Abstract

Mobile data networks offer a cost-effective and efficient alternative for data communication. In order to present some aspects of mobile data technology, this article offers some insight into the basic networking layers of a popular and widely deployed network, MOBITEX. MOBITEX technology offers a versatile architecture to support wireless packet data service inside an extended geographical area with internetwork roaming and interoperability features. This technology has become quite popular, mainly due to its open architecture and its vast equipment/applications availability. The authors provide an overview of the MOBITEX architecture, services, and subscription types, and a detailed examination of the network, data link, and physical layers. The power-saving features of MOBITEX are also discussed.

Mobile Packet Data Technology: An Insight into MOBITEX Architecture

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Despite the explosive evolution of the cellular[1] industry during the past decade, mobile data networks keep on spreading and providing data services to numerous subscribers all over the world. This is shown by the fact that the most important wireless packet data networks, namely, MOBITEX, ARDIS, and CDPD (cellular digital packet data), are facing increasing activity in many areas, including technical and business.

ARDIS (Advanced Radio Data Information Service, a subsidiary of Motorola) is one of the biggest wireless data service providers in the United States. It employs RD-LAP technology and offers wireless packet data messaging service in over 400 metropolitan areas in the United States, Puerto Rico, and the Virgin Islands, and covers about 90 percent of the urban business population [1]. The network was initially created as a private network for IBM and was later made available for public use (as a 50/50 joint venture between Motorola and IBM [2]), offering 19.2 kb/s signaling in 25 kHz channels, wide roaming, robust link layer and coding schemes, and significant overall message throughput. IBM is still ARDIS' largest customer, with more than 12,000 field engineers using the ARDIS network. RD-LAP architecture has also spread to other countries, including Canada and Germany.

CDPD [3] is a new technology that has begun to spread, although perhaps not as rapidly as expected [4]. In the first nine months of 1995, CDPD service availability climbed from 12 metropolitan statistical areas (MSAs) to 49, and at the end of the year it reached over 50. CDPD was introduced by IBM as a packet-switching overlay to the existing analog cellular voice network and frequencies. This technology uses idle voice channels to multiplex short data messages and to hop among the available frequencies to find those idle channels. 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 cellular channels.

MOBITEX wireless data networks are becoming widely accepted all over the world. MOBITEX technology has become a true worldwide *de facto* standard. In the United States, RAM Mobile Data (RMD) operates MOBITEX systems nationwide in 7700 cities and towns, covering over 90 percent of America's urban business population, and over 11,000 mi of interstate highway, with automatic seamless roaming across all service areas [5]. Furthermore, additional coverage is being implemented now in order to expand the service area in the near future. MOBITEX networks are either installed or being deployed in 16 countries on five continents, including Canada, the United Kingdom, France, Sweden, Finland, Norway, Belgium, the Netherlands, and Australia. There is a MOBITEX Operators Association (MOA) to oversee the specifications, coordinate software and hardware development, and further evolve technology. The specifications are published by the MOA without any license or fee; thus, there are a number of terminal suppliers and equipment developers.

The primary reason that mobile data has managed to withstand the cellular (again, we refer to the cellular phone networks) competition so far, is the increased performance of data transmission. Mobile data systems are designed for packet-switched ("asynchronous") rather than circuit-switched ("isochronous") operation, the latter being the case for data over cellular. Therefore, communication resources are more efficiently utilized, resulting in superior overall performance and lower cost.

Figure 1 illustrates how the cost of data transmission over mobile data and cellular networks changes relative to the size of data per transmission [6]. The figure is only representative and aims at revealing that mobile data networks are most cost efficient when small quantities of data are transmitted at one time.

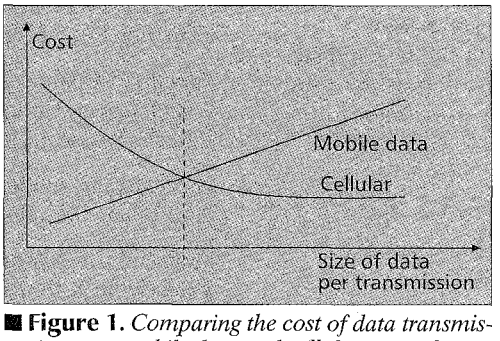

Figure 1. *Comparing the cost of data transmission over mobile data and cellular networks.*

[1] *It is customary to use the word "cellular" to refer to cellular phone networks like AMPS and GSM.*

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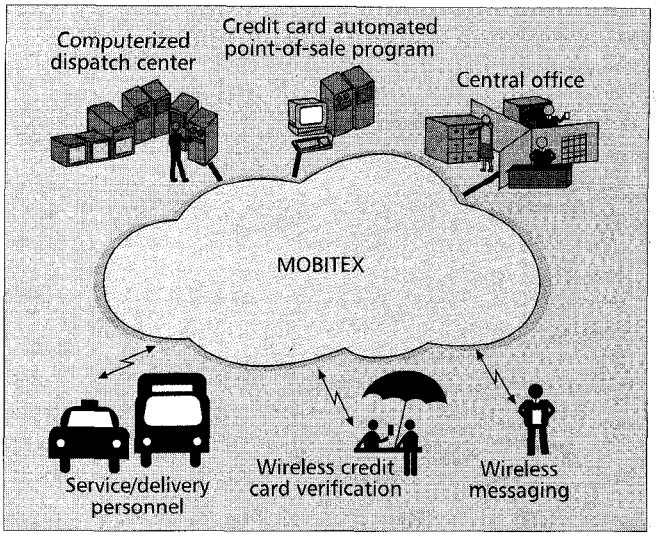
Transporting data over cellular, however, becomes most cost efficient when large data transfers are taking place in each transaction.

Another major advantage mobile data networks have over cellular is their store-and-forward capabilities. With cellular the wireless terminals have to be continuously attached and working to receive messages,[2] whereas with mobile data messages are stored even when the radio modem is switched off or out of radio coverage, so there is no always-in-contact requirement.

