Messages, when transmitted, will be directed to a specific reduced coverage area, and will not be transmitted throughout the entire system. Direction of the message to the specific coverage area desired will be accomplished through computer controlled radio location methods based on signal strength and other parameters.

PAGING CONTROL

As shown in Figure 1, the person desiring to communicate with a subscriber creates an incoming message. The message type is identified as either a voice or a numeric message. If the message is voice, it is digitized in the A/D Converter and stored for later retrieval. A request to locate is sent to the Locate Subsystem, which encodes a message including the pager's address and the request to acknowledge. These messages are queued along with the digital pages for transmission on the simulcast channel, much like pages are handled today.

If the message is numeric, the pager simply stores the message and alerts the subscriber. Voice or longer digital messages trigger the pager's acknowledgment transmitter which transmits a brief unique identification code message on the ACK channel. As shown in Figure 2, the Locate Subsystem is alerted to watch for an ACK message from the particular pager. This message will come from one of several ACK receivers and be supplied to the subsystem.

The incoming ACK messages are received and evaluated and the best serving voice transmitter location is chosen as described above. This information is output to the voice page controller.

A great deal of intelligence is incorporated into the Network Controller to determine the optimum message transmitter site. Starting with a database including digitized terrain, buildings, and vegetation, each message transmitter's coverage area is predicted. (See CNet Letter). This database is then modified based on field measurements and actual user's experience. The end result is an increasingly accurate message transmitter lookup table to indicate the one optimum message transmitter site for any location in the system's coverage area.

Information obtained from the ACK receiver system is compared to the predictive propagation table for each message to a pager. The message is then forwarded to that one ideal server. Potential problems in simply selecting the closest transmitter are thus minimized.

Figure 3 shows the voice page controller which encodes a second simulcast message to the pager assigning it to a specific voice page channel. This assignment message is queued to the Simulcast system and transmitted in turn. When the message is transmitted, the voice page controller is advised. At the same time that the frequency assignment message is being encoded, the actual message is retrieved and supplied to the voice page controller. When the controller has both the frequency assignment confirmation and the voice message itself, it forwards the message to the switch with instructions as to which channel and which site to use to transmit the message.

The message is received by the pager and stored. The pager alerts the subscriber that a message has been received, and the subscriber can then play it back at his discretion.

Inherent in the system design is the flexibility to "borrow" channels from adjacent, more lightly loaded cells on a dynamic basis. The VoiceNow Network Controller can track system resource usage in real time, reallocating channels to adjacent cells to accommodate peak demands in a particular area. This dynamic allocation of resources contributes further to the overall system capacity.

PAGERS

Pagers will be capable of two major classes of operation. If the message is a short digital page (such as a 10 digit telephone number), that message will be transmitted over the simulcast channel, as is now the case in conventional numeric pagers.

For voice messages, the message transmitter, selected as described above, transmits the digitized voice page. The pager has the capability of storing these digitized voice messages, performing the digital to analog conversion and playback at the subscriber's convenience.

The pager's ACK transmission is triggered automatically by the incoming message, thus assuring that contending of pagers for the receive network will not occur. The ACK transmitter in the pager is capable of approximately two watts in pulse bursts with a duration of approximately 200 ms. (Discussions with a major pager manufacturer indicate that these power levels can be attained easily, adding approximately one cubic inch to the pager. High current drain required for the transmissions will be accomplished through a dual disparate battery combination). Other characteristics described, such as digital voice storage and reconstitution for playback are current technology.

THE SIMULCAST SYSTEM

The simulcast system will perform much as in standard paging installations. Several transmitters, each on the same frequency, will transmit pages. The transmitted page, however, is one of two distinct types, simple message and longer message.

The simulcast system will require 25 kHz of spectrum, and will transmit two bits per symbol at 3125 baud resulting in 6250 bps. This will allow the system to serve about 330,000 subscribers (assuming 100% voice pages), compared to current digital systems serving a maximum of about 150,000.

The message consists of three main segments. Two of the segments provide adequate service to a large number of paging situations, and the third provides augmented message capability where required. Normally only two segments are required for a given message transmitted.

The first segment transmitted addresses a specific pager, notifying that pager that a message is on the way. The second segment can provide two pieces of information, each of which will result in distinct behavior on the part of the pager. Only one of the two is normally transmitted. The first is a simple 10 digit numeric message. The second asks the pager to acknowledge (ACK transmission) and to await further instruction.

Upon determination of the approximate location of the pager by the ACK receiver system, and identification of the appropriate message transmitter, the simulcast system instructs the pager to change frequency and wait for a message.

Once contact on the proper message transmitter is established, the message is sent. Forward error correction techniques are used to assure that the message is correctly received. In the event of incorrect receipt of a message, the pager requests re-transmission of the information.

Using Current Simulcast technologies (ERMES), and a busy hour call rate (BCHR) of 0.26, a reasonable maximum number of voice only pages which may be served on the simulcast system can be calculated at 330,000 units. Interleaving of numeric messages increases the user population appreciably.

RECEIVER SYSTEM

The ACK receiver system is very flexible, consisting of receivers located throughout the served market. Receive antenna heights are lower than the transmit antenna heights, and the sites are not collocated with message transmitter sites.

Based on an analysis performed by Raymond C. Trott Consulting Engineers, Inc. (attachment 2) and the experimental results of PageNet's Los Angeles tests, it has been determined that the potential for various types of interference at congested metropolitan sites limits the possibility of collocation of ACK receivers with simulcast or message transmitters. Receiver sites must be selected carefully to reliably perform with the weak signal coming from the pager.

