernet like IEEE 802.11?

12.6 Compare the WTAM reference model of Figure 12.3 with the IEEE 802.11 reference model in Figure 11.1 in terms of functionality of elements, connection to the backbone, and the changes needed in the infrastructure to support mobility.

12.7 Explain the differences between the protocol stacks of the WATM given in Figure 12.4 and that of IEEE 802.11 given in Figure 11.3.

12.8 What were the aspects of WATM trials that impacted the formation of HIPERLAN-2 standard?

12.9 Which WLAN standard first adopted the 5 GHz band operation?

12.10 Explain the similarities between the HIPERLAN-1 and IEEE 802.11.

12.11 Explain the similarities between the HIPERLAN-1 and HIPERLAN-2.

12.12 Explain the differences between NPMA and CSMA/CA medium access control mechanisms used in HIPERLAN-1 and IEEE 802.11 respectively.

12.13 How is priority implemented in HIPERLAN-1 and what is its difference from the priority schemes in the IEEE 802.11 and HIPERLAN-2?

12.14 Explain the architectural differences between HIPERLAN-2 and IEEE 802.11.

12.15 Explain the differences between the protocol stacks of HIPERLAN-2 given in Figure 12.10 and that of IEEE 802.11 given in Figure 11.3.

12.16 What are the purposes of scrambler and interleaver in the HIPERLAN-2 modem?

12.17 What is the basic difference between the medium access control of the HIPERLAN-2 and IEEE 802.11?

12.18 How many transport channels and logical channels are implemented in the HIPERLAN-2 DLC layer?

12.19 What is the length of the frame in the HIPERLAN-2 MAC and how is it divided into traffic and signaling messages?

12.20 What is the difference between a logical and a transport channel in HIPERLAN-2?

12.21 What are BCH and FCH channels in HIPERLAN-2 and what are their functionalities?

12.22 Explain similarities between the medium access control of the HIPERLAN-2 and DECT.

12.23 What is the symbol duration and guard time of the IEEE 802.11a/HIPRLAN-2 OFDM modems? What is the purpose of the guard time?

PROBLEMS

12.1 Compare the overhead of an IEEE 802.11 frame with that of an ATM packet. Do your calculations for the maximum and minimum frame lengths in the case of 802.11. Comment on your results.

12.2 Consider the HIPERLAN-2 standard that uses BPSK and $r = 3/4$ codes for 9 Mbps information transmission and 16-QAM with the same coding for the actual payload data transmission rate of 36 Mbps.

a. Calculate the coded symbol transmission rate per subcarrier for each of the two modes. What is the bit transmission rate per subcarrier for each of the two modes?

b. If one switches from 36 Mbps mode to 9 Mbps mode, how much more (in dB) of the path-loss can it afford?

c. If the system was covering up to 50 meters with 36 Mbps, what would be the coverage with 9 Mbps mode? (*Hint:* use the distance power gradient of the JTC model for an office to calculate this distance.)

12.3 Experimental measurements indicate that the coverage of a 5 GHz WLAN is 47 m at 11 Mbps and 25 m at 54 Mbps. How do these numbers compare with the results of Problem 12.2? If there are any discrepancies, what might be the reason?

12.4 The following parameters are available for HIPERLAN-1 mobile stations trying to access the wireless medium after a busy period. Explain clearly what happens during each part of the channel access cycle and which MS survives which phase. Which of the mobile stations is ultimately able to transmit data? Under what different circumstances would a collision occur?

Station	Priority	Elimination burst (slots)	Yield time (slots)
MS 1	1	7	4
MS 2	3	3	3
MS 3	2	12	5
MS 4	1	5	1
MS 5	2	12	6
MS 6	1	7	3

12.5 IEEE 802.11a/HIPERLAN-2 use BPSK and $r = 1/2$ convolutional coding for 9 Mbps information transmission and 64-QAM with $r = 3/4$ convolutional coding for 54 Mbps.

a. What is the difference in maximum acceptable path loss (in dB) between the 9 Mbps and 54 Mbps modes of operation? Assume that the stronger $r = 1/2$ codes provide about 1 dB advantage over the weaker $r = 3/4$ codes.

b. If the modem operating at 54 Mbps covers up to 30 meters in a home, what would be the coverage in 9 Mbps mode? Assume JTC model for residential areas is valid for power calculation of this scenario.