A Survey of Mobile Data Networks

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Abstract

The proliferation and development of cellular voice systems over the past several years has exposed the capabilities and the effectiveness of wireless communications and, thus, has paved the way for wide-area wireless data applications as well. The demand for such applications is currently experiencing a significant increase and, therefore, there is a strong call for advanced and efficient mobile data technologies. This article deals with these mobile data technologies and aims to exhibit their potential. It provides a thorough survey of the most important mobile packet data services and technologies, including MOBITEX, CDPD, ARDIS, and the emerging GPRS. For each technology, the article outlines its main technical characteristics, discusses its architectural aspects, and explains the medium access protocol, the services provided, and the mobile routing scheme.

Historically, wireless data communications was principally the domain of large companies with specialized needs; for example, large organizations that needed to stay in touch with their mobile sales force, or delivery services that needed to keep track of their vehicles and packages. However, this situation is steadily changing and wireless data communications is becoming as commonplace as its wired counterpart.

The need for wireless data communications arises partially because of the need for mobile computing and partially because of the need for specialized applications, such as computerized dispatch services and mobile fleet management.

Mobile computing, which aims to migrate the computing world onto a mobile environment, is affected primarily by two components: portability and connectivity. Portability, i.e., the ability to untether computers from the conventional desktop environment, is getting increasingly feasible because with the continuous improvement in integration, miniaturization, and battery technology, the differences in performance and cost between desktop and portable computers is shrinking. Therefore, the processing power of desktop computing is becoming available to portable environments and this is highly desirable as far as productivity is concerned.

Regarding the connectivity, i.e., the ability to connect to external resources and have access to external data, wireless data technology plays a significant part because it can offer ubiquitous connectivity, that is, connectivity at any place, any time. For this reason, wireless data technology can be of real value to the business world since computer users become more productive when they exploit the benefits of connectivity. The explosive growth of local area network (LAN) installations over the past several years is ample evidence of the importance placed on connectivity by the business world.
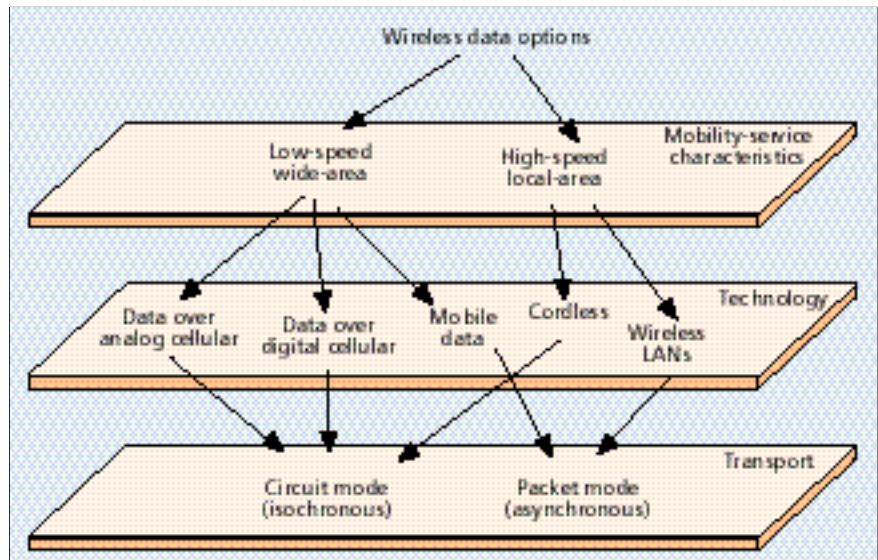
■ Figure 1. Categories of wireless data networks.
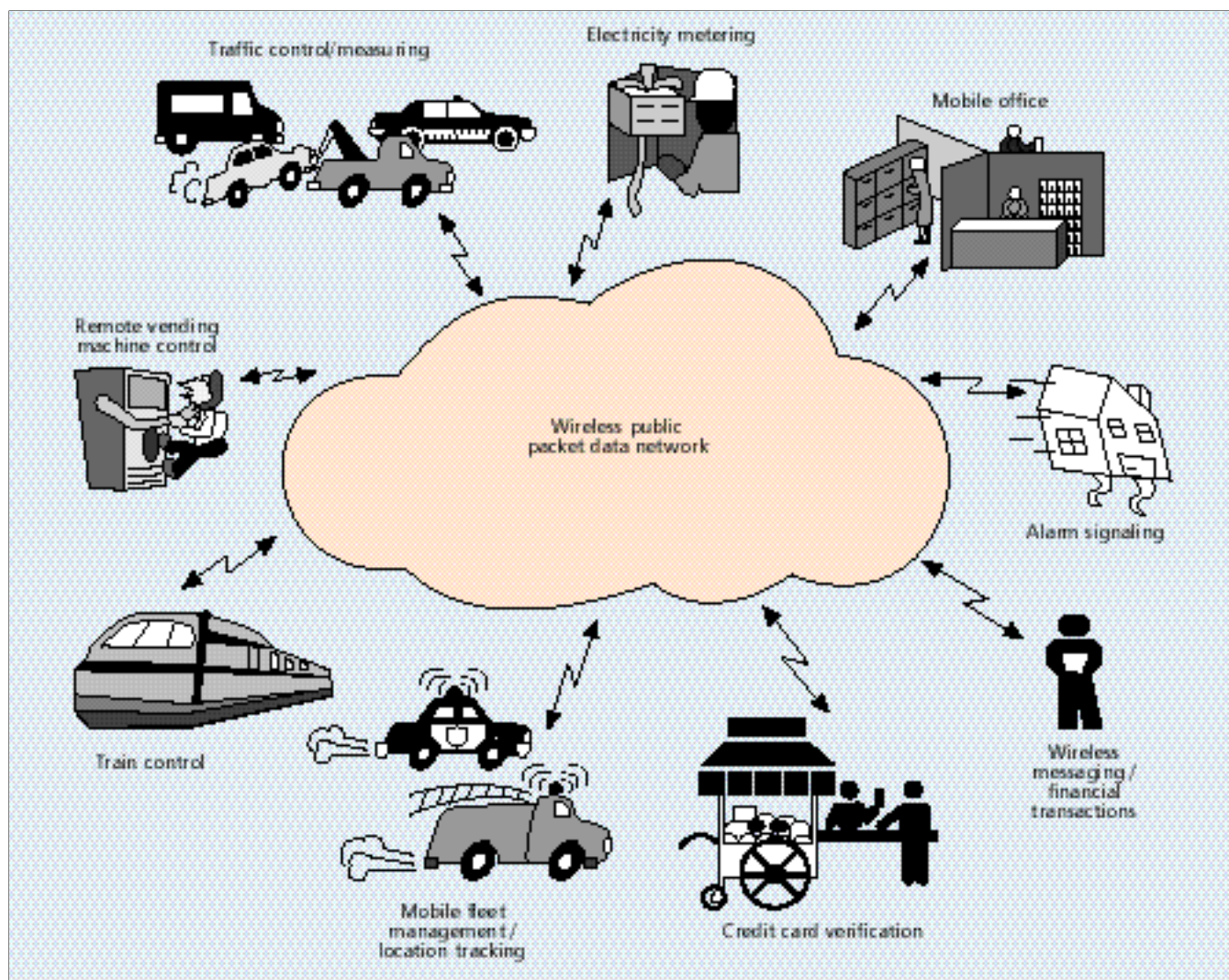
FIGURE 2. Schematic illustration of mobile data applications.

Usually, portability and connectivity are at odds: the more portability increases, the more difficult it becomes to connect to external resources. However, wireless data technology provides the means to effectively combine both capabilities and, therefore, it is an essential technology for mobile computing.

Fig. 1 presents the various wireless data technologies, which are essentially divided into two categories according to their mobility characteristics. For wide-area mobility there are mainly two available technologies: data transmission over cellular networks, whether analog or digital, and data transmission over mobile data networks. As shown in Fig. 1, the main difference between these two technologies is the data transport mode. Cellular networks, being primarily voice oriented, utilize circuit switching technology[1] and, therefore, are optimized to isochronous data traffic conditions, whereas mobile data networks employ packet switching technology and are ideal for asynchronous data traffic transmission. Currently, due to physical layer constraints, wide-area networks typically feature low-speed wireless data transmission, on the order of 9600 b/s. However, with the emerging new protocols, much higher data transmission speed is supported. For example, GPRS will support data transmission rates up to 115

kb/s, and HSCSD is designed to offer up to 56 kb/s over conventional voice channels.

On the other hand, local-area wireless data networks, which are typically employed as private systems in businesses, conference rooms, university campuses, and so on, provide wireless data service in a small geographical area and, for this reason, they do not experience the same rough physical layer constraints of their wide-area counterparts. Therefore, they are capable of supporting high-speed wireless data transmission, on the order of a few Mb/s. For local-area mobility there are mainly two alternatives: data transmission over cordless systems (e.g., over CT-2 or DECT) and over wireless local area networks (LANs). As indicated in Fig. 1, cordless systems provide circuit-switching transport service, whereas wireless LANs provide packet-switching transport service.

From the previous discussion it becomes apparent that there are two wireless packet data technologies: mobile data networks, which support wide-area, low-speed service, and wireless LANs, which support local-area, high-speed service. These technologies use packet switching to transport data rather than circuit switching, which is typically used in cellular or cordless networks.

The rest of this article is devoted to mobile data technology. The next section provides an outline of the most important mobile data applications and discusses several service providers that operate mobile data networks worldwide. The following four sections discuss in detail the MOBITEX,

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[1] Some digital cellular networks (such as GSM) will utilize packet data service in the near future.

Application area	Specific applications
Mobile office	• Remote office access or database access • File transfer • Administrative control • Two-way communications • Internet browsing via the World Wide Web
Financial and retail communications	• Transactions such as electronic cash or fund transfers which, generally, do not have very high communication requirements • Card authorization at points of sale in retail outlets
Remote control and monitoring	• Traffic and transport informatics • Traffic light monitoring and traffic movement measurements • Route guidance systems • Variable message signs on the roadside to inform drivers of forthcoming events or problems on the road ahead • Train control systems • Vehicle fleet management • Gas, water, and electricity metering systems • Remote monitoring and controlling of vending machines • General telemetry systems
Alarm signaling	

■ **Table 1.** Wireless packet data applications.

CDPD, GPRS, and mobile data technologies/services, respectively, addressing the most significant issues of each technology. The final section summarizes our main conclusions.

MOBILE DATA APPLICATIONS

Circuit-switching and packet-switching can make a great difference in terms of transmission cost, throughput, and service quality. There are some applications that are best suited to the circuit-switching model, while others are best suited to the packet-switching model. In general, packet switching is more efficient and consequently less costly for "bursty" applications that transmit small quantities of data at every transmission. On the other hand, circuit switching is more efficient for large file transmissions.

