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WIRELESS NETWORKS

This article provides an overview of wireless information networks. Wireless networking is the enabling communications technology of the 1990s and beyond. The field of wireless communications is experiencing unprecedented market growth, as evidenced by the rapid increase in the cellular and cordless telephone, paging, mobile data, and wireless local area network (*LAN*) industries. In the next section we introduce different medium access techniques in wireless networks and discuss channel characteristics, followed by a general classification of wireless networks. Cellular, cordless, and personal communication services and standards are then described. Another section describes the mobile data services and military networks. Then we consider wireless local area networks: the IEEE 802.11 standard in the United States, and HIPERLAN and BRAN standardization activities in Europe. The next section discusses wireless local loop technology, which is gaining importance especially in developing countries. Broadband wireless access research and standardization are then considered, and finally satellite networks.

Wireless Access

Medium Access in Wireless Networks. The spectrum is a valuable resource and is not unlimited. In the United States the Federal Communication Committee *(FCC)* is in charge of controlling the frequency and bandwidth allocation. Thus, it is imperative that the spectrum and, often, the backbone equipment be shared among users. In short, users in a given area must contend for a limited number of channels.

There are different approaches to dividing up the spectrum and providing users access to it in an organized way. The simplest and most straightforward method is known as frequency division multiple access (*FDMA*). In *FDMA*, the available spectrum is divided into nonoverlapping slots in the frequency dimension (domain). These frequency slots or channels are then put into a pool and assigned to users on either a manual or an automated basis for the duration of their particular call. For example, a 150 kHz block of spectrum could be divided into five channels, or frequency slots, each 30 kHz wide. Such an arrangement would allow six simultaneous conversations to take place, each with its own carrier within its own frequency slot. In the example, this would mean that each user would be continuously accessing one-fifth of the available spectrum during the duration of the conversation. *FDMA* is perhaps the most familiar way of dividing spectrum, and it has been traditionally associated with analog systems.

In time division multiplex access (*TDMA*), by using nonoverlapping time slots in the time domain, the available spectrum is shared. These time slots or channels are then put into a pool and assigned to users for the duration of their particular call. To continue the example given above, in a *TDMA* system the 150 kHz of spectrum would be divided into recurring groups (frames) of five time slots, and each time slot would carry a sequence of bits representing a portion of one of five simultaneous conversations. The five conversations each take turns using the available capacity. In other words, each user would be accessing all of the available spectrum but only for one-fifth of the available time. Rather than each signal having a particular frequency slot as in *FDMA*, in *TDMA* each conversation occupies a particular time slot in a sequential fashion. The frames are repeated fast enough that there is no interruption or delay in the conversation as experienced by the user.

As seen by user, there is no difference in capacity between *FDMA* and *TDMA*. Namely, you get access to one-fifth of the capacity all of the time or all of the capacity one-fifth of the time, to continue the example. Note further that, in the practical world, digital systems are typically a combination of *FDMA* and *TDMA*. In other words, the systems are designed so that the capacity is divided into both the frequency and time dimensions, so that a user contends for a particular channel and then a time slot within that channel.

A third access method is *code division multiple access* (*CDMA*). *CDMA* is both a modulation and an access technique that is based upon the spread spectrum concept. A spread spectrum system is one in which the bandwidth occupied by the signal is much wider than the bandwidth of the information signal being transmitted. As an example, a voice conversation with a bandwidth of 3 kHz would be spread over 1 MHz or more of spectrum. In spread spectrum systems, multiple conversations simultaneously share the available spectrum in both the time and frequency dimensions. Hence, in a *CDMA* system, the available spectrum is not channelized in frequency or time as in *FDMA* and *TDMA* systems, respectively. Instead, the individual conversations are distinguished through coding; that is, at the transmitter, each conversation channel is processed with a unique spreading code that is used to distribute the signal over the available bandwidth. The receiver uses that code to accept the energy associated with the corresponding signal. The other signals present are each identified by a different code and simply produce background noise. In this method, many conversations can be carried simultaneously within the same block of spectrum, but the accumulation of background noise from multiple users will limit the number of users.

Another issue that should be addressed is duplexing. In many communication systems, it is desirable to be able to communicate in both directions at the same time. This system characteristic, which is known as full-duplex operation, is desirable because it lets one party in a voice conversation interrupt the other with a question or one device to immediately request a retransmission of a block of information received in error during a data communications session. There are two basic ways of providing for full-duplex operation in a radio system. The most common is to assign two different frequency slots per conversation—one for transmitting and one for receiving. By separating the slots sufficiently in frequency, filters can be used to prevent the transmitted information from interfering with the simultaneously received information. Thus, in many land mobile radio bands, a channel actually consists of two frequency slots—one for each direction of transmission in a full-duplex conversation. This arrangement is called *frequency division duplexing* (*FDD*).

Another, much less common means of achieving full-duplex operation in the digital world is through what is called *time division duplexing* (*TDD*). In *TDD*, a single channel is used, with each end taking turns transmitting. Each end sends a burst of information and then receives a burst from the other end. As in the case of the *TDMA* access technique, this process is repeated rapidly enough that the user does not perceive any gaps or delays in what is heard. To the user it appears as a true full-duplex connection.

Characteristics of Wireless Radio Frequency Channels. There are several causes of signal corruption in an indoor wireless channel. The primary causes are signal attenuation due to distance, penetration losses through walls and floors, shadowing, and multipath propagation.

Effect of Distance

Signal attenuation over distance is observed when the mean received signal power is attenuated with increasing distance from the transmitter. The most common form of this, often called *free space loss*, is due to the signal power being spread out over the surface of an expanding sphere as the receiver moves farther from the transmitter. In addition to free space loss effects, the signal experiences decay due to ground wave loss, although this typically comes into play only for very large distances (on the order of kilometers). For indoor propagation this mechanism is less relevant, but effects of wave guidance through corridors can occur. Also, penetration losses through walls and floors contribute to the path loss.

Shadowing. Wireless networks use base stations and antennas to provide radio coverage to an area surrounding each station. The degree of coverage depends on the height of the antenna and the presence of obstacles such as mountains and buildings for outdoor applications and walls and floors for indoor applications. The variation of received signal level due to these obstacles is known as shadowing. Since these signal variations follow a lognormal distribution, the term lognormal fading is also used to describe this phenomenon. A lognormal distribution implies that received signals specified in decibels will display a normal distribution.

Multipath Reception. The mobile or indoor radio channel is affected by multipath reception: The signal to the receiver contains not only a direct line-of-sight radio wave, but also a large number of reflected waves. Multipath reception results from the fact that the propagation channel consists of several obstacles and reflectors. Thus, the received signal arrives as an unpredictable set of reflections and/or direct waves, each with its own degree of attenuation and delay.

The *delay spread* is a parameter commonly used to quantify multipath effects. The maximum delay time spread is the total time interval during which reflections with significant energy arrive. Multipath propagation leads to variations in the received signal strength over frequency and antenna location. The distribution of signal level is Rayleigh when there is no one dominant signal component, or Rician when there is a dominant (typically line-of-sight) signal component.

These reflected waves interfere with the direct wave, causing significant degradation of the performance of the receiver. A wireless receiver has to be designed in such a way that the adverse effect of these reflections is minimized. Although channel fading is experienced as an unpredictable, stochastic phenomenon, powerful models have been developed that can accurately predict system performance.

Some examples for the effect of multipath reception are:

- For a fast-moving user: rapid fluctuations of the signal amplitude and phase
- For an analog television signal: ghost images (shifted slightly to the right)
- For a stationary user of a narrowband system: good reception at some locations and frequencies; and poor reception at others.
- For a satellite positioning system: strong delayed reflections, possibly leading to severe miscalculation of the distance between user and satellite.

Rate of fading. Time variation of the channel occurs if the communicating device (antenna) or components of its environment are in motion. Time variation in conjunction with multipath transmission leads to variation of the instantaneous received signal strength about the mean power level as the receiver moves over distances less than a single carrier wavelength. Time variation of the channel becomes uncorrelated every half carrier wavelength over distance. Fortunately, the degree of time variation in an indoor system is much less than that in an outdoor mobile system.

One manifestation of time variation is spreading in the frequency domain. Given the conditions of typical indoor wireless systems, frequency spreading should be virtually nonexistent. Doppler spreads of 0.1 Hz to 6.1 Hz (with rms 0.3 Hz) have been reported.

Some researchers have considered the effects of moving people. In particular it was found by Ganesh and Pahlavan (1) that a line-of-sight delay spread of 40 ns can have a standard deviation of 9.2 ns to 12.8 ns. Likewise, an obstructed delay spread can have a standard deviation of 3.7 ns to 5.7 ns. For wireless *LANs* this can mean that an antenna placed at a local multipath null remains in fade for a very long time. Measures such as diversity and adaptive equalization are needed to guarantee reliable communication irrespective of the position of the antenna.

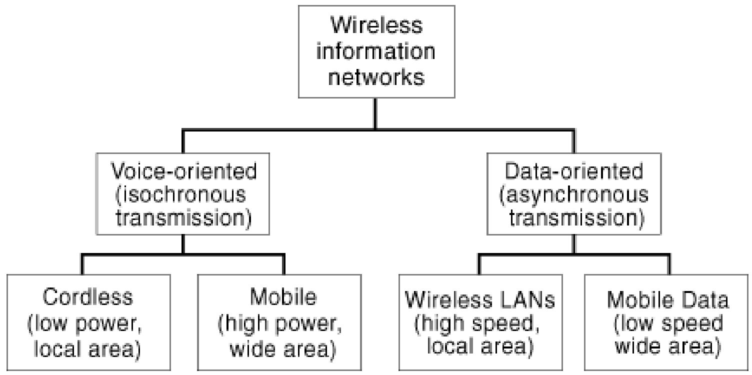

Fig. 1. Categories of wireless information networks.

General Overview and Classification of Wireless Networks

We can divide the evolving wireless information network (*WIN*) systems into terrestrial services, satellite services, and military services.

The existing terrestrial wireless services can be logically divided in two classes: voice-oriented or isochronous networks, and data-oriented or asynchronous networks. Voice-oriented networks use a connection-based backbone infrastructure, such as the public switch telephone network (*PSTN*) or integrated service digital network (*ISDN*), that is supported by circuit switch technology. The wireless access method adopted in these services is an assigned or connection-based method such as *TDMA* or *CDMA* in one or another version. The existing wireless data services use connectionless packet-switched data network (*PSDN*) infrastructures as the backbone, and the terminal accesses the backbone using connectionless random-access protocols such as *ALOHA* or carrier sense multiple access (*CSMA*) in one or another version. Voice-oriented networks are divided into low-power (high-quality) local services such as personal communication services (*PCS*), wireless private branch exchange (*PBX*), and telepoint on one side and on the other side high-power, wide-area, lower-quality cellular services. The data-oriented networks are divided into high-speed wireless local area networks (*LANs*) and low-speed wide-area mobile data services. Figure 1 illustrates these four categories of existing services.

Wireless access has been defined as "end-user radio connection(s) to core networks," where core networks include, for example, the *PSTN*, *ISDN*, public land mobile network (*PLMN*), *PSDN*, Internet, wide area network (*WAN*), *LAN*, and cable television (*CATV*). Technologies in use today for implementing wireless access include cellular systems, cordless phone and cordless telecommunication systems, satellite systems, and specialized point-to-point and point-to-multipoint radio systems. New technologies and systems such as IMT-2000/FPLMTS, wireless broadband *ISDN*, and wireless asynchronous transfer mode (*ATM*) also form part of wireless access if their application satisfies the basic criteria of end-user radio connection(s) to core networks.

