PERMUTATION MODULATION FOR ADVANCED RADIO PAGING

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ABSTRACT

The multicarrier permutation modulation technique proposed in this paper provides higher bit rates and spectrum efficiencies than that achieved in any state-of-the-art radio paging system. It can be used in simulcast networks with high power transmitters, where long symbol intervals and noncoherent detection are required. The technical feasibility of the proposed modulation technique is established through a set of laboratory and field experiments. Variations of the proposed modulation technique are discussed with regard to performance and complexity of receivers and transmitters.

I. INTRODUCTION

Current radio paging systems deliver numeric, alphanumeric, or tone only (beep) messages to small, low power, receive only devices known as pagers. Typically, the gross bit rate of 1200 bps is achieved through a 25 Khz radio channel by binary Frequency Shift Keying (FSK). Recently, MTEL, Jackson, MS, has pioneered a step up of bit rate to 2400 bps, by a modification of its existing network. The next generation paging system, ERMES (European Radio Message System), will achieve 6250 bps in 25 kHz channel by a 4-level FSK modulation.

Since there is no return channel for acknowledgement and/or user location tracking (for possible hand-offs to nearest network transceiver), special care has to be taken to boost the reliability of reception and coverage area. A major contribution to these goals can be made by simulcasting, i.e. by the simultaneous broadcast of the same information, in the same channel, by a number of transmitters with overlapping coverage areas.

The development of lap-top and palm-top PCs, which can conveniently deal with longer alphanumerical messages than standard pagers, has increased pressure for increased bit rates in paging radio channels. Also the spectral efficiency of the existing paging channels is increasingly questioned, especially in comparison with cellular networks.

This paper describes our efforts to increase both bit rate and spectral efficiency in simulcast paging networks, while keeping receivers simple, and low power consumption devices.

II PROPOSED MODULATION TECHNIQUE

First we propose doubling the channel bandwidth in order to allow higher throughput. This should be done by moving the current emission mask boundaries away from the center frequency by +/- 12.5 kHz. This would give a 35 kHz pass band in the middle of the channel and 7.5 kHz guard bands on each side for the skirts of the spectrum. (See dashed lines in Figs. 1 and 2).

In order to fully utilize the allocated spectrum, and provide fast fall-off of the spectrum in the guard band we propose eight subcarriers spaced 5 kHz apart, so that there is exactly 35 kHz spacing between end subcarriers. Further we propose that during each symbol interval a combination of four distinct carriers is ON, while other four are OFF. This type of modulation falls into general class of permutation modulation, [1] which has features of constant energy for each symbol, efficient spectrum utilization and low requirement for symbol energy to noise density ratio [2]. It can be classified also as a Multicarrier Modulation [MCM] [3] with properties of good immunity to impulse noise and fast fades, and no need for equalization. The proposed code book has M distinct symbols, where

$$M = C_4^8 = \frac{8!}{(8-4)!4!} = 70 \qquad (1)$$

We propose that 64 out of 70 symbols are used for data transmission, which corresponds to 6 bits per symbol, while the remaining 6 symbols are reserved for overhead functions (synchronization, control, etc). Symbols are transmitted at a 4 kbaud rate, which gives a gross bit rate of 24 kbps.

The spectrum efficiency of the proposed modulation is 0.48 bps/Hz, which is much higher than standard 1200 bps paging channels, (0.048 bps/Hz), or even ERMES system, (0.25 bps/Hz). This is still not as good as some digital cellular networks, which can be attributed to the following differences.

The spectrum mask for the paging system has to be tighter in order to reduce interference when a foreign transmitter in an adjacent channel is closer than the monitored transmitter (near-far problem). In cellular systems the network detects user proximity to different antenna sites and switches connection to the nearest one (handoff feature). This effectively eliminates the near-far problem and allows a higher level of interchannel interference.

Further, the simulcast environment prevents using coherent detection, since a moving pager would need to rapidly switch lock from one transmitter to another according to fading variations. This eliminates implementation of quadrature modulation techniques and effectively halves the efficiency.

Finally, the receiver DC power efficiency dictates operation with brief receiver enable intervals (tens of symbols) followed by extended "sleep" periods, which prevents complex equalization algorithms based on equalizer training procedures. Therefore most of the modulation techniques currently used in cellular systems are not applicable in paging networks.