From the user's perspective, wireless packet data networks (which employ packet-switching) offer an alternative that usually guarantees both cheaper and improved services in a vast

Operator	URL	Service	Equipment	Encoding	Coverage (population)	Roaming
Belgium/Ram Mobile Data	http://www.ram.be	Ram Mobile Data	Handheld terminals; radio modems	Mobitex 8 kbit/s	97%	The Netherlands, U.K.
Finland/Telecom Finland	http://www.tele.fi	Mobitex Network	Vehicle-mounted terminals; radio modems	Mobitex 1.2 kbit/s	95%	No
Germany/ Detemobil	http://www.t-mobil.de	Modacom	Handheld terminals; radio modems	Datatek 6000 9.6 kbit/s	95%	No
Netherlands/Ram Mobile Data	http://www.ram.nl	Ram Mobile Data	Handheld terminals; radio modems	Mobitex 8 kbit/s	98%	Belgium, U.K.
Sweden/Telia Mobile	http://www.mobitex. telia.com	Mobitex	Vehicle-mounted terminals; radio modems	Mobitex 1.2 kbit/s	98%	No
U.K./Cognito	http://www.cognito. co.uk	Cognito Mobile Data Solutions	Cognito Messager terminal; Cognito radio modem	Cognito encoding 9.6 kbit/s	87%	No
U.K./Paknet	http://www.vodafone. co.uk	Paknet	Handheld terminals; radio modems	Paknet encoding 8 kbit/s	95%	No
U.K./Ram Mobile Data	http://www.ram.co.uk	Ram Mobile Data	Handheld terminals; radio modems	Mobitex 8 kbit/s	89%	Belgium, The Netherlands
U.K./Securicor Datatrak	http://www.securicor. co.uk	Datatrak Network	Vehicle-mounted terminal; radio modems	Securicor encoding 10 kbit/s	Not disclosed	No
USA/Bellsouth	http://www.bellsouthwd. com	Bellsouth Wireless Data	Handheld terminals; two-way pagers; radio modems	Mobitex 8 kbit/s	93% of metro areas	USA
Canada/Rogers Cantel	http://www.cantel.com	Rogers Cantel Wireless Data	Handheld terminals; two-way pagers; radio modems	Mobitex 8 kbit/s	Main metro cities	Canada
USA/American Mobile	http://www.ammobile. com	ARDIS	Handheld terminals; two-way pagers; radio modems	RD-LAP 4.8 kbit/s and 9.6 kbit/s	430 markets	USA, Puerto Rico, U.S. Virgin Islands

■ **Table 2.** Some of the most important wireless packet data networks and operators.

range of applications. Some of these applications, which effectively drive the market for today's wireless packet data networks, are listed in Table 1. The list divides the applications into four categories and lists the potential of wireless packet data technology. Fig. 2 also illustrates some of the essential wireless packet data applications in a schematic form.

The primary packet data services currently available for mobile applications include ARDIS, RAM Mobile Data, and a number of other services based on cellular digital packet data (CDPD) technology. Several of the most important mobile data networks and service providers are summarized in Table 2. CDPD services, not included in this table, are also available [9].

MOBITEX

MOBITEX packet data technology is widely accepted globally and is considered a true *de facto* standard. This technology was originally developed by Swedish Telecom, now called Telia Mobitel, as a private mobile alarm system used by field personnel. However, mainly for economic reasons, it evolved into a public mobile radio service. Continuing development has been made by Eritel AB under the guidance of the MOBITEX Operators Association (MOA) [1] and Ericsson Mobile Communications AB [2]. Commercial operation was introduced in Sweden in 1986 and, since then, a number of networks have been deployed in Europe, the United States, and Australia [3, 4]. Only the radio frequency differs depending on the country: 900 MHz is used mainly in the U.S. and Canada, and most other countries operate in the 450 MHz range.

In the United States, MOBITEX technology was introduced by RAM Mobile Data, a company that was originally formed in 1989 as a joint business venture between worldwide leaders in telecommunications, including BellSouth and RAM Broadcasting Corporation. Today, RAM Mobile Data is a wholly owned subsidiary of BellSouth, with a nationwide system with more than 1200 base stations installed. The service is provided in more than 7700 cities and towns, covering approximately 93 percent of America's urban business population, and more than 11,000 miles of interstate highway, with automatic seamless roaming across all service areas. Furthermore, additional coverage is being implemented in order to expand the service area in the near future.

MOBITEX networks are either installed or being deployed in 19 countries on five continents, including Canada, the U.K., France, Sweden, Finland, Norway, Belgium, the Netherlands, and Australia. The MOA oversees the specifications,
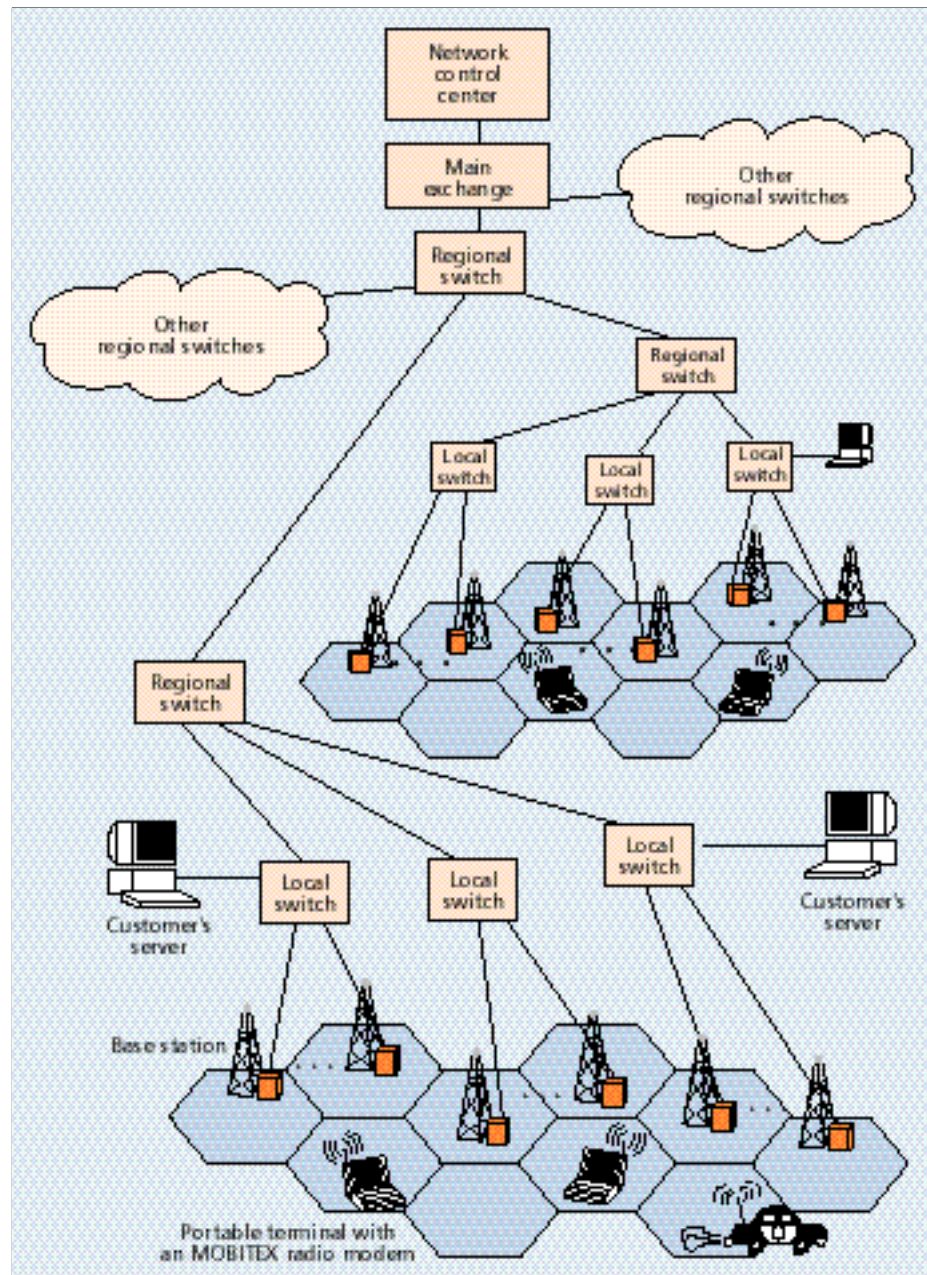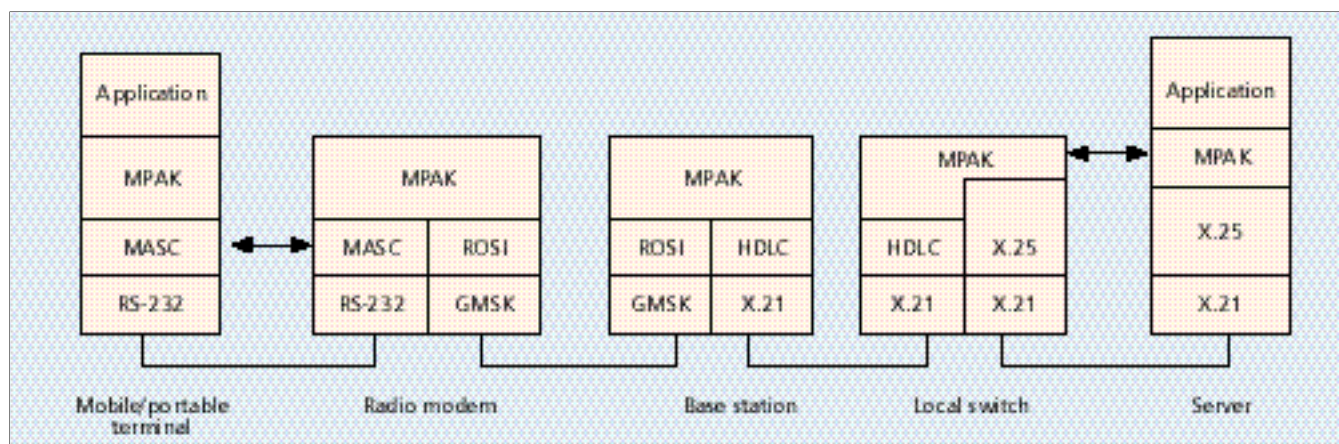

■ FIGURE 3. MOBITEX architecture.

coordinates software and hardware development, and evolves the technology. The specifications are published by the MOA without any license or fee, thus there are many terminal suppliers and equipment developers.

MOBITEX technology offers many critical features [5]:
• Transparent, seamless roaming, eliminating the need for mobile users to "register" as they move from city to city or for others to know the location of a subscriber to send him a message.
• Store-and-forward, to ensure messages are delivered regardless of the user's location or status at the time the message is sent.
• Dependability, with a proven reliability factor greater than 99.99 percent, ensuring accurate transmission for every message.
• Interoperability and more connectivity options, offering access to an expanding range of options in hardware, connectivity, and messaging destinations.
• Capacity to support millions of subscribers.

■ FIGURE 4. Typical protocol architecture within MOBITEX.

• Security that makes it virtually impossible to "tap" and decipher wireless data.

SYSTEM DESCRIPTION

The MOBITEX system employs a cellular layout in order to provide wireless communication services to a specific geographical area. It utilizes a hierarchical structure that may contain up to six levels of network nodes, depending on the size and the area of coverage. As shown in Fig. 3, the infrastructure comprises three types of nodes: base stations (base), local switches, and regional switches. The cells served by the same local switch form a service area or a subnet. In each service area 10 to 30 frequency pairs (called channels) are allocated to radio service [2]. Each base station typically utilizes from one to four channels, depending on the anticipated cell loading. All these channels have 12.5 kHz bandwidth and support a data rate of 8 kb/s. The allocated RF spectrum in the U.S. is 935 MHz to 940 MHz for the downlink (base to mobile) and 896 MHz to 901 MHz for the uplink (mobile to base).

