9) It is stated in the PageMart submission that the control channel is a binary FM 4800 baud simulcast channel, which could be increased to 9600 baud and higher.

The present approach by PageMart is to "utilize a channel bandwidth of 25 kHz in conjunction with a conventional paging receiver design capable of 4800 bps or higher". The polling channel operates at that chosen data rate and with a "simulcast POCSAG protocol signal throughout the coverage region" (p. A-16). As a method of achieving higher data rates, PageMart propose "to set that bandwidth at 25 kHz and optimize the modulation and coding to maximize the data throughput at a given lower bound on bit error rate (BER) for this RF link (e.g. 9600 bps to 12000 bps)" (p. A-25).

There is some doubt about the ability of PageMart to achieve a simulcast data rate of any higher than 3000 baud, which is felt by Mtel to represent a reasonable upper limit on the simulcast channel baud rate. A simple analysis can be used to demonstrate the reasons for these concerns. In a previous example in this document (item 2), the coverage distance was estimated for the following situation;

- 500 Watt ERP base station
- -110 dBm portable receiver sensitivity threshold
- receiver antenna height of 10 feet
- base station antenna height of 100 feet
- in-building coverage, allowing 15 dB of building penetration loss

Under these conditions, the coverage radius for the cell site was found to be 4.29 miles. Lee [7, p. 52] indicates that that the reuse distance for a 7-cell reuse pattern, which is a generally accepted cell reuse strategy, is 4.6 times the cell coverage radius. Beyond this reuse distance co-channel interferers are not considered to contribute significant interference, whereas co-channel cells closer than this distance create significant interference. For the simulcast transmission situation, this means that all simulcast transmitters within a distance of 4.6 -1 cell radii, or 3.6 times the cell coverage radius, will be received at the portable receiver. The spread in time delays between these received signals at the portable is the "simulcast time delay spread". Simulcast transmitters up to a distance of 3.6 times this distance from the base station, or 15.4 miles, result in the maximum delay. The minimum delay occurs for a portable terminal near the cell site transmitter. Thus simulcast delay spread will be the order of 83 μseconds.

As was discussed in the Mtel documents, a general rule of thumb is that the baud element time duration should be at least four times the simulcast delay spread. In the scenario just discussed, the maximum baud rate should be the order of 3000 baud. The baud rate proposed by

PageMart is almost two-thirds greater than this rate, which would indicate that the 4800 bps polling channel rate will provide a marginal degree of operation even if it could operate at all. Lowering the data rate to something the order of 3000 baud would appear to be required. Attempts to increase the polling channel data to 9600 baud or higher does not appear to feasible in the type of system proposed by PageMart.

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TAB B

Comments on the Data Link Layer Aspects of the "Petition For Rulemaking" before the Federal Communications Commission by Pagemart Inc., dated February 28, 1992

R. Lukas, June 1992

MPR Teltech Ltd
PART OF THE B.C. TEL GROUP

MPR Teltech Ltd

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1. Executive Summary

The analysis in this report has concentrated on the data link protocol aspects of the Advanced Messaging Service proposed by PageMart Inc. in the Petition for Rulemaking before the Federal Communications Commission. Our assessment and conclusions with regard to these issues are as follows:

