Paging Systems: Network Architectures and Interfaces

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Abstract

In the past few years, the penetration rate of paging service has significantly increased. Paging service is competitive because paging networks offer inexpensive service in large service coverage areas, and pagers are cheap and easy to carry. This article provides an overview of the one-way paging network architecture and the interfaces among the paging network elements. The author also briefly describes two-way paging services and uses GSM short message service as an example to illustrate how two-way messaging can be offered under the cellular platform.

In its original definition, *paging* is a one-way, personal selective wireless calling system. The first paging system was developed by Charles F. Neergard, a hospitalized radio engineer who could not tolerate the constant, loud voice paging of doctors in the hospital [1]. At the end of 1995, there are approximately 80 million paging subscribers worldwide [2]. The largest paging industry in the world is the one in the Asia-Pacific region. Consider Taiwan as an example: the subscriber population has increased by at least 20 every year since 1986 (Fig. 1a). The subscriber density in Taiwan has increased rapidly (Fig. 1b) and is ranked fifth in the world. In the United States, the paging service penetration rate increased from 13 to 15.5 in 1996.

Although paging service does not provide real-time interactive communications between the calling and the called parties, it has several advantages over other personal communications services (PCS), such as cellular telephony. For example, the paging system requires less radio bandwidth (thus, the service is inexpensive), the paging service coverage area is larger, the pager is cheaper, lighter, and smaller, and the battery lasts longer. As long as paging continues to keep these advantages, paging service will be a strong competitive PCS service in the future.

This article describes paging systems with the emphasis on the network architectures and interfaces. Paging air protocol issues such as power saving, repeat intervals, and out-of-band confirmations are not covered in this article; these issues are discussed in [3, 4]. The reader is encouraged to visit Bradley Dye's home page http://idt.net/~braddye for information on advanced paging technologies.

Paging Message Types

A paging message can be one of the following four types:

An Alert Tone

The receiver is a *tone pager*. A tone pager has a dedicated telephone number; when the number is dialed, the pager is triggered. The advantage of tone paging is that it utilizes a small amount of air time. However, there are only a few kinds (typically four) of alert tones that can be used to identify callers.

A Voice Message

In some systems, a voice message may be transmitted after the beep. The receiver is a *voice pager* [5] that can receive up to 12 min of voice messages. However, speech consumes a lot of air time, and may not be cost-effective for most public paging systems.

Some voice paging systems utilize the spare capacity of the existing cellular networks using non-real-time transmission. Even in non-real time, messages are typically sent within minutes of receipt.

A Digit String

The receiver is a *numeric pager*. The pager has a small LCD screen to display the digit string. Typically, the string is the telephone number of the caller. In Hong Kong and Singapore, the string can be a coded message. The coded message is generated by the paging center at the request of the caller, and the message is decoded by a code book (which may be built into the pager). This type of paging is efficient in air time usage just like tone paging. Numeric paging was introduced in the early 1980s and is the most popular form of paging.

Some Text Strings

The receiver is an *alphanumeric pager*, which has a large screen to display several text strings. Alphanumeric paging was introduced in the late 1980s. Since the caller needs special

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input devices or a special input procedure with a phone set, alphanumeric paging is not as popular as numeric paging.

Depending on the paging system, the paging process can be done either manually or automatically. In a manual paging system, the caller sends a message to the paging operator by a telephone call. The operator then delivers the message to the pager through the paging network. In an automatic paging system, a paging terminal automatically processes caller requests and delivers messages to the pagers [6]. This article will focus on automatic paging.

The Paging Network Architecture

Figure 2 illustrates an example of the paging network architecture. The network consists of six basic elements.