The base stations are connected to local switches via local telephone facilities using either X.25 or HDLC data links. Similarly, the local switches are connected to higher level nodes (regional nodes) via long distance facilities and usually employ the same data link protocols. At the head of the hierarchy lies the main exchange, which interconnects with other networks. Finally, another network element, the network control center (NCC), supports network-wide management and supervision functions.

A key feature of a MOBITEX network is that message switching occurs at the lowest possible level (this is not the case for some other networks), ensuring quick response times and reduced backbone traffic. In other words, communication between two mobile users inside the same cell involves only the cell's base station. If the mobile users roam in different cells belonging to the same services area, the message turn around occurs at the service area's local switch. Only mobility, authentication, and other signaling messages need to travel upward in order to maintain proper operation. Furthermore, if the link between a base station and its superior switch is lost, the base station may still operate in autonomous mode, where it handles only intracell communications. This feature is supported by Ericsson's BRS2 base stations (see www.ericsson.com).

Another important feature of MOBITEX is the possibility to forward one packet to a number of recipients. In order to efficiently utilize radio resources, the originator does not transmit multiple copies of the same packet but, instead, only one packet, which includes the desired recipient list in the header. The direct address for this packet is the MOBITEX network (this is a special address). The first network node that receives the packet will split the packet into a number of individual packets, each addressed to an individual recipient included in the original address list. Subsequently, each packet is separately routed through the wireline facilities.

PROTOCOL ARCHITECTURE

Fig. 4 shows a layered picture of the MOBITEX interfaces. MOBITEX architecture is associated only with the first three layers of the OSI model. However, the three protocol layers of MOBITEX are not clearly mapped into the corresponding OSI layers. Layers four to seven are employed and controlled by the applications using the network.

The mobile terminating unit, i.e., the radio modem, interfaces with a mobile or portable terminal from one side and with the MOBITEX infrastructure from the other side, through the air-interface protocol. Both these interfaces are standardized by MOA and their specifications are extensively described in [7]. The interface between the mobile/portable terminal and the radio modem is either physical, or logical in cases where both elements are implemented in a single physical unit. When the terminal and the radio modem are physically apart, the MOBITEX ASynchronous Communication (MASC) protocol is used for their interface. This protocol provides reliable transfer of data to/from the radio modem and control and status monitoring of the modem.

Traffic at the network layer is used to:
• Transfer information from one subscriber (or application) to another, such as text messages, data messages, status messages, and higher protocol data messages.
• Transfer alert messages, i.e., high-priority data traffic.
• Transfer network-layer signaling packets, such as login/logout requests and terminal activated/inactivated notifications.

Every network-layer protocol unit, called MPAK (see top of Fig. 5), identifies the entity (e.g., an application) that originated it. An MPAK includes a class and a type label that indicate its significance and its priority level inside the packet-switched wireline backbone. For example, alert messages have higher priority than text messages and, in case of congestion, they may maintain the required quality of service. Furthermore, every MPAK indicates whether it can be stored in the recipient's mailbox or not. The mailbox is a temporary storage that can be used to buffer packets whenever they cannot be delivered immediately (e.g., when the recipient is in a tunnel). The network forwards the mailbox contents to the intended recipient as soon as the recipient becomes available.

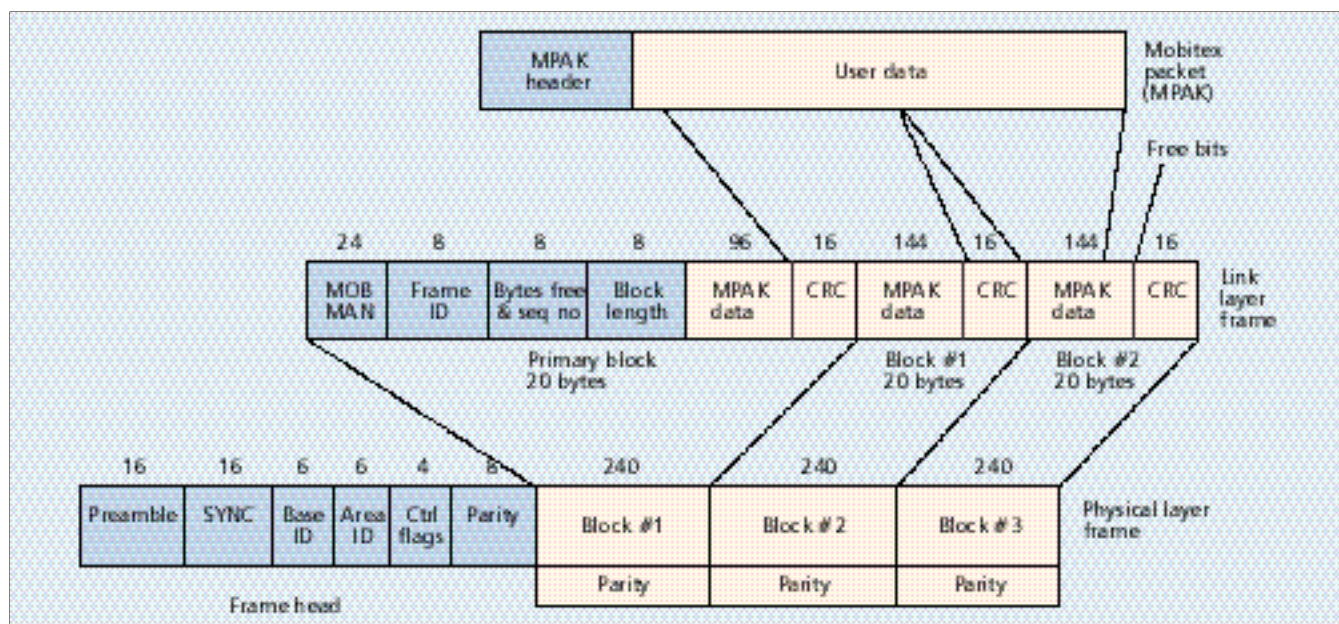The data link layer at the radio interface, which is called

■ FIGURE 5. MOBITEX frame structures.

ROSI (radio OSI), takes care of the transmission toward the MOBITEX infrastructure. The functionality of the data link layer is provided by the combined action of the base station and the mobile station, and includes:
• The selection of the most suitable base station, in terms of communication reliability, with which to communicate. (This process is called roaming and is described in [6].)
• The retransmission of data link frames that were either destroyed by the mobile channel impairments or collided with neighbor transmissions.
• The channel access procedure.

The data link frame structure is shown in the middle of Fig. 5. It consists of a series of fixed-length (20 bytes) blocks, each having a 16-bit CRC (cyclic redundancy check) for error protection. The data link layer employs a selective ARQ (automatic repeat request) scheme at the block level to effectively recover from transmission errors. After a frame transmission, the addressee checks the received blocks for errors. If all the blocks are correct, it replies with a positive acknowledgment; otherwise, it requests the retransmission of only the corrupted blocks. A new frame can be transmitted only after the previous frame has been positively acknowledged. In other words, a stop-and-wait ARQ scheme is employed at the frame level.

The physical layer frame structure is depicted in the lower part of Fig. 5. It starts with a frame head that is used to establish frame synchronization and to uniquely identify a base radio station. The preamble field includes a synchronization pattern that enables all the prospective receivers to acquire bit synchronization and to correctly decode the rest of the frame. The preamble contains eight pairs of alternating 1s and 0s. If the frame is transmitted from a base station the pattern starts with two 1s (i.e., 1100110011001100) whereas, when it is transmitted by a mobile station, the pattern starts with two 0s (i.e., 0011001100110011). In other words, the physical layer can identify if a frame comes from a base station or from another mobile station.

The SYNC code word that follows is used to establish frame synchronization. It is important to note that every MOBITEX network maintains its own unique SYNC code word. Therefore, SYNC is used as a network identification number at the physical layer. If a mobile receives frames from a network that uses a different SYNC from the one currently selected, it will not be able to acquire frame synchronization and the received frames will be discarded at the physical layer. This feature does not introduce any problems during the roaming procedure, i.e., when a mobile station evaluates the communications quality of neighbor channels, because this evaluation is based only on signal strength measurements and no frame decoding is required [6].

The base ID and area ID fields uniquely identify a base radio station in a MOBITEX network. Frames originated from a base will carry its own base and area ID, while frames originated from radio terminals will carry the base and area ID of the destination base. These ID fields make it feasible for a radio terminal to accept physical layer frames only from one base station (the one that has been selected by the roaming entity). If, maybe due to favorable propagation conditions, a mobile station receives frames from a distant base station, these frames are discarded.

Error correction coding is performed at the physical layer. All bytes contained in the data link blocks are put into a matrix. Every byte is independently encoded using a shortened (12, 8) Hamming code and the parity bits that result from the coding are appended to each one. Thus, for every eight data link bits, 12 physical layer bits are transmitted in order to combat the mobile channel impairments. The employed code can correct all single errors (inside a byte) with a hard decision decoding.

The modulation scheme employed in MOBITEX is typically Gaussian minimum shift keying (GMSK) with a modulation index of 0.5. As stated before, the RF channel spacing is 12.5 kHz and the modulation rate is 8 kb/s.