Receivers, upon receipt of a pager's transmission, transfer information back to the computerized ACK system via telephone line, fibre optics, point to point microwave radio, or even satellite.

The computerized network control center then analyzes the signal to insure that it is coming from an authorized pager, and compares the signal strength and other parameters received from various receivers to determine the approximate geographic location of the pager. Each ACK receiver will forward all received data to the Network Controller, accompanied by a measure of the signal strength. Thus, for each acknowledgment transmission from a pager, the network will have data from one or more receivers with varying signal strengths. The Network Controller will use this information to estimate the location of the pager as follows: Digitized terrain and obstacle information for the coverage area of each receiver can be used to estimate the distance from that receiver as a function of the received signal strength. The combination of this information from whatever number of receivers report the acknowledgment are used to determine the location of the pager. That information is then referenced to another table of Message Transmitter coverage predictions as described above in "Paging Control."

On Map 3, three simulated acknowledgment receive locations have been situated around each of 3 paging transmitter locations (RX1, RX2 and RX3 around cell E, RX4, RX5, and RX6 around cell V, and RX7, RX8, and RX9 around cell X) as they might be in an initial design for an operating system. A "best server" study was run from each of these sites. In this case, transmitter power was limited to 1 watt, antenna heights were set at 100' AGL, and the plotting threshold was set at -85 dBm, or about 12.5 uV, as before, so that the model would be conservative.

As the map shows, the propagation model predicts that the acknowledgment receive sites can be expected to provide effective coverage in an area of several square miles around each. Indeed, it suggests that the acknowledgment receive sites as shown are more closely spaced than required. A comparison of the two best server plots will show the voice paging transmitter site and acknowledgment receiver site most likely to serve any particular area. It is reasonable to assume that the paging transmitter selection will be that associated with the particular acknowledgment receiver receiving the strongest signal from the pager, but that need not always be the case. This is shown most clearly on Map 2 in the area of San Pedro to the southeast of Cell I where, due to terrain shielding, the best serving paging transmitter is not the closer Cell I but the nearly twice distant Cell L. Therefore, receipt of a paging acknowledgment from the San Pedro area would key the system to transmit the voice page from Cell L rather than Cell I.

This information is based initially on the theoretical design with further adjustment and "fine tuning" based on experience.

MESSAGE TRANSMITTERS

The message transmitters will occupy eight 25 kHz channels, thus they may be utilized for large numbers of simultaneous voice messages. Should heavy traffic occur continuously over time on a single message transmitter, the number of transmitters in that coverage area can be increased (more message cells), with simultaneous addition (if necessary) of additional ACK receivers to allow more precise location of the desired pager. Like cellular operation, more calls into that area can then be processed.

Map 2 shows the area around downtown Los Angeles as far south as Huntington Beach, west to Woodland Hills and north to the San Gabriel Mountains. Shown on Map 2 are several assumed paging transmitter locations, generally at existing Paging Network sites. A total of 6 sites have been designated Sites A, E, I, L, V and Z.[1] This study makes use of a terrain sensitive propagation model developed for Moffet, Larson, and Johnson, Inc. by Philip Rice, formerly with the National Bureau of Standards and co- developer

1 These symbols were chosen so that the plotted symbols corresponding to receiver input power would be easily distinguishable one from another.

of the Longley-Rice propagation model. For this "best server" study, the target area is subdivided into a grid. The study takes into account, among other factors, antenna height and radiation pattern, ERP and terrain (from the USGS 3 or 30 second terrain database) to predict a value of receiver input power arriving at each grid square from each transmitter site in the study. Each plotted symbol on Map 2 represents a grid square, the symbol identifies the transmitter site providing the strongest predicted signal at that location, and the symbol color indicates the strength of that strongest predicted signal. As the key shows, plotted symbol values of predicted receiver input power range from -95 dBm (approximately 4 uV in 50Ω) upward. -95 dBm was chosen so that the prototype study results would be conservative.

For the purposes of this demonstration, Map 2 represents the coverage in the study area which might be expected from transmitters located as shown. In the proposed Paging Network, Inc. system, these would be typical of the sites of both the simulcast paging channel and the several voice paging channels.

MODULATION

The choice of digital modulation for the message channels as well as for the simulcast transmitter was made for several reasons. First, it allows more than one mode of information to be transmitted. Longer messages assigned for transmission to the digital channels can be digitized voice messages, or alphanumeric information. Additionally, digital transmission with adequate forward error correction provides a robust form of communication, relatively insensitive to noise and spurious signals. The use of a digital storage medium in the pager allows even voice pages to be stored for later playback. Finally, use of digital transmission allows operation in reduced C/I conditions, permitting co-channel cells to be closer together.

In response to these requirements, Dr. Bernhard E. Keiser[2] was retained to confirm our direction in selecting the optimum modulation and encoding method for VoiceNow service. As he mentions in his letter to PageNet, the use of 16-QAM digital modulation with 2400 bps Linear Predictive Coding should provide the quality and throughput necessary for digital voice paging service.

[2] Bernhard E. Keiser is a consulting engineer in telecommunications and related fields. He received his D.Sc. in electrical engineering from Washington University in St. Louis, Mo. He is a Fellow of the IEEE, the Washington Academy of Sciences, and the Radio Club of America. He is the author or co-author of several books on telecommunications, and teaches a course in Digital Cellular Telephony at The George Washington University, Washington, DC.