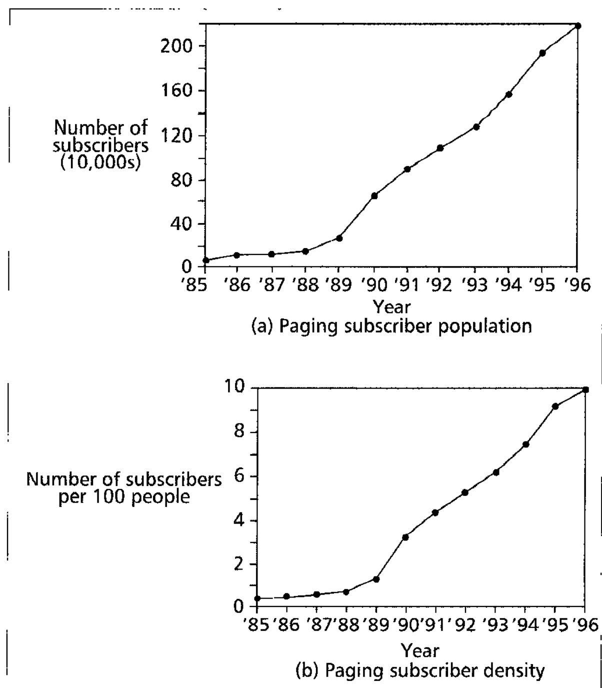
User Terminal Equipment (Input Device)

The caller sends messages by using user terminal equipment (common telephone handsets, computer with modem, or specific input devices). The alert tone and numeric messages are typically generated from telephone handsets and delivered through the public switched telephone network (PSTN), while alphanumeric messages are generated by computers or telephone handsets (through the operator of a paging center) and delivered to the paging network through the public switched data network (PSDN).

Paging Terminal

Through the user access interface, messages are sent to the *paging terminal*. A high-capacity paging terminal may support more than 1 million pagers, and is typically connected to a central office of the PSTN through T1 (up to 24 subscriber lines) or E1 (up to 30 subscriber lines) trunks. A high-capacity paging terminal can support more than 1900 input lines. It may also connect to other paging terminals, and the connected paging terminals communicate with each other via an internetwork interface. The paging terminal maintains a customer database that contains information necessary to alert the individual pager (e.g., pager number, pager code, and types of message) and for billing. Based on the alerted pager's record in the customer database, the paging terminal may deliver the message to its base station controllers or forward the message to other paging terminals. A voice message can be converted into text for an alphanumeric pager. The paging terminal may store the message in a mailbox (with capacity for several hundred hours of voice storage).

The paging terminal can be maintained locally (e.g., removing or installing cards) or remotely when the system is operational.



■ Figure 1. *Paging subscriber population in Taiwan.*

The Operation and Maintenance Center

The operation, administration, and maintenance functions of a paging network are conducted by the operation and maintenance center (OMC). The OMC accesses the customer database of the paging terminal to add new customer records, delete terminated customer records, collect billing information, and so on. The OMC may also page the customers through the paging terminal. Typical OMC commands include read (from the paging terminal database), write (to the paging terminal database), and alert (a specific pager).

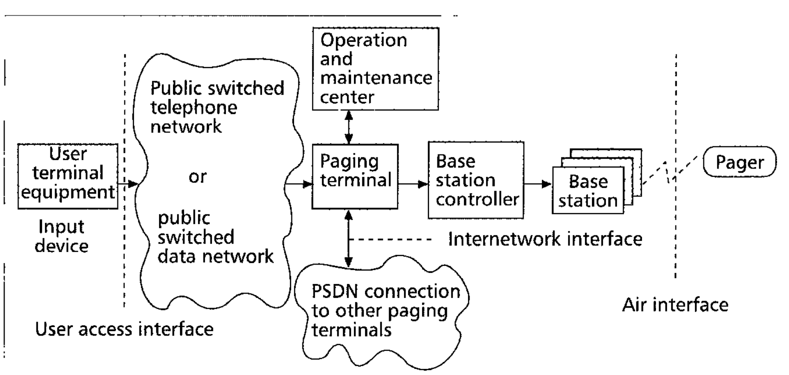
The Base Station Controller

A base station consumes high power when transmitting a paging signal, and is in low-power mode when it is idle. Since the services of an alerted pager may be limited to specific geographical areas smaller than the area covered by the paging terminal, a base station controller is used to link the paging terminal to the base stations to control the base stations to be powered up.

If the radio channel is shared by different paging service providers, the base station controllers must be coordinated so that at most one paging signal is transmitted in the air at a time. The paging signal may be sent to multiple paging transmitters simultaneously (simulcast paging) or sequentially (transmitter sequencing). Although transmitter sequencing does not use air time efficiently (it takes longer to communicate with a pager), it may be required when simulcasting from two transmitters creates a region where the pager cannot receive reliable data from either transmitter.