CHANNEL ACCESS

The multiple access protocol in the MOBITEX is a variation of the well known slotted ALOHA. A mobile terminal (MOB) that has traffic to send is allowed to transmit only during specific free cycles. These cycles (i.e., repeated time periods) are initiated by the base station in every cell with the transmission of a FREE frame on the downlink channel. A free cycle is composed by a number of time slots, all with equal length. The number and the length of the time slots in
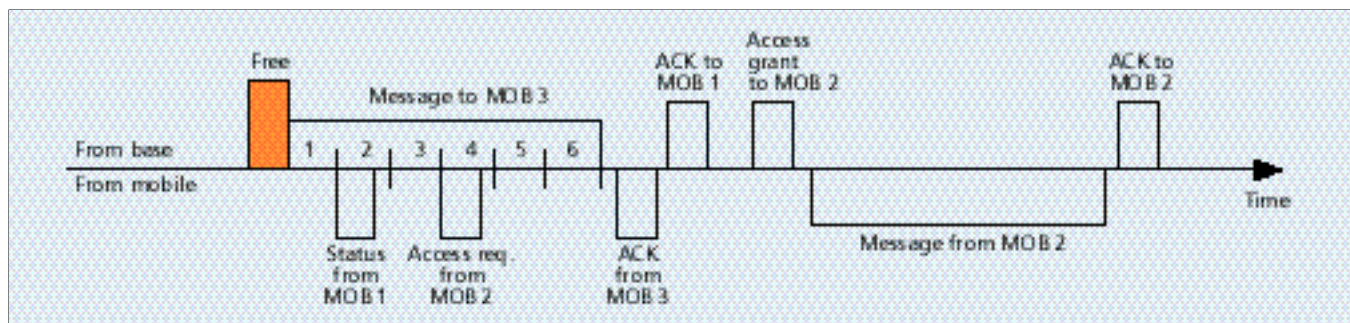
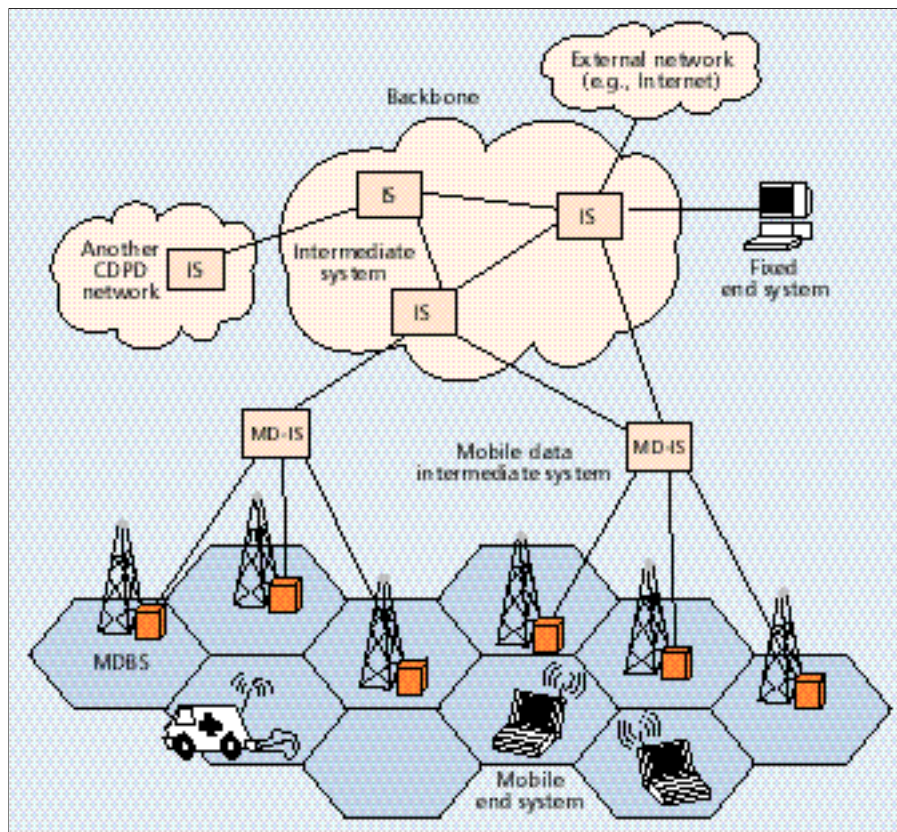**■ FIGURE 6.** MOBITEX channel access activity (example).

a free cycle are specified by the FREE frame that initiates the free cycle.

After the reception of a FREE frame, a MOB with pending transmission traffic chooses at random a slot and schedules its transmission at the beginning of that slot. Since no transmission can last longer than a time slot, a collision takes place only if two or more MOBs schedule their transmission at the beginning of the same slot. A MOB that gets ready for transmission somewhere in the middle of a free cycle does not choose a random time slot; rather, it schedules its transmission at the next time slot. This is reasonable since the instances that some MOBs get ready for transmission are expected to be uniformly distributed inside a free cycle.

If a MOB has a large data frame to send, which exceeds the duration of a time slot, it sends a short access request message instead of the data frame itself. At the end of a free cycle, the base station will grant access permission to every mobile that has successfully sent an access request and thus, one after the other, all MOBs will eventually transmit their data frames (though outside of a free cycle) before the next free cycle.

An example of a free cycle is illustrated in Fig. 6. After the FREE frame, which initiates a free cycle with six total slots, the base station transmits a large frame to MOB 3. At the same time, it receives the frames transmitted from the mobile stations. In this example, MOB 1 transmits a status message at slot 2 and MOB 2 transmits an access request at slot 4. Both these slot numbers (2 and 4) have randomly been selected, provided that MOB 1 and MOB 2 were waiting for transmission at the beginning of the free cycle. After the end of the free cycle, MOB 3 transmits an acknowledgment to indicate that the large frame transmitted from the base station was correctly received. Also, the base station acknowledges the correct reception of the status message from MOB 1 and grants channel access to MOB 2, which afterward proceeds to the transmission of its large data frame.

Packet collisions are treated as channel errors: a MOB that transmits a packet in a FREE cycle waits for a positive acknowledgment from the base until the beginning of the next FREE cycle. If this acknowledgment is not received before the next FREE cycle, the MOB assumes erroneous transmission (due to collision or channel errors) and retransmits the same packet. This procedure continues until an acknowledgment is received from the base station.

CDPD

CDPD, cellular digital packet data, is a mobile data technology that permits subordinate data operation on the spectrum assigned to the Advanced Mobile Phone Service (AMPS). It was first introduced by IBM as a packet-switching overlay to the existing analog cellular voice network and frequencies. Later, a CDPD system specification [8] was created by a consortium of cellular carriers including AirTouch, McCaw Cellular, Southwestern Bell Mobile Systems, NYNEX, Ameritech, GTE, Bell Atlantic Mobile, and Contel Cellular. CDPD technology is being deployed by a number of cellular companies in the U.S., including Bell Atlantic, Ameritech, GTE, and McCaw Cellular. Equipment is provided by a variety of manufacturers.

CDPD systems are designed to take advantage of the idle voice channels of an analog cellular network, such as AMPS. These idle channels are used to transmit short data messages and establish a packet-switching

■ FIGURE 7. CDPD network architecture.

service. In order to utilize those idle channels, CDPD implements a hopping procedure among the available cellular frequencies. The air interface operates at a raw data rate of 19.2 kb/s and provides forward error correction to combat the interference and fading of the cellular channels.

The Wireless Data Forum [9] is an industry association that handles the shaping of the CDPD technology and supports the growth of the commercial marketplace. This forum aims to help the operators, equipment providers, and billing system developers through the complicated issues they face. Among other things, the forum tries to help all of the CDPD operators to develop inter-operator roaming and invoicing.

According to the Wireless Data Forum, by the end of the third quarter 1998, CDPD was available in 195 markets in the United States: 118 metropolitan statistical areas (MSAs), 41 rural statistical areas (RSAs), and 36 international markets, and was available to 53 percent of the U.S. population.

SYSTEM DESCRIPTION

The primary elements of a CDPD network are the end systems (ESs) and the intermediate systems (ISs), as shown in Fig. 7. The ESs represent the actual physical and logical end nodes that exchange information, while the ISs represent the CDPD infrastructure that stores, forwards, and routes the information.

There are two kinds of ESs: The mobile end system (M-ES), which is a device used by a subscriber to access the CDPD network over the wireless interface, and the fixed end system (F-ES), which is a common host, server, or gateway
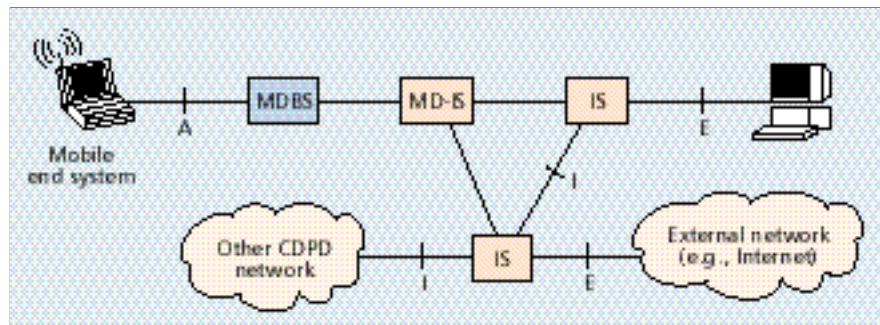
■ FIGURE 8. Standardized interfaces within CDPD architecture.

that supports or provides access to data and applications. By definition, the location of an F-ES is fixed, whereas the location of an M-ES may change.

Typically, each M-ES consists of a mobile terminal (personal computer, personal digital assistant, or other standard device), and an additional device, the radio modem, that attaches to the mobile terminal and manages the radio links and protocols. These devices usually communicate over standard serial protocols, such as the Serial Line Internet Protocol (SLIP), or the Point-to-Point (PPP) protocol.

On the other hand, there are two kinds of ISs: a "generic" IS, which is simply a (IP) router that has no knowledge of CDPD and mobility issues, and a mobile data intermediate system (MD-IS), which is a specialized IS that routes messages based on its knowledge of the current location of an M-ES. More specifically, a MD-IS is a set of hardware components and software functions that provide switching, accounting, registration, authentication, encryption, and mobility management functions. The mobility management software allows the switching system to track M-ESs regardless of their location in the network, and allows M-ESs to use a single network address. The CDPD mobility management software follows the mobile-IP model [10], established by the Internet Engineering Task Force (IETF).

Besides the ESs and the ISs, there is also another element called the mobile data base station (MDBS), which is analogous to the AMPS base station. A MDBS is a combination of a computer, power amplifiers, and a radio transceiver. It performs no networking functions but it is a link-layer relay; it sends and receives information from the M-ESs and relays it back to the MD-IS. It also controls the radio interface and manages the radio communications, and monitors the activity on the voice network (to ensure that data and voice do not interfere with each other). The MDBS creates an air link comprising two RF channels for forward and reverse communications with multiple M-ESs.

Fig. 8 shows the standardized interfaces used across the CDPD network. The M-ESs are connected to the CDPD network through the A-interface (the air interface), while the F-ESs are connected through the E-interface. The E-interface is also used to interconnect with external networks. Finally, the I-interface is used in the backbone, between the various ISs, and at the interconnection points with other CDPD networks. All these interfaces and the associated protocols are extensively described in [8].
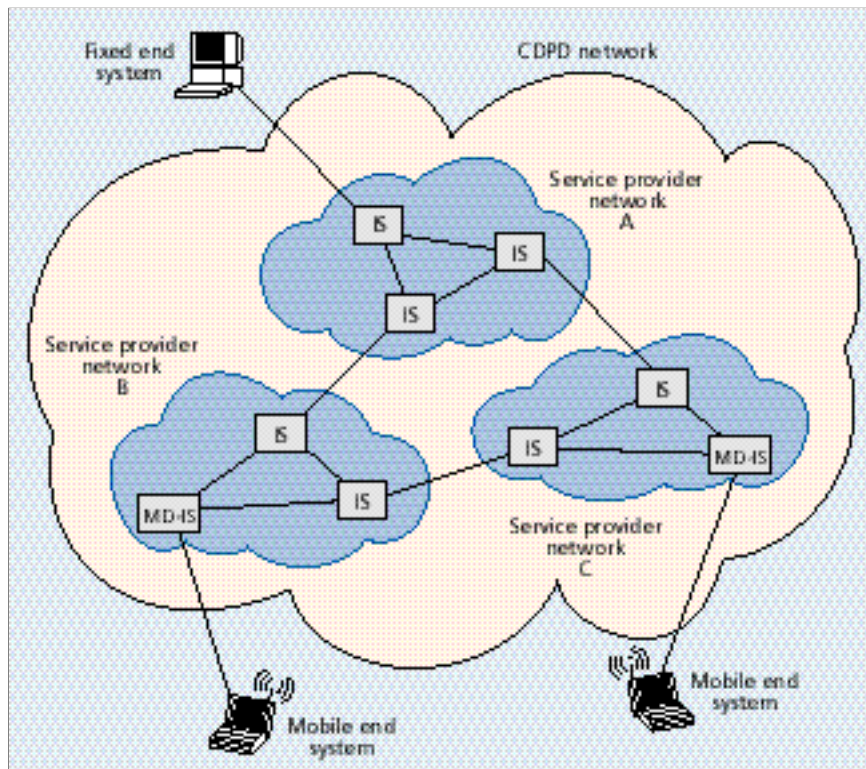
■ FIGURE 9. CDPD service with interoperability between service providers.