Wireless access may be considered from many perspectives, for example:

- Mobility capabilities of the terminal: fixed, nomadic, mobile, restricted mobility (within a single cell)
- Service support capabilities: narrowband, broadband, multimedia
- Type of telecommunication service: conversational, distribution, information retrieval.
- Connectivity (which would depend on the switched network that the terminal accesses, such as Internet, *PSTN*, etc.)
- Radio transmission technology: access technique (*TDMA*, *CDMA*, etc.), modulation technique (analog, digital, etc.), duplex technique (*FDD*, *TDD*, etc.), etc.
- Transport mechanism: terrestrial, satellite, etc.

Table 1. Existing Analog Cellular Systems

Standard	Forward Band (MHz)	Reverse Band (MHz)	Channel Spacing (kHz)	Region	Comments
AMPS	824–849	869–894	30	America; also in Australia, SE Asia, Africa	
TACS	890–915	935–960	25	EC	Later, bands were allocatec to GSM
ETACS	872–905	917–950	25	UK	
NMT 450	453–457.5	463–467.5	25	EC	
NMT 900	890–915	935–960	12.5	EC; also in Africa and SE Asia	Freq. overlapping
C-450	450–455.74	460–465.74	10	Germany, Portugal	
RTMS	450–455	460–465	25	Italy	
Radiocom 2000	192.5–199.5 215.5–233.5 165.2–168.4 414.8–418	200.5–207.5 207.5–215.5 169.8–173 424.8–428	12.5	France	First two bands are regiona second two are national
NTT	925–940 915–918.5 922–925	870–885 860–863.5 867–870	25/6.25 6.25 6.25	Japan	First band is nationwide, others regional
JTACS/NTACS	915–925 918.5–922 843–846	898–901 860–870 863.5–867	25/12.5 25/12.5 12.5	Japan	All are regional

There are different kinds of wireless access systems, among which wireless local loop, Global System for Mobile Communications (*GSM*), and IMT-2000/FLPMTS are most recognized by consumers and the industry. We describe them briefly later.

Cellular, Personal Communication, and Cordless Services. Today it is customary among the cellular telephone manufacturers and service providers to divide the existing wireless communication systems into three generations. The first generation comprises the analog cellular and the cordless telephone. The second generation comprises digital cellular services and personal communication services (*PCS*), which also support limited data services. The third generation is expected to combine the cellular and personal voice services with a variety of packet-switched data services. To further generalize these classifications we may extend the first generation to cover data services such as wide-area paging and low-speed local data services such as those using walkie-talkie bands for low-speed local wireless communications. The second generation is likewise extended to include wireless *LANs* and mobile data services. The third generation will remain the same in its purpose of providing wireless access to support all services, but the infrastructure is expected to be an *ATM*-oriented network that is expected to support a reliable communication for both connectionless and connection-based services.

Table 1 shows the first generation analog cellular systems. The technology for the analog cellular was developed in AT&T Bell Laboratories in the early 1970s. The first deployment of these systems took place in the Nordic countries under Nordic Mobile Phone (*NMT*), followed by deployment of the Advanced Mobile Phone Services (*AMPS*) in 1983. In the United States, since it is a larger country and other commercial and military radio applications are more popular there, frequency administration issues were more complicated and the process took more time. Analog cordless telephone services appeared in the US market in the early 1980s.

Paging services were deployed around the same period. In the early 1980s a group of computer hackers in Vancouver, British Columbia connected a number of personal computers using voice-band modem chip sets and commercially available walkie-talkies. These products were operating at the speed of voice-band modems ($<$9600 bits/s) in a local area. These were the first wireless LAN-like products in the market. The data rate of these products was two orders of magnitude less than that of the existing *LANs*, but the applications were similar.

The second generation systems include digital cellular services such as GSM, IS-54, IS-95, JDC; digital cordless telephone services such as CT2, DECT, IS-136, PHS, DCS-1800/1900, PACS; mobile data services such as ARDIS, Mobitex, CDPD; and wireless local area network/metropolitan area network (*LAN/MAN*) services such as IEEE 802.11, RES-10's HIPERLAN, TETRA, Metricom's MAN.

The motives for the digital cellular systems in the United States and the European Community were different. The successful early deployment of the NMT systems in the Nordic countries and the rest of Europe led to the need for international roaming. The Group Special Mobile (*GSM*) was formed under CEPT in 1982 to address this issue. The group developed the first digital cellular standard and changed the name to Global System Mobile. In the United States the move toward digital cellular was motivated by the limitation of capacity in particular major cities such as New York and Los Angeles. Narrowband FM and digital cellular telephony in *TDMA* and *CDMA* were adopted in the IS-54 and IS-95 standards to address this problem. By the end of 1995 there were 41 million cellular subscribers, 25 million of whom were in the United States.

Different types of cellular systems employ different methods of multiple access. The traditional analog cellular systems, such as those based on the AMPS and Total Access Communications System (*TACS*) standards, use *FDMA*. *FDMA* channels are defined by a range of radio frequencies, usually expressed as a number of kilohertz (kHz), out of the radio spectrum.

A common multiple access method employed in digital cellular systems is *TDMA*. *TDMA* digital standards include North American Digital Cellular (know by its standard number IS-54), GSM, and Personal Digital Cellular (*PDC*).

Global System for Mobile Communications. *ISDN* compatibility was one of the goals in designing GSM with regard to the services offered and the control signaling used. However, radio transmission limitations, in bandwidth and cost, do not allow the standard *ISDN* B-channel bit rate of 64 kbit/s to be practically achieved.

Using the ITU-T definitions, telecommunication services can be divided into bearer services, teleservices, and supplementary services. The most basic teleservice supported by GSM is telephony. As with all other communications, speech is digitally encoded and transmitted through the GSM network as a digital stream. There is also an emergency service, where the nearest emergency-service provider is notified by dialing three digits (similar to 911 in the United States).

A variety of data services is offered. GSM users can send and receive data, at rates up to 9600 bit/s, to users on plain old telephone service (*POTS*), *ISDN*, packet-switched public data networks, and circuit switched public data networks, using a variety of access methods and protocols, such as X.25 or X.32. Since GSM is a digital network, a modem is not required between it and the user, although an audio modem is required inside the network to interwork with POTS.

Other data services include group 3 facsimile, as described in ITU-T recommendation T.30, which is supported by use of an appropriate fax adapter. A unique feature of GSM, not found in older analog systems, is the Short Message Service (*SMS*). *SMS* is a bidirectional service for short alphanumeric (up to 160 bytes) messages. Messages are transported in a store-and-forward fashion. For point-to-point SMS, a message can be sent to another subscriber to the service, and an acknowledgement of receipt is provided to the sender. SMS can also be used in a cell-broadcast mode, for sending messages such as traffic updates or news updates. Messages can also be stored in the subscription identification module (*SIM*) card for later retrieval.

Supplementary services are provided on top of teleservices or bearer services. In the current (phase I) specifications, they include several forms of call forwarding (such as call forwarding when the mobile subscriber is unreachable by the network) and call barring of outgoing or incoming calls (for example, when roaming in another country). Many additional supplementary services will be provided in the phase 2 specifications, such as caller identification, call waiting, and multiparty conversations.

Code Division Multiple Access. *CDMA* is a spread spectrum technique for multiple access. In *CDMA*, each user is assigned a pseudonoise (*PN*) code to modulate transmitted data. The PN code is a long sequence of ones and zeros similar to the output of a random number generator of a computer. The numbers are not really random, but a special algorithm makes them appear to be. Because the codes are nearly random, there is very little correlation between them. In addition, there is very little correlation between a specific code and any time shift of that same code. Thus, the distinct codes can be transmitted at the same time and over the same frequencies and the signals can be decoded at the receiver by correlating the received signal (which is the sum of all transmitted signals) with each PN code.

With the growing interest in integration of voice, data, and imagery traffic in telecommunication networks, *CDMA* appears increasingly attractive as a wireless access method. For cellular telephony, *CDMA* is a digital multiple access technique specified by the Telecommunications Industry Association (*TIA*) as IS-95. In March 1992, the TIA established the TR-45.5 subcommittee with the charter of developing a spread spectrum digital cellular standard. In July 1993, the TIA gave its approval of the *CDMA* IS-95 standard. IS-95 systems divide the radio spectrum into carriers that are 1250 kHz (1.25 MHz) wide.

One of the unique aspects of *CDMA* is that while there are certainly limits to the number of phone calls that can be handled by a carrier, it is not a fixed number. Rather, the capacity of the system will be dependent on a number of different factors, including the bandwidth efficiency, the number of sectors in each base station antenna, the voice activity factor (what percentage of the time the voice is active), and the interference increase factor.

The cordless telephone and the paging technologies are relatively simple. The importance of these services is in their direct effect on people's lives and the large market that they gained in a short time. Marketable technologies of this sort generate substantial capital and consequently allow more advanced technologies to expand their applications. Exploration of the second generation digital cordless services started in 1982 in United Kingdom with the CT-2. Second World War wiring of the UK infrastructure and the high cost of new wiring in the brick buildings were among the major causes for early interest for further development of the cordless telephone industry in the United Kingdom.

In 1985 the digital enhanced cordless telecommunication (*DECT*) standard for wireless PBX services was promulgated in Europe. The idea of PCS appeared in the late 1980s and early 1990s. The basic differences between the digital cellular and PCS services were perceived to be those that are shown in Table 2.

The first commercially available PCS services were PHP in Japan and DCS-1800 in the United Kingdom. The name PHP was later on changed to PHS. PHS is a new standard that conforms with the specifications of Table 3. DCS-1800 uses the GSM standard at 1800 MHz, which does not conform with the PCS specifications in the table. However, both technologies are very successful in the market. Auction of the PCS bands in the United States started in 1995, and during that year \$7.7 billion worth were auctioned. By 1999 this had grown to around \$20 billion.

The PACS standard, which is a full-duplexed, high power version of the PHS, was finalized in 1995. PACS provides two versions for unlicensed and licensed PCS bands. The technologies that are expected to evolve in the PCS bands are PACS, DCS-1900, IS-136 (modified IS-54), DECT, and *CDMA*. Table 2 shows the historical summary of the PCS and digital cellular technologies. Table 4 compares the technical aspects of the major digital cellular and PCS standards. The PCS bands are also considered for new applications such as wireless access to the Internet and wireless local loops.

Table 5 shows the history of wireless voice services.

Mobile Data Services. The commercial packet-switched mobile data services emerged as a sequel to the success of the short message one way paging systems. Mobile data networks provide two way low speed data communication links with some restrictions on the size of the message (10 kbyte to 20 kbyte in the early systems). The first commercial mobile data network was ARDIS, a private network developed between IBM and Motorola in 1982 to provide wireless access to the computing facilities for personnel in the field.