DYNAMIC FREQUENCY REALLOCATION

High density message cells will be capable of operation with four transmitters. Two will be planned for use in each cell during most periods, but all four may be available. The message transmitter computer control program will monitor usage at each message transmitter site, and will be able to identify message coverage areas where paging demand is high. Sensing a high message rate in a given message transmitter coverage area, it will disable adjacent message transmitters temporarily, allowing up to four transmitters to be used at any given time. Thus when paging is heavy in a given area, delays in page transmission may be minimized by using up to four transmitters to increase throughput in that message coverage area, while adjacent cells are experiencing lower rates of use. Once the paging logjam is dissipated, the system will go back to normal operation. This is very similar to the channel borrowing now in use in cellular but, in this case, the borrowing will be dynamic. The flexibility of this system even permits short term "borrowing" of a voice message channel on a system-wide basis for use as a second simulcast paging and control channel should a logjam occur on the primary simulcast channel. Similarly, on a site by site basis, the voice message transmitters can serve as back-up simulcast channel transmitters.

The dynamic allocation of facilities during extremely busy periods increase the throughput of the total system, maximizing service and the built in redundancy assures higher overall system reliability.

SIMULCAST CAPACITY

The basic capacity of a paging channel is a function of the type of page, the busy hour call rate, and the number of messages which can be sent.

The Busy Hour Call Rate (BCHR) is the number of subscribers who may be called during the busiest hours, usually stated as a proportion of the total number of subscribers. This is known from experience to be approximately 0.26 for PageNet users.

The basic formula is: $P = 3600 (N/BCHR)$

Where: P is the number of users

N is the number of message per second

BCHR is the Busy Hour Call Rate

The number of messages per second can be calculated from a basic knowledge of the paging system to be used, in this case ERMES. [3/]

The formula is:

$$\frac{\text{(Usable Codewords per batch) X bps}}{\text{(Codewords/batch) X (bits/codeword)}} = \text{Codewords/Sec}$$

Substituting the proper numbers:

141 X 6250/154 X 30 = 191 Codewords/sec

Using the assumption that all pages would be voice pages, and assuming four codewords each are required for the address and for the command to switch to a message channel, the number of users that the system can accommodate is:

191/8 X 3600/0.26 = 330,600 users

If a combination of voice and numeric pages are transmitted, the number of users served by a single simulcast channel can climb significantly.

3/ "ERMES AND POCSAG COMPARISON," Andrei Godoroja, Publication by Glenayre Electronics Limited, March 15, 1992.

IMPROVEMENT OF VOICE PAGING COMMANDS

Moffet, Larson and Johnson is continuing to study a method to reduce what is now considered the minimum number of codewords necessary to transmit the ACK request signal, and also the command to change frequency to a message channel to minimize signalling time on the simulcast transmission system, thus increasing the number of users served.

MESSAGE CAPACITY

Using existing techniques, such as 16 QAM modulation, it is at least theoretically feasible to carry as many as 33 simultaneous channels in a 25 kHz bandwidth. Very conservatively, carrying 10 channels simultaneously, would provide an operation message rate per hour (15 second messages) of:

4 Messages/minute X 60 X 10 = 2400 messages/hour

Assuming a maximum busy hour call rate (BHCR) of 0.25, a total pager population of 9600 pagers per message transmitter could be accommodated. (16 QAM would ideally allow 19,200 pagers, since 20 channels could be practically used. Such heavy loading will be tested and implemented should it prove robust.)

Two transmitters in each cell would allow accommodation of approximately 19,200 pagers per cell, if one assumes the extremely conservative use of 10 simultaneous channels derived from 16 QAM modulation.

Using this approach, PageNet has the ability to provide high quality voice service as well as high quality digital information transfer in the same channel, while maintaining excellent information throughput in a robust system.

Through use of many message cells in a community, each transmitting message information to pagers at known locations, the voice throughput can be very high compared to current techniques.

This is especially true of paging systems covering extremely large areas. Example: 10 sites each with two available message channels, could handle 192,000 average subscribers.

NETWORKING OF SYSTEMS

In response to the increasing demand by users for regional and nationwide service, it is understood that the networking of VoiceNow systems will be required. The same digital speech coding which provides effective throughput over the air will also lend itself to low cost transmission between paging systems. Thus, the networking of VoiceNow systems to provide seamless regional and nationwide service could be accomplished in much the same way that PageNet provides that service today.

CONCLUSION

The paging system described is clearly a breakthrough in paging technology. However, as our detailed analysis has shown, it is also very realistic.