The Base Station

Base stations may be designed for two-way voice, although most are for one-way paging. Three transmission technologies are possible for delivering



■ Figure 2. *An example of the paging network architecture.*

the message from the paging terminal to the base stations: leased telephone lines, PSDN (X.25), or satellite-based networks. Satellite communications technology is typically used between the paging terminal and the dispersed base stations. In some advanced paging services, satellites can serve as base stations to broadcast messages to the pagers [7].

Base stations broadcast the message to the pager by radio signal. The radio path between a base station and the pagers can be dedicated paging channels, FM radio, or subcarriers of TV stations [8]. (In the last case, a signal is superimposed on the normal TV or radio channel, which does not interfere with the normal TV broadcast. The signal is extracted by the pager to obtain the paging message.) The base stations have high transmitter power (hundreds of watts to kilowatts to penetrate walls of buildings) and high antennas (for a large coverage area). Strong one-way radio transmission allows low-complexity, low-power paging receivers.

In simulcasting, messages from the paging terminal may arrive at the base stations asynchronously (because the distances from the paging terminal to the base stations may not be the same). Different time lag values or *audio equalizers* are used at the base stations to synchronize the message receipt of the base stations.

The Pager

A pager consists of four basic components: a receiver, decoder, controller logic, and display. The receiver is tuned to the same radio frequency (RF) as the base station to receive and modulate the paging signals. The decoder decodes the binary information and identifies the code for the pager (and rejects messages for other pagers). A pager may share the same code with other pagers for group paging, or may be assigned multiple page codes (typically up to four) for different paging functions. The control logic provides service features and operation functions such as duplicate message detection (repeated messages will not be stored in memory), message locking (selected messages are not overwritten), message freeze (the message is kept on the screen when reading), multiple alerting modes (e.g., audible tone, visual flashing, and silent vibration), and so on.

A pager is typically powered by a single AA battery. Battery-saving techniques are used to conserve power by periodically switching the pager into low-power mode. When the pager is off, stored messages are retained in nonvolatile memory.

User Access Interface

The caller sends a paging request to the paging terminal through the user access interface. Protocols for this interface include analog trunk protocols and digital protocols. We describe two digital protocols, Telocator Alphanumeric Input Protocol (TAP) [9] and Telocator Message Entry Protocol (TME) [10].

Telocator Alphanumeric Input Protocol

In TAP, the caller prepares the pages to be sent in advance (thus, text creation does not consume any air time). To send the message, the input device dials the paging terminal's number. After the line is connected, the caller (input device) and paging terminal exchange messages as described below.

Msg1 (Caller → PT) — The input device repeats the carriage return

Msg1 = *<CR>*

at 2-s intervals until the paging terminal replies. If the paging terminal does not reply after three repetitions, the paging request fails.

Msg2 (PT → Caller) — Within 1 s of receipt of Msg1, the paging terminal requests the input device to provide the pager ID by sending the sequence

Msg2 = ID =*<CR><LF>*

where *<LF>* is the line feed symbol.

Msg3 (Caller → PT) — The input device sends a string

Msg3 = *<ESC><SST><PPPPPP>*

to the paging terminal. The escape character <ESC> indicates that the paging information will be sent in automatic dump mode. The first two alphanumeric characters *SS* represent the type of service. For example, the combination *SS* = PG represents that the information will be sent as a pair of two fields where field 1 contains the pager ID and field 2 contains the message. The last character, *T*, represents the type of input device. For example, IXO or PET devices are in the category *T* = 1. The (optional) six digits *<PPPPPP>* are the password of the input device, which may be interpreted as a caller ID or system entry key.

Msg4 (PT → Caller) — When the paging terminal receives Msg3, one of the following three situations occurs:

- If the request is accepted, an acknowledgment is sent to the input device:

  Msg4 = *<CR><ACK><CR>*

- If the format of Msg3 is not correct, the paging terminal will request retransmission by sending a nonacknowledgment message:

  Msg4 = "*<CR><NAK><CR>*"

- If the paging terminal is not available to handle the paging request, the request is rejected by a forced disconnect message:

  Msg4 = "*<CR><ESC><EOT><CR>*"

where *<EOT>* means "end of transmission."