Table 2. PCS and Cellular Specications

Specication	PCS	Cellular
	System Aspects	
Cell size	5–500 m	0.5–30 km
Coverage	Zonal	Comprehensive
Antenna height (m)	15	15
Vehicle speed (km/h)	5	200
Handset complexity	Low	Moderate
Base station complexity	Low	High
Spectrum access	Shared	Exclusive
	Design Aspects	
Average handset power (mW)	5–10	100–600
Speech coding	32 kbit/s ADPCM	7–13 kbit/s vococ
Multipath mitigation	Antenna division (optional)	Div./equal./Rake
Duplexing	Usually TDD	FDD
Detection	Noncoherent	Coherent

Table 3. Digital Cellular

System	IS-95	GSM	IS-136	PDC
Region	Worldwide	Worldwide	Americas	Japan
Access Method	CDMA	TDMA/FDMA	TDMA/FDMA	TDMA
Freq. Band (MHz)	824–849 869–894 1850–1910 1930–1990	890–915 935–960 1710–1785 1805–1885 1850–1910 1930–1990	824–849 869–894	810–826 940–956 1477–148 1429–144 1501–151 1453–146
Carrier Spacing (kHz)	1250	200	30	25
Channels per Carrier	Soft capacity	8	3	3

Table 4. Digital Cordless

System	CT-2/CT-3	DECT	PHS	PACS
Region	Europe, Canada	Europe	Japan	US
Access Method	FDMA	TDMA/FDMA	TDMA/FDMA	TDMA/FDMA
Freq. Band (MHz)	864–868 944–948	1880–1900	1895–1918	1850–1910 1930–1990
Carrier Spacing (kHz)	100	1728	300	300
Number of Carriers	40	10	77	16 per pair
Channels per Carrier	1	12	4	8 per pair

General services provided by mobile data networks can be classified as follows:

- Transaction processing: credit card verification, vehicle theft, paging, notice of voice or electronic mail, etc.
- Broadcast services: general information services, weather and traffic advisories, advertising.
- Interactive services: terminal access to host, remote LAN access, games.
- Multicast service: subscribed information services, law enforcement, private bulletin boards.

In 1986, Swedish Telecomm and Ericsson introduced the Mobitex technology. In 1991, RAM Mobile started to distribute this service in the United States. In the same year IBM and nine operating companies announced the formation of the cellular digital packet data (*CDPD*) forum to develop an open standard for multi vendor environment for a packet switched network using the physical infrastructure and frequency bands of the AMPS systems. The CDPD specification was completed in 1993, and deployments are in progress.

Table 5. History of Wireless Voice Services

Exploration of rst generation mobile radio at Bell Labs	Early 1970
First generation cordless phones	Late 1970
Exploration for second generation digital cordless CT-2	1982
Deployment of rst generation Nordic analog NMT	1982
Deployment of US AMPS	1983
Exploration of the second generation digital cellular GSM	1983
Exploration of wireless PBX DECT	1985
Initiation for GSM development	1988
Initiation for IS-54 digital cellular	1988
Exploration of the QUALCOMM CDMA technology	1988
Deployment of GSM	1991
Deployment of PHS/PHP and DEC-1800	1993
Initiation for IS-95 standard for CDMA	1993
PCS band auction by FCC	1995
PACS nalized	1995

Table 6. Mobile Data Services

System	ARDIS	Mobitex	CDPD	TETRA	Metricom
Frequency Band (MHz)	(800 bands, 45 kHz separation)	935–940 896–961	869–894 824–849	380–383 390–393	902–928 (ISM bands)
Channel Bit Rate (kbit/s)	19.2	8.0	19.2	36	100
RF Channel Spacing (kHz)	25	12.5	30	25	160
Channel Access/Multi-user Access	FDMA/ALOHA	Slotted ALOHA	FDMA/ALOHA	ALOHA	FHSS/BTMA
Modulation Technique	4-FSK	GMSK	GMSK	p/4-DQPSK	GMSK

The European Telecommunications Standard Institute (*ETSI*) standard for mobile data services is TETRA, which was completed in 1998 and for the time being is supporting a vertical market, primarily for security. More recently, the digital cellular standards such as GSM, IS-95, PHP, PACS, and IS-54 have been updated to support packet-switched mobile data services at a variety of data rates.

Table 6 provides a comparison among the existing mobile data services. The early market predictions for the mobile data services were expecting 13 million users in the United States by the turn of the century. However, the growth of the market so far is well below the predicted value. Table 7 shows the history of wireless data services.

In 1970 engineers at the University of Hawaii performed an experiment with radio as the medium for sending and receiving computer data in short self-contained informational bursts called *packets*. The Hawaii researchers used packets because they realized that it was not necessary for a computer to communicate with another on a continuous basis. Computers could communicate at appropriate times between computational tasks, leaving time between transmissions for other computers to transfer their data. The University of Hawaii system, referred to as ALOHA, used two radio channels: one multiaccess channel sharing among a number of remote radio-equipped terminals to reach a central radio-equipped computer and one channel for the central computer to transmit responses back to the terminals. The US Department of Defense began to study packet radio for military computer communications. Under the government's Defense Advanced Research Projects Agency (*DARPA*), the *ALOHA* packet radio communication system was extended to include mobile packet radio users. Each user in the DARPA network of mobile stations, which was called the PRNET, shared the identical frequency. Each mobile user also had the ability to relay or repeat packets from site to site on a flexible basis, as DARPA's dynamic network was intended to be effective in combat situations where some stations

Table 7. History of Wireless Data Services

Diffused infrared	1979 (IBM Rueschlikon Labs Switzerland)
Spread spectrum using SAW devices	1980 (HP Labs, Californi
Wireless modems	Early 1980s (Data Radio)
ARDIS	1983 (Motorola/IBM)
ISM bands for commercial spread spectrum applications	1985
Mobitex	1986 (Swedish Telecom and Ericsson)
IEEE 802.11 for wireless LAN standards	1990
Announcement of wireless LAN products	1990
RAM mobile	1991 (Mobitex)
Formation of WINForum	1992
ETSI and HIPERLAN in Europe	1992
Release of 2.4, 5.2, and 17.1–17.3 GHz bands in EC	1993
PCS licensed and unlicensed bands for PCS	1993
CDPD	1993 (IBM and 9 operati companies)
IS95	1994 (Qualcomm)
Mobile broadband systems	1996

might be lost and few would remain in fixed geographical locations for very long. The PRNET was intended to keep the various tactical computer units coordinated and talking to each other regardless of combat conditions.

Synchronous protocols are the most efficient for use over radio networks. The stop and start bits in asynchronous data communications would reduce the throughput of the link by at least 25%, depending on the number of stop bits used. A version of X.25 known as AX.25 has been formulated for use on radio networks by the American Radio Relay League (*ARRL*) and the Amateur Satellite Company (Amsat). It contains a certain amount of overhead, but in most cases it is more efficient than asynchronous transmissions.

AX.25 allows for high speed (up to 19.2 kbaud), error-free digital communications over radio. The frequencies used are in the VHF and UHF region, in particular the 144 MHz, 220 MHz, and 440 MHz bands, with some activity on microwaves as well. Besides communications via shortwave gateways (shortwave stations hooked up to the packet net) and satellites, there are also bulletin board systems (*BBSs*), and AX.25 makes it easy to have large digital conferences at will. It also doesn't use the phone lines, making communications free. The lack of a forward error-correcting code in AX.25 is one great deficiency. The other deficiency is using a go back N retry algorithm rather than a selective repeat algorithm. The latter would be far better in a radio environment because of its greater spectral efficiency.

Recently, DARPA has been involved in several telecommunications projects for defense-related activities. The Global Mobile Information Systems (Glomo) project recognizes the fact that most tactical military units are heavily dependent upon wireless communications, and the inherent unreliability of wireless communications has necessitated research that enhances technologies at the communications channel level, the networking level, and the software application level in order to compensate for the inherent shortfalls in mobile wireless channels. Several subprojects focus on adaptive wireless networking, support for distributed multimedia applications over wireless networks, network protocols, waveforms, etc. (2).

Another important DARPA project is the Small Unit Operations–Situation Awareness System (SUO–SAS) project, which considers innovative ideas that employ highly advanced communications, geolocation, communications networking, and situation awareness technologies. The primary objective of the SUO–SAS program is to develop a communications and situation awareness system for tactical ad hoc connectivity among widely dispersed individual warfighters operating in highly restrictive RF propagation environments such as inside and/or adjacent to buildings, tunnels, and other urban structures, caves, mountainsides, and natural overhangs, and under double canopy foliage in jungles and forests. The basic system will be designed to support deployments of 1 to 70 small teams of 8 to 30 warfighters each operating over an area of approximately 200×200 km (40,000 km^2). This should be accomplished with minimal installed infrastructure. The SAS should have the capability of scaling upward to support larger teams and forces and larger areas of coverage (3).

Wireless Local Area Networks

In this section we discuss wireless local area networks (*WLANs*) that provide high bandwidth data access to users in limited geographical areas like their wired counterparts. We discuss the IEEE 802.11 and HIPERLAN standards and European activities in this area. Wireless *LANs* provide very high data rates (above 1 Mbit/s) in a local area ($<$ 100 m). Since the demand for the data rate is very high and the distances are very short, a variety of modem design technologies can be adopted.

Many factors are important in *WLAN* performance, such as application types (4), channel characteristics, type of protocol, and access method. In *WLAN* design and implementation, other factors such as cost and availability also should be considered. For real-time traffic such as voice, some other criteria such as delay are considered as well (5). The effect of a naturally hidden terminal that reduces the throughput because of the limited range of its antenna should be evaluated carefully (6). These design criteria are satisfied by a range of technologies that are available for physical layer of the *WLAN*, such as radio access or infrared access.

The implementation of the first experimental wireless LAN using diffused infrared (*DFIR*) technology was explored in IBM Reschelicon Laboratories in Switzerland in the late 1970s (7). Almost at the same time, another experimental project at HP laboratories in California considered the direct sequence spread spectrum technology for this purpose. The first attempt at implementation of a wireless LAN in 1.7 GHz bands was initiated at Codex/Motorola in Massachusetts. In 1985 HP Laboratories developed an experimental directed beam IR (*DBIR*) *LAN*. None of these efforts ended in development of a product. In May 1985 the *FCC* released the unlicensed ISM bands to be used with DSSS and frequency-hopping spread spectrum (*FHSS*) technologies. In 1990, the first wireless LAN products appeared on the market, and IEEE 802.11 was formed to develop a standard for wireless *LANs* at 1 Mbit/s and 2 Mbit/s. In 1992, ETSI chartered the RES-10 committee to develop a standard for the HIPERLAN, and the WINForum was formed by the Apple Computers in the United States to obtain bands for the so-called data PCS.

IEEE 802.11. The IEEE standard for *WLANs* started in 1988 as IEEE 802.4L, a part of the IEEE 802.4 token bus wired LAN standard. In 1990 the IEEE 802.4L changed its name to IEEE 802.11 to form a standalone *WLAN* standard in the IEEE 802 LAN standards organization. The technical aspects of this standard (5) were completed in 1998. Throughout this unexpectedly long endeavor, the 802.11 group developed a framework to incorporate wireless-specific issues such as power control, frequency management, roaming, and authentication in a LAN standard. The IEEE 802.11 standard was based on existing products in the market, and so it addresses both technical and marketing issues. The 802.11 standard (7, 9) specifies data rates up to 2 Mbit/s using spread spectrum technology in the 2.4 GHz ISM bands.

In addition to the contention-based CSMA/collision avoidance (*CSMA/CA*) access method suited for asynchronous data applications, the IEEE 802.11 also supports a contention-free prioritized mechanism to support time-bounded isochronous applications. The medium access control (*MAC*) services in the IEEE 802.11 support authentication, encryption, frequency management, and power conservation mechanisms that are not available in the MAC layer of other 802 standards such as 802.3.