From the user perspective, mobile data systems offer an alternative that usually guarantees both cheaper and improved services (as compared to cellular) in a wide range of packet-data applications such as wireless messaging, remote data collection, remote database access, wireless credit card verification, automatic vehicle location, computerized dispatch, and Internet access (Fig. 2). All these applications drive the market of the present mobile data networks. Prospective customers include companies such as couriers, emergency services, taxis, and trucking that need a system to provide accurate, real-time vehicle and driver status, routing and scheduling, and two-way communication between drivers and dispatchers. Furthermore, companies that use applications such as e-mail, remote data access, data collection, and point of sale need a system to connect their mobile workforce to a central computer without the constraints of wired telephone connections. Mobile data networks bring new opportunities to these businesses without excessive cost requirements.

The rest of this article presents some insight into the operational aspects of mobile data networks by describing the basic networking layers of a popular and widely deployed network, the MOBITEX.



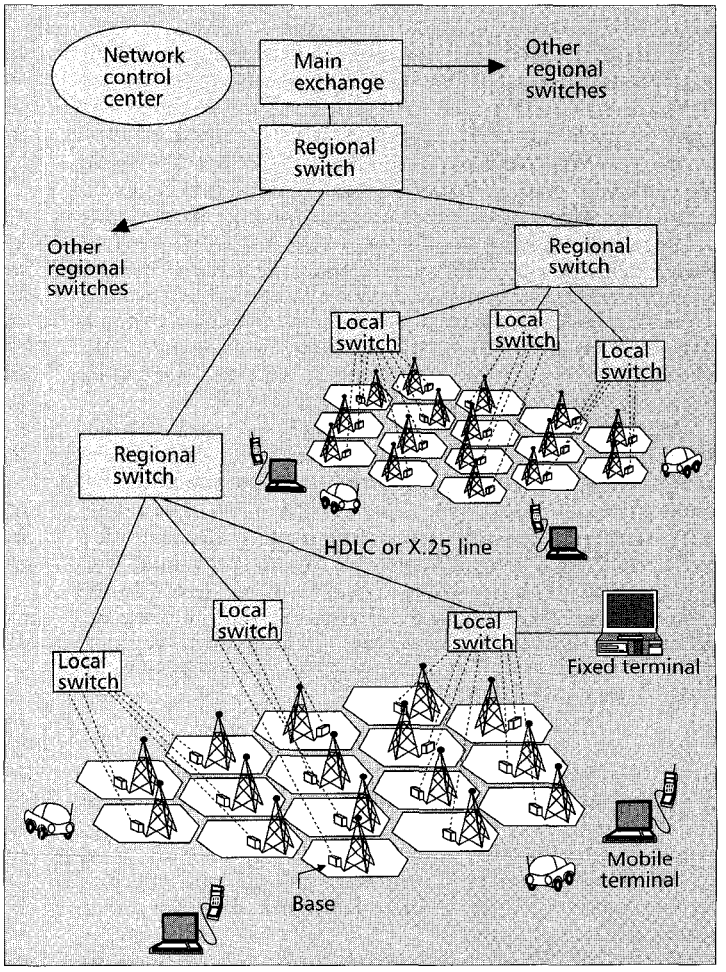
■ **Figure 2.** *Common applications of mobile data networks.*

MOBITEX System Architecture

The MOBITEX architecture was originally developed by Swedish Telecom, now called Telia Mobitel, as a private mobile alarm system used by field personnel. However, mainly for economical reasons, it evolved into a public mobile radio service. Continuing development has been done by Eritel AB under the guidance of the MOA and Ericsson Mobile Communications AB. Commercial operation was introduced in Sweden in 1986; since then, a number of networks have been constructed in Europe, the United States, and Australia [2, 5]. Only the radio frequency differs, depending on the country: 900 MHz is used mainly in the United States and Canada; most other countries operate in the 450 MHz range. In the rest of this section the main functional elements of the MOBITEX network and the interfaces between these elements are defined.

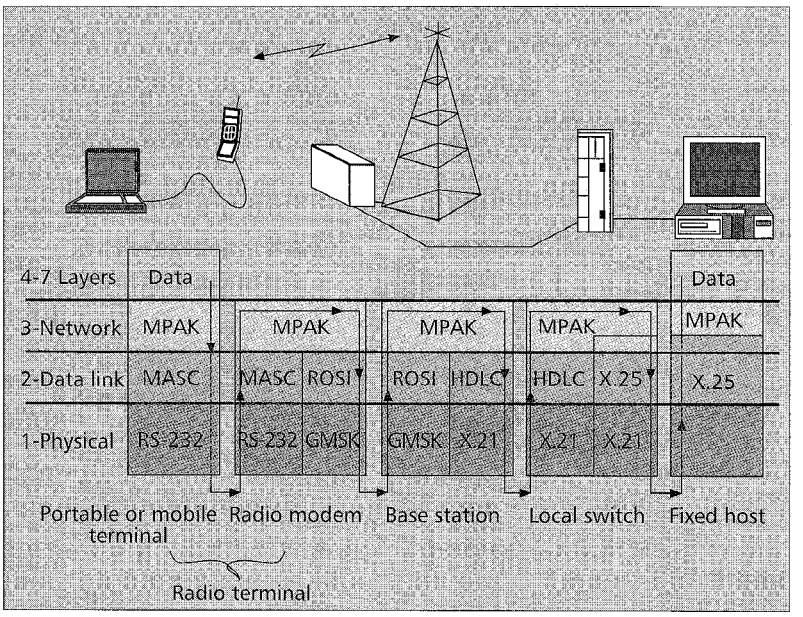
The MOBITEX system employs a cellular layout in order to provide wireless communication services to a specific geographical area. It utilizes a hierarchical structure that may contain up to six levels of network nodes depending on the size and the area of coverage. As shown in Fig. 3, the infrastructure 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 subnet. In each service area 10 to 30 frequency pairs (called channels) are allocated to radio service [5]. Each base station usually 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 United States is 935 to 940 MHz for the downlink (base to mobile) and 896 to 901 MHz for the uplink (mobile to base).