III EXPERIMENTS

In order to investigate the technical feasibility of the proposed modulation technique we have carried out a set of laboratory and field experiments at the University of Mississippi in the 930 MHz frequency band. The transmitters are constructed by Glenayre, Quincy, IL. Each transmitter has four subtransmitters capable of 4-FSK over a subset of the 8 frequencies. Outputs of the subtransmitters are combined and sent to a common antenna. Two transmitters were installed seven miles apart and synchronized to provide a simulcast overlap area with approximately 35 dBμV/m signal strength.

A receiver, constructed by Wireless Access, San Jose, CA, consists of an RF section which down converts the signal to a frequency band below 100 kHz, an A/D converter, a DSP processor which performs signal detection through DFT analysis, and a PC to control the operation and present results. Error free reception has been achieved both in laboratory and field tests for several hours, which corresponds to a BER $< 10^{-5}$.

The signal spectrum at transmitter output is presented in Fig. 1, and 2. Fig. 1 shows a spectrum of a single symbol (frequencies 1, 2, 4, and 8 ON, and 3, 5, 6, 7 OFF) repeatedly transmitted. It shows a low level intermodulation products. The dashed line represents the proposed emission mask, with the pass-band level 6 dB above peaks, corresponding to the level obtained when all subtransmitters broadcast on the same frequency.

Fig. 2 shows the spectrum of the signal sending pseudo random data (a repeated 512 symbols long message), together with the emission mask (dashed line). It is evident that the allocated frequency band is fully utilized, which indicates the spectrum efficiency of the proposed modulation technique.

Fig. 3 shows the spectrum of several isolated symbols the signal obtained by FFT processing in a digital oscilloscope. The FFT window was rectangular with 200 μs width (which corresponds to a 5 kHz bin separation), synchronized externally to fit the middle of the 250 μs symbol interval. Four traces are shown in the plot, each obtained for different symbol. Such a diagram corresponds to eye diagrams, except it is in frequency domain instead of the time domain. It shows that symbols are distinguishable by a proper processing.

IV POSSIBLE VARIATIONS

Alternatives that were considered include multicarrier on-off keying (MOOK) with all eight subcarriers independently keyed. This would increase the bit rate to 32 kbps, but increase the complexity of both transmitters and receivers.

The transmitters would require eight subtransmitters with amplitude modulated power amplifiers, and one more step in the cascade of hybrid circuit combiners. Alternately a single linear power amplifier could be used, with symbols generated by DSP processing in the baseband, brought up to the target frequency range by SSB modulation. This approach is expected to have difficulties meeting the emission mask, due to intermodulation products.

The MOOK system would increase complexity of the receiver with respect to automatic gain control and threshold setting for subcarrier detection. Alternative receiver design, with battery of filters instead of FFT processing, is rejected based on computer simulation which predicted high intercarrier interference.