Table 8. Terms Used by the IEEE 802.11 Standards Committee

Access point (AP)	A device used to bridge the wireless–wired boundary, or to increase accessible distan as a wireless packet repeater.
Ad hoc network	A network composed solely of stations with mutual communication range of each oth via a wireless medium. An ad hoc networl typically created in a spontaneous manne
Association	A function that maps a station to an AP.
Basic service area (BSA)	The conceptual area within which members a BSS can communicate.
Basic service set (BSS)	A set of stations communicating wirelessly the same channel in the same area.
BSSID, ESSID	Data elds identifying a station's BSS and ESS.
Channel	A radio frequency or infrared band used for shared communication.
Clear channel assessment (CCA)	A station function used to determine when is O.K. to transmit.
Distributed coordination function (DCF)	A coordination function such that the same logic is active in every station in the BSS whenever the network is in operation. In 802.11 it is based on contention among s tions to access the channel.
Distribution system (DS)	A system used to interconnect a set of BSSs and integrated LANs to create an ESS.
Distribution system services (DSS)	The set of services provided by the distribu system that enable the MAC to transport MSDUs between stations that are not in d rect communication with each other over single wireless medium.
Extended service set (ESS)	A set of BSSs and wired LANs with APs that appear as a single logical BSS.
Infrastructure	Includes the DS medium, AP, and portal ent ties, as well as being the logical location c distribution and integration service functions of an ESS. An infrastructure contain one or more APs and zero or more portal addition to the DS.
MAC protocol data unit (MPDU)	A data frame passed between MAC and PHY
MAC service data unit (MSDU)	A data frame passed between user and MAC
Point coordination function (PCF)	A possible coordination function whose logi active in only one station in a BSS at any given time that the network is in operatio In 802.11, it is based on contention-free a cess to the channel.
Portal	The logical point at which MSDUs from an i tegrated, non-802.11 LAN enter the DS of an ESS.

The material presented in this section summarizes the key issues in the standard. Table 8 provides a glossary of the terms used in its body. The overall architecture and the physical and MAC layers are described in the following sub-subsections.

Architecture. The 802.11 standard considers two network topologies: infrastructure-based and ad hoc (see Fig. 2). In an infrastructure network [Fig. 2(a)], mobile terminals communicate with the backbone network through an *access point* (*AP*). The AP is a bridge connecting the 802.11 network to the backbone wired infrastructure. In 802.11 a *basic service set* (*BSS*) is defined as a set of wireless stations communicating on the same channel in the same area. The corresponding *basic service area* (*BSA*) is the conceptual area within which members of a BSS can communicate. In this context, an *extended service set* (*ESS*) is a set of BSSs and wired *LANs* with APs that appear as a single logical BSS. The *distribution system* (*DS*) is used to create the ESS by interconnecting a set of BSSs and integrated *LANs*.

In infrastructure configuration, a mobile terminal can roam among different BSSs in one ESS without losing the connectivity to the backbone. In ad hoc configuration [Fig. 2(b)], the mobile terminals communicate with each other in an independent BSS without connectivity to the wired backbone network. In this case some of the functions of the AP, such as release of a beacon with a defined ID and timing reference, that are needed to form and maintain a BSS are provided by one of the mobile terminals. The cells in both configurations shown in Fig. 2 can overlap with one another.

Direct communication among mobile terminals is also possible in the infrastructure configuration. The APs in infrastructure configuration supports roaming, which makes mobility possible among them. In the ad hoc configuration, the mobile terminals can only communicate with each other and there is no connectivity to the wired backbone network; therefore there is no access to fixed resources in that network. In both configurations, overlapped cells are allowed (8).

Figure 3 represents the MAC architecture of the 802.11 standard, which consists of the MAC entity, MAC management layer and the physical layer (*PHY*). The latter contains physical layer convergence protocol (*PLCP*), physical layer management (*PLM*), and station management. The MAC entity provides a basic access mechanism that will be explained in the sub-subsection entitled "Medium Access Control." The MAC entity is also responsible for privacy and access control. 802.11 provides an authentication mechanism that has provisions for *Open* (no authentication), *Shared Key*, and proprietary authentication extensions. 802.11 also specifies a data encryption algorithm called *wired equivalent privacy* (*WEP*) that is only for station-to-station (not end-to-end) traffic, and uses the RC4 PRNG algorithm developed by RSA Data Security Inc., which is based on a 40 bit secret key (no-key distribution standardized), and a 24 bit *initialization vector* (*IV*) that is sent with the data. Only payloads of data frames are encrypted. Another responsibility of the MAC entity sublayer is providing fragmentation and reassembly of data to cope with different PHY characteristics.

MAC layer management is responsible for synchronization, power management, association, reassociation, and management information base (*MIB*) maintenance. For synchronization the station should find and stay with a wireless LAN and, through a time synchronization function (*TSF*) timer, be in synchronization with the AP (in infrastructure mode) or other stations (in ad hoc mode) by getting the time information from beacons.

Most of the devices in which the 802.11 standard will be used have power limitations, and the power management section in MAC layer management is responsible for providing functionality that stations can sleep and save power without missing any messages (8). In power-saving mode with the infrastructure configuration, the AP should buffer all the frames that are sent to the doze station. The station periodically wakes up and listens to selected beacons sent by the AP. If the station hears a control frame indicating that the AP has queued data for the station, the station sends a special poll frame that tells the AP to send the data. In ad hoc configuration, the power-saving stations wake up for only short predefined periods of time to hear if they should remain on to receive a frame.

Other responsibilities of MAC layer management are associating (joining to) a wireless network, roaming (that is, moving from the coverage area of one AP to another one), and scanning for wireless *LANs*. Maintaining

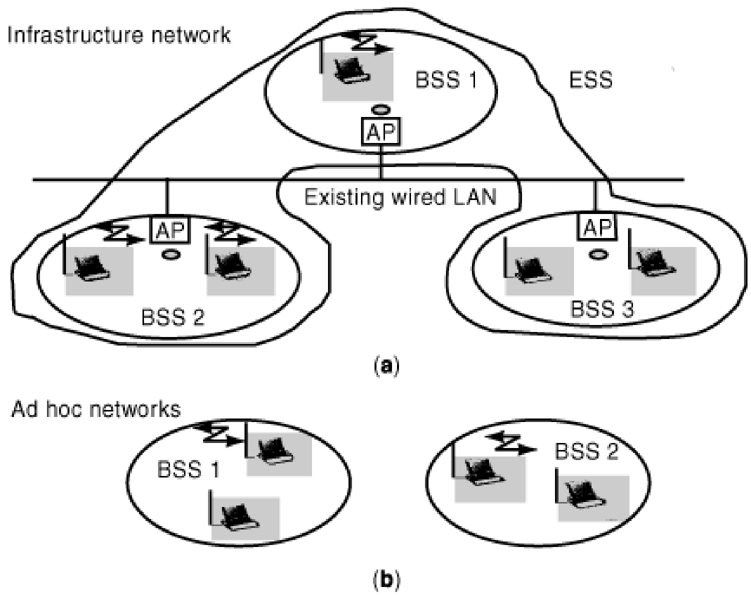

Fig. 2. Network topologies supported by IEEE 802.11 standard.

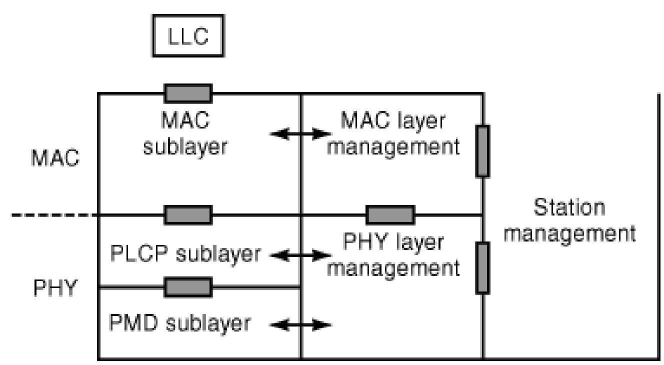

Fig. 3. 802.11 MAC architecture.

an MIB that has all the required parameters for MAC functions is the last responsibility of MAC layer management.

The physical layer convergence protocol (*PLCP*) sublayer provides carrier sensing, which in 802.11 is called *clear channel assessment* (*CCA*). Modulation and coding are done by a physical-medium-dependent (*PMD*) sublayer. PHY layer management is responsible for channel tuning and physical layer MIB maintenance. Interacting with both MAC management and PHY management is done by station management.

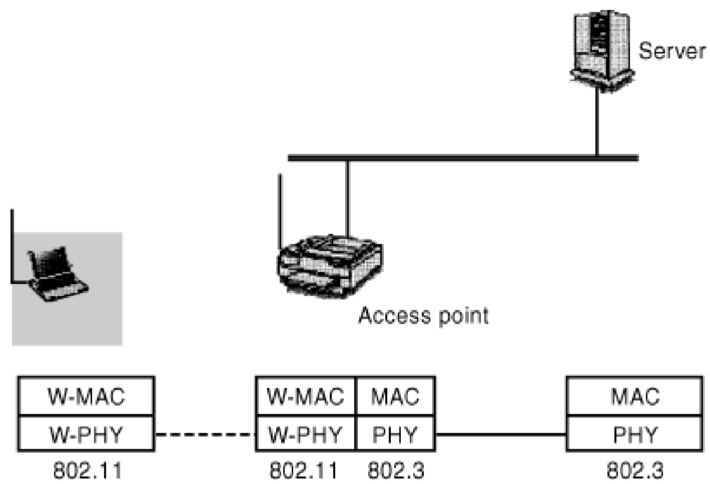

Fig. 4. Layered MAC Architecture in station and AP.

The above MAC architecture exists on all the stations in the 802.11 network. In an AP, in addition to the wireless MAC, a wired MAC (802.3) should be installed to access the wired backbone network. In this case the AP is acting as a bridge between wireless 802.11 protocol and wired backbone, as represented in Fig. 4.

Physical Layer. The 802.11 standard allows several different PHYs:

- Frequency-hopping spread spectrum (*FHSS*)
- Direct sequence spread spectrum (*DSSS*)
- Baseband infrared

Spread spectrum is a technique that enables coexistence of multiple networks or other devices in the same area. In FHSS the transmitter sends data on a given frequency for a fixed length of time and then switches to the next frequency. The transmitter and receiver should be in synchronization for pursuing the frequency pattern. The 802.11 frequency-hopping PHY uses 79 nonoverlapping frequency channels in North America and Europe and 23 hopping channels in Japan, with 1 MHz channel spacing in the 2.4 GHz to 2.4835 GHz ISM band with at most 1 W power. The frequency hopping enables operation of up to 26 collocated networks with high aggregate throughput because 26 frequency patterns are defined. Adjacent or overlapped BSSs should have different patterns to minimize interference. FHSS is resistance to multipath fading through the inherent frequency diversity mechanism. Gaussian shaped frequency-shift keying (*GFSK*) has been selected for FHSS modulation to achieve 1 Mbit/s or 2 Mbit/s data rate. FSK is selected because it is a well-known technology, field-proven and low cost. A predesigned computer-generated pseudorandom list of 79 frequencies has been provided in the 802.11 standard with a minimum hop distance of 6 channels (8).