Msg5 (PT → Caller) — If Msg4 is an accept acknowledgment, the paging terminal will prepare for message input, and when ready it sends a "go ahead" sequence to the input device:

Msg5 = *<CR>* [*p* *<CR>*

Msg6 (Caller → PT) — The input device starts to send the paging information to the paging terminal. The information is partitioned into data blocks of 256 bytes. Every block consists of three control characters, a message text of length up to 250 characters, and a three-character checksum. For illustration purposes, we assume that the service type is PG1, and the paging information is partitioned into two data blocks (i.e., two transmissions are required to deliver the message text). Then the first block is delivered in the following format:

Msg6 = *<STX>Pager_ID<CR>Text<CR>Cksum<ETB>*

where *<STX>* means "start transmission," and *<ETB>* is used as a block terminator if the transaction is continued into the next block. *Pager_ID* is a string of ASCII digits to identify the destination pager, *Text* is a part of the paging message, and *Cksum* is the three-character checksum.

Msg7 (PT → Caller) — After receiving Msg6, one of the following occurs:

- If the transmission is correct, an acknowledgment is sent back to the input device:

  Msg7 = *<Message_Sequence><CR><ACK><CR>*

- If a transmission or checksum error occurs, the following message is sent to request the input device to resend Msg6:

  Msg7 = <*Message_Sequence*><*CR*><*NAK*><*CR*>

Note that *Message_Sequence* is optional, and in some systems may only be included in the last response message (i.e., Msg10) before disconnect.

Msg8 (Caller → PT) — Suppose that the input device is to send the last block. The message is of the form

Msg8 = <*STX*>*Pager_ID*<*CR*>*Text*<*CR*>*Cksum*<*EXT*>

where <*EXT*> indicates that Msg8 delivers the last piece of the paging information.

Msg9 (PT → Caller) — When the paging terminal receives Msg8, one of three situations may occur. The first two situations are the same as those for Msg7; the third occurs if the transmission violates a system rule (e.g., the destination pager cannot be paged). Then Msg8 is abandoned by the following replied message:

Msg9 = <*Message_Sequence*><*CR*><*RS*><*CR*>

The reason for abandonment is given in *Message_Sequence*.

Msg 10 (Caller → PT) — If Msg9 is of type <*ACK*> or <*RS*>, the input device completes the transmission by sending

Msg10 = <*EOT*><*CR*>

Msg11 (PT → Caller) — The paging terminal breaks the connection by sending

Msg11 = <*Message_Sequence*><*CR*><*ESC*><*EOT*><*CR*>

where *Message_Sequence* reports the degree of acceptability of information on this service.

After the paging terminal sends a message, a timer of at least 4 s is set (for Msg2, the timer is 8 s). Similarly, a timer of at least 10 s is set for the input device after it sends a message. The connection is disconnected after timer expiration.

Telocator Message Entry Protocol (TME)

TME is the data input protocol of the Telocator Data Protocol (TDP) [10]. TME is considered the successor to the TAP protocol. TME relaxes the 7-bit, even-parity TAP coding format by allowing unrestricted 8-bit data transfer. It also relaxes the conventional TAP short ASCII text messages by providing entry for long messages of text or binary data (e.g., e-mail with attached files, spreadsheets, and database information). TME extends TAP one-way paging to two-way communications (to be addressed in a forthcoming revision). It also provides new service features such as priority paging (to indicate that a request is a priority or emergency page to be sent immediately), deferred paging (to send a page at a particular time of day), periodic paging (to send a page periodically until a cancel message is received), message forwarding, message deletion (e.g., to cancel periodic paging), and so on.

TME follows the open systems interconnection model except that no presentation and session layers are required. Transmission Control Protocol/Internet Protocol (TCP/IP) is recommended to serve as the lower-layer (the network layer and below) protocol of TME, although other protocols such as X.25 [11] can also be used to support the TME application layer. When the input device requests connection to the paging terminal in the TCP/IP solution, it must include the TCP port number 4076 and an available unregistered port number to uniquely identify itself as the client application. More details of the TME lower-layer protocols can be found in [10].

The TME application layer is specified by the remote operations service element (ROSE) [12, 13], and all TME operations are defined by using the Abstract Syntax Notation 1 (ASN.1) notation and Packed Encoding Rules (PER) [14]. There are ten basic TME operations; three of them are listed below. The reader is referred to [10] for details of the other operations.

