IEEE COMMUNICATIONS SURVEYS
The Electronic Magazine of Original Peer-Reviewed Survey Articles

A SURVEY OF MOBILE DATA NETWORKS

APOSTOLIS K. SALKINTZIS
THE UNIVERSITY OF BRITISH COLUMBIA

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.

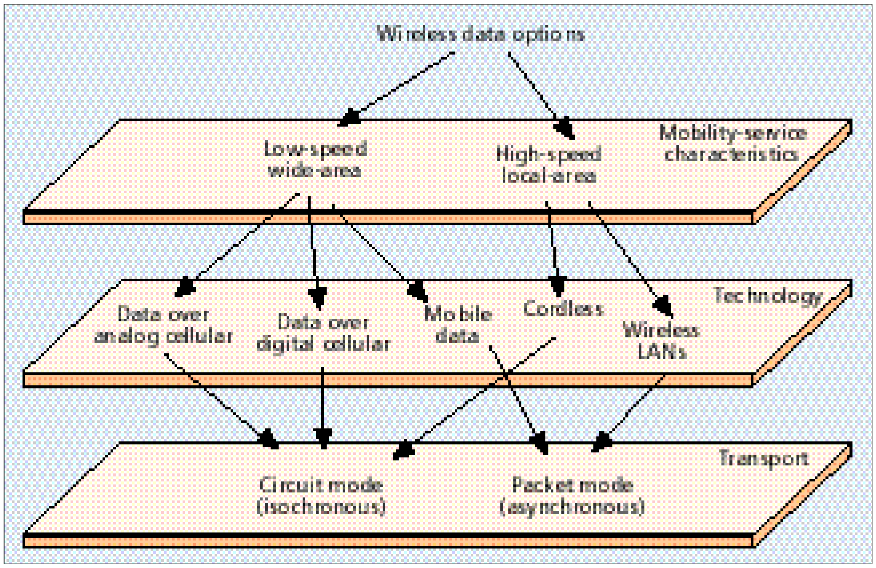

FIGURE 1. Categories of wireless data networks.