In DSSS the signal symbol is spread with a 11 chip Barker sequence that needs wider bandwidth but less power density than FHSS. This coding gain (10.4 dB) makes DSSS robust against interference, noise, and time delay spread. DSSS can support multiple channels (11 overlapping channels, but only 3 of them are nonoverlapped), similar to those in FHSS, in the 2.4 GHz to 2.4835 GHz ISM band. Differential binary phase shift keying (*DBPSK*) and differential quadrature phase shift keying (*DQPSK*) are used to modulate DSSS at 1 Mbit/s and 2 Mbit/s respectively. In summary, since an FHSS system can offer a larger number of channels

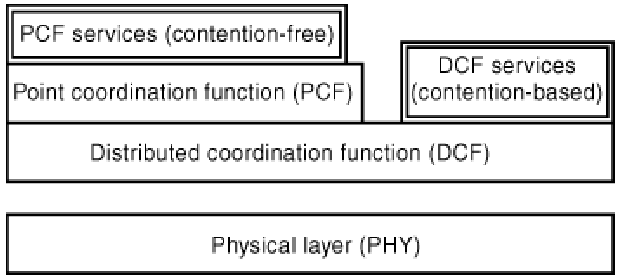

Fig. 5. Coexistence of PCF and DCF.

than a DSSS system, it is more useful for dense environments in which cells have overlaps with many adjacent cells.

The infrared PHY uses diffuse infrared transmission in a nearly visible frequency band (850 nm to 950 nm). The receiver and transmitter do not have to be in line of sight. This PHY is used only in building. The modulation technique for the 1 Mbit/s data rate is 16 pulse position modulation (*PPM*), and for 2 Mbit/s is 4 PPM.

In all PHYs, channel sensing is done by the CCA function. CCA is used to initiate frame reception and avoid transmitting when the channel is busy.

Medium Access Control. In 802.11 a single MAC supports multiple channel PHYs with different medium sense characteristics. Two access methods in general are provided in 802.11: distributed coordination function (*DCF*) and point coordination function (*PCF*). *DCF* uses contention for sharing the medium among different users, while PCF is contention-free. DCF is useful for transferring asynchronous traffic, and PCF for time-bounded or real time traffic. As shown in Fig. 5, both DCF and PCF can operate simultaneously in one network.

The basic access method for sharing channels in DCF is CSMA/CA, which is a listen before talk (*LBT*) protocol. Since the radio medium does not permit the use of a collision detection mechanism, (such as is used in CSMA/CD for wired *LANs*), CSMA/CA needs acknowledgment to detect collided frames. CSMA/CA also uses exponential backoff to reduce the likelihood of collisions. In this protocol, a random backoff time is distributed uniformly, and the upper range of the distribution, called the *contention window* (*CW*), will be doubled in each successive unsuccessful transmission. In the 802.11 backoff algorithm (in contrast with the 802.3 back-off algorithm), the backoff timer elapses only when the medium is idle. Figure 6 shows the primary access mechanism in 802.11 with an interframe space (*IFS*) that can take on three different values representing priorities for accessing the shared channel. The highest priority frames are transmitted using *short IFS* (*SIFS*). One of the highest priority frames is the acknowledgment frame, which uses the SIFS time delay. PCF has the next priority for accessing the channel, for transferring the time-sensitive frames.

DCF has the least priority and the longest IFS, which is named DCF IFS, or DIFS. Physical sensing of the carrier causes a hidden node problem in which a single receiving station can hear two different transmitters, but the two transmitter stations cannot detect the carrier signals of one another because they are too far apart. In this case the transmitters send frames without performing backoff and collision is highly probable. The 802.11 MAC provides a request-to-send/clear-to-send (*RTS*/*CTS*) mechanism as a solution to this problem by using channel reservation functionality based on a *net allocation vector* (*NAV*). The RTS frame requests the channel for some time interval that is stored in the NAV from the AP, and if the AP accepts this request, then it sends CTS with the time duration set. This notifies all stations in AP range not to initiate transmission.

The RTS/CTS mechanism (Fig. 7) is not suitable for short messages because of the overhead. Since 802.11 can reserve channel with RTS/CTS and the physical carrier is unable to show this reservation, another functionality, called *virtual carrier sensing*, is required to check whether the medium has been reserved or not.

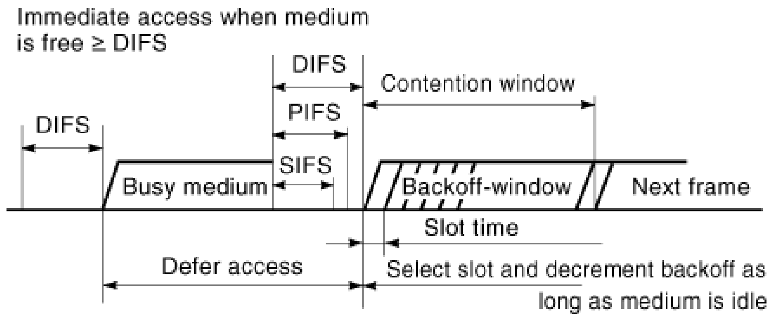

Fig. 6. CSMA/CA primary access mechanism.

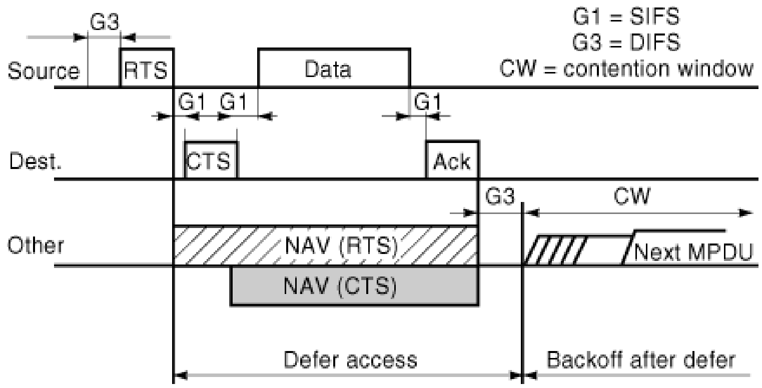

Fig. 7. RTS/CTS access mechanism.

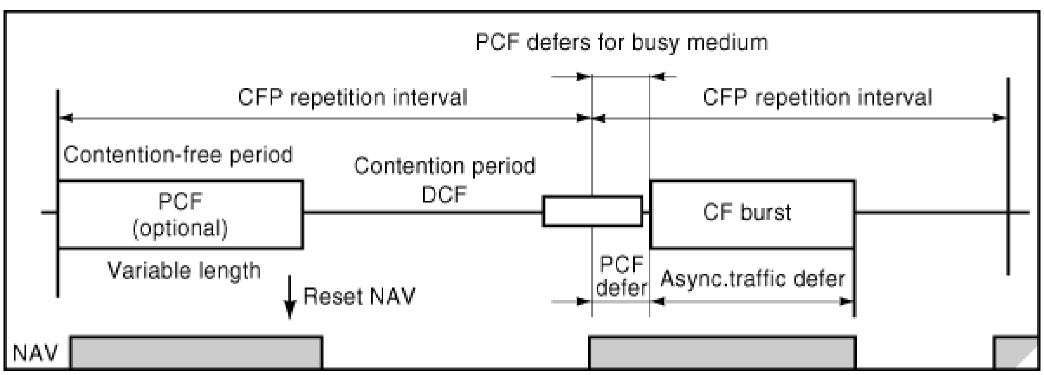

Fig. 8. Alternation of contention-free and contention periods under PCF control.

The 802.11 standard uses PCF (Fig. 8) to support time-bounded services. This access method is used in infrastructure configuration, and the AP is the point coordinator, which has priority control of the medium.

At the beginning of the contention-free period (*CFP*), the *AP* sends a beacon with its NAV set to the contention-free period to notify all the stations not to initiate transmissions for the CFP. PCF then allows a given station to have contention-free access through the use of a polling frame that is sent by the AP. At the end of CFP the AP sends a CF_END frame to notify stations that they can use the channel by contention. Both PCF and DCF defer to each other, causing PCF burst start variations.

Although 802.11 uses a CSMA-based protocol for the DCF access method, its features are much more complicated than other implementations such as 802.3. Comparing different features in 802.3 and 802.11 shows that collision detection and the single wired physical layer have simplified MAC protocol design in 802.3. The 802.3 MAC features are:

- Wired access for network connectivity
- Support of asynchronous data transfer at 10 Mbit/s
- Use of CSMA/CD (fast reaction to collision) for channel access
- Provision for stable and secure network access
- Provision for hub-based installation, which has lower wiring cost than ring and bus configurations

The 802.11 MAC features are:

- Support for isochronous as well as asynchronous data
- Support for priority
- Association/disassociation to an AP in a BSS or ESS
- Reassociation or mobility management to transfer association from one AP to another.
- Power management to save battery time
- Authentication to establish identity of the terminals
- Acknowledgment to ensure reliable wireless transmission
- Timing synchronization to coordinate the terminals
- Sequencing with duplication detection and recovery
- Fragmentation and reassembly

New Developments. The *inter-access-point protocol* (*IAPP*) is a protocol that specifies how APs from different vendors communicate with each other to support mobile stations roaming across cells and how they communicate across the backbone network to hand over mobile stations. The IAPP specification builds on the baseline capabilities of the IEEE 802.11 standard and uses higher-level OSI layers, such as logical link control, that facilitate inter-AP communications and support interoperability between products. Thus the specification should be applicable to a large infrastructure.

The IEEE 802.11 working group has set up two task groups to evaluate and propose standards for higher data rate physical layers. Task Group A is focusing on the unlicensed national information infrastructure (*U-NII*) bands around 5 GHz, in particular Lucent's proposal that uses OFDM with DBPSK, DQPSK, and 16-QAM to achieve data rates of 5 Mbit/s to 30 Mbit/s. Task Group B is considering physical layers based on proposals from Lucent/Harris, Alantro, and Micrilor in 2.4 GHz ISM bands. A wearable personal area network (*WPAN*) study group has been set up to develop a standard for wearable computers with a range of 0 to 10 m, data rates of less than 1 Mbit/s, low power consumption, small size ($\approx$ 0.5 in. 3 = 8 cm^3 without antenna), and low cost.

ETSI RES-10 HIPERLAN. The HIPERLAN standard (10,11,12,13,14) started in 1992, and a draft of the standard, from which this section was prepared, is available to the public. Following the structure of the last subsection on the IEEE 802.11, in this subsection, after providing the glossary (Table 9) of the standards committee, the architecture, physical layer, and MAC layer are introduced.

Architecture. The HIPERLAN network supports ad hoc configuration. Each node in the HIPERLAN network has a node identifier (*NID*). A HIPERLAN network identifier (*HID*) is used to differentiate HIPERLANs from each other. A HIPERLAN node that holds a HID is said to be a *member* of that HIPERLAN. Each node in the HIPERLAN network is recognized with the pair (*HID*, *NID*). The dynamic creation of HIPERLANs in

Table 9. HIPERLAN Terms

Ad hoc network	An application of HIPERLAN in which no xed structures exist.
Colocation tolerance	The minimum distance between two HIPERLAN nodes that are guaranteed to operat
Connection set	A subset of HIPERLAN nodes that are in direct radio communication range of each other.
HIPERLAN	A set of HIPERLAN nodes that have the san HID and that have the logical ability to interchange trafc.
HIPERLAN identier (HID)	A HIPERLAN subnetwork identier used to differentiate HIPERLANs from each other
Inter-HIPERLAN forwarding	A dynamic routing mechanism that enables HIPERLAN node to provide connectivity t nodes identied as being members of another HIPERLAN.
Intra-HIPERLAN forwarding	A dynamic routing mechanism that enables HIPERLAN node to provide connectivity within one single HIPERLAN.

the medium requires dynamic allocation of HIDs. HIPERLAN nodes may be members of several HIPERLANs simultaneously.