The base stations are connected to local switches via local



■ **Figure 3.** *MOBITEX hierarchical architectecture.*

[2] *In order to fulfill this objective, a number of complicated error-correcting protocols have emerged such as Microcom's MNP-10, AT&T's ETC (Enhanced Throughput Cellular), Celleritas' TX-CEL (though not actually a protocol), and V.42 and V.34.*



■ **Figure 4.** *Protocol layering in various network elements.*

telephone facilities using either X.25 or a high-level data link control (HDLC) data link. 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 the network is that message switching occurs at the lowest possible level (not the case for other networks, e.g., CPDP), 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 mobile users roam in different cells belonging to the same service area, message turnaround occurs at the service area's local switch. Only mobility, authentication, and other signaling messages need to travel upwards 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 [7].

Another key feature of MOBITEX is store-and-forward capabilities. A temporary store-and-forward facility allows applications to deal more effectively with mobile units that are temporarily unavailable (e.g., turned off or in a tunnel). Each registered subscriber has a storage space allocated within the MOBITEX system (a mailbox). If a packet is undeliverable, it may, at the sender's discretion, be stored in the recipient's mailbox. When the recipient's radio modem reestablishes contact with the system, it automatically registers with a base station and all the accumulated packets in his mailbox are then forwarded to him.

Subscriptions

Network subscribers can access the network services through a physical network access point, that is, either a fixed host terminal (connected to a local switch, see Fig. 3) or a radio terminal which complies with the MOBITEX air interface specification [8]. Standard connection interfaces are specified for both types of access terminals in order to establish a standardized access platform.

The MOBITEX system supports various types of subscriptions to efficiently accommodate a wide range of applications and requirements. Generally, every fixed host needs a *host terminal subscription*; similarly, every radio terminal is associated with a *mobile terminal subscription*. Whenever a radio terminal is switched on, it uses its own subscription profile to register with the nearest base station and to log into the MOBITEX system. During this phase the radio terminal transmits its Electronic Serial Number (ESN), which is hard-coded into each radio modem, and the network verifies that the transmitted ESN matches the ESN stored in its subscription profile. Any mismatch triggers an alert to the NCC, and a command is sent to the radio terminal, rendering it inactive.

Furthermore, every individual who needs access to the MOBITEX must have a *personal subscription*. Every personal subscription is associated with a PMAN (personal MOBITEX access number) and a password, which protects from unauthorized use and helps with correct billing. In order to access the network a person must use the nearest access terminal (radio or host terminal) to request login using his own PMAN and password. The access terminal transmits the login request to the network side for authentication. In this way, the network finds out the physical access point (i.e., the address of the employed radio or host terminal) of every logged-in personal subscription, and thus can subsequently route the subscription's incoming traffic appropriately. Up to eight personal subscriptions may be active on a radio terminal at a time.

It is to be noted here that the utilization of both *mobile terminal* and *personal subscriptions* effectively offer personal mobility (a significant concept in personal communications), because a person is not bound to a specific terminal. In every case, a person may select and use a preferred (and maybe different) terminal to gain access to the network.

Additionally, there are *group subscriptions* that comprise a number of mobile and host terminal subscriptions and are used for receiving group messages (e.g., from all the field workers of a company). This service minimizes the work of dispatch personnel by broadcasting identical messages to numerous subscriptions. A group broadcast message is sent to terminals in a controlled geographical area selected by the customer. There is no definite acknowledgment from each recipient of a group broadcast message, so there is no guarantee that a radio terminal will receive the message. However, the network will broadcast a group message several times.

Lastly, there are *host group subscriptions* that enable a mobile user to access a group of host computers as if they were a single host, or allows a single host to have multiple network appearances (for a detailed description see [5]).

The addresses used to identify subscriptions, groups, and external networks are called MOBITEX access numbers (MANs).

Protocol Layering

Figure 4 shows a layered picture of the MOBITEX interfaces. It is evident, that the MOBITEX architecture is associated only with the first three layers of the open systems interconnection (OSI) model. However, the three protocol layers of MOBITEX are not clearly mapped into the corresponding OSI layers. For example, in the physical layer of MOBITEX an error correction coding is defined, which is not a physical-layer function in the OSI model. Layers four to seven are employed and controlled by the applications using the network.

The mobile terminating unit (i.e., the *radio modem*) inter-

faces 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 [8]. 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.

The standard MOBITEX (mobile/portable) terminal interface is called MASC (MOBITEX ASynchronous Communication). This interface provides for both the reliable transfer of data to/from the radio modem, and the control and status monitoring of the modem.

The rest of this article focuses on the air interface protocol, describing the main features of the network layer (MPAK), the data link layer (ROSI – Radio OSI protocol), and the physical layer.

Network Layer

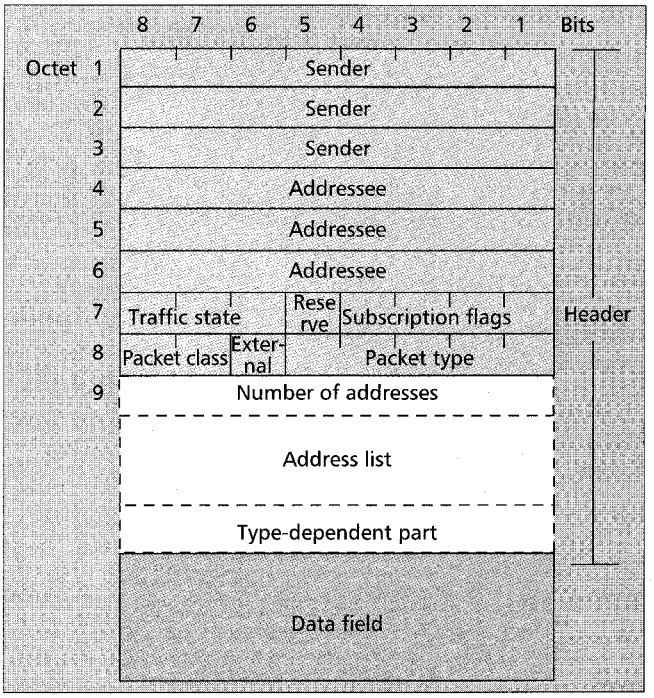
Although the MOBITEX specification defines both packet- and circuit-switched (mainly for voice communication) transmission facilities, most operators are restricted to data communications and provide only packet-switched services. This is why the MOBITEX is mainly classified as a mobile data network despite the initial provision for voice communications.