Jeffrey M. Bixby
Senior Engineer

Charles G. Perry, III, P.E.
Senior Engineer

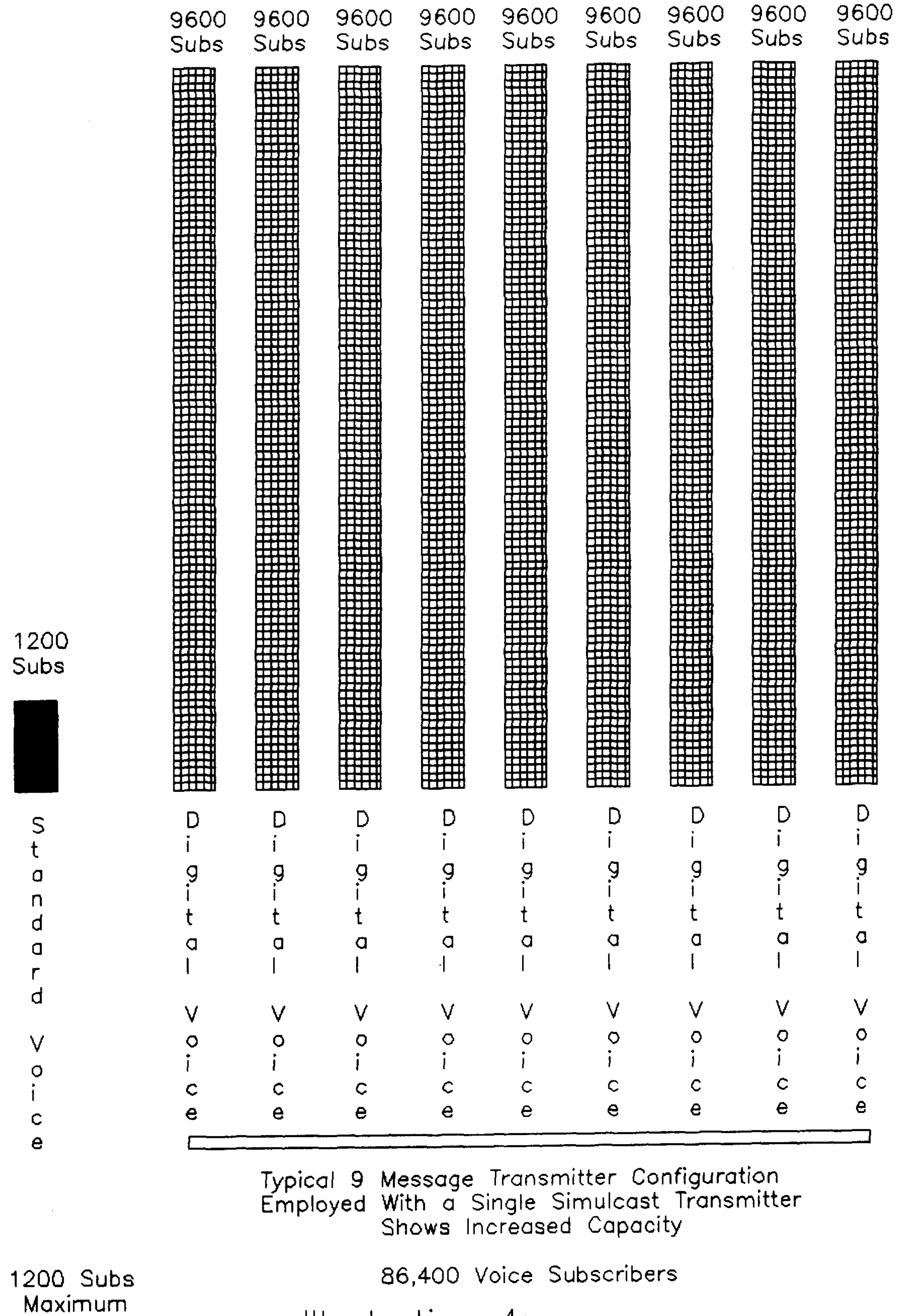