Since a HIPERLAN's shared radio channel is not readily bounded, *HIPERLAN overlap* may occur, in which multiple HIPERLANs' radio ranges overlap in the same radio channel. While wired *LANs* are implicitly distinct, HIPERLAN overlap does not make a HIPERLAN implicitly distinct. On the other hand, due to the limited radio range, mobile HIPERLAN nodes, and adverse propagation conditions, *HIPERLAN fragmentation* may occur, in which a HIPERLAN is effectively partitioned into multiple disjoint communication subsets. Therefore, a HIPERLAN needs to be identifiable so that a fragmented HIPERLAN can reemerge automatically whenever the radio environment allows.

Both HIPERLAN overlap and fragmentation call in principle for globally unique HIPERLAN identification that needs some kind of administrative coordination. This need for global coordination would make HIPERLAN deployment impractical. Therefore, the HIPERLAN MAC protocol uses a HIPERLAN identification scheme that does not enforce globally unique HIPERLAN identification. In the HIPERLAN identification scheme, each HIPERLAN is assigned a numerical HIPERLAN identifier and a character-based HIPERLAN name.

The HIPERLAN employs multihop routing to extend communication beyond the radio range. Each HIPERLAN node is neither a forwarder or a nonforwarder. A nonforwarder never forwards the packet that it has received, but a forwarder does when it is appropriate. *Intra-HIPERLAN forwarding* is used to forward packets within a HIPERLAN, and *inter-HIPERLAN forwarding* is used to forward packets between two different HIPERLANs. Inter-HIPERLAN forwarding needs bilateral cooperation and agreement between two HIPERLANs. Each nonforwarder node should select at least one of its neighbors as forwarder. In this case the node is called a source multipoint relay (*SMR*). HIPERLAN node should use some information bases for routing. The forwarder should establish and maintain the following information bases:

- *Neighbor Information Base.* Records the information about each communication link with its neighbors.
- *Hello Information Base.* Records the neighbor's provided information.
- *SMR Information Base.* Records the information about each of its SMRs.
- *Topology Information Base.* Records the information about each of the SMRs of other forwarders.

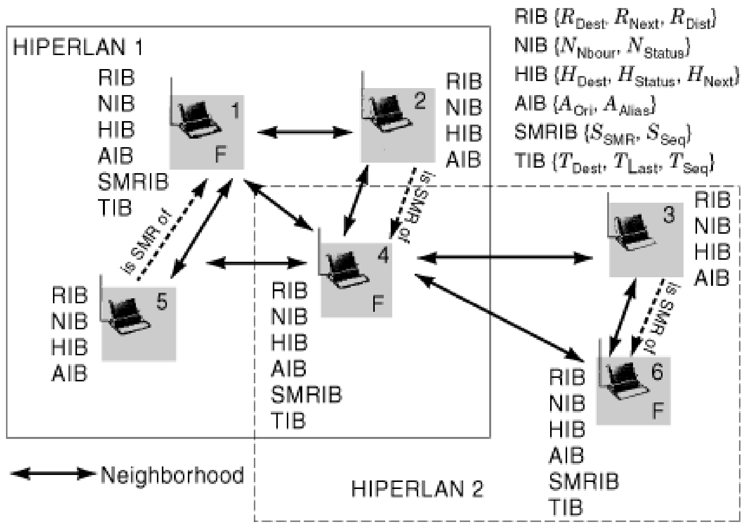

Fig. 9. HIPERLAN ad hoc network configuration.

- *Alias Information Base.* Records the information about the alias address of a node outside of the HIPERLAN.
- *Route Information Base.* Records the information about a route and is updated based on topology and neighbor information bases.

The nonforwarder has all the forwarder information bases except SMR and topology information bases.

Figure 9 shows an example of two HIPERLAN networks. The nodes with label F are forwarders.

The HIPERLAN MAC sublayer interfaces to the physical layer through an abstraction layer, which hides the mechanism of transmission to the MAC layer, called the *channel access mechanism* (*CAM*). Figure 10 shows the layered architecture and functionalities of the MAC layer.

The system coordination function (*SCF*) interface is responsible for:

- Creating a HIPERLAN and enabling an individual node to join or leave a given HIPERLAN
- Controlling encryption of data
- Enabling and disabling HIPERLAN forwarding
- Enabling cooperating HIPERLAN devices using power conservation techniques to communicate in a satisfactory manner
- Enabling HIPERLAN operation in a multichannel environment
- Collecting statistics

The data transfer service (*DTS*) provides the following:

- Local queuing and delivery of data
- Derivation of the CAM priority to provide a best attempt to meet the requested quality of service (QoS)
- Delayed transmission to provide a way to communicate with devices that are known to be implementing power conservation
- Encryption and decryption of data

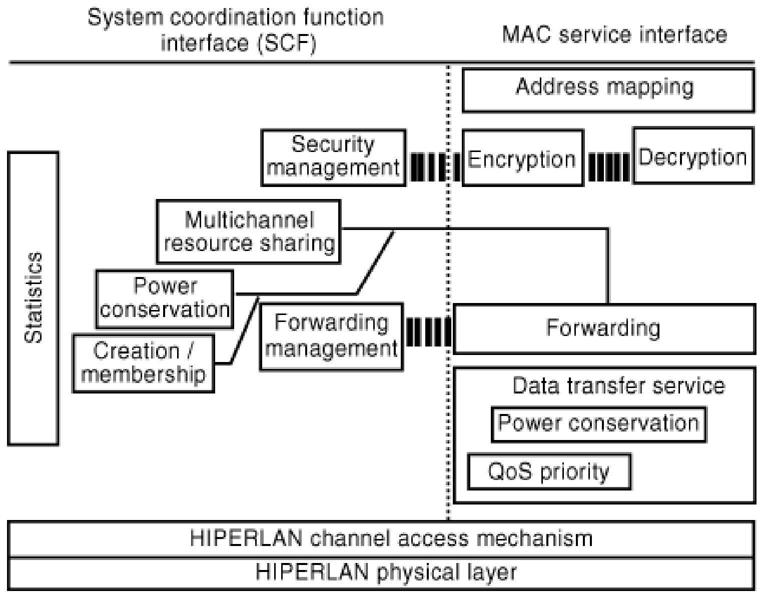

Fig. 10. System coordination function and MAC.

DTS will discard the frame if the QoS cannot be satisfied.

The forwarding scheme provides a means of point-to-point, multicast, and broadcast communications and is done in such a way as to minimize the number of replicated messages. The forwarding sublayer decides the route for the frames, based on the destination HIPERLAN address. Any change in a forwarder's neighbors results in the generation of sufficient topology information to enable all the forwarders within that HIPERLAN to update their forwarding tables.

Physical Layer. CEPT allocated the 5.15 GHz to 5.30 GHz band to HIPERLAN. For the high transmission rate (23.5294 Mbit/s) it uses nondifferential Guassian minimum shift keying (*GMSK*) modulation with bandwidth data rate product BT = 0.3, mainly for reducing the adjacent channel interference and for reasons of amplifier channel efficiency. It also uses error control forward error correction (*FEC*) and Bose-Chaudhuri-Hocquenghem (*BCH*) (31,26) coding. The coding scheme offers protection from at least two random errors and from burst errors less than 32 bits long. Data packets consist of multiple blocks of user data. Each block has 416 bits of user data, and there are at most 47 blocks per packet. The high bit rate of indoor use of HIPERLAN will require equalization to mitigate the effects of intersymbol interference. The standard specifies the use of a particular 450-bit training sequence in every data packet. For low transmission rate (1.470588 Mbit/s), FSK should be used. The HIPERLAN physical layer supports five channels, of which the lower three are available in all European countries and the upper two only in some countries. The channels are separated by 23.5294 MHz.

Medium Access Control. The MAC protocol is based on a carrier-sensing mechanism, but is quite different in its details from that used in IEEE 802.3 and 802.11. In the HIPERLAN access method, if the medium has been sensed free for a time accommodating more than 1700 bits, immediate transmission is allowed. If the channel is not free with the mentioned criterion, the channel access consists of three phases: prioritization, contention, and transmission.

Figure 11 represents different phases in the HIPERLAN access method. The prioritization phase is aimed at allowing only nodes having packets of the highest available priority to contend further for channel access. This phase consists of a number of slots, with a node having a packet with priority p transmitting a burst in

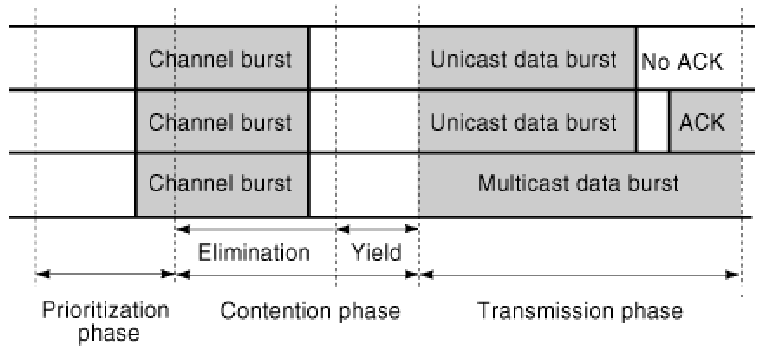

Fig. 11. The HIPERLAN access method.

slot $p+1$ if it has heard no higher-priority burst. At the end of the first burst on the channel, the prioritization phase ends and the contention phase begins. The contention phase consists of an elimination interval and a yield interval.

In the elimination interval, nodes that transmitted a burst during the prioritization phase now contend for the channel. This is achieved by each node transmitting a burst for a geometrically distributed number of slots and then listening to the channel for one time slot. If another burst is heard while listening to the channel, the node stops contending for the channel. Thus, only the node(s) with longest burst will, in the absence of the hidden terminal problem, be allowed to further contend for the channel.

Immediately after the longest burst and listening period of the elimination interval is the start of the yield interval. In this interval, each of the surviving nodes defers transmission for a geometrically distributed number of slots, while listening to the channel. At least one contending node will survive the yield interval.

After the yield interval in the contention phase, the transmission phase starts and the node(s) with winning contention status can transmit packet(s). If a broadcast transmission is required, the transmission is always successful from the access method point of view, but if a unicast transmission is required, the transmission is successful only if the transmitter receives an acknowledgment after transmitting the packet (14).

QoS has been addressed in the HIPERLAN standard through maximum transfer delay, delay variance, a discard parameter, and user priority. The maximum transfer delay will be updated during the lifetime of the packet as a residual transfer delay indication. The maximum packet transfer delay should be specified in integral milliseconds with a range of 0 to 32,767 ms (default value, 500 ms). When the demand on the channel is well below the channel capacity, the data transfer operations are merely based on the transit time delay parameter to get all packets within their deadline. On the other hand, when the demand on the channel exceeds the channel capacity, the scheduling algorithm uses the priority parameter to detect which packet will be transmitted and which one will be deleted.

The discard parameter and the don't-acknowledge-me (*DAM*) parameter are two other additional parameters that are supported for QoS. The discard parameter is related to the maximum statistical loss for given packet traffic. This parameter is not manageable on a per packet basis. A packet holding a higher discard parameter will have a greater chance of being selected and a greater chance of being transmitted before the expiration of its real residual transit delay parameter. The DAM parameter shows that the packet should not be acknowledged.