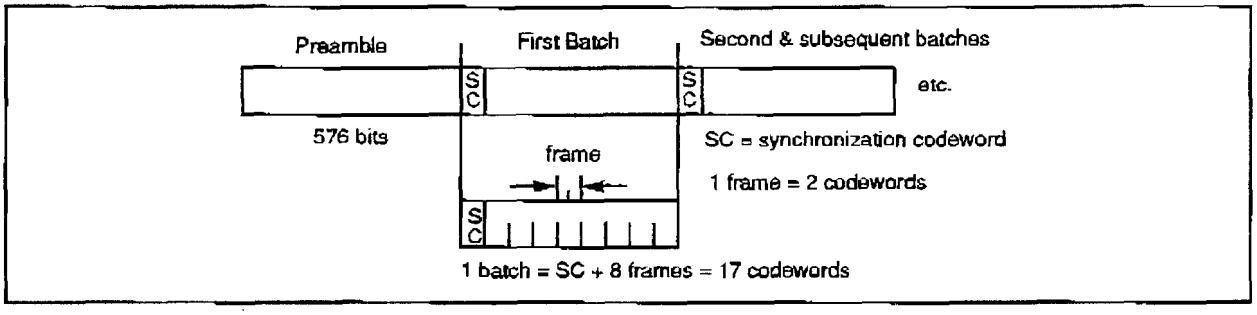
- The simulcast poll channel, used for radiolocation and data channel assignments, is a constraining factor in overall system capacity. Using PageMart's message model, the best case scenario could support no more than 3000 messages per hour, the equivalent of 12,000 subscribers per MSA. This is an order of magnitude less than the 100,000 to 200,000 subscribers claimed for a 4800 bps system.
- Each data channel can support no more than 600 subscribers. Total system capacity is dependent on implementing a large number of non-interfering cells, subject to the limits of the poll channel.
- The return link media access protocol cannot work as described. The information content of the required messages cannot fit within their allocated time slots, and no allowance has been made for real-world device characteristics in terms of timing, synchronization and turn-on times. A realistic return link protocol would restrict the poll channel transaction rate even further, reducing system capacity accordingly.
- The inbound data channel traffic capacity is severely hampered by the design of the channel access protocol. In the best case, inbound traffic can not exceed one-sixteenth of the outbound traffic, based on number of messages.
- The proposed Mtel NWN system is 2.7 times more spectrally efficient than the equivalent PageMart PIMS system, when considering the bits delivered per frequency domain, time domain and space domain.

2. Channel Protocol

PageMart states that the "polling channel continuously transmits a simulcast POCSAG[1] signal throughout the desired continuous coverage region"[2] and also implies POCSAG formatting is used on the return link channel and on the data channels[3].

POCSAG is a well-established protocol used in one-way paging applications by many paging system operators. It is capable of tone-alert, numeric and alphanumeric messaging. The most commonly deployed paging systems transmit a POCSAG signal at 512 bps, but bit rates of 2400 bps are just beginning to be deployed. For the purposes of analysis in the following sections, a brief description is given here.

The POCSAG code format is based upon 32 bit codewords comprising a BCH(31,21) forward error correcting codeword with an appended overall parity bit. Sixteen codewords are concatenated in the form of 8 frames together with a leading synchronization codeword to form a batch. Any number of batches may be transmitted, but in practice, a preamble "batch" is inserted



at periodic intervals to allow subscriber devices to obtain bit synchronization. A codeword may be either an address or part of a message, based on the first bit. The address format permits up to 2,000,000 subscriber devices. To allow battery economy, addresses are divided into eight groups and subscriber devices only listen to one frame out of eight, based on device address, plus the synchronization codeword, when not actively receiving a message. The properties of the BCH(31,21) codeword allow correction of any two bit errors and detection of any three, with about 62% coding efficiency (38% of transmitted bits are redundant error protection bits).

In general, the code is fine for random single bit errors and short burst errors, but problems are seen with POCSAG error detection and correction in long messages because the code provides little protection against long burst errors, such as seen in a multipath fading environment. This lowers the probability that a message will be fully received as the message gets longer. PageMart acknowledges this limitation by proposing to limit the maximum packet size to "2 to 5 POCSAG batches"[4] and using ARQ retransmission techniques. Average retransmission as a fraction of total

1. POCSAG (Post Office Code Standardization Advisory Group) was created under the guidance of the British Post Office and first published in 1978. In 1982 the POCSAG code was accepted by CCIR as a recommended code for international paging.

2. page A16

3. pages A10, A15, A17, A20. Also exhibits XV, XVI.

4. page A20

batches is assumed to be 95% (i.e. 1.05 transmissions per message), but no supporting evidence is given in terms of the RF signal strength required to achieve the necessary bit error rate.