- The `login` operation establishes a session connection between the input device and the paging terminal. Password is an optional argument of the `login` operation. Note that the caller password is required if operations such as `deleteOp` (to delete a paging request) or `dir` (to list the messages currently in the system, which have been sent to or from the subscriber's account) are to be performed in the session.
- The `send` operation sends a message from the input device to the paging terminal. The message consists of an envelope and the message content to be delivered. The paging terminal only forwards the message content to the pager, which can be transparent data, tone only, numeric and alphanumeric data, or 8-bit wireless message format (WMF) [10] data.
- The `logout` operation terminates a communication session. This operation may be issued under the request of the input device or system operator, or due to the expiration of the inactivity timer or session timer. The session can also be terminated if situations such as security violation or resource shortage occur.

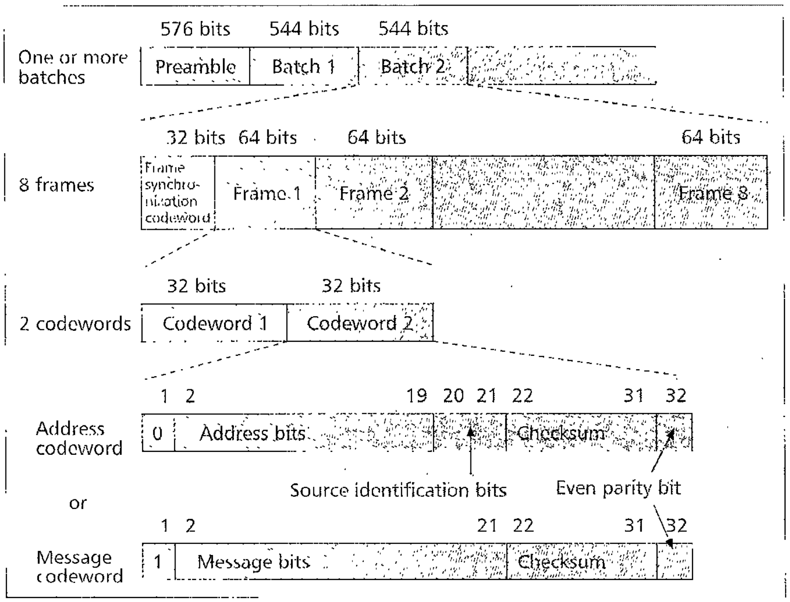
The Intersystem Interface

To extend paging service coverage, paging terminals can be connected to form paging terminal networks. In order to receive intersystem paging services, the pager should keep the paging terminal updated about its locations. This information specifies the group of paging terminals to receive the paging requests and is stored in the customer database of the paging terminal. Several proprietary protocols such as the Glenayre Data Link Module (DLM) protocol and Spectrum Data Link Handler (DLH) protocol have been developed for paging terminal networks. Note that paging terminals using different protocols cannot talk to each other, and network paging gateways are needed to perform protocol conversion. Several hundred types of gateways are used to connect paging terminal networks.

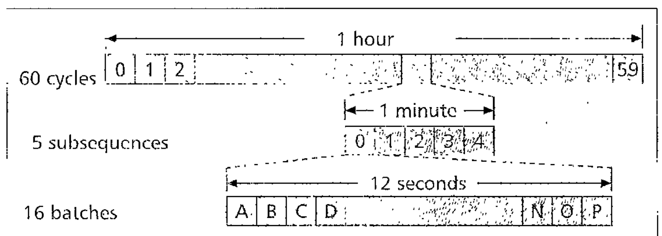
An industry standard protocol, Telocator Network Paging Protocol (TNPP) [15, 16], has been developed for paging terminal connection. TNPP is a point-to-point communication protocol which can be built on top of TCP/IP networks [17]. To move paging request data from the source to the destination in a TNPP network, a routing algorithm is required, although routing of paging requests is not covered in the TNPP specifications. The DLH network follows the same point-to-point philosophy. On the other hand, the DLM network uses a token-passing protocol; that is, a token is passed around the DLMs (every paging terminal is connected to a DLM). The DLM who grasps the token will transmit the paging request data. All other DLMs will listen, and the destination DLMs will read the data from the network and pass the data to their paging terminals.

A TNPP packet has a 4-byte source address and a 4-byte destination address. It uses a 2-byte sequence number to distinguish between new and retransmitted packets. A 2-byte inertia counter is used to limit the number of nodes visited by the packet so that the packet will not travel in the network forever.