Generally, traffic at the network layer is used either to transfer information from one subscriber to another (consider two-way messaging), between applications (e.g., on credit card verification), or to update information resources stored in network specific elements (e.g., login-logout indications). Data packets are divided into four classes according to the type of service they are engaged in:

- PSUBCOM-class packets transfer information from one subscriber (or application) to another, such as text messages, data messages, status messages, and higher protocol data messages. The message type is encoded in the type field of a packet, so the network elements and applications can treat the various types accordingly.
- PSOSCOM-class packets are used to transfer alert messages (i.e., high-priority data traffic).
- CSUBCOM-class packets are used to set up and control circuit-switched connections (to support real-time connections). These kinds of packets are not used in data communication, so we do not pay any further attention to this class.
- DTESERV-class packets are basically network-layer signaling packets used to update status information. For example, they are used to change the status of personal and group subscriptions (e.g., login, logout requests), to change a terminal's status (e.g., active-inactive messages), and to transfer terminal-specific information (e.g., terminal information request/response) to the network.

The network-layer protocol unit in MOBITEX is named MPAK (MOBITEX PAcKet), the general structure of which is shown in Fig. 5. The packet header is composed of three parts; the first is mandatory to all MPAKs, while the other two are optional and type-dependent. As shown in Fig. 5, the mandatory part is octets 1–8. When a packet is destined to multiple individual recipients, the second part contains the address list of these recipients. The third (type-dependent) part is included only in various packet types where additional information is required to support a given service.

The fields *sender* and *addressee* inside an MPAK contain the subscription numbers (MANs) of the originator and recipient of the packet. The sender MAN can be a terminal subscription, personal subscription, or network MAN, while the addressee MAN may be all these plus a group MAN.



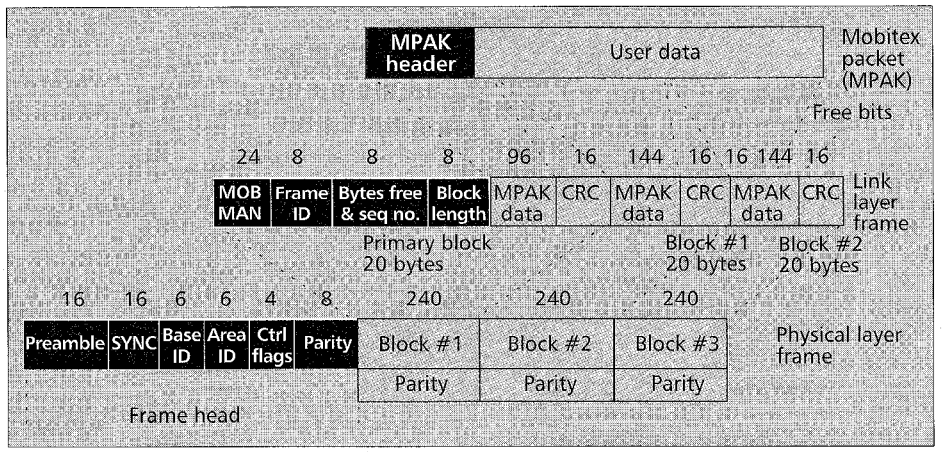
■ **Figure 5.** *MPAK structure.*

Traffic state flags represent the transfer status of a message and are checked during an MPAK reception. They encode various error conditions in cases where a packet is undeliverable (e.g., congestion, bad format, network busy). If traffic state flags indicate no error (traffic state = 0), the received MPAK is forwarded to the ultimate destination: the upper layer or the network-layer management entity. Furthermore, if a message comes from a user's mailbox (placed earlier, when the user was unavailable), the traffic state flags will indicate this. Also, if we are attempting to transmit a packet to a recipient who is currently unavailable, the packet will be placed in a recipient's mailbox for future delivery, and will return with the traffic state flags indicating so.

Subscription flags are set by the packet originator to define whether the packet may or may not be stored in the recipient's mailbox, if a positive acknowledgment for this packet is needed (packets are by default not acknowledged at the network layer), if the packet contains an address list inside, and so on.

Finally, the *packet class* associates the packet with one of the four classes mentioned above, PSUBCOM, PSOSCOM, DTESERV, and CSUBCOM, and the *packet type* specifies an individual type within the designated class. For example, a text message will have PSUBCOM class and type = 1, while a data message will have the same class but type = 2. Similarly, if we try to log in, the login request message will have DTESERV class and type = 1.

A unique 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 only one packet, which includes the desired recipient list in the header. The direct addressee for this packet is the MOBITEX network (this is a special address). The first network node that receives the packet (i.e., the selected BASE station) will split the packet into a number of individual packets, each addressed to a recipient included in the original address list. Afterwards, each packet is separately switched through the wireline or wireless facilities.



■ **Figure 6.** *MOBITEX frame structures.*

Data Link Layer

The data link layer specifies the functions used to provide efficient, error-free transmission over the wireless medium. It mainly provides the functionality of the data link layer as defined in the OSI model. It implements functions for error detection and correction through a block-selective ARQ scheme, channel multiaccess algorithms, priority facilities and roaming procedures. Generally, the data link layer ensures proper communication with the MOBITEX infrastructure

- By selecting the most suitable (in terms of communication reliability) base station with which to communicate
- By retransmitting data link structures that either were destroyed by the mobile data channel impairments or collided with neighbor transmissions
- By efficiently accessing the shared transmission resources available for communication

The general link layer frame structure used in MOBITEX, is shown in the middle of Fig. 6. It consists of a series of blocks, each one with a constant size of 20 bytes and each with a 16-bit CRC (cyclic redundancy check) appended at the end for error protection.