HIPERLAN supports power conservation mode (*PCM*) for power saving. Any HIPERLAN node wanting to operate in PCM will broadcast a packet indicating its intention to use periodic sleep states. For getting

Table 10. Comparison of WLAN Standard Technologies

Standard	Frequency Band	Modulation Technique	Data Rate (Mbit/s)	Access Method	Topologies	MAC Services	QoS	Availability
802.11	Spread spectrum direct sequence: 2.4–2.4835 GHz; frequency hopping: 2.4–2.4835 GHz; diffused infrared: 850–950 nm	Spread spectrum direct sequence: DBPSK, DQPSK; spread spectrum frequency opping: 2GFSK, 4GFSK, BT 0.5; diffused infrared: 16 and 4 PPM	1 and 2	Basic CSMA/CA, RTS/CTS, PCF with polling list, 20 frames	Ad hoc, infrastructure	Authentication encryption, power conservation, time-bounded services	No explicit support for QoS, but includes infrastructure topology and priority scheme in PCF that are useful for quality assurance.	Technical standard nalized. Products (e.g. DEC Roamabout) and chipsets (e.g. Harris PRISM and Raytheon RAYLINK) are available.
HIPERLAN	5.15–5.30 GHz	Low bit rate: FSK; high bit rate: GMSK (BT 0.3)	1.47 and 23.53	Nonpreemptive multiple access (NPMA), 10 PDU	Ad hoc	Encryption, power conservation, routing and forwarding, time-bounded services	Advanced user priority scheme and packet lifetime mechanism to support QoS.	Standard is nalized. No product on the market. Two prototypes: HIPERION, fully standards compliant, and LAURA, not fully compliant

[a] Ref. 7.

the broadcast messages, a *sleeping broadcaster* (*SB*) should be defined by node. In Table 10, we provide a comparison of IEEE 802.11 and HIPERLAN technologies.

BRAN. In continuation of the HIPERLAN project, a new project has been initiated by EC Advanced Communications Technologies and Services under the name Broadband Radio Access Networks (*BRAN*) (15) for covering licensed and license-exempt applications. These broadband radio access networks are to be capable of efficiently carrying existing services such as voice and *ISDN*, as well as providing the transport mechanisms for future services. Both circuit-oriented and packet-oriented transport protocols, including *ATM*, are to be supported at a peak rate of at least 25 Mbit/s at the user network interface. The main application environments to be addressed with licensed broadband access systems are residences and small to medium business premises. The main application environments for license-exempt broadband access systems are general office use, industrial automation, and audiovisual production.

BRAN will provide an alternative to or compete with wired access systems delivering telecommunications services into and within residences and businesses via transport mechanisms such as asymmetric digital subscriber line (*ADSL*), very high speed digital subscriber line (*VDSL*), and cable modems. It is also intended that BRAN should support global multimedia mobility (*GMM*) targets.

BRAN will provide specifications for broadband fixed radio and cordless premises access systems. Services on BRAN are core-network-independent, and therefore POTS, (*B)-ISDN*, *ATM*, frame relay, and TCP/IP are supported via interworking specifications.

Table 11. ETSI BRAN Activities

System	Total Spectrum Requirement (MHz)	Part of Spectrum (GHz)	Minimum Contiguous Block Size
HIPERLAN 1, 2, and 3	100	5.150–5.250	Already allocated.
HIPERLAN 1, 2, and 3	Extra 150 (min.)	P5 GHz	100 MHz
HIPERLAN 4	200 (min.)	17.1–17.3	
Semirural BRAN FWA	150 (min.) per operator	10	To be determine
Urban BRAN FWA	1500 per operator	10	To be determine

The following items are among BRAN's technical objectives:

- Provision of multimegabit data rates per end user
- Support for multimedia applications and services such as Internet and video on demand (such services typically require variable, often very asymmetrical data rates as well as control over QoS on a connection basis)
- Support for *ISDN* and low rate services such as POTS
- Interworking with public, private, and corporate networks
- Support for access and communications security consistent with the privacy needs of users and the accounting needs of network operators and users
- provision for network management features necessary to support unattended operation and remote management.

BRAN supports different network types with data rates of 25 Mbit/s 155 Mbit/s as follows:

- HIPERLAN/2 provides high speed (25 Mbit/s typical data rate) communications between portable computing devices and broadband *ATM* and internet protocol (*IP*) networks, and is capable of supporting multimedia applications. The typical operating environment is indoors. User mobility is supported within the local service area.
- HIPERACCESS (or HIPERLAN/3) provides outdoor, high speed (25 Mbit/s typical data rate) radio access, provides fixed radio connections to customer premises, and is capable of supporting multimedia applications. (Other technologies such as HIPERLAN/2 might be used for distribution within the premises.) HIPERACCESS will allow an operator to rapidly roll out a wide area broadband access network to provide connections to residential households and small businesses. However, HIPERACCESS may also be of interest to large organizations wishing to serve a campus and its surroundings and to operators of large physical facilities such as airports and universities.
- HIPERLINK (or HIPERLAN/4) provides very high speed (up to 155 Mbit/s data rate) radio links for static interconnections and is capable of multimedia applications; a typical use is the interconnection of HIPERACCESS networks and/or HIPERLAN APs into a fully wireless network.

The precise needs of the BRAN project are still evolving. However Table 11 attempts to clarify the current position with regard to spectrum for both license-exempt *WLANs* and licensed, fixed wireless access (*FWA*) networks.

In general, the project will produce standards and specifications that are independent of the licensing regimes, which are determined by regulatory authorities. The standard has been scheduled at mid 1999 for the first draft and will be finalized by 2002.

Wireless Local Loop Technology

From the beginning of telephony, the local loop connection from the central office to the subscriber has been furnished by twisted copper wire pairs. Today's wireless technologies can also provide local loop connectivity. As the cost of deploying such technology decreases to a level comparable to that of deploying copper wires, the decision to use wireless local loop technology depends on its other relative advantages and disadvantages.

Wireless local loop (*WLL*) technology (16, 17) offers one solution to provide network access for telecommunication terminals. Various wireless technologies can provide access to the telephone network, including point-to-point and point-to-multipoint microwave, cellular mobile radio, (*PCS*) [or, equivalently, personal communications networks (*PCN*)], wireless PBX, and satellite systems. A wireless PBX uses small base stations to connect mobile phones to a PBX within a building. These base stations provide radio coverage to one or more rooms or floors using small (pico) cells, with handover from cell to cell to allow the mobile user to roam throughout a building. The wireless PBX either uses an unlicensed frequency band, or uses the cellular band in a low power version that allows sharing of frequencies without interference.

Many WLL systems are based on cellular or PCS technology, either analog (*AMPS*, *TACS*, etc.) or digital (*GSM*, *DECT*, *PDC*, *CDMA*, etc.).

Subscribers in a WLL system receive phone service through terminals linked by radio to a network of base stations. The WLL terminals may be handsets that allow the subscriber varying degrees of mobility, they may be integrated desktop phone and radio sets, or they may be single- or multiple-line units that connect to one or more standard telephones. Terminals may be mounted indoors or outdoors, and they may or may not include battery backup for use during line power outages. The differences in WLL terminal designs reflect the use of different radio technologies in wireless local loop systems and the varying levels of services that can be supported—from POTS to advanced broadband services.

The base stations in a WLL system are deployed as needed to provide the necessary geographic coverage, with each base station connected back to the telephone network by wireless links. The extent of the coverage area is determined by the transmit power and the frequencies at which the base station and subscriber terminal radios operate, by the associated local propagation characteristics depdending on the local geography and terrain, and by the radiation patterns of the base station and subscriber terminal antennas. Direct connection to *PSTN* switches can be through either analog or digital interfaces. Analog two- or four-wire interfaces are provided by all central office switches to support copper line local loops, and some WLL systems are able to use them effectively. Digital interfaces using 64 kbit/s PCM voice channels, on the other hand, can be more convenient and less expensive. In particular, the V5.2 landline digital interconnect standard has been standardized by ETSI as the recommended open digital interface between a landline switching office and a WLL system, remote switch unit, or PBX.

The work on WLLs is being carried out in ITU-R by the Joint Rapporteurs Group 8A-9B (18). This group is formed by experts of ITU-R Working Party 8A and 9B, responsible for the mobile and fixed services aspects of WLLs, respectively.

Broadband Wireless Access

Current broadband wireless access (18, 19) data rates over individual circuit paths range from about 1.5 Mbit/s to 45 Mbit/s, and are expected to reach at least 310 Mbit/s within the next few years, as radios utilizing higher order modulation schemes become available (see Recommendation ITU-R F.758-1). The variety of possible broadband wireless access network configurations includes: conventional point-to-point (P–P), conventional point-to-multipoint (P–MP), and combinations of them such as P–P systems deployed in multisectored P–MP configurations. These systems are predominantly deployed in dense urban, suburban, and campus environments.

Local Multipoint Distribution Service. Local multipoint distribution service (*LMDS*) is a broadband wireless P–MP communication system operating above 20 GHz (depending on the country of licensing) that can be used to provide digital two-way voice, data, Internet, and video services.

Various network architectures are possible within LMDS system design. The majority of system operators will be using P–MP wireless access designs, although P–P systems and TV distribution systems can be provided within the LMDS system. It is expected that the LMDS services will be a combination of voice, video, and data. Therefore, both *ATM* and IP transport methodologies are practical when viewed within the larger telecommunications infrastructure system of a nation.

Wireless system designs are built around three primary access methodologies: *TDMA*, *FDMA*, and *CDMA*. These access methods apply to the connection from the customer premise site to the base station, referred to as the upstream direction. Currently, most system operators and standards activities address the *TDMA* and *FDMA* approaches.

As LMDS wireless access systems evolve, standards will become increasingly important. Standards activities currently underway include activities by *ATM* Forum, Digital Audio Visual Council (*DAVIC*), *ETSI*, and the International Telecommunications Union (*ITU*). The majority of these methods use *ATM* cells as the primary transport mechanism.

Wireless *ATM*. The wireless *ATM* (*WATM*) model is based on a vision of the demand for wireless access to *ATM*-based networks, likely to evolve in the future. According to this vision, a *WATM* system is a customer premises network, owned and operated by the user. The operation environment is almost entirely indoors, and the system supports both fixed and mobile terminals. The mobile terminals can move up to the speed of walking while maintaining active connection to the network. The QoS supported by the wireless access should be close to that offered by a wired access.

The indoor operation environment and the high frequency used limit the size of the radio cells; usually at least one base station is needed for each room. The use of small cells gives the system the ability to support a large number of broadband connections simultaneously. The use of small cells will also increase the number of handovers. The bursty nature of the data requires the system to be most flexible; bandwidth should be dynamically available on demand. There are some ongoing projects in *WATM*, such as the European Advanced Communications Technologies and Services (*ACTS*) Wireless *ATM* Network Demonstrator (*WAND*) and a demonstrator at *NEC* (20).

To merge these *WATM* studies, the *WATM* working group of the *ATM* Forum was formed to create *WATM* standards. The work of this group started in 1996 and it is planning to develop specifications for the radio access, MAC layer, and mobility support for *WATM*. The standard is aiming for completion in 1999 so that products can appear on the market by the turn of the century.