3. Poll Channel Capacity

As noted above, the poll channel continuously transmits a simulcast POCSAG signal throughout the desired continuous coverage region. The poll channel traffic consists of "Radiolocation Polls", "GOTO Channel" commands, "Data Channel Assignments" to requests from subscriber devices, acknowledgments to data messages originating from subscriber devices, and base station call sign broadcasts. Assuming that 4800 bps transmission is possible (but see comments in companion MPR Teltech report[1]), POCSAG format is capable of transmitting approximately 68 frames per second. This is calculated using a practical value of thirty batches per packet (i.e. one "preamble" batch every thirty batches).

According to PageMart, the base station call sign identification is transmitted at periodic intervals, and occupies an entire batch[2]. If we assume a call sign transmission once per cycle of thirty batches, we are left with 65.9 frames per second to transmit the remaining poll channel traffic.

Each outbound or inbound data packet requires two transmissions on the poll channel. The minimum length for these poll channel messages must be at least two codewords (one address + one data codeword), i.e. one frame. In the outbound (network to subscriber) direction, the required poll channel messages are the "Radiolocation Poll" and the "Goto" command. In the inbound (subscriber to network) direction, the required poll channel messages are "Data Channel Assignment" and "ACK". Therefore the system serving one MSA is capable of handling in the absolute best case 32.9 poll channel transactions per second. Accounting for the assumed retransmission factor, 95%, one MSA could theoretically handle 31.3 poll channel transactions per second (112700 per hour), divided between outbound and inbound data traffic. In practice, however, it is unlikely that 100% utilization of the poll channel could be achieved, given batch packing constraints. In fact, PageMart estimates average message utilization of 80%[3], which still achieves over 90,000 poll channel transactions per hour.

However, data messages are estimated at an average of 6000 characters. In POCSAG format, this requires some 2400 codewords, or 150 batches. For error protection reasons, PageMart has decided to segment messages into packets of "2 to 5 POCSAG batches". The implication is that each data packet must be assigned a data channel via the poll channel protocol, because each packet is individually acknowledged and retransmitted if required, which would require 30-75 transactions on the poll channel. Best case, then, the poll channel could handle the equivalent of 3000 average size data messages per hour, assuming a 5 batch packet length. At a 2 batch packet length, this decreases to 1200 data messages per hour.

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1. TR92-1895, "Comments on the Physical Layer Aspects of the "Petition for Rulemaking" before the Federal Communications Commission by PageMart Inc., date February 28, 1992", MPR Teltech Ltd., June 1992.

2. page A9, "Petition for Rulemaking", PageMart Inc., February 28, 1992.

3. page A22

With PageMart's subscriber message model (2.5 messages/subscriber over a 10 hour period)[1], the poll channel could therefore support a theoretical maximum of not more than 12,000 subscribers per MSA. This is an order of magnitude less than the 100,000 to 200,000 subscribers claimed by PageMart for a 4800 bps system.[2] Thus, it appears that the poll channel capacity may be the limiting factor in determining overall system throughput in the proposed PIMS system.

4. Data Channel Capacity

The data channel is also implied to use POCSAG format, at least for error protection encoding. With the specified average message length of 6000 characters, each message will be encoded as 2400 BCH(31,21) codewords, or 150 POCSAG batches. At 4800 bps, 95% retransmission factor, and 80% channel utilization, each data channel is therefore capable of handling 150 messages per hour[3], shared between inbound and outbound traffic. With PageMart's subscriber messages model, this is equivalent to 600 subscribers per channel.

Total data channel capacity is intimately related to the success of the channel reuse plan. To derive total system data capacity, we must know the total number of concurrently transmitting cells and the total number of data channels per cell. If the four cell reuse plan is possible (but see comments in companion MPR Teltech report TR92-1895), a national licensee with 8 data channels spread over 40 geographic cells could conceivably handle 40 / 4 x 8 = 80 concurrently transmitting data channels. PageMart estimates that an average of 70% of cells will be in use at any one time[4], yielding some 8414 messages per hour per MSA. A local licensee with only 4 data channels could achieve half this figure. With the given subscriber message model, a 40 cell, 4-cell reuse, 8 channel system could support less than 34,000 subscribers per MSA. This figure does not account for in-building cells.