The first block is the primary block and contains mandatory link control information. The link address (MOB MAN) at the beginning specifies the address of a mobile terminal which either has generated the frame or is the immediate destination of the frame. Additionally, the primary block specifies the type of the frame, the number of blocks in the frame, the sequence number of the frame, and the number of valid bytes in the last block.[3] A data link layer frame may comprise only the primary block; the following blocks may or may not exist depending on the frame type. For example, in Fig. 6, two blocks were required after the primary, in order to transfer an MPAK. In acknowledgments, however, only the primary block is necessary.

The data link layer employs a block selective repeat automatic repeat request (ARQ) scheme to efficiently recover from transmission errors. That is, after a frame transmission (say from mobile to base) the addressee checks the received blocks for errors. If all the blocks are correct, it replies with an ACK frame (positive acknowledgment); otherwise, it replies with a repetition request REB frame that explicitly indicates which blocks have to be retransmitted. There may be cases, for example, when the primary block is corrupted or a frame is addressed to a group, where a recipient should not transmit an acknowledgment. Actually, there is a single flag in the link header that indicates if an acknowledgment is needed for a particular frame. It should be noted that a frame is transmitted only after the previous one has been acknowledged (i.e., a stop-and-wait ARQ scheme is employed at the frame level).

The data link protocol of MOBITEX is quite different and simpler than the data link protocol of CDPD. The latter is HDLC-based (similar to International Telecommunications Union — Telecommunications Standardization Sector, ITU-T, Recommendation Q.921) and establishes data link connections between the mobile terminals and the network, whereas, the former is a custom connectionless protocol. Both, however, employ error detection/correction schemes and selective retransmissions.

Channel Access

The multiple access protocol in the MOBITEX is a variation of the well-known slotted ALOHA [9]. A mobile terminal (MOB) that has traffic to send is allowed to transmit only during specific free cycles.[4] These cycles (repeated time periods) are initiated by the base station in every cell, by transmitting a FREE frame on the downlink. The free cycles are divided into slots of equal length. After a FREE frame reception, a ready MOB (one with awaiting traffic) randomly chooses a slot and starts transmission at the beginning of that slot. If an MOB becomes ready during a free cycle, it transmits at the next available slot. Of course, due to random access, collisions may occur when two or more MOBs choose the same slot to transmit.

The slot length (`SLOT_LENGTH`) as well as the total number of slots (`FREE_SLOTS`) in a free cycle are explicitly stated in the `FREE` frame that initiated the cycle. Both these variables can change depending on the amount and length of downlink traffic. The `SLOT_LENGTH` parameter in the `FREE` frame actually specifies the maximum length of a data frame that can be sent without a preceding access request. To explain this further, consider an MOB that has a data frame to send. If the total length of the frame is greater than the `SLOT_LENGTH` parameter specified in the previous `FREE` frame, it must send an access request instead of the data frame itself. At the end of the free cycle the `BASE` will grant access permission to every mobile that has successfully sent an access request. Thus, one after the other, the mobiles will eventually transmit their data frames (though outside of a free cycle) before the next free cycle.

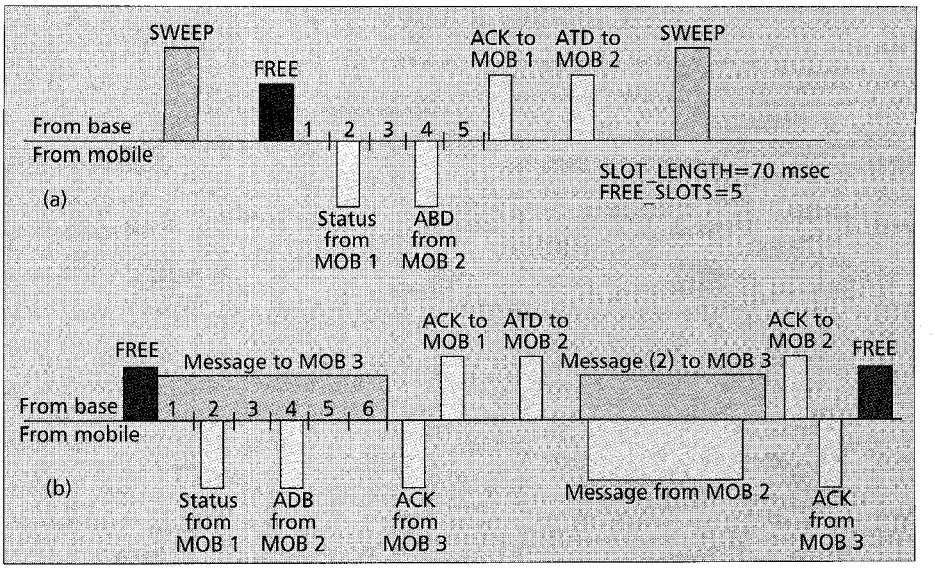
In Fig. 7a, 5 free slots are illustrated with a length of 70 ms each. In this example, MOB 1 generated the random number "2" and sent a status message in the second slot, while MOB 2 generated the random number "4" and sent an access request (ABD). At the end of the free cycle the BASE acknowledges the status message of MOB 1 and also grants access permission to MOB 2 by transmitting a (properly addressed) access grant frame (ATD).