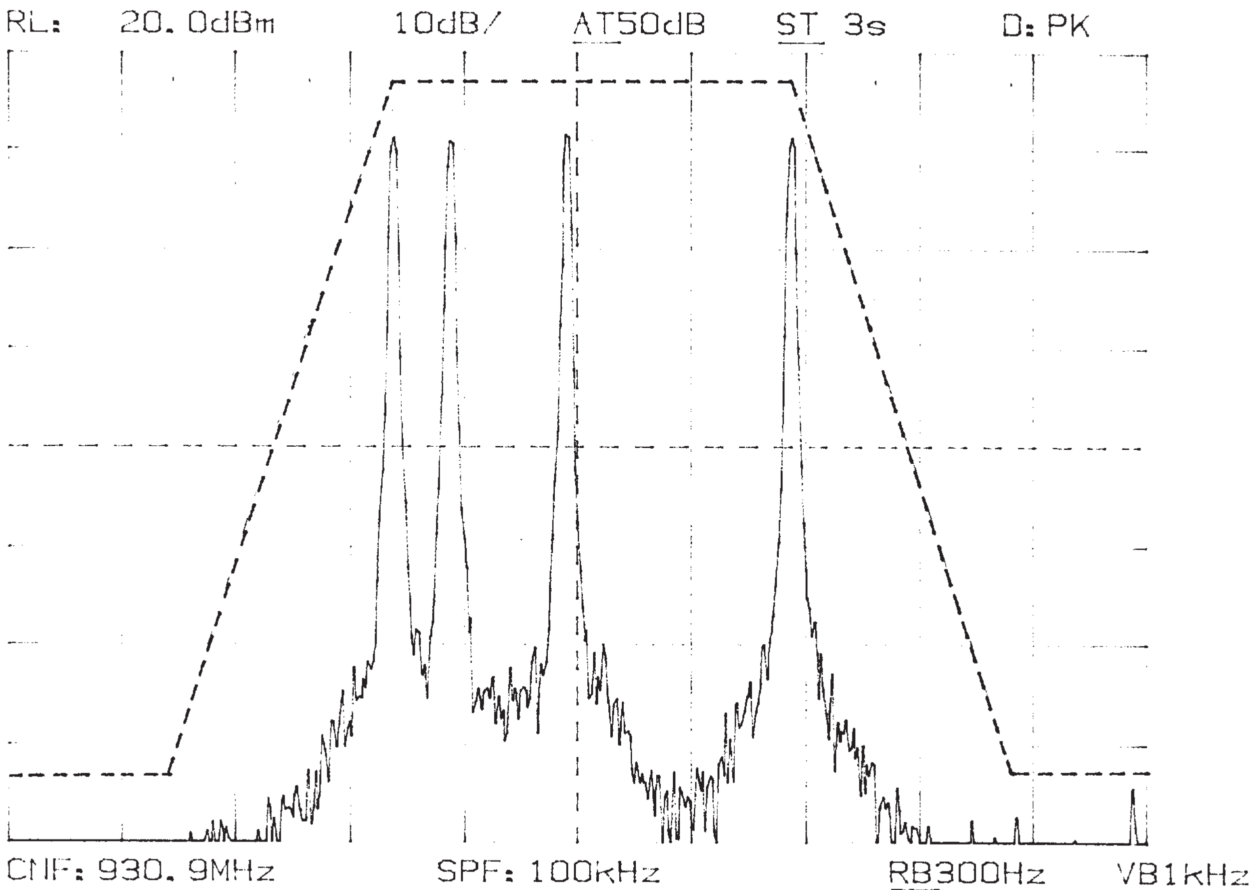
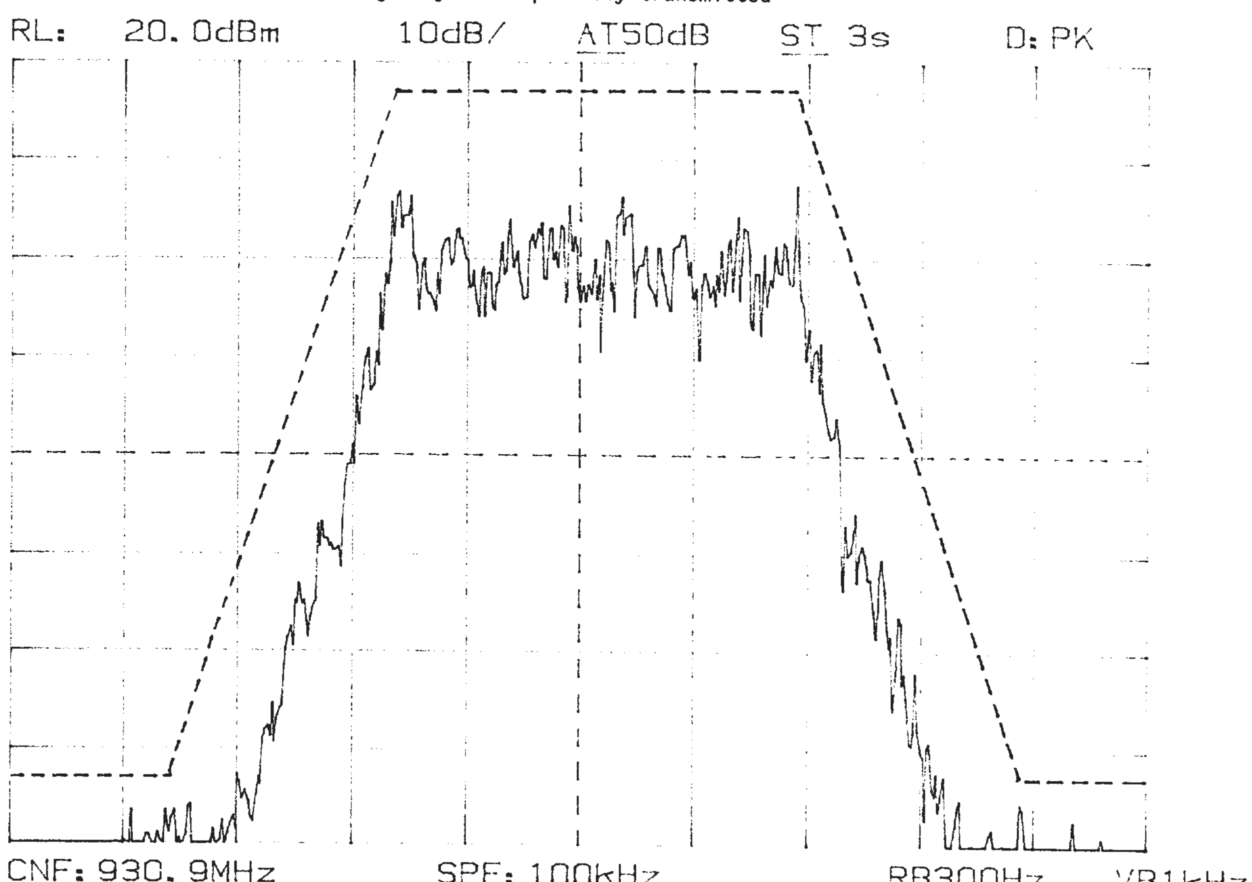