The CDPD backbone provides connectionless transport services, also called "datagram" services. This means that the network individually routes packets, based on the destination address the packet carries and on the knowledge of the current network topology. For the routing of packets, CDPD supports both the Internet Protocol (IP) [11] and the Connectionless Network Protocol (CLNP), which is an OSI standard protocol.

The CDPD system is designed to facilitate the interoperability between the networks of different service providers [12]. Especially in CDPD, where there may be many different operators in a given geographical area (since there may also be many different cellular operators, each one deploying its own CDPD infrastructure), interoperability is a main concern. Interoperability means that all subscriber equipment, components, functions, and processes of the CDPD system work together within all the cooperating CDPD networks. Interoperability allows for seamless roaming inside a large geographical area and provides the means for ubiquitous CDPD service. In fact, the CDPD network is envisioned as an internetwork composed of multiple administrative domains, each one operated by a different service provider (see Fig. 9).

Additional information about the CDPD technology can be found in [13-25].

PROTOCOL ARCHITECTURE

The protocol architecture of the CDPD air interface is illustrated in Fig. 10. The physical (PHY) layer in CDPD corresponds to a functional entity that accepts a sequence of bits from the medium access control (MAC) layer and transforms them into a modulated waveform for transmission onto a physical 30 kHz RF channel. As illustrated in Fig. 10, communication between a MDBS and a M-ES takes place over a pair of such RF channels (having a fixed frequency separation). The first channel, called the forward channel, accommodates transmissions in the direction from the MDBS to the M-ESs and is either dedicated to CDPD use or shared with the voice cellular network. In any case, transmission on the forward channel is continuous as long as it is in use for CDPD. The second channel, called the reverse channel, accommodates transmissions in the direction from the M-ESs to the MDBS and is shared among all M-ESs communicating with the same MDBS. A pair of associated reverse and forward channels forms a CDPD channel stream.

The PHY interfaces with another entity, the radio resource management entity (RRME) [14]. Through this control interface the RRME can:
• Tune the physical layer to a specific RF channel pair.
• Set the transmission power level to the desired value.
• Measure the received signal level of a RF channel and estimate its potential to offer acceptable communication.
• Suspend and resume the operation of the physical layer in cases where power saving facilities are required.

The modulation employed on a RF channel stream is GMSK with BT = 0.5 [21]. A frequency greater than the central carrier frequency represents a logical 1, while a logical 0 is represented by a frequency less than the central carrier frequency. The modulation rate on both the forward and reverse RF channels is 19.2 kb/s.

The MAC layer models a functional entity logically operating between the PHY and LLC layers. The MAC layer within an M-ES cooperates with the corresponding MAC layer within the MDBS. The purpose of this layer is to convey information, namely, link protocol data units (LPDUs), between peer LLC entities across the CPDP air interface.
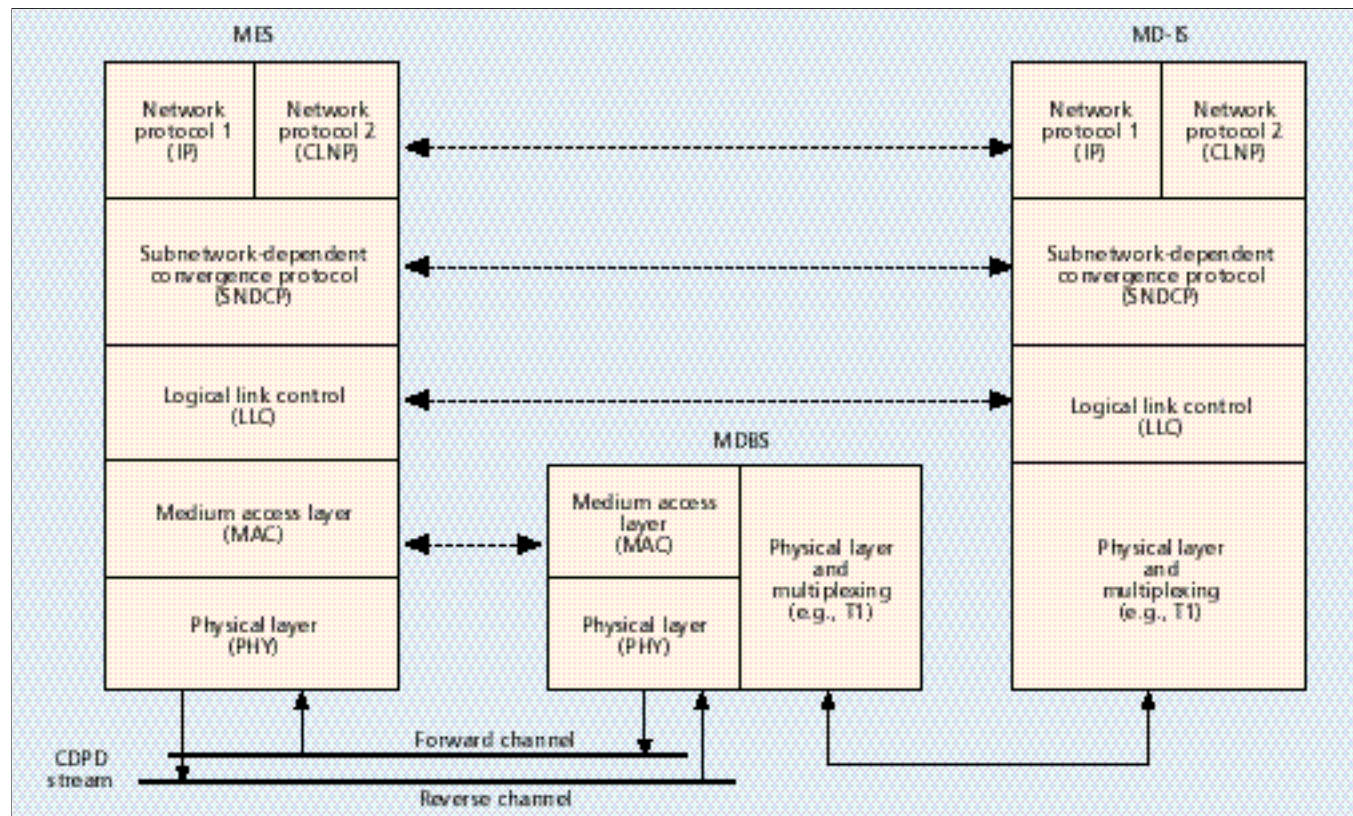

■ FIGURE 10. Protocol architecture of CDPD air interface.

For this purpose, the MAC layer provides the following services:
- Encapsulates LPDUs into frame structures to ensure LPDU delimiting, frame synchronization, and data transparency.
- Encodes LPDUs to provide error protection against mobile channel impairments.
- Detects and corrects bit errors within received frames.
- Arbitrates access to the shared reverse channel.
- Synchronizes with the forward channel transmissions to make feasible the reception of data as well as control information transmitted in every CDPD cell.

The purpose of the LLC layer is to convey information between network layer entities across the CDPD air interface. The protocol applied in this layer is called the Mobile Data Link Protocol (MDLP). As illustrated in Fig. 10, the MDLP in an M-ES communicates with a peer MDLP located in its serving MD-IS. Hence, it is seen that the functionality of a MDBS is restricted within the physical and MAC layers. Above the MAC layer, a MDBS is completely transparent.

The primary service offered by the MDLP to the upper layer (SNDCP) is the provision and the control of one or more logical data link connections on a CDPD channel stream. Above the LLC layer, these data link connections are treated as individual bit pipes that may be used to convey messages back and forth between a MD-IS and one or more M-ESs. Within each data link connection, one or more network traffic flows may be accommodated through facilities provided by the SNDCP. Discrimination between data link connections is made by means of an address label contained in each message (frame). This address label is called the temporary equipment identifier (TEI) and is a pure LLC layer concept, i.e., it is used internally by the LLC layer and is not necessarily known by other functional layers.

Functionally, the Subnetwork Dependent Convergence Protocol (SNDCP) lies between the data link layer and the network layer. The latter is assumed to be subnetwork independent, i.e., it is built to work over virtually any data link and therefore it does not take into account the specific features of the MDLP. For this reason, the services assumed by the network protocol(s) may not map directly into the services provided by MDLP. In this case, the SNDCP is operated to provide the required cooperation.

More specifically, the SNDCP provides the following functions:

SEGMENTATION: Network protocol data units (NPDUs) are segmented and reassembled where needed in order to be accommodated within the limited length of the data link frames. With this segmentation, the maximum size of a NPDU can be 2048 bytes, while the maximum size of user data supported by MDLP is considerably smaller (default value is 130 bytes).

ENCRYPTION: To provide user data confidentiality over the CDPD air interface the NPDUs are encrypted after being segmented. The secret keys used for the encryption and decryption are obtained by means of a security management entity (SME) that operates on top of SNDCP as a network layer entity [13].

MULTIPLEXING: The SNDCP provides the means for multiplexing a number of network-layer traffic streams within the same data link connection. (Note that this facility is not provided by the MDLP.) This makes feasible the simultaneous utilization of various network-layer entities on top of SNDCP. For example, as illustrated in Fig. 10, two (or more) network protocols may simultaneously operate on top of SNDCP. Each one is discriminated by its own network layer protocol identifier (NLPI).

HEADER COMPRESSION: The SNDCP compresses and recovers redundant network-control information to increase data link performance and efficiency.

DATA COMPRESSION: To further increase the data link performance, the data portion of the NPDUs is compressed according to ITU-T V.42 bis specification (as done by all V.34-compliant wireline modems).

QUALITY OF SERVICE: Two data transport modes are provided by the SNDCP: the acknowledged mode, which transfers NPDUs within the data link control procedures, and the unacknowledged mode, which transfers NPDUs outside the data link control. The transport service mode utilized depends on the quality of service parameter requested by the network layer.

CHANNEL HOPPING

Since CDPD was added to the voice system after the latter was already operational, its design was subject to the constraint that no changes should be necessary to the existing voice system. For this reason, CDPD was designed to be completely transparent to the underlying voice system [16-20]. Consequently, when the voice system selects a new channel for voice transmission, it is not aware of the existence of CDPD and it may select to use the channel currently used by CDPD. To avoid collisions in such cases, CDPD transmissions should preempt the currently used channel as soon as possible and hop to another idle channel.

CDPD monitors the transmit signal of the underlying voice system by sensing the power that enters into its transmit antenna. As soon as a power ramp-up is detected, which indicates the initiation of voice traffic, a channel hopping procedure begins. First, the MDBS sends a special signal that closes down the channel. This should be accomplished within 40 ms after the start of power ramp-up, because it takes so long before any voice is transmitted. While closing the CDPD channel, the MDBS may also announce the new CDPD channel where it will hop (if it is already known). Afterward, the MDBS finds a new idle voice channel and starts transmitting an identification signal in this channel. In the case where the CDPD channel was closed without an announcement of a new channel number, mobile terminals must hunt around among a designated set of potential CDPD channels in order to find the new one [19].