In Fig. 7b another channel activity example is shown. Because the base station operates in full duplex it can simultaneously receive and transmit messages. The base station attempts to make the most efficient use of air time by arrang-

[3] *Remaining bytes in the last block are filled with zeros.*

[4] *This is a main characteristic of MOBITEX. Other mobile packet networks such as CDPD allow terminals to transmit at any time.*

ing messages by size and coordinating with the inbound traffic from the mobiles. Considering Fig. 7b, after the first FREE frame, the base station transmits a message to MOB 3 and also generates six random access slots. To increase channel efficiency, the duration of random slots is made approximately equal to the duration of the outbound message to MOB 3. After the free cycle ends, MOB 3 acknowledges the message sent by BASE and the BASE responds to the packets sent by MOB 1 and MOB 2 (with an ACK and ATD, respectively). Afterwards, MOB 2 sends its long message packet (it has been granted channel access), and simultaneously the base station sends a second message to MOB 3. It then sends an acknowledgment in response to the long message from MOB 2 and also receives an acknowledgment frame from MOB 3.



■ **Figure 7.** *Channel access timing.*

An important characteristic of the channel access procedure is that transmit permission in a free cycle may be given only to a subset of mobiles, in order to reduce the number of access attempts. This is accomplished by either addressing the FREE frame to a number of mobiles (using a specific address mask field), specifying a priority level (above which transmit permission is granted), or specifying a particular traffic type (alert, data, etc.) that is acceptable in the free cycle.

Every data frame (or access request) transmitted by a MOB during a free cycle must be acknowledged by the BASE before the next FREE frame (i.e., before the start of the next free cycle). Frames that have not been acknowledged (maybe because they have collided) are retransmitted using a repetition policy managed by the network operator. Generally, an MOB has to wait for k free cycles before retransmitting. The specified default value for k is zero (i.e., retransmission may occur at every free cycle); however, k may become progressively larger as the repetition number increases (for a complete backoff policy description see [8]). Finally, if too many repetitions have been tried, the data frame is returned to the network layer and a recovery mechanism is triggered (usually a roaming procedure) in order to re-establish a reliable data link contact.

Roaming

The portion of the data link management entity that is responsible for finding the best network access point (i.e., base station) and retaining the best radio link quality possible is called the *roaming entity*. Usually, the roaming entity deploys the primitives provisioned by the first two or three layers of the OSI network reference model.

The main roaming procedure is somewhat similar in every cellular network with roaming capabilities. That is, a mobile station monitors the quality of the currently selected radio channel as well as the quality of other system channels which are highly likely to provide an acceptable radio communication. The main differences that exist in various approaches include the way "quality" is translated, the means for quality measurement [10], and the frequency of these measurements.

MOBITEX roaming procedures generally conform to the above principle. Every MOB, in addition to monitoring the signal quality of the currently registered base station (the CURRENT_BASE), is periodically scanning other system channels and evaluates the average value of the received signal strength in these channels. This average value is often referred to as the *roaming value* of the channel.

Inside every cell, many variables related to the scanning and channel measurement processes are broadcast by means of special signaling frames. The most important frame belonging to this category is the SWEEP frame, which contains many parameters needed for operator-assisted roaming. An MOB that receives a valid SWEEP frame from BASE will update some internally maintained parameters and will also mark the start of a new sweep cycle. Figure 8 illustrates the format of a (type 1) SWEEP frame.

The primary block is always present in a SWEEP frame, but the following blocks may or may not exist. Whenever they exist, these blocks identify a list of neighbor system channels that should be monitored by the MOBs in a specific cell. Thus, every MOB may use these blocks to maintain in memory a *neighbor* (or *current channel*) list[5] for roaming purposes. It is the job of the network operation center to properly configure every BASE relative to how often this channel list will be broadcast and which channels will be included in the list.

The ordinary roaming procedure implemented by every MOB is as follows (Fig. 9): After the reception of a SWEEP frame some internal parameters including the *current channel* list are updated. Also an internal timer, T_s, is started as an indication of a new sweep cycle beginning. The concept of sweep cycle is important in the MOBITEX system; it specifies a time period in which a roaming procedure takes place. At the end of a sweep cycle, all the neighbor channels are evaluated and the best BASE station is chosen. A typical sweep cycle duration is 10 s.

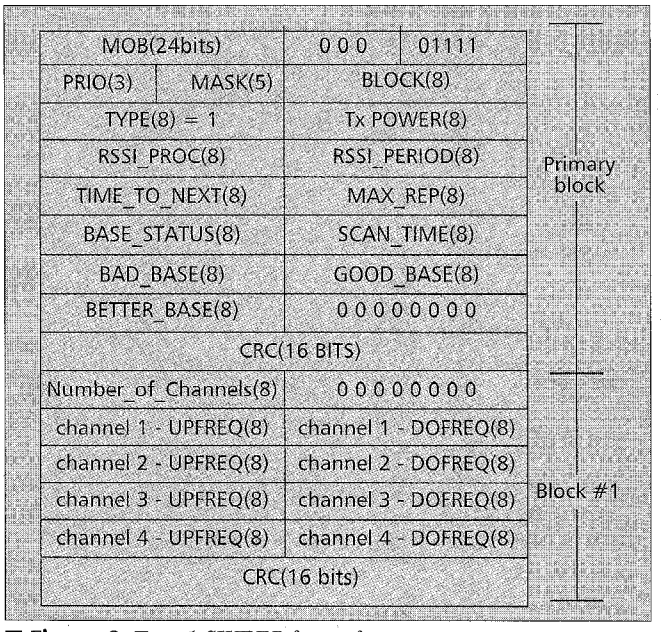
Timer T_s will time out after a period t which depends on the terminal's own subscription number[6] (MAN) according to the following relations:

t = TIME_TO_NEXT − 10 ms − SCAN_TIME, if MAN is even or

t = TIME_TO_NEXT − 10 ms − 2*SCAN_TIME, if MAN is odd

[5] *Every MOB also holds a default channel list in nonvolatile memory which contains all the network system channels. If the current channel list is not available, the default channel list is used.*

[6] *Partitioning the mobile terminals in this way ensures that data traffic can be forwarded to terminals with even (odd) MANs while terminals with odd (even) MANs are in the midst of normal channel monitoring.*



■ **Figure 8.** *Type 1 SWEEP frame format.*

where SCAN_TIME is the overall length of the neighbor-channel scanning period (including channel switching) and TIME_TO_NEXT is the interval before the next SWEEP frame. All these parameters are defined in the primary block of a SWEEP frame (Fig. 8).