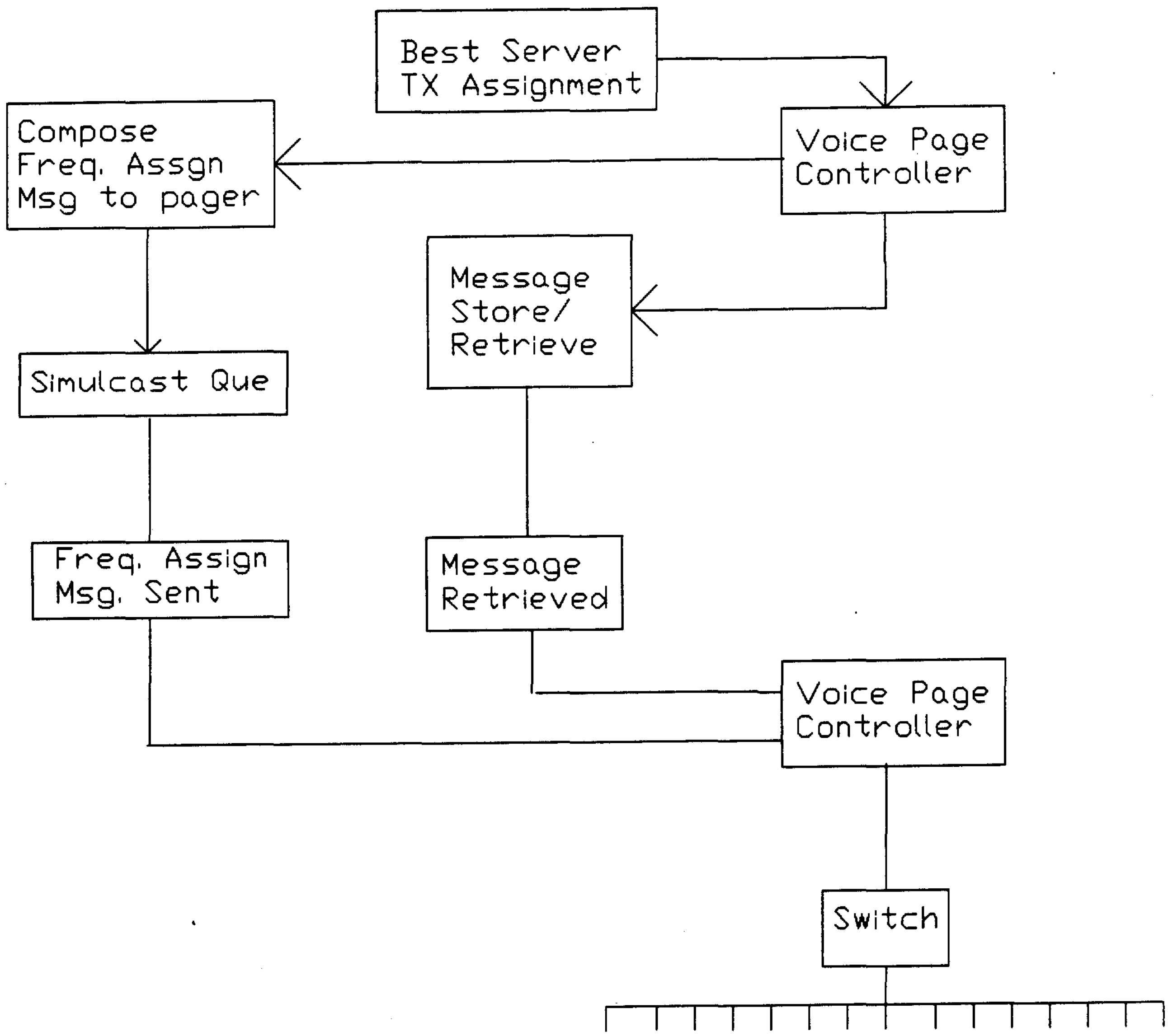
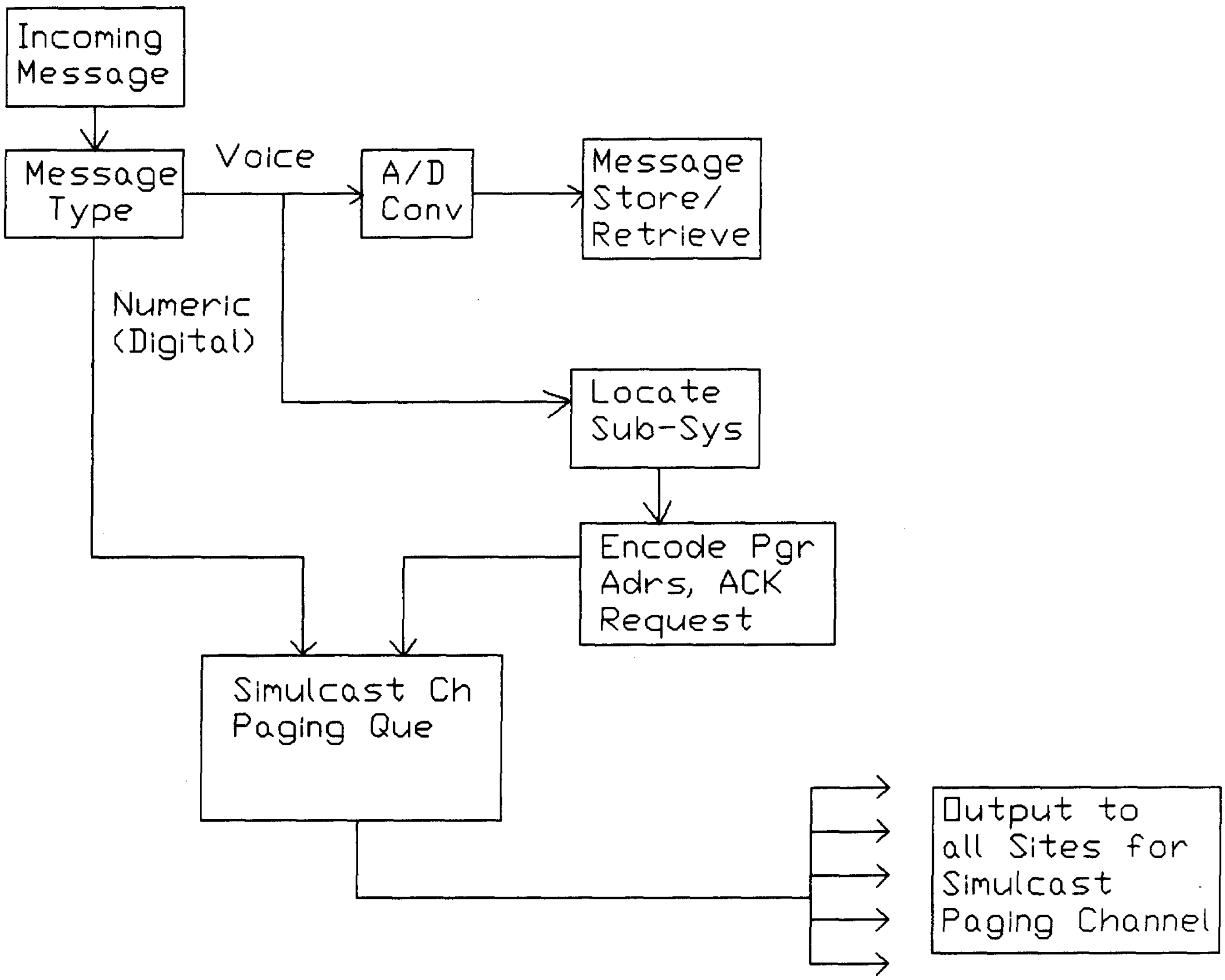


