EXPERIMENTAL RESULTS FOR EXTENSIONS TO THE IS-136 TDMA STANDARD BASED ON HIGHER LEVEL MODULATION, COHERENT DETECTION, AND EQUAL GAIN ANTENNA COMBINING

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Abstract - **In previous work [1][2][3], techniques for improved end-user data rate extensions to the IS-136 North American TDMA standard were presented. These techniques were studied for operations in an indoor environment, particularly focused on the downlink (base station to terminal) channel. The indoor channel, with its slow fading characteristics, places special constraints on the system design, which were addressed through handset preselection antenna diversity and improved coding techniques.**

The work presented in this paper is twofold: to be able to demonstrate a complete end-to-end system, an enhanced IS-136 uplink had to be added to the prototype, leading to investigation of different methods of timing synchronization and diversity combining. In addition, recent standards activities have extended the scope of the original work to address operation in outdoor cellular environments where other receiver techniques were investigated.

I. INTRODUCTION

As it currently exists, the North American TDMA standard, IS-136, provides 8 kb/s end user data rate in a high mobility, wide-area cellular environment. Extensions to IS-136 have considered a variety of combinations of the following items: (a) operations in an indoor environment, (b) enhanced speech coding, (c) range extension, and (d) additional traffic channels. Experimental work investigating extensions to IS-136 to address the first two items was previously reported [2]. The focus for that work was on improved speech quality in an indoor environment. There, channel delay spread is much less than outdoors, but multipath can produce “dead spots” that would degrade system performance for slow moving users.

A central feature of the indoor investigation was the use of preselection diversity and antenna polarization diversity at the handset [3]. While this technique seems to be the most desirable option for the downlink and the handset receiver in an indoor environment, it was not obvious that it would provide the desired performance in an outdoors environment. Further, preselection diversity is not an option for the IS-136 uplink, so other options needed to be considered.

At the beginning of these investigations, it appeared that the 16 kb/s G.728 Low Delay-Code Excited Linear Prediction speech coder (LD-CELP) was appropriate for use in the indoor system. Related investigations indicated that the GSM Enhanced Full Rate coder (GSM-EFR) might offer better performance on poor channels while maintaining acceptable performance on good channels. Due to the lower data rate of the GSM-EFR coder, additional coding was possible for this system. In addition, the G.728 coder has a more uniform sensitivity to bit errors while the GSM-EFR coder includes bits that are more and less error tolerant. Consequently, bit error rate and block error rates varied considerably for the two systems.

II. IS-136 BASICS/ENHANCEMENTS

IS-136 provides six slots during a 40 ms frame. With the currently standardized format [4], each slot has 130 QPSK symbols available for coded user data. With two bits per symbol and two slots per user per frame, this provides 13 kb/s channel capacity for each user. With the IS-136 channel coder, approximately 8 kb/s is available for the speech coder. Figure 1 illustrates the IS-136 frame structure.

The first enhancement to IS-136 was to replace the QPSK data symbols with 8-PSK symbols, while leaving the synchronization and signalling intact. This provides a raw channel data rate (exclusive of coding) of 19.5 kb/s. With coding [5], an end user data rate of up to16 kb/s is attainable.

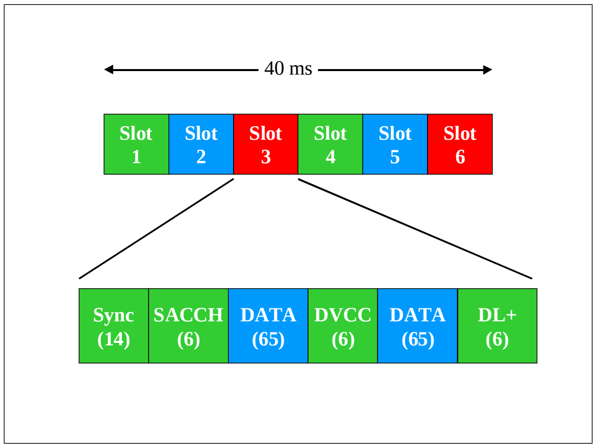

Figure 1 - IS-136 Frame Structure (downlink)

The second enhancement to IS-136 was to add pilot symbols to the frame to allow estimation of channel phase, facilitating coherent detection. This structure is illustrated in Figure 2. Unlike the initial enhancement, the coherent detection enhancement used all available symbols and thus relinquished compatibility with non-enhanced terminals.

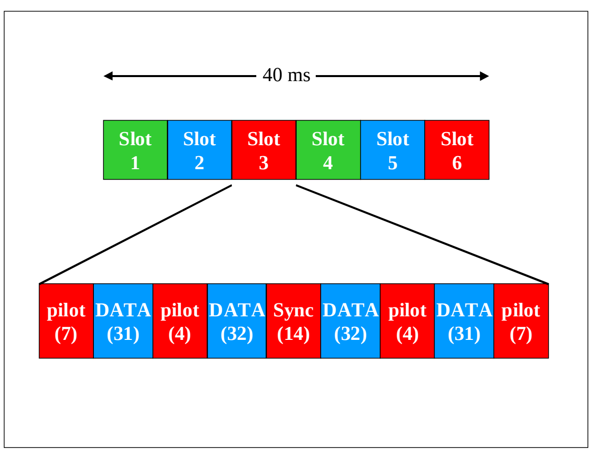

Figure 2 – Coherent IS-136 Frame Structure

Known symbols were transmitted during the synchronization interval as well as during the pilot symbol intervals. By correlating the received symbols with the expected data, it was possible to estimate the phase of the channel at five points during the TDMA burst. The channel phase estimate was then interpolated for the intermediate data symbols.

III. SYSTEM ARCHITECTURE

While earlier investigations focused solely on downlink performance (base station to mobile), the investigations reported here included the implementation of an IS-136 uplink. Lower power transmission from the terminal suggests that some type of receive diversity would be needed. The preselection diversity used in the downlink was not an option, since the terminal only transmits during its assigned TDMA burst. Thus, two complete receiver chains with a baseband combining technique were required at the base station. Equal gain combining was chosen for ease of implementation. For the two-branch system that was implemented, this resulted in a theoretical .5 dB degradation in average SNR, compared to maximal ratio combining [6].

Figure 3 illustrates the architecture of the experimental setup for the Enhanced IS-136 system.