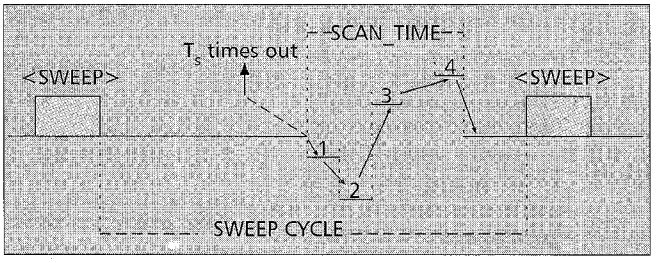
System channels specified in SWEEP frames are scanned by the MOB in a round robin fashion, and a roaming value is evaluated for each one. As indicated in Fig. 9, *normal channel monitoring* starts as soon as timer T_s times out. During the SCAN_TIME period the MOB leaves the current channel, tunes to the next system channel in turn for a period specified by the RSSI_PERIOD, and measures the received signal strength. It then proceeds similarly with the next channel, until either the SCAN_TIME period elapses or a full list scan has been performed (i.e., all the channels in the current channel list have been monitored). Whatever the case, the MOB returns to the current system channel and, at the next sweep cycle, either restarts or resumes the channel list scanning.

The measurement method applied to estimate the received signal strength depends on the RSSI_PROC parameter, specified in the SWEEP frame. If RSSI_PROC = 0 (FRAME method) the radio modem measures the received signal strength of the frame heads (shown in Fig. 6) that are received during the RSSI_PERIOD period. If RSSI_PROC = 1 (CONTINUOUS method) the measurement is continuous, meaning that the signal strength is evaluated during the entire RSSI_PERIOD and not only during the frame heads.[7]

In order to ensure that during the RSSI_PERIOD there will be some traffic on the target channel to make the signal strength measurement feasible, every base station periodically transmits a roaming signal (typically 2/s, Fig. 10), which is actually a frame head with the roaming_flag set.

The number of channels scanned during a sweep cycle is based on the relationship between SCAN_TIME and RSSI_PERIOD. Taking the default values specified in the MOBITEX Interface Specification [8] (i.e., RSSI_PERIOD = 2960 ms, SCAN_TIME = 3 s), only one channel is scanned per sweep cycle. On the other hand, the current values employed by RAM Mobile [5] (i.e., RSSI_PERIOD = 100 ms, SCAN_TIME = 1.5 s) allow as many as 15 channels to be scanned during a single sweep cycle. Thus, if the current channel list contains 10 channels a full list scan will take 100 s in the first case and 1 s in the second.

[7] *No base station ID can be identified in this method because no bit or frame synchronization is achieved.*



■ **Figure 9.** *Neighbor channel monitoring inside a sweep cycle.*

At the end of each sweep cycle, a roaming evaluation for every channel is made and all the radio channels having a signal strength greater than CURRENT_BASE + BETTER_BASE are identified (CURRENT_BASE is the calculated signal strength of the current system channel). Generally, the MOB will switch to the best system channel (i.e., the best neighbor base station) that fullfils the above criteria, if this criteria still holds after a small delay period (to compensate for the short-term signal fluctuations).

Physical Layer

The physical layer protocol describes the way in which the mobile terminal handles the radio channel. Various functions implemented in the physical layer include frame and bit synchronization, slot synchronization (during free cycles), system channel identification, base station and area identification, received signal strength measurement, transmission power level setting, and error correction coding. As already mentioned, the error correction coding *is not* a physical layer function in the OSI reference model (ISO-7498 of the International Organization for Standardization).

In order to achieve high transmission reliability the link layer frames are divided into blocks, and each block is separately coded. The physical layer frame structure is depicted in the lower part of Fig. 6. It starts with a frame head that is used to establish 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. It contains eight pairs of alternating 1s and 0s. If the frame is transmitted from a base station the pattern starts with a couple of 1s (i.e., 1100110011001100), whereas when it is transmitted by a mobile station, the pattern starts with a couple of 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 (whereupon it will probably be discarded).

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; thus, SYNC is used as a network identification number at the physical layer. The MOBITEX specification defines that, in order to roam into base stations in other networks, it should be possible to *manually* change the frame synchronization word from the application layer. However, it is clear that if a mobile receives frames from a network which uses a different SYNC (from that currently selected), it will not be able to acquire frame synchronization, and the received frames will be discarded at the physical layer.

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 IDs, while frames originated from radio terminals will carry the base and

area IDs of the destination base. Obviously (from Fig. 6), there may be up to 64 (2^6) areas in every network and each area may contain up to 64 (2^6) base stations. These ID fields make it feasible for a radio terminal to accept physical layer frames from only one base station (the one selected by the roaming entity). If, maybe due to favorable propagation conditions, a mobile station receives frames from a distant base station, these frames will be discarded.

The four `Ctrl flags` are used by base stations to communicate signaling and synchronization information at the physical layer. The `set_slot_flag`, whenever set, is used to reset a slot clock inside every radio modem, and thus to establish common slot timing. There is also a `roaming_flag` which is set in every roaming signal (a frame that contains only a frame head and is used to aid the roaming procedure, Fig. 10) and is periodically transmitted from every base station. Lastly, the `silence_flag` is set whenever the BASE wants to withdraw the uplink channel access permission from all the mobiles that reside in a particular cell.

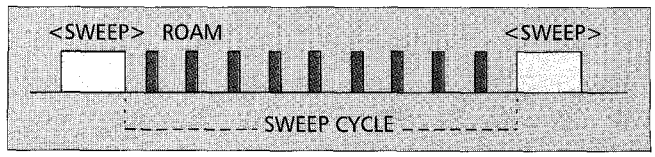
Apart from producing and decoding physical-layer frames according to the aforementioned fields, the physical layer provides various other functions, the most important of which are outlined below.