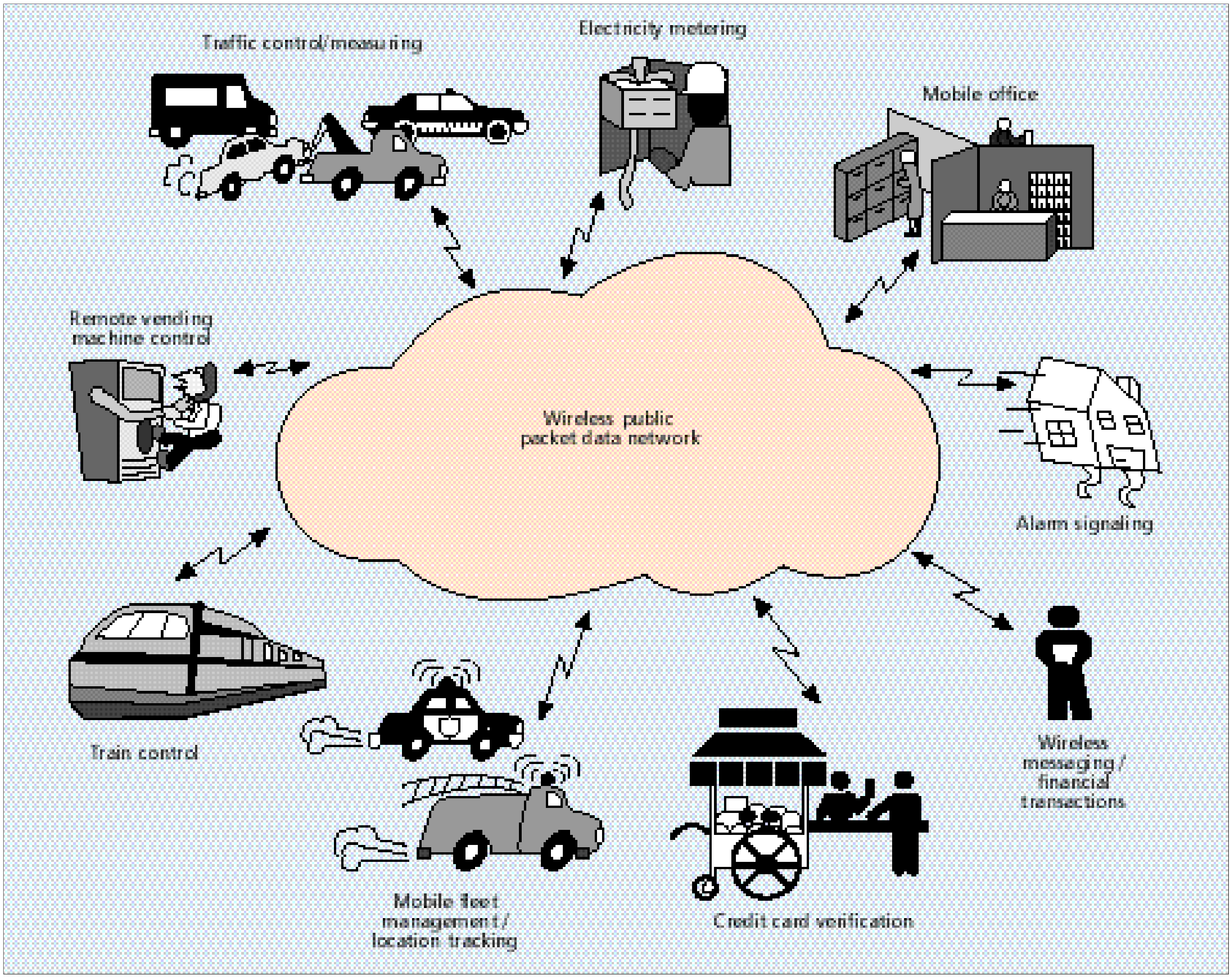

FIGURE 2. Schematic illustration of mobile data applications.

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,

[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 Nether-lands, 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].