It can be seen that system capacity is totally dependent on implementing a large number of cells with a high frequency reuse factor. For example, if only 20 cells are required to cover a MSA, capacity drops in half. Or if the cell reuse factor requires a 9 or 12-cell reuse pattern (as suggested in the companion MPR Teltech report TR92-1895 for a fading environment), the system capacity drops according, to supporting less than 15,000 subscribers. Retaining a four cell reuse plan would create an environment with high co-channel interference, resulting in significant bit error rates and inefficient use of spectrum due to retransmissions.

Thus, implementing non-interfering in-building and office cells is absolutely essential to achieving the levels of capacity and number of subscribers claimed possible by PageMart. This has obvious implications in terms of network cost and complexity.

5. Return Link Media Access Protocol

One frequency per MSA is allocated for use as the return link channel. The return link channel is

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1. page 14, page A22.

2. page A24. Also note the 2.5 messages/subscriber figure includes both inbound and outbound traffic.

3. 68 x 2 cw/sec / 2400 cw/msg * 3600 * 0.80 * 0.95

4. page A22

time-synchronized to the poll channel and uses POCSAG batch formatting.[1] Traffic on the return link consists of responses to radiolocation polls, ARQ responses to outbound data messages, and data channel reservation requests for subscriber originated messages. In exhibits XV, XVI and accompanying text, PageMart illustrates the return link media access protocol. Although the text is vague in its description, the rules for access are implied as follows:

- Radiolocation poll responses are transmitted exactly one batch time later in the same numbered frame as the poll, and are one codeword in length[2]. Thus, all odd-numbered codewords are reserved for poll responses.
- ARQ responses are transmitted in the second half of a frame numbered the same as the data channel, and are one codeword in length[3]. Thus, ARQ responses for data channel 3 occur in codeword 2 of frame 3.
- Requests for inbound data channel reservation are transmitted in a random access manner also in codeword 2 of each frame. Frames are reserved by capcode[4] address for random access attempts. Exhibit XVI implies odd-numbered batches are reserved for ARQ responses and even-number batches are reserved for random-access attempts for data channel reservation requests.

PageMart claims that for poll and ARQ responses, "collision on the return link channel is not possible" and "no collision between subscribers can occur with the algorithm employed", and that the "probability of a collision between two different subscribers' messages requests for a data channel is reduced"[5].

There are several problems with the return link protocol as described. First, the radiolocation poll response is specified to contain the "base station ID or call sign, and its POCSAG address plus the disposition of this message"[6]. This will require a response of at least two codewords minimum, possibly three or four, depending on length of the base station ID (Page A9 implies the base station ID is one frame (2 codewords) in length). Thus, the poll response cannot be transmitted within its reserved time slot and the maximum poll rate of the system must be reduced (and thus maximum system capacity) to reserve adequate return link time for poll responses. Receiver reuse may help here, if the system can tolerate some collisions in the poll response slot. In effect, the system would gamble that the spatial separation between subscriber devices would allow more than one poll response to be picked up over the total network of receivers simultaneously. Alternately, the device's POCSAG address may not need to be transmitted, since the system knows which device's response is expected, albeit at a cost of increased complexity in the network processing.

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1. page A10.
2. Exhibit XV.
3. Exhibit XV, and page A15.
4. Capcode refers to the division of the address space into eight groups, and the bits of the subscriber unit id which identify the associated group.
5. page A10, A15 and A17.
6. page A10.

Second, a similar problem occurs for the ARQ response and for the random access slots. The ARQ response message is also likely to require two codewords to encode the device's POCSAG address, ACK/NAK status and message number (required for duplicate detection/elimination). The data channel reservation request "indicates the message length to be transmitted, the serving transmitter site identification and the subscriber unit identification"[1], which would require anywhere from 2-4 codewords, depending on length of the base station id.

Thus, none of the return link channel messages will fit within the time slot allocated for their transmission. We could suppose that the return link traffic level is such that the messages can spill over into adjacent codewords with small probability of collision, and a high degree of spatial receiver network reuse, but this would seriously limit the maximum capacity of the system. Just responding to radiolocation polls requires the entire return link channel capacity, if collisions are to be avoided (we cannot know the location of the device before polling it, thus no allowance can be made for spatial receiver network reuse). Accordingly, the maximum transaction rate of the simulcast poll channel must be reduced, and it has already been identified as a limiting factor to system capacity (i.e. the return link protocol will not permit the poll channel to operate at its maximum capacity of 3000 messages/hour).

However, the more serious problem is that the return link media access protocol as described can not be implemented in real devices in a cost-effective manner. Back-to-back single codeword transmissions from different subscriber devices are required, with absolutely no time allocated for preamble, word synchronization or guard time between transmissions. This would require the simulcast transmitter network, all dedicated and co-located base receiver sites and all subscriber devices to be synchronized to each other within fractions of a bit interval. It would mean, for example, a system-synchronized clock would have to be distributed to all receiver sites, whether at co-located base stations, dedicated geographic receivers, building or office cells.

Even assuming such clock synchronization were economically feasible, allowance must still be made for the non-zero transmitter turn-on and decay times in the subscriber transceiver module. Fast attack and decay transceivers would significantly add to the cost of the STM, especially since they must be frequency agile as well.

To eliminate this non-realizable requirement for perfect synchronization, the return link protocol must be redesigned to allow for reasonable attack, synchronization and decay times, as well as expected message lengths. A reasonable conjecture might be to allow an additional codeword interval per return link message to allow for preamble, sync and guard intervals.

Thus, it would appear that in order to prevent collisions between subscriber originated messages, the return link channel is the limiting factor in determining total system capacity. An accurate estimate of capacity cannot be given without proper design of the return link protocol, but based strictly on ratio of expected message lengths, it would appear the return link channel protocol capacity is less than half that of the poll channel, with a corresponding decrease in system capacity.

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1. Page A17.

6. Return Link Data Reservation Capacity

Assuming for the moment that the return link protocol could be made to work, some codeword intervals have been reserved for use as a random access data reservation request intervals. One fourth of the total return link is dedicated to this function and is accessed in a slotted-ALOHA manner. PageMart proposes to require subscriber devices to transmit only in the frame number assigned to them by capcode, "thus, the probability of a collision between two different subscriber's messages requests for a data channel is reduced by a factor of eight"[1]. This is an incorrect statement and indicates a misunderstanding of the nature of random access protocols. Random access is just that, random, and constraining the choice of slots to different segments of the population does not affect the probability of collision once the size of the population outweighs the number of available slots.

As mentioned elsewhere in this report, slotted-ALOHA allows a maximum channel throughput efficiency of 37%, but experiences extremely long delays and a large number of collisions when operating near capacity[2]. A stable region of operation, such as 25%, would imply the maximum inbound data channel traffic is one-sixteenth of the POCSAG frame rate, i.e. one-sixteenth of the poll channel message rate, hence, the system design is heavily weighted in favor of outbound traffic. At a level of 25% throughput, the probability of collision between data reservation requests is 51%, i.e. less than half of the requests for an inbound data channel allocation are successful.

Thus, the inbound data channel traffic capacity is severely hampered by the design of the channel access protocol.

7. Base Station Call Signs

PageMart proposes two alternatives to transmitting the base station call sign. In the first alternative, "one geographic cell, in each four geographic cell group, is to broadcast its station identification in each frame for a designated batch. During this batch, the other three geographic cells simply broadcast the sync pulse and power down"[3]. Presumably, these high powered transmitters will be able to power down instantaneously, and power up again instantaneously, so as not to interfere with the call sign transmission of the neighboring cell. It also implies that the signal strength measurement is to be taken during this interval, during the normal wakeup period of the subscriber device, i.e. 2 codewords or 13.3 milliseconds.

In the second alternative, "a more spectrum efficient approach ... is to transmit the station identification concurrently and synchronously with the polling channel signal at a low data rate using a small percentage of the modulation"[4]. Although this indeed may obtain a better SNR, it does not explain how to avoid the co-channel interference from adjacent poll channel transmitters,

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1. Page A17.

2. Throughput as a function of offered traffic is given by the equation $S = Ge^{-G}$ for slotted-ALOHA. The probability of collision is given by the equation $P = 1 - e^{-2G}$.

3. Page A9.

4. Page A9.

who presumably are also transmitting their own unique call signs. It also does not explain how the required signal strength measurement could be taken relative to a single base station.

8. Cost Implications of In-building vs. Free-space Capacity

The PIMS system as proposed by PageMart must implement inbuilding and office cells to achieve the system capacity targets. The PageMart system capacity model (page A21-23) assumes the majority (>70%) of traffic is inbuilding or office cells, for a "configuration of 40 geographic cells, 40 building cells and 400 office cells"[1]. This has obvious implications in cost and complexity.

The model also assumes that 50% of the geographical network must be shut down 50% of the time to allow to inbuilding cells to operate, due to expected co-channel interference on the data channels[2].

Further, dynamic data channel assignment to cells based on local cell traffic demand has obvious implications in base transmitter and receiver cost per site. PageMart proposes that "most cells will operate with more than one data channel and in many cases up to eight (8) different data channels along with the polling channel and return link channel"[3], requiring multiple transmitters at all sites, either tunable or keyable. Presumably, the system controller can handle the increased complexity to schedule the use of data channels per cell, while maintaining the co-channel interference in the cell reuse plan to acceptable levels while working with the allotment of eight (four in the local licensee case) data channels.

The cost problem is further compounded in the inbound direction, since every network receive site will also need multiple receivers, a large cost increment given the ratio of receive sites to transmit sites. In effect, allowing eight data channels to be used in a cell will quadruple the cost of the cell site equipment over the static allocation of two channels per cell in a four cell reuse plan. The additional equipment is underutilized, since the additional channels can be used only by disabling the six neighboring cells (assuming a standard hexagonal cell pattern).

The conclusion is that PageMart must build an extensive network of underutilized, costly sites to achieve the system capacity targets stated in the petition.

9. Comparison of Mtel NWN and PageMart PIMS

The assessment in this report of the PageMart PIMS protocol could be summarized as follows:

Under the conditions proposed by PageMart, namely:

(a) 250khz block of spectrum, used as 10 25khz channels, operating a 4800 baud.
(b) Serving one MSA with a 4 cell reuse pattern and a single simulcast poll channel.
(c) 6000 character average message size, packetized in lengths of 5 POCSAG batches.
(d) 2.5 messages/subscriber over a 10 hour period.

a maximum 3000 messages/hour, and 12,000 subscribers can be supported.

1. Page A21.
2. Page A22.
3. Page A20.

Applying the same conditions to the Mtel NWN protocol[1], namely:

(a) One zone is equivalent to an MSA.

(b) Use a 250 khz block of spectrum, as 5 50khz NWN systems, operating at 3000 baud.

(c) Use the same average message size and subscriber busy hour call rate.

(d) Packetize the messages in 500 character packets with CRC protection.

a maximum of 8150 messages/hour, and 32,600 subscribers could be supported.

Thus, strictly on a comparsion of hertz x seconds x square miles basis for spectral efficiency, (i.e. bits delivered per frequency domain, time domain and space domain), the Mtel system is 2.7 times more spectrally efficient than the PageMart system.

1. An analysis of the Mtel NWN protocol was presented in MPR Teltech report TR92-1883, "Performance and Efficiency Considerations for the MTEL Nationwide Wireless Network (NWN) Protocol", May 1992.

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