IMT-2000/FPLMTS. These are third-generation mobile communications systems, now in a planning and specification stage, that will follow their second-generation counterparts such as digital cellular phones. IMT-2000 (21) stands for International Mobile Telecommunications, and the 2000 designation has been chosen because the goal is to launch services around the year 2000. FPLMTS, which stands for Future Public Land Mobile Telecommunication Systems, was the original name used by the ITU. The features of these systems include:

(1) High transmission speeds (below 2 Mbit/s and capable of' transmitting simple moving pictures)
(2) The realization of global services accessible anywhere in the world
(3) High quality in a mixed networks

IMT2000 supports a wide range of services based on those of the fixed telecommunication network and those specific to mobile users. Services will be available indoors and outdoors, and ranging from dense urban situations—including high intensity office use—through suburban and rural areas. Land, maritime, and aeronautical situations are included so that the user in a vehicle, on a ship, or in an aircraft will have continuous availability of services. Services range from basic wide area paging, through voice telephony (probably the prime requirement of the personal terminal) and digital data services, to audio and visual communications. The actual services obtained by a user depend on his or her terminal capabilities and subscribed set of services, and on the service set provided by the network operator.

The user of the personal terminal will be able to take it anywhere in the world and have access to at least a minimum set of services comprising voice telephony, a selection of data services, access to Universal Personal Telecommunication (*UPT*), and an indication of other services available.

FPLMTS covers the application areas presently provided by separate systems such as cellular, cordless, telepoint, mobile data, and paging. FPLMTS provide terminal mobility, i.e. the ability to move continuously over large areas while maintaining access to telecommunication services, and even while maintaining a call in progress. This mobility feature is inherent in radio access and the radio terminal itself. Additionally, logical separation of the user from the physical terminal is being considered for FPLMTS in order to introduce some additional security and flexibility.

UPT provides personal mobility, i.e. the ability for a UPT user to receive telecommunication services on any terminal in any network based on a unique, personal UPT number. UPT is currently being defined by ITU-T as an advanced concept for personal telecommunications. It includes personalized service profiles with variable routing tables and routing filters (based on, for example, time, calling party number, current registration point, or requested service). FPLMTS and UPT provide essentially complementary mobility, and FPLMTS is defined to support UPT, i.e., a UPT user using a FPLMTS terminal is able to receive UPT services as agreed between the UPT subscriber and the UPT service provider. There is no technical requirement that this FPLMTS network operator be a UPT service provider (i.e. implement all UPT features). If not, the FPLMTS network acts as an intermediate link between the UPT user (at the FPLMTS terminal) and the UPT service provider (having his own network).

The standardization of FPLMTS is targeted at implementation dates around the year 2000 and beyond. Therefore, new and evolving technologies on the telecommunications network side are fully considered. One such area is the concept and standardization of *intelligent networks* (*INs*). *FPLMTS* network issues are studied in close cooperation by ITU-R and ITU-T, and to a great extent as an integral part of ITU-T work on IN concepts and capabilities. Later versions of IN will include, in their switching and signaling standards, the management of mobile and radio access as a natural part of the protocols. This includes location registration/updating and paging as well as certain types of handover between radio cells.

The different service aspects and service environments for FPLMTS, and the importance of making the best use possible of the limited radio spectrum, call for a very flexible solution for the radio interface and its interworking with the transmission technology used in the fixed networks (e.g. dynamic resource on demand, within a fraction of a second). Broadband *ISDN* (*B-ISDN*) technologies will also be in an advanced stage when FPLMTS are introduced. Therefore, *B-ISDN* access and interworking and the flexibility of *ATM* transmission technology are taken into account, and efficient interworking with *ATM* will be specified. FPLMTS also need to be interconnected to many earlier analog and digital fixed networks.

FPLMTS are specified so that services can be provided by a standalone network with gateway connections to the fixed networks, including the *PSTN*, *ISDN*, and packet-switched public data network (*PSPDN*), as well as existing PLMNs. But it is equally possible to implement FPLMTS functionalities as an integral part of the nodes of the fixed network.

The evolution of FPLMTS is sketched in Figure 12.

Universal Mobile Telecommunication System. The Universal Mobile Telecommunication System (*UMTS*) (22) is a third generation mobile communication system currently being developed in Europe. *UMTS*

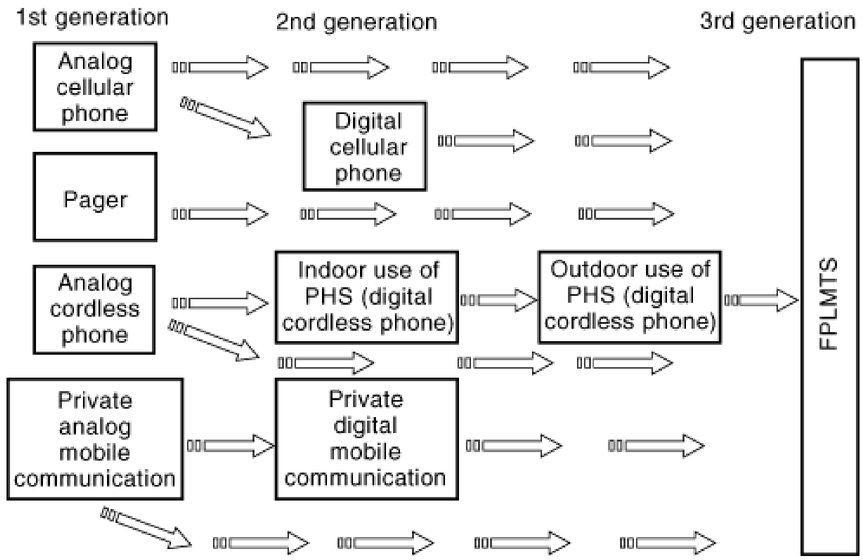

Fig. 12. Evolution third-generation wireless.

related activities are led by research conducted within the UMTS Forum program and standardization activities within the ETSI.

UMTS is designed.

- To support existing mobile services and fixed telecommunications services up to 2 Mbit/s
- To support unique mobile services such as navigation, vehicle location, and road traffic information services, which will become increasingly important in a pan-European market
- To allow the UMTS terminal to be used anywhere, in the home, the office, and the public environment, in both rural areas and city centers.
- To offer a range of mobile terminals from a low cost pocket telephone (to be used by almost anyone anywhere) to sophisticated terminals to provide advanced video and data services.

The UMTS Forum is a nonprofit organization that was set up in December 1996 to promote a common vision for the development of UMTS and to ensure its success as a worldwide radio system. The Forum has over 70 members and includes manufacturers, operators, regulators, the Commission, ETSI, and the CEPT.

In its regulatory framework report the Forum recommended that the full 155 MHz reserved for terrestrial UMTS should be made available for UMTS services by the year 2005. The CEPT is seen as the best route for making the required spectrum available throughout Europe, which is a vital prerequisite for the success of UMTS. For the global success of IMT-2000 (of which UMTS is the proposed European member), spectrum will be required worldwide, and the best mechanism for that is the ITU. It is expected that UMTS and IMT-2000 will be compatible so as to provide global roaming, but it is too early yet to say whether this goal will actually be achieved.

Other European Broadband Wireless Activities. The ACTS program in Europe is involved in several wideband wireless activities. In the Wireless Customer Premises Network/Mobile Broadband System (*WCPN/MBS*) domain there are four major wideband projects (23). The MEDIAN project is evaluating and implementing a wireless LAN capable of operating at 60 GHz and providing 155 Mbit/s. The prototype will demonstrate one base station at 155 Mbit/s and two portables, one at 34 Mbit/s and the other at 155 Mbit/s.

The Magic WAND project has demonstrated wireless *ATM* transmission at 5 GHz. The System for Advanced Mobile Broadband Applications (*SAMBA*) has developed an MBS trial of two base and two mobile stations operating at 40 GHz. The Advanced Wireless *ATM* Communications Systems (*AWACS*) is a cooperative project between Europe and Japan (*ACTS* and *NTT*). It is based on a 19 GHz *ATM* wireless LAN testbed already available through NTT and targets the development and demonstration of wireless access to *B-ISDN* services through this testbed. The terminals are of low mobility and operate at 19 GHz with data rates of up to 34 Mbit/s. This projects aims at investigating superhigh frequency (*SHF*) bands due to the shortage of spectrum at the lower frequencies in Japan.

Japanese Broadband Wireless Activities. In Japan (24) the Ministry of Post and Telecommunications (*MPT*) is the primary agency involved in future wideband wireless networks. Radio regulation was updated to provide 26 MHz of bandwidth in the 2.4 GHz band for small power data communications under IEEE 802.11. The major problem with this band appears to be the small bandwidth of 26 MHz, compared to 84 MHz available in the ISM bands in the United States. There is another 80 MHz of spectrum available for licensed local area radio stations at 19 GHz that is similar to the frequencies used by Motorola's ALTAIR product.

The more recent activity in Japan in local wideband wireless networks is related to the Multimedia Mobile Access Communication (*MMAC*) committee, which has proposed two systems for a mobile communication infrastructure that works seamlessly with fiber optic networks. Terminals such as notebooks and PCs that can operate both indoors and outdoors at 6 Mbit/s to 10 Mbit/s (high speed wireless access) and those that operate only indoors (desktops and workstations) without handoffs (ultrahigh speed radio LAN) systems, both operating at millimeter wave frequencies, are being investigated by MMAC. Equipment development in system design and fundamental RF technologies and standardization is expected to be completed by 2000, and commercial services are expected to start by 2002. An Ethernet group that will cooperate with IEEE 802.11 and an *ATM* working group to interact with ETSI–BRAN and *ATM* Forum have also been set up by the MMAC.

Satellite Networks

Low orbit telecommunication satellites have been around since the beginning of the space age. Satellites that are placed on geosynchronous orbits appear to be stationary for users on the Earth's surface, thus eliminating the need for tracking the satellite. This type of satellite has been used since 1965 for fixed and mobile applications. The general trend in telecommunication satellite services, and particularly mobile service, has been towards simplification of the ground segment. Significantly, for mobile services, attention has been focused on terminals rather than earth stations. Miniaturization of such terminals makes it possible to design mobile systems of high capacity compared with the present situation, where mobile communications by satellite are supported by geostationary satellites offering global coverage, which entail a low capacity system with bulky and costly terminals. One of the keys to the problem of simplification of terminals is the size of the cells forming the coverage area of the satellite. By narrowing the elementary beam that produces these cells, power required at the terminal decreases. Various solutions may be envisaged, including use of constellations of low earth orbit (*LEO*) satellites (altitude between 700 km and 1500 km) or medium earth orbit (*MEO*) satellites (altitude around 10,000 km).

LEO and MEO systems have the vantage of being able to form small beams on the ground (of the order of a few hundred kilometers in radius), but with on-board antennas of acceptable size. On the other hand, as LEO and MEO satellites are in drift orbit, several satellites are needed to ensure continuous service over a given area (the pass time of a satellite is of the order of a few minutes for *LEOs* and a few hours for *MEOs*). The next generation of mobile communications systems using LEO satellites should enable communications with portable terminals by around the year 2000. The second generation of these systems is expected to emerge by around 2010. User needs for this second generation are projected to include more personal services with multimedia capabilities.

The Iridium (25) consortium has completed successfully launching a constellation of 66 LEO satellites in a cross grid around the earth at a distance of 780 km to provide wireless connection between any two points on earth. Commercial paging and cellular telephony services began in late 1998. The Iridium system will employ a combination of *FDMA* and *TDMA* signal multiplexing to make the most efficient use of limited spectrum. The L band (1616 MHz to 1626.5 MHz), serves as the link between the satellite and the Iridium subscriber equipment. The Ka band (19.4 GHz to 19.6 GHz for downlinks; 29.1 GHz to 29.3 GHz for uplinks) serves as the link between the satellite and the gateways and earth terminals.

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