Like TAP, TNPP is an ASCII-oriented protocol. After a packet delivery, the destination node may reply with one of four characters to the source node: <*ACK*> (the delivery is successful), <*NAK*> (an error has occurred, and the packet should be resent), <*CN*> (the destination address is invalid and the packet is canceled), and <*RS*> (the destination node



■ Figure 3. *The POCSAG coding format.*



■ Figure 4. *The ERMES frame structure.*

cannot process the packet). Note that the source and destination nodes can send packets to each other at the same time.

TNPP can be used for satellite communications between paging terminals. Note that the destination paging terminal cannot acknowledge receipt of information in TNPP satellite communications. To provide reliable satellite transmission, a retransmission technique is used to transmit multiple copies of data to the destination.

The Air Interface

Several signaling formats have been used in the paging air interface. POCSAG (Post Office Code Standardization Advisory Group) was initiated by the British Post Office in 1970. Most paging systems are based on this protocol. In early 1990, several high-speed protocols became available, including ERMES (European Radio Message System) [18], approved by the European Telecommunications Standards Institute (ETSI); FLEX [6], developed by Motorola; and APOC (Advanced Paging Operations Code), developed by Philips Telecom. We describe POCSAG and ERMES in this article.

POCSAG

POCSAG is designed for a one-frequency, one-operator paging network, and cannot be extended for multinetwork operation. The POCSAG coding format can accommodate 2 million pagers. The original format was specified to operate at 512 b/s. Without modifying the coding format, POCSAG can be operated at 1200 b/s, and up to 2400 b/s for some applications.

The POCSAG coding format (Fig. 3) consists of a 576-bit preamble and one or more 544-bit batches. The preamble is a string of an alternating "1010..." pattern, which is used to identify the POCSAG signal. The decoder of the pager utilizes the preamble to synchronize with the data stream.

Every batch consists of one 32-bit frame synchronization codeword and eight 64-bit frames. The frame synchronization codeword has a unique bit pattern, which is used to identify the beginning of a batch. Every frame consists of two 32-bit codewords. A codeword can be an address, a message, or an idle pattern. An address codeword consists of five fields. The first field is a bit 0. The second field is an 18-bit address. The third field is a 2-bit source identifier used to identify four different paging sources. The fourth field is a 10-bit error detection and correction code, which can be used to correct single-bit errors and detect multiple-bit errors. The last field is an even parity bit. The structure of a message codeword is similar to the address codeword, except the codeword begins with 1, and bits 2–21 are occupied by the message text. An idle codeword is a unique bit pattern. An address codeword is always followed by zero or more message codewords. If the second half of a frame is empty, it will be padded with the idle codeword to ensure that every frame has 64 bits.

A pager can only be paged at one of the eight frames (the 3-bit pattern of the frame is stored in the pager). Thus, the receiver of the pager can be turned off during the other seven frames to reduce power consumption. POCSAG is efficient for large volumes of data transmission. For a lightly loaded mixture of encoding formats, air time may be wasted (many frames will be inserted with idle codewords).

ERMES

ERMES is an open system developed by consensus with operators and manufacturers. It is the only International Telecommunications Union (ITU) recommended paging code standard. The ERMES air interface I1 operates with 16 frequencies in the radio band 169.4125–169.8125 MHz. It uses a 4PAM (four-level pulse amplitude modulated) frequency modulation (FM) scheme. In this scheme, four frequencies are used to represent the binary codes 00, 01, 10, and 11. At any moment, only one of the four is used to transmit the signal, and two-bit information is delivered at the moment. The effective transmission rate of a frequency is at 3750 b/s. ERMES has improved the paging capacity over POCSAG by a factor of four (in terms of the number of users per hertz). Every ERMES pager is identified by a 35-bit radio identity code. Thus, the address space is large enough to accommodate hundreds of millions of pagers.

ERMES partitions every hour into 60 *cycles*, as shown in Fig. 4. Every cycle is partitioned into five subsequences, and every subsequence is partitioned into 16 batches. Battery-saving mode is implemented such that a pager is programmed to be paged on specific subsequences or cycles. Like POCSAG, information in a batch is partitioned into codewords. Every nine codewords are grouped into a *codeblock*. Instead of transmitting the codewords sequentially, the codewords in a

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