Fig. 1 Spectrum of a single symbol repeatedly transmitted



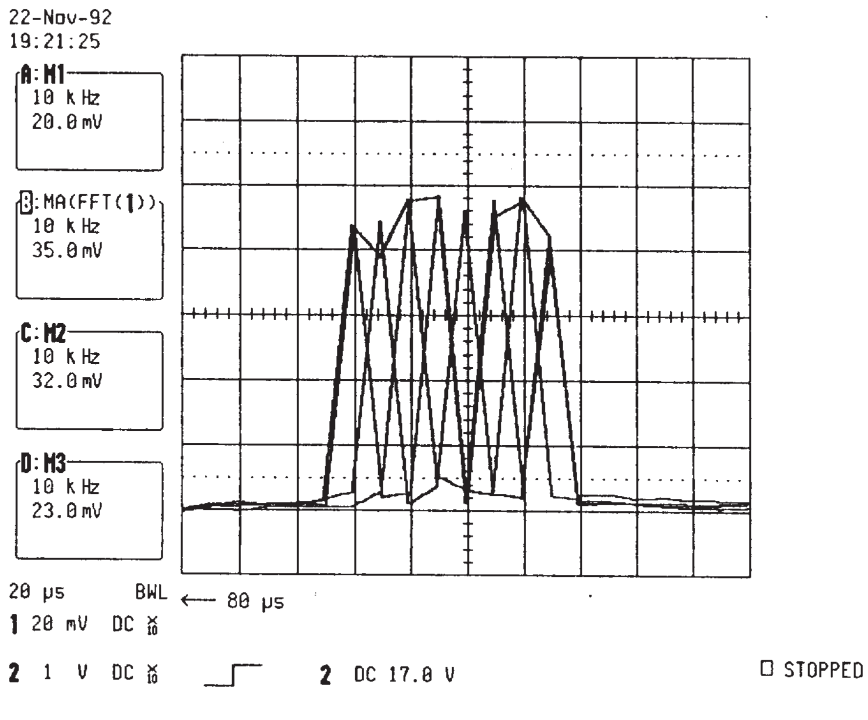


Fig. 3 Frequency domain eye diagram obtained by FFT processing

V CONCLUSION

The permutation modulation technique delivers higher bit rates and better spectrum efficiency than modulation techniques currently used for paging. The higher efficiency attained in cellular networks is a result of the inherent differences in the type of services offered. The choice is made based on simulcast operation with long symbol intervals and noncoherent detection, and moderate cost, low power receiver based on digital processing.

Laboratory and field tests proved the technical feasibility of the proposed technique. The research regarding optimization of receivers and transmitters, symbol synchronization based on digital processing, code table optimization, etc., is underway.

This modulation technique has been included in MTEL's petition to the FCC for the Nationwide Wireless Network service [4], and, the FCC has granted a tentative pioneers preference to this proposal [5].

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