The RSSI (received signal strength indication) measurements related to the roaming procedure of the data link layer (as explained in the previous section) are actually performed by the physical layer. Whenever the data link carries out a channel scan procedure, it orders (via implementation-specific primitives) the physical layer to measure the average received signal strength of a specific channel for a specific time period. After that period, the physical layer makes an upcall and passes the measured RSSI to the data link layer.

Error correction coding is also performed at the physical layer. As indicated in Fig. 11, all the 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 8 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.

After the block coding, the block matrix is interleaved to give protection against burst errors. The block matrix, as indicated in Fig. 11, is sent column-wise, starting at position (1,1), and received the same way. Finally, before actual transmission, all the encoded and interleaved blocks (except the frame head) will pass through a nine-stage scrambler, which generates a scrambling sequence identical to the recommended test sequence described in ITU-T Recommendation V.52.

After the above processing stages, the logic sequence for transmission is converted into a binary nonreturn to zero (NRZ) waveform with an 8 kb/s rate. This digital waveform is filtered by a lowpass filter with linear phase characteristics[8] (usually, a Gaussian filter is used [5, 11]) and directly applied to the FM (frequency modulation) modulator input. The frequency deviation is set to yield a transmitted frequency 2 kHz higher (when a logic 1 is sent) or 2 kHz lower (when a logic 0 is sent) than the channel center frequency; that is, the modulation index is 0.5. With these settings the RF channel bandwidth is restricted to 12.5 kHz.



■ **Figure 10.** *The roaming signals on a system channel.*

MOBITEX radio modems are also capable of dynamic power control. This capability provides increased capacity in high-density service areas. The number of cells in a service area can be increased by reducing the base stations' coverage pattern and adding more base stations.

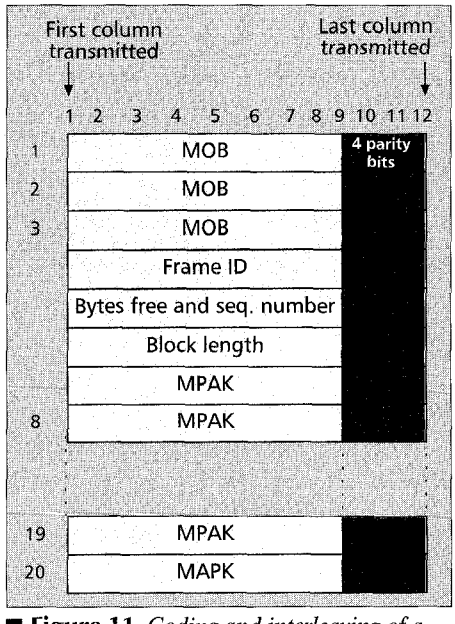
Finally, as has already been implied, the transmission mode is full duplex for the base stations and two-frequency simplex for the radio terminals. MOBITEX specifications indicates that receive/transmit switching times of a radio modem should be kept less than 20 ms in order to keep high system efficiency.

Power Saving in MOBITEX

In MOBITEX, power-saving mode is an optional mode of operation that may be requested by a mobile terminal by sending a proper MODE packet. A radio modem in power-saving mode may be in standby state, where only time-keeping functions are in operation, or in operating state, where normal transmit/receive procedures take place. Whenever the radio modem wants to transmit a message it enters the operating state, awaits a FREE frame, and transmits in a randomly chosen slot. The radio modem then stays in operating state for some time (to be able to receive a quick response) before it goes back to standby state again.

The BASE buffers the packets destined to terminals in power-saving mode. That is, if new frames for a terminal in power-saving mode arrive, the network shall not attempt to immediately transmit these frames. Instead, the network shall broadcast at periodic intervals a message containing a list of terminal addresses for which downlink channel traffic is pending. Mobile terminals are expected to wake up at periodic intervals *in synchronization* with these traffic notification broadcasts, and determine if data for them is pending. When they find any pending traffic for them, they should keep their receivers in operation until they receive the forthcoming frames.

The above procedure is a general approach adapted by various mobile data networks (including MOBITEX and CDPD) in order to support power-saving features. Other approaches have been proposed [12–16] that do not require any synchronization and aid the mobile terminals in implementing autonomous, independent power management. These approaches are based on a page-and-answer principle: The base station continuously broadcasts paging messages (announces the terminals that have pending forward



■ **Figure 11.** *Coding and interleaving of a data link block structure.*

[8] *Specifications indicate that the preferred implementation method is a FIR filter with symmetric coeffiecients.*

channel traffic) until an answer is received that indicates a mobile terminal is ready to receive. Mobile terminals themselves alternate between operating and standby state *whenever they are willing to*, and, as far as the base station is conserned, their operation is probabilistically described. Such protocols have been proposed in two variations; either using inband [12, 13] or outband paging [14–16]. A similar approach for power-saving has been adapted in the 802.11 wireless local area network (LAN) standard [17, 18].

Conclusion

This article aimed to shed some light on mobile data technology through the MOBITEX system. An attempt was made to outline the basic network elements of MOBITEX, their functionality, and the interfaces between them, in order to visualize how mobile data service is provided. We extensively focused on the MOBITEX air interface protocol, which specifies the elements and procedures required to establish communication between a mobile/portable terminal and the fixed network infrastructure. Special consideration has been given to the roaming and channel access strategies, together with some engineering aspects. In this context, it was shown that the common communication resources are statistically shared under central control with an access scheme similar to slotted ALOHA.

As a final remark, it may be noted that MOBITEX has become the *de facto* mobile data standard in Europe and continues to spread through Asia and the Western Hemisphere. Its penetration in Europe would be much deeper if the final standardization of TETRA (Trans-European Trunked Radio) was not expected by the European Telecommunications Standards Institute (ETSI). MOBITEX offers a versatile architecture to support wireless packet data service inside an extended geographical area with internetwork roaming and interoperability features. It has become quite popular, mainly due to its open architecture and its vast equipment/applications availability.

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