In this way, CDPD can occupy any idle capacity in a cell, without interfering with the voice system. However, nothing in the design prevents having dedicated CDPD channels. Actually, as CDPD grows in popularity, providers are more likely to reserve channels exclusively for it.

CHANNEL ACCESS

As stated above, all M-ESs that communicate with the same MDBS (i.e., they are in the same cell) share a common transmission channel, called the "reverse" channel. On the other hand, the MDBS uses the "forward" channel to transmit information to the M-ESs. The reverse and the forward channels are different RF channels and can be used simultaneously.

An M-ES can access the reverse channel using a slotted non-persistent digital sense multiple access with collision detection (DSMA/CD) algorithm. This algorithm is similar to the carrier sense multiple access with collision detection (CSMA/CD) used in Ethernet. However, in CDPD, because M-ESs cannot sense the status of the reverse channel directly (since they employ different reception and transmission frequency bands), a different collision detection scheme is applied.

The DSMA/CD algorithm makes use of the busy/idle flag and the decode status flag, which are periodically transmitted on the forward channel. The busy/idle flag is a 5-bit sequence that is transmitted once every 60 bits, that is, once every 1 microslot period. This flag provides periodic binary information with one microslot resolution indicating whether the reverse channel is busy or idle. On the other hand, the decode status flag is a 5-bit sequence that indicates whether the MDBS has decoded successfully or not a data block previously transmitted by an M-ES.

An M-ES wishing to transmit senses first the busy/idle flag (actually, a locally stored version of it, which is updated once every a microslot period). If the reverse channel is found busy, the M-ES defers for a random number of microslots and then repeats the sensing of the busy/idle flag again. Because the M-ES does not persist in continuously sensing the busy/idle flag, the access scheme is referred to as non-persistent. Once the reverse channel is found idle, the M-ES may initiate transmission. Note that a transmission may be initiated only at a microslot boundary, which is why the access scheme is termed slotted. As soon as the MDBS detects a transmission start on the reverse channel, it sets the busy/idle flag in order to prevent further transmissions.

After an M-ES gains access to the reverse channel, it transmits its data as a sequence of fixed-length blocks [13]. As mentioned before, the decode status flag provides "real-time" information regarding the successful reception of these blocks. The M-ES checks this flag and continues transmission if the MDBS has encountered no decoding errors. In the opposite case, it ceases transmission and attempts to regain access to the reverse channel after an appropriate exponential backoff retransmission delay. This delay is increased exponentially by a factor of two on every subsequent retransmission attempt, hence the name exponential backoff.

GPRS

GPRS, general packet radio service [26-28], is a GSM Phase 2+ bearer service that provides wireless packet data access to mobile GSM users. Its introduction is one of the key steps in the evolution of today's GSM networks to the third generation, and GSM operators around the world are upgrading their networks with a view to launching commercial GPRS services in 2000. The main feature of GPRS is that it reserves radio resources only when there is such a need and that these radio resources are shared by all mobile stations (MSs) in a cell. Therefore, as is the case for all packet data services, effective resource utilization is provided for bursty data applications, such as telemetry, train control systems, interactive data access, toll road charging systems, and Internet browsing using the World Wide Web. Data rates of up to 115 kb/s would be supported.

The main objective of GPRS is to offer a mobile packet interface to standard data networks (such as TCP/IP, X.25, and CLNP). This interface should be embedded in the conventional GSM network architecture, which was originally designed for circuit-switched integrated services. For this purpose, GPRS introduces some new functional elements to the general GSM architecture and it modifies some mobility management functions. Some cooperation still exists between the elements of the standard GSM services and GPRS [27]. In comparison with CDPD, it is important to note that GPRS provides a data overlay within the standard GSM infrastructure (with some new functional elements), while CDPD provides a packet data overlay but with a totally separate infrastructure.

SYSTEM DESCRIPTION

The GPRS reference model is depicted in Fig. 11. GPRS allows the subscriber to send and receive data in an end-to-
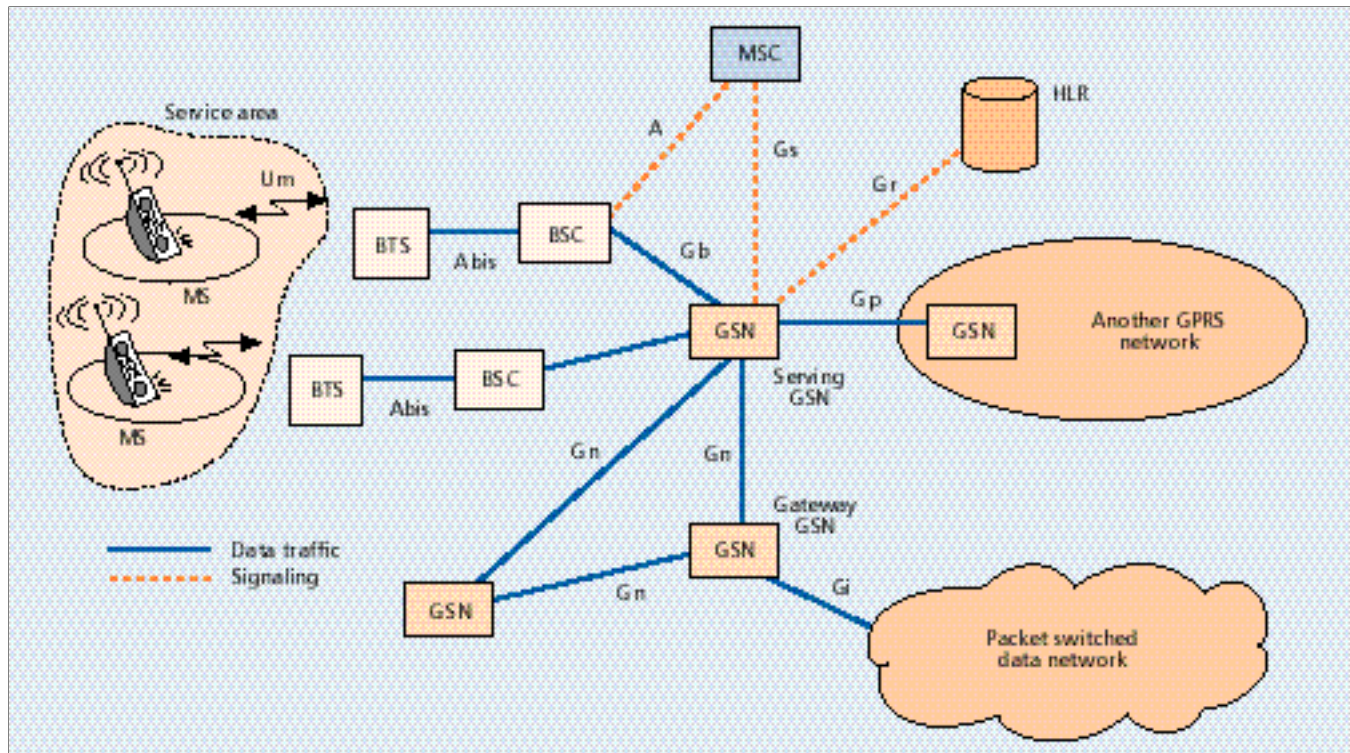

■ FIGURE 11. GPRS system architecture.

end packet transfer mode, without using any network resources in circuit-switched mode. This allows for autonomous operation of GPRS and best fits the bursty traffic characteristics. Packet routing and transfer within the public land mobile network (PLMN) is supported by definition of a new logical network node called a GPRS support node (GSN). The GSN is basically a packet router with additional mobility management features and connects with various network elements through standardized interfaces. The GSN node that acts as a physical interface to the external packet data networks (PDNs) is called as the gateway GSN (GGSN), whereas the GSN node that connects with a BSC (base station controller) and directly handles packet delivery to and from MSs is called as the serving GSN (SGSN). Each SGSN is responsible for the delivery of packets to the MSs within its service area.

The general packet routing procedure is performed as illustrated in Fig. 12. In the case where a mobile originates traffic for a fixed host, the SGSN encapsulates the data packets and routes them to the appropriate GGSN, where they are forwarded to the correct packet switched data network (PSDN). Specific routing policies are applied inside this PSDN to send the packets to the corresponding host. On the other hand, packets coming from a corresponding host are first routed to the GGSN through the PSDN, based on the examination of the destination address. The GGSN checks the routing context associated with this destination address and determines the address of the SGSN currently serving the addressed MS. Subsequently, the original data packet is encapsulated into another packet (this procedure is called tunneling), which is forwarded to the SGSN and ultimately delivered to the correct MS. The GPRS backbone network is a private IP network. The IP addresses used in this backbone are selected by the GPRS operator and they are not known outside the PLMN. Routing between GPRS mobile terminals is usually accommodated through inter-PLMN packet networks, as illustrated in Fig. 12.

Within GPRS, two different encapsulation schemes are used. First, between the GSNs all packets are encapsulated by means of a GPRS tunneling protocol (GTP) in order to enable usage of different packet data protocols, even if these protocols are not supported by all SGNSs. Second, encapsulation between the MS and SGSN is performed to decouple the logical link management from the network-layer protocols.

PROTOCOL ARCHITECTURE

The GPRS service is based on the layered architecture shown in Fig. 13(a). At the top of the protocol layer, there may be a number of network protocols, which are treated as prospective users of the GPRS service. The subnetwork-dependent convergence protocol (SNDCP) provides a multiplexing layer that aids the transmission of multiple network layer messages onto a single logical link connection. Furthermore, the SNDCP includes ciphering, segmentation, and
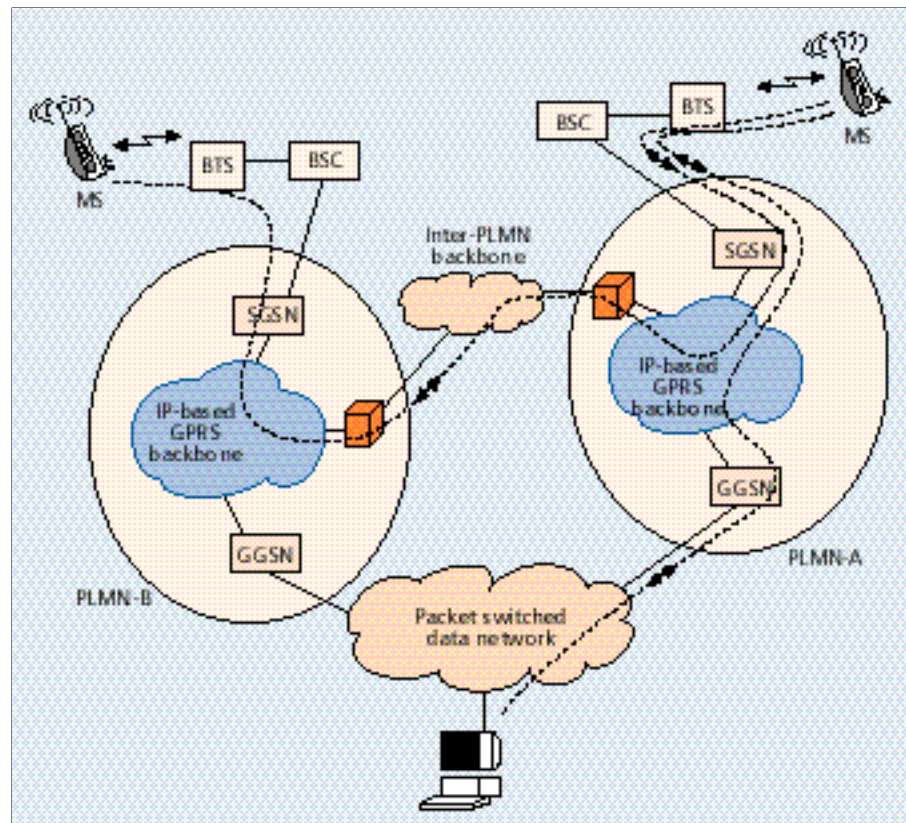
■ FIGURE 12. Typical routing within GPRS.

compression facilities. Its functionality is very similar to the functionality of the SNDCP layer in CDPD, explained previously.

The logical link control (LLC) layer, at the bottom of the SNDCP layer, provides a logical link between the MS and SGSN. Protocol functionality is based on LAPD as used within the GSM signaling plane, but additional features are supported, e.g., point-to-multipoint transmission. This link control protocol is sometimes called link access procedure on the G-channel (LAPG).

The radio link control/medium access control (RLC/MAC) layer arbitrates access to the shared medium between the MSs and the network, and also provides a reliable link between an MS and a base station. It is worth noting that RLC is specific to the radio technology used in the wireless interface, while LLC is independent of the wireless interface characteristics. The protocol data units at the LLC layer are segmented into one or more RLC frames, which are handed over to the MAC sublayer. In turn, each MAC frame is translated into four fixed-length blocks which, after bit-interleaving, are transmitted on four consecutive TDMA frames (using the same time slot in each frame) [21]. Apart from the efficient multiplexing of data and signaling information, the functionality of the RLC/MAC layer includes contention resolution, QoS control, framing, and error handling. The MAC protocol for the GPRS radio interface is essentially a slotted ALOHA reservation protocol and operates between the MS and the BTS (base station transceiver).

Before an MS is capable of using the GPRS service, it must attach to this service. Effectively, this attachment corresponds to the establishment of a logical link between the MS and its serving GSN. As a result, a temporary logical link identity (TLLI) is assigned to the MS. A logical condition after this assignment is illustrated in Fig. 13(b). As explained previously, a logical link can accommodate more than one traffic flow through the multiplexing facilities provided by the

SNDCP layer. MSs roaming within the service area of a given SGSN are communicating with this SGSN through the reserved GPRS resources, and via separate logical links. Each link has its own unique TLLI. Additionally, within each logical link, a number of different traffic flows (e.g., different network protocols) are multiplexed with the aid of the SNDCP protocol.

After attachment, one or more routing contexts for one or more network protocols can be negotiated with the SGSN. In order to verify that a given MS is allowed to use a network protocol, the home location register (HLR) is queried. Among other things, the subscription profile found in the HLR includes the matching GGSN address. If access is permitted, the GGSN is requested to update the routing context (i.e., the serving SGSN address and tunneling information) accordingly. As explained before, this information is used to support the routing procedure in a mobile environment.

During the GPRS session, the location of an MS is being tracked. When in ready state (i.e., during active communication), the MS informs the SGSN about every cell change. However, when in standby state (i.e., when waiting for an event to trigger transmission/reception), the MS requests location updates upon a routing area (RA) change. The routing area consists of an operator-defined group of cells. If a RA update takes place and the new RA is handled by another SGSN, then the new SGSN asks the old SGSN to send the mobility management information of the MS. Subsequently, the GGSN and the HLR are updated with the new routing context, and the old SGSN deletes the corresponding information of this MS.

CHANNEL ACCESS

When a network operator decides to offer GPRS-based services within a cell, one or several physical channels from the pool of available channels are dedicated to packet mode transfer. Each of these so called packet data channels (PDCHs) is mapped onto one physical time slot. In order to support a flexible adaptation to different traffic requirements, allocation of PDCHs is based on demand.

Prior to packet transmission, an MS initiates a random access request, that is, it sends a short request on a control uplink channel, called the packet random access channel (PRACH). Together with the access request, the MS indi-
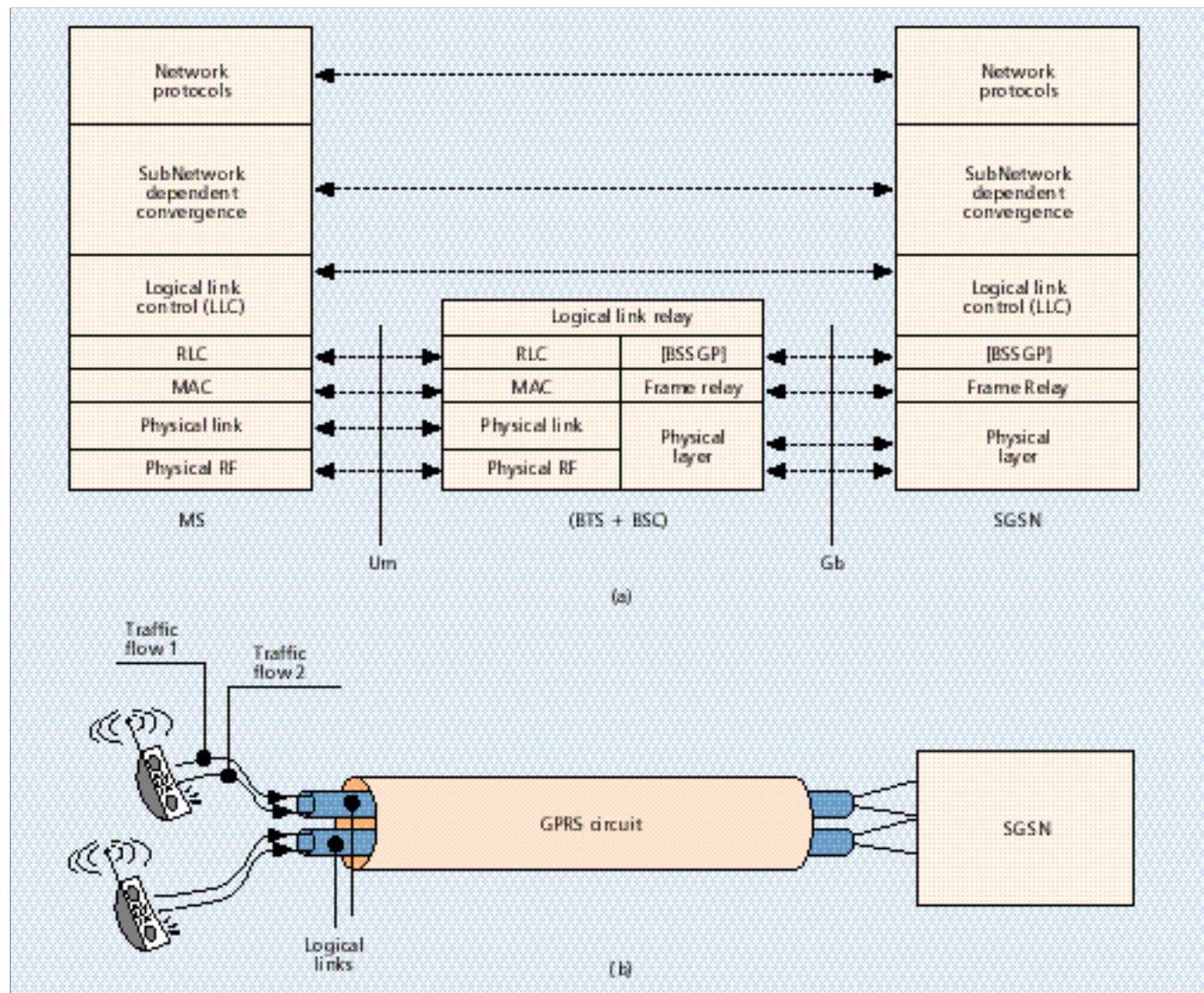
■ FIGURE 13. (a) GPRS protocol architecture; (b) schematic presentation of traffic and logical link multiplexing in GPRS.

cates the number of GPRS slots required for the forthcoming transaction. This access request is handled by the BSC, which provides the radio resource management functionality. Upon correct reception of the access request, a control downlink channel (the packet access grant channel) is used to identify the reserved slots and the timing advance [26-28, 30]. If an MS receives no response to an access request, a retransmission procedure takes place after a random backoff time up to a maximum number of access attempts.

After the transmission in the reserved time slots is completed, the BTS acknowledges the reception status of the transmitted blocks. It sends either a negative ACK (NACK) to specify the erroneous blocks, or a positive ACK to specify no errors. A NACK message lists the erroneous blocks that should be retransmitted and also includes an appropriate channel reservation for the retransmission to take place with minimal delay. If, after transmission of data, the MS does not receive an ACK within a certain time period, a data recovery procedure is initiated by attempting a new random access.

■ FIGURE 14. ARDIS network architecture.

In the case of mobile-terminated traffic, the network sends a page to a specific MS through the packet paging channel (PPCH). If the cell wherein this MS is located is known, this page message may include either a direct reservation of uplink slots for uplink transmission, or an indication of downlink slots for data reception. In this case, the MS may immediately start data reception/transmission on the pre-reserved slots. On the other hand, if the accurate location of the MS is not known, no slots are reserved for immediate transmission. Instead, a single slot is reserved for a paging response that precedes the channel reservation and therefore the collision-sensitive random access is avoided. Of course, if a page without reservation is sent, the MS initiates the usual random access procedure and asks for the reservation of one block to be able to identify itself after access is granted.

A study of the GPRS channel access protocol can be found in [29], and further information about the GPRS logical channels can be found in [31]. In addition, [32] provides an extended description of the GPRS service and [33] provides details on the RLC/MAC protocol.

ARDIS

Advanced radio data information services (ARDIS)[2] is a two-way radio service that is based on Motorola's RD-LAP technology. It was originally created and jointly owned by Motorola and IBM to serve IBM field technicians. In 1995, Motorola acquired 100 percent ownership of ARDIS and in 1998, ARDIS was acquired by the American Mobile Satellite Corporat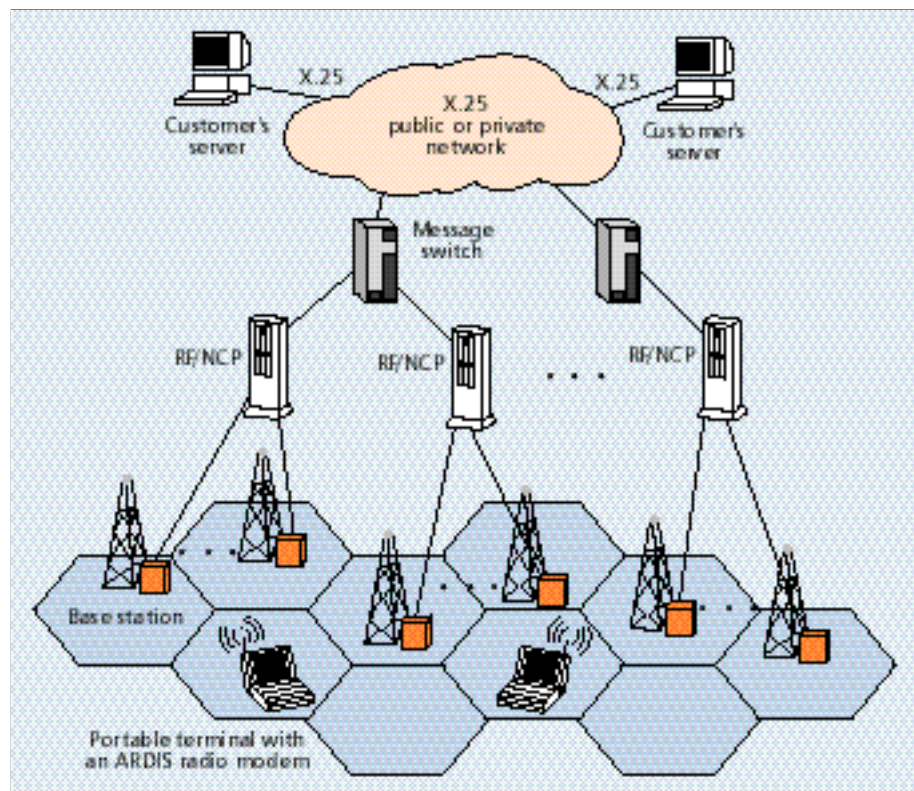ion. ARDIS is quoted as covering 90 percent of the urban business population and more than 400 metropolitan areas in the United States, Puerto Rico, and the Virgin Islands. It is estimated that it has more than 40,000 users, and many of them are still IBM customer engineers.

Motorola has developed two proprietary air-interface protocols for the ARDIS packet network: the MDC-4800, which provides 4,800 b/s service, and the RD-LAP, which provides 19,200 b/s service. MDC-4800 service has been deployed throughout the ARDIS network and only a few major service areas have been enhanced with RD-LAP capability.

ARDIS co-founded the Worldwide Wireless Data Network Operators Group (WWDNOG) [34], an international forum for wireless data network service providers, which includes network operators in Canada, the United Kingdom, Germany, Hong Kong, Australia, Malaysia, and Thailand. The group facilitates the development of common software applications for RD-LAP technology and enables interconnectivity among its member networks.

SYSTEM DESCRIPTION

ARDIS' network is deployed through base stations that are connected back to radio network controllers via dedicated leased lines. ARDIS has approximately 1400 base stations occupying 1100 cell sites. Remote users access the system from laptop radio terminals, which communicate with the base stations. Each of the ARDIS base stations is tied to one of the several radio network controllers, as shown in Fig. 14. A radio network controller is a specialized computer also called a radio frequency/network control processor (RF/NCP) [35]. The RF/NCP manages the RF resources, including the radio base stations and data sent over the radio channels. Both inbound and outbound channels are managed using totally different delivery strategies. The RF/NCP evaluates the strength of the signal received from every wireless device transmission at each base station for each inbound data packet that it "hears." It then selects the best base station to com-

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[2] In 1998, ARDIS merged with American Mobile Satellite Corporation and formed American Mobile.
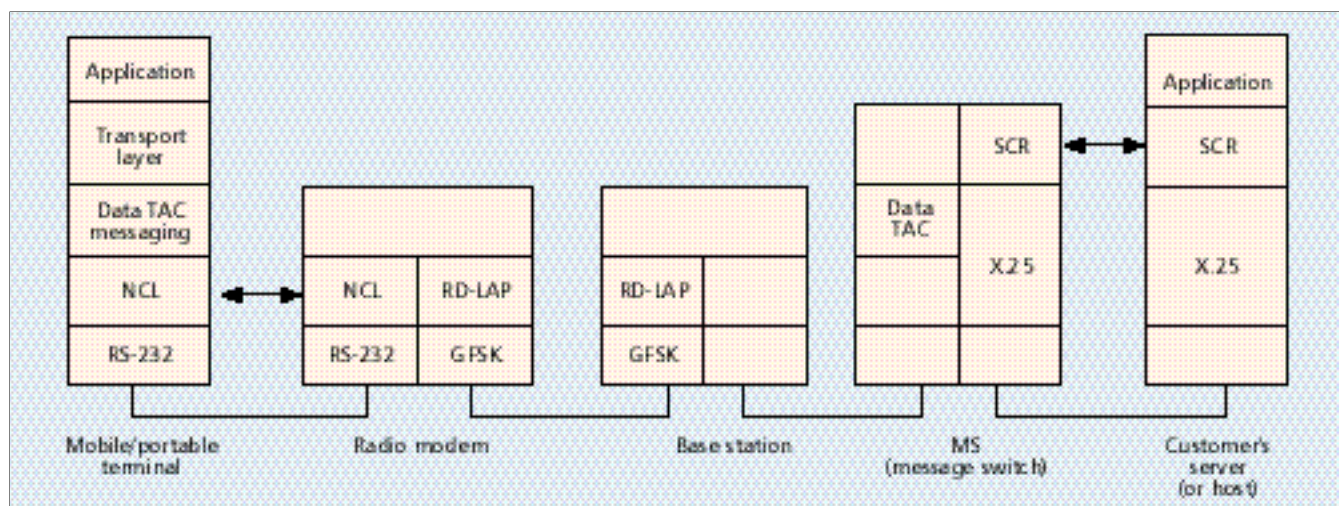
■ FIGURE 15. Key protocols in ARDIS.

municate with that particular wireless device and will send the next outbound message through that base station. This process ensures the optimum selection of a site, although subscriber devices may be moving or be subject to RF noise.

The RF/NCP is one network component that helps manage the automated roaming capability of the ARDIS network. Wireless devices can automatically move (roam) between any of the ARDIS frequencies on either of the two air protocols (MDC-4800 or RD-LAP 19.2), or between any of the ARDIS layers that have been configured for in-building or on-street usage. Furthermore, through the periodic transmissions of "channel marker messages," each wireless device is assured of the most efficient service available in that area.

Each RF/NCP is connected by a high-speed digital line to a message switch (MS). The RF/NCP passes information relating to source, destination, and length of each message to the MS, which enables ARDIS to carry out network analysis of traffic density in each site. The MS passes information to the RF/NCP relative to whether the subscriber unit is properly registered to the network and whether it is entitled to access various services.

Each MS is a general-purpose computer that acts as the heart of the ARDIS network. It routes messages to the proper destination, stores subscriber registration information and performs accounting and billing functions. It also serves as an access point for the customers' mainframe computers [35], performs protocol conversion, handles problem determination and provides a monitoring and testing function for the network management system. The linking between a customer's computer and an MS is accomplished using async, bisync, SNA, or (more typically) X.25 dedicated circuits.

The operating frequency band is 800 MHz and the RF links use separate transmit and receive frequencies, 45 MHz apart, that are simultaneously used to form a full-duplex channel. As already stated, ARDIS was initially implemented with a RF channel data rate of 4800 b/s per 25 kHz channel, but it has been upgraded to 19,200 b/s in some service areas. The base station power is approximately 40 W, which provides line-of-sight coverage up to a radius of 10 to 15 miles. On the other hand, the radio terminals operate with 4 W of radiated power. The areas covered by the individual base stations overlap to increase the probability a signal from a radio terminal to reach at least one base station. The overlapping coverage, combined with designed power levels and error-correction coding in the transmission format, insure that ARDIS can support portable communications from inside buildings, as well as on the street. This capability for in-building coverage is an important characteristic of the ARDIS service.

Inside every cell, the ARDIS radio terminals access the network using a random access method called data sense multiple access (DSMA). Before every transmission, a radio terminal listens to the base station transmitter to determine if a "busy bit" is on or off. This bit indicates whether the base station is currently receiving data (busy bit is on) or not (busy bit is off) and, effectively, it encodes the current state of the shared uplink channel. When this bit is on, radio terminals are prohibited from transmitting and, in that phase, the packet collisions are avoided. On the other hand, when the busy bit is off, a radio terminal is allowed to transmit. However, if two terminals happen to begin transmission at the same time, the packets collide and retransmission will be attempted, as in other contention-based multiple-access protocols.

More details about ARDIS can be found in [34-37].

PROTOCOL ARCHITECTURE

Fig. 15 shows some of the key protocols used by ARDIS. Proprietary data exchange protocols are used to transport data at the various interface points [36]. At the customer's server (or host), the Standard Context Routing (SCR) protocol is used to transport data between this server and the MS. The messages for transmission are broken into packets, each one with a header, containing routing and size information, and a data message. Host messages can be one of the following three basic types:
- Host message delivery request (HR), used by the host to send messages to mobile terminals.
- Host message delivery confirmation (HC), used by the MS to confirm message receipt.
- Mobile device message delivery indication (MI), used by the mobile to acknowledge message receipt.

In addition, extended SCR message types are used to monitor the mobile's activity, perform loopback diagnostics, and check status.

At the mobile terminal end, the Native Control Language (NCL) protocol is used as a link layer protocol between the client application on the mobile terminal and the radio modem. The NCL protocol provides a transaction-oriented service particularly suitable for connectionless applications. A command is issued from the application and a response is elicited from the radio modem for each command issued. Information is exchanged between the mobile terminal and the radio modem in packets called service data units (SDUs). NCL provides three types of SDU:
- Command SDUs, which issue instructions such as "send" and "receive" messages.

- Response status SDUs, which are responses to commands.
- Event report SDUs, which can be enabled or disabled.

In addition to message routing using SCR and NCL protocols, ARDIS networks provide dataTAC messaging (DM), also known as peer-to-peer routing. With the aid of this protocol, messages can be sent from one mobile terminal to another and, thus, a two-way messaging service is established. For this service, an intermediate DM host is used inside the ARDIS infrastructure.

Within the radio portion of the network, between a radio modem and a base station, the RD-LAP (or MDC-4800) protocol provides link layer and some network layer functionality. The maximum transmission length supported is 512 bytes for the RD-LAP and 256 bytes for the MDC-4800. The modulation technique at the physical layer is Gaussian frequency shift keying (GFSK).

CONCLUSION

This article discussed the technical characteristics of the most significant mobile data technologies, namely, the MOBITEX, CDPD, GPRS, and ARDIS. The discussion aimed to provide a technological insight into these mobile data technologies, which currently are facing an important evolution in many areas, including technical and business. These technologies provide the economical means for realization of mobile computing and of a number of other applications ranging from financial and retail communications to remote control and alarm signaling. However, mobile data networks experience severe physical layer constraints and currently supply low-speed wireless data transmission, typically on the order of 9600 b/s. In this context, significant evolution and innovation is to be expected in the future with the introduction of wireless packet data services in third-generation systems, such as universal mobile telecommunication systems (UMTS). The deployment of GPRS in 2000 will be the first step toward this evolution. GPRS will be able to provide cost-effective wide-area packet data services with transmission rates up to 115 kb/s. Further GSM evolution is expected with the implementation of EDGE (enhanced data rates for global evolution). EDGE will allow GSM operators to use existing GSM radio bands to offer wireless multimedia IP-based services and applications at speeds up to 384 kb/s or even higher. In effect, EDGE will enable the advantages of GPRS to be fully explored, with fast connection set-up and higher bandwidth than traditional GSM. The combination of GPRS and EDGE will also result in much improved utilization of the radio network. The introduction of new high-speed data capabilities, including GPRS, EDGE, and the evolution to UMTS, will provide the potential for a whole range of mobile multimedia services, such as Web surfing, access to corporate LANs and intranets, and financial transactions from a mobile terminal.

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BIOGRAPHY

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