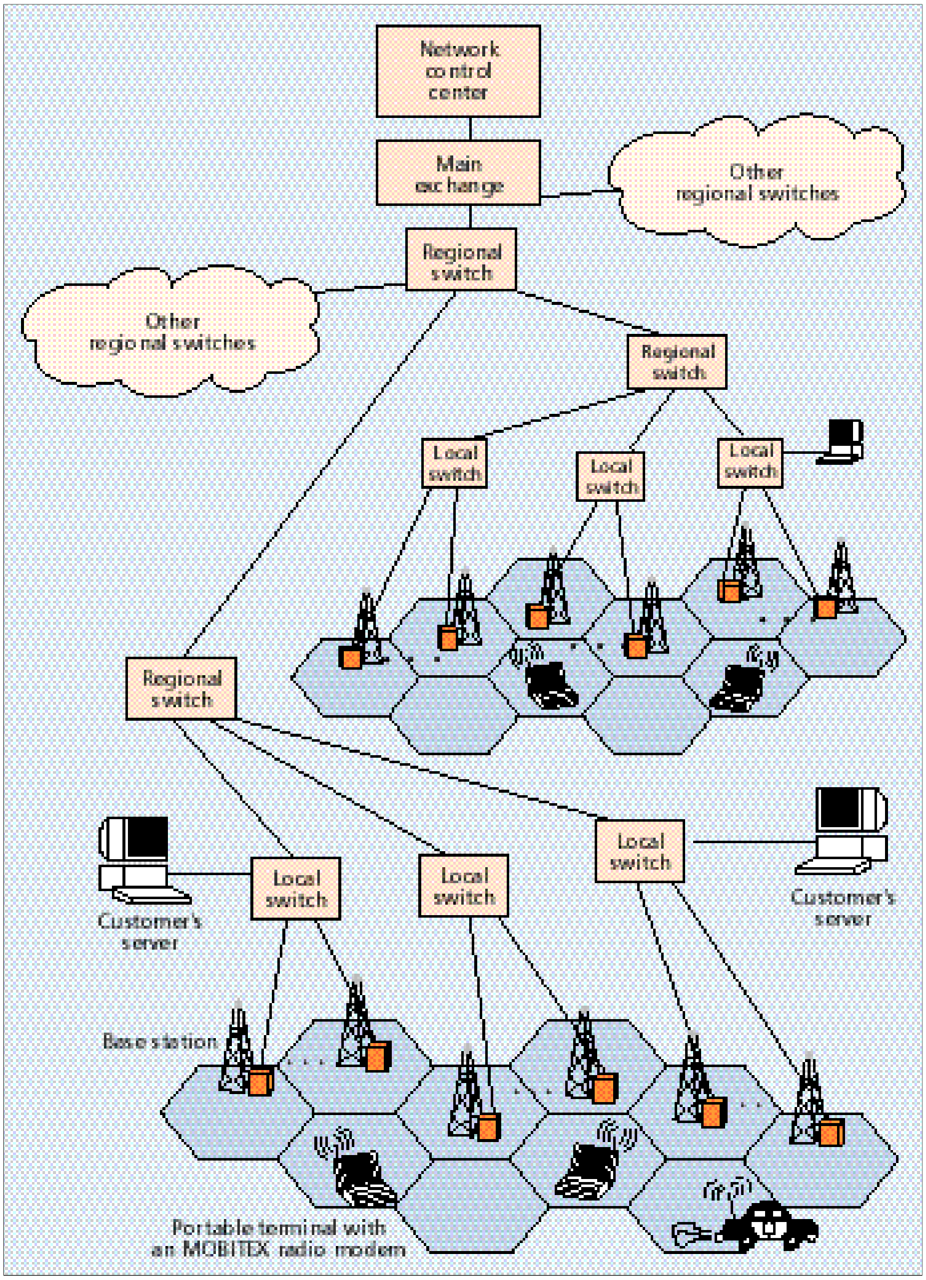

FIGURE 3. MOBITEX architecture.

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, 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.

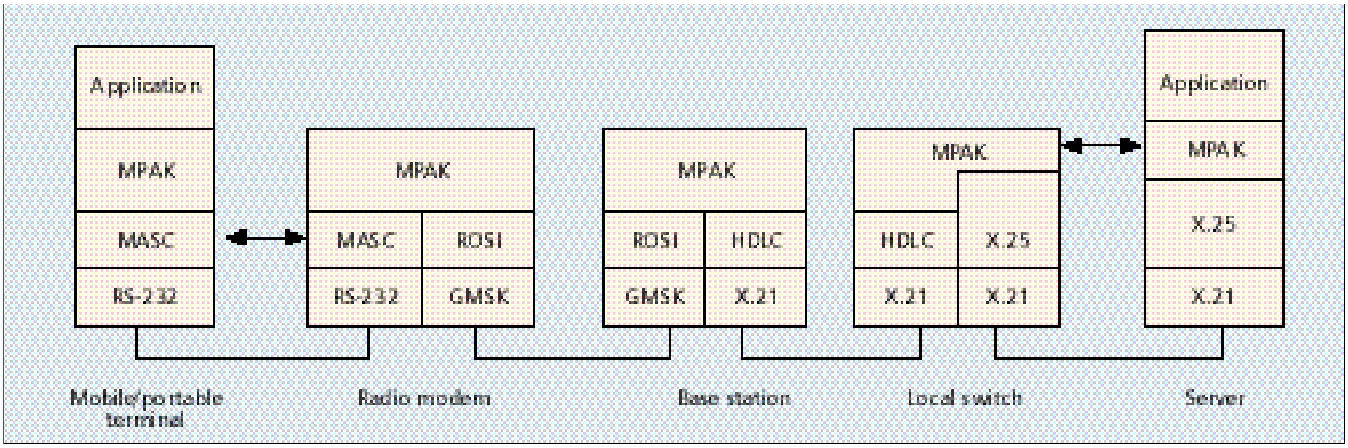

FIGURE 4. Typical protocol architecture within MOBITEX.

- 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

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.