Illustration 4:
Simulcast Voice Compared to Digital Cellular Voice Paging Systems



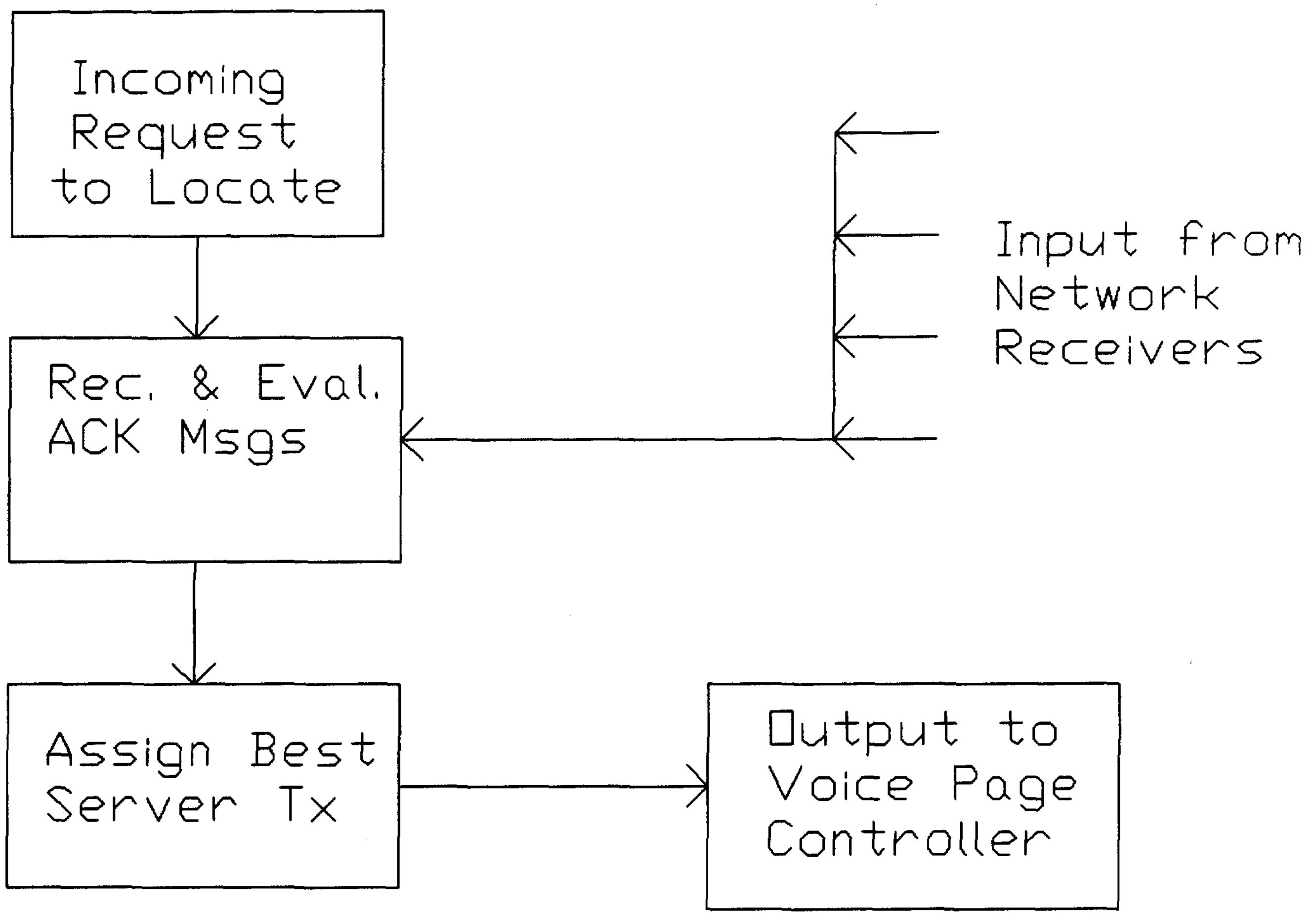
Paging Network, Inc.

Figure 3



Paging Network, Inc.

Figure 1



Paging Network, Inc.

Figure 2

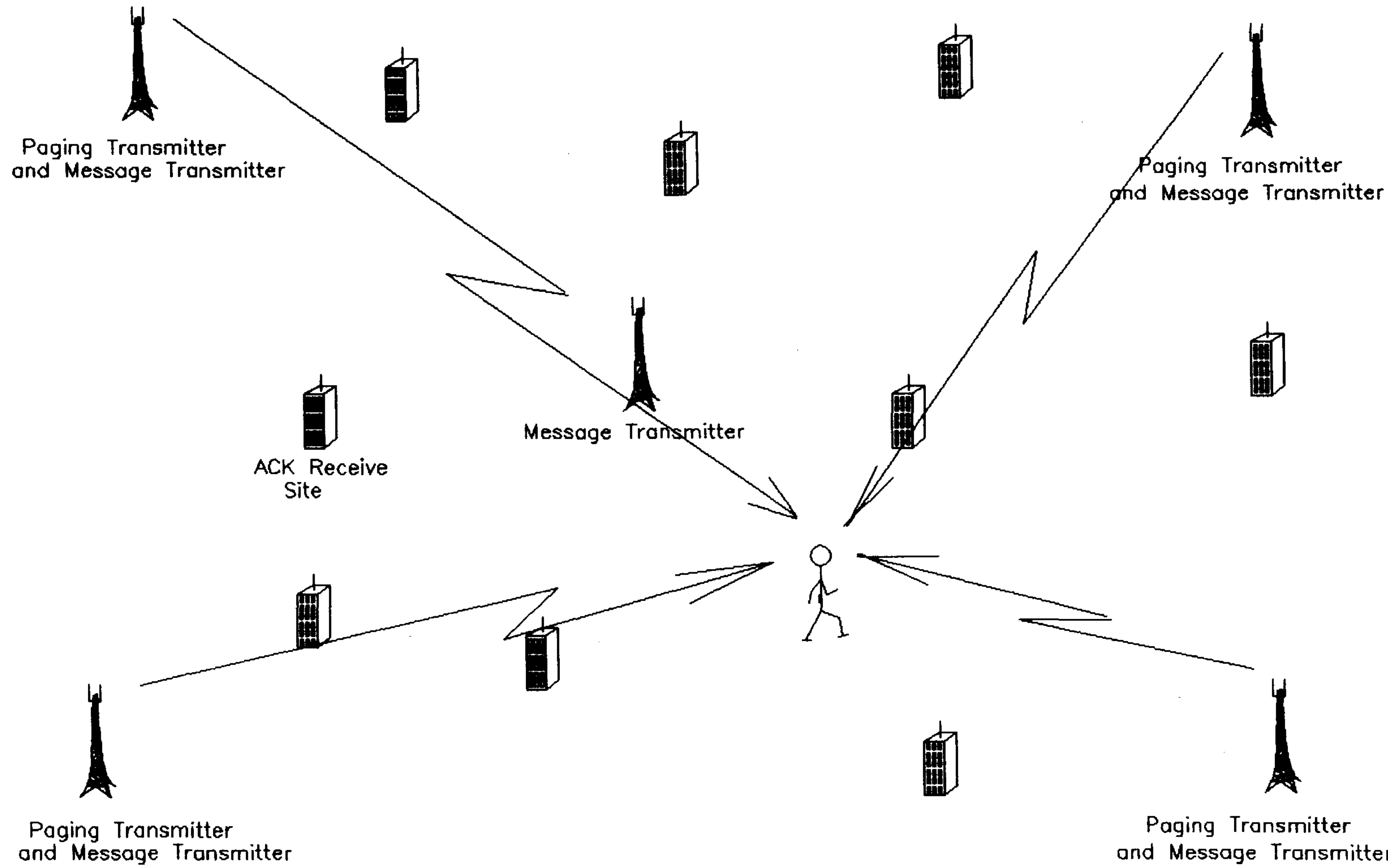


ILLUSTRATION 1:
Simulcast System
Transmits Voice
Message Alert

Moffet, Larson and Johnson, Inc.

VoiceNow
Cellular Paging System

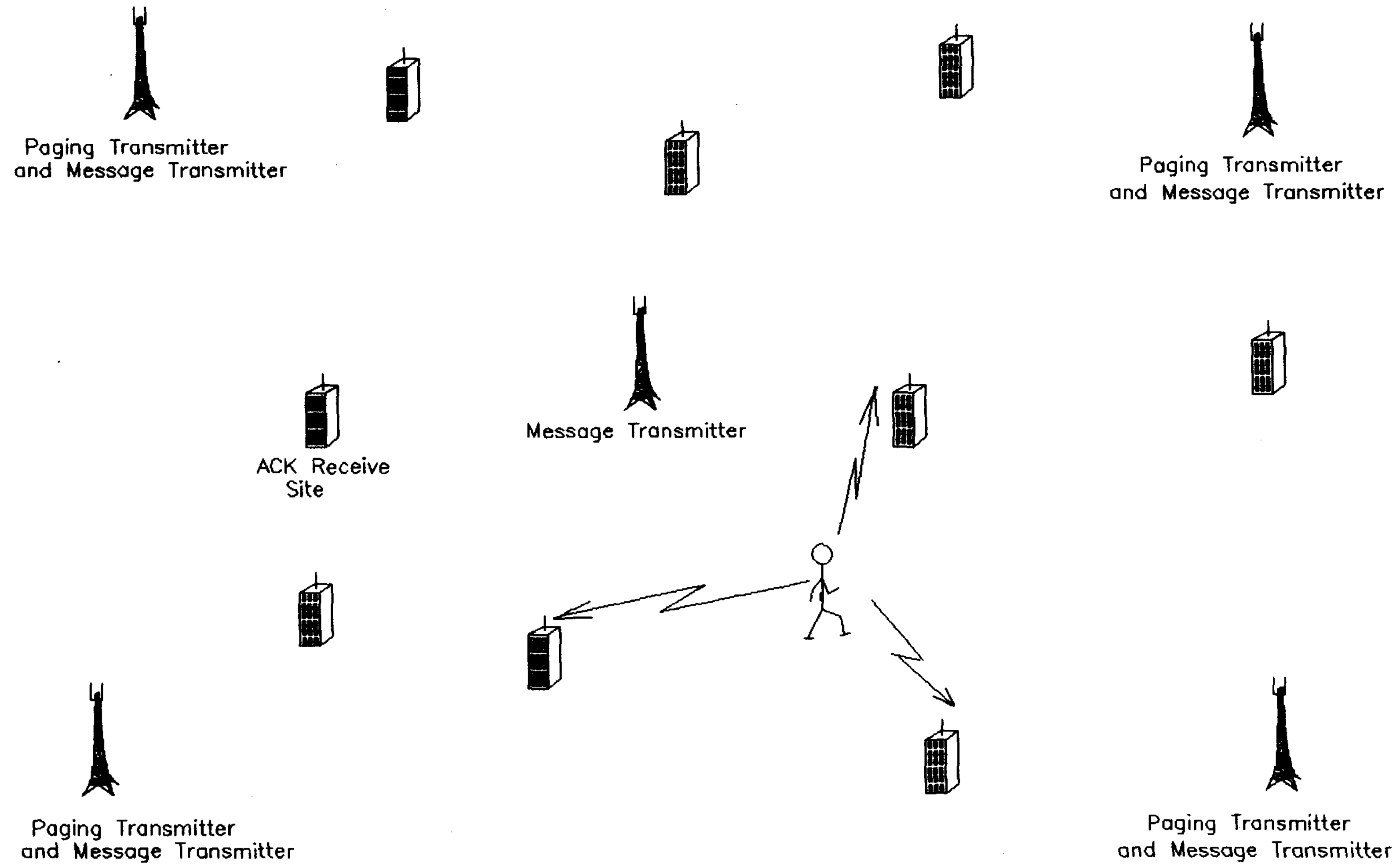


Illustration 2:
ACK Message is
Sent from Pager

Moffet, Larson and Johnson, Inc.

VoiceNow
Cellular Paging System

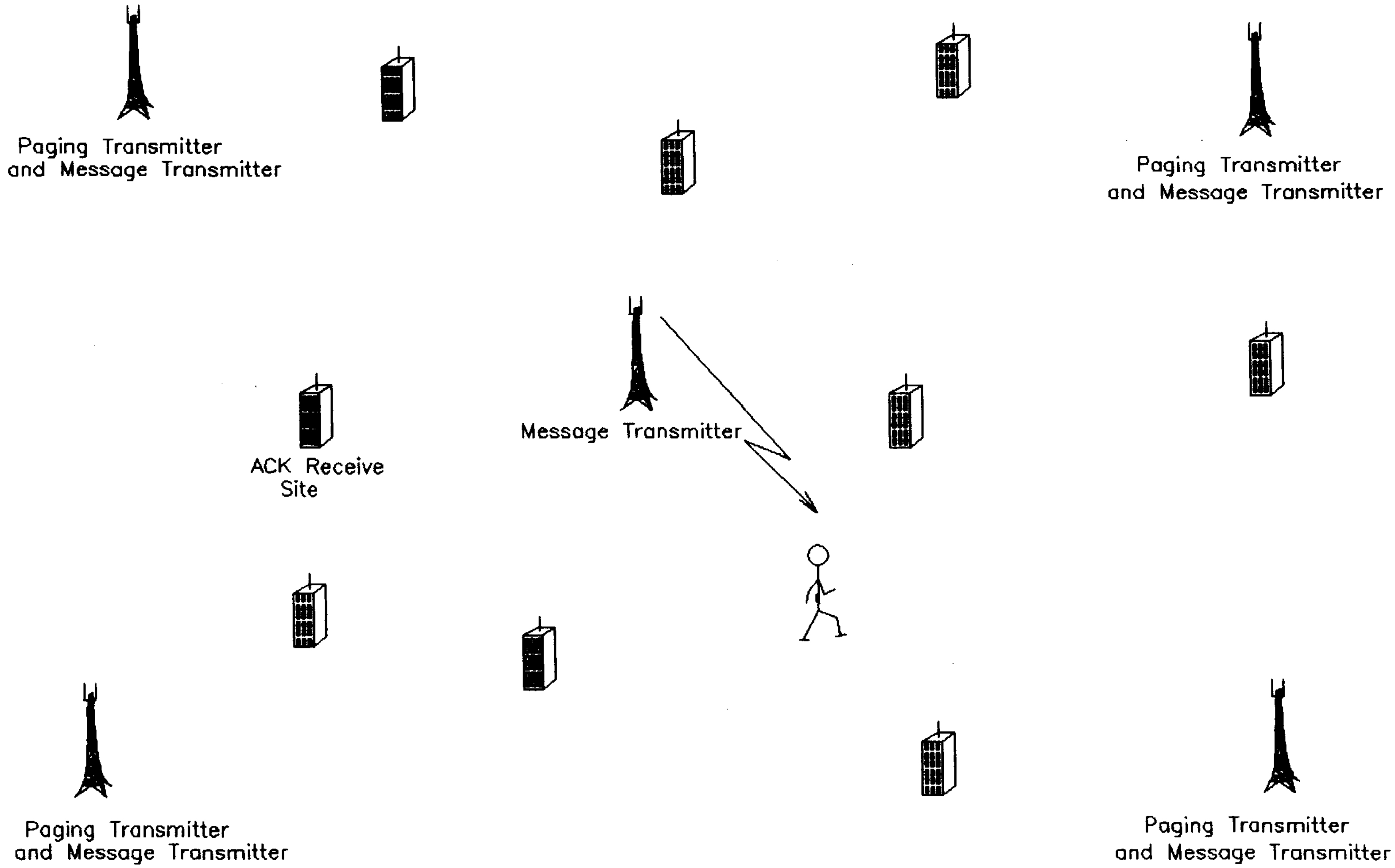


ILLUSTRATION 3:
Message Transmitter
Transmits Voice Message

Moffet, Larson and Johnson, Inc.

VoiceNow
Cellular Paging System


118° 30′
118° 15′
118° 00′
CELL A
CELL E
CELL X
Castaic Junction
Santa Clarita
Saugus
Newhall
Mint Canyon
Duarte
ARCADIA
MONROVIA
TEMPLE CITY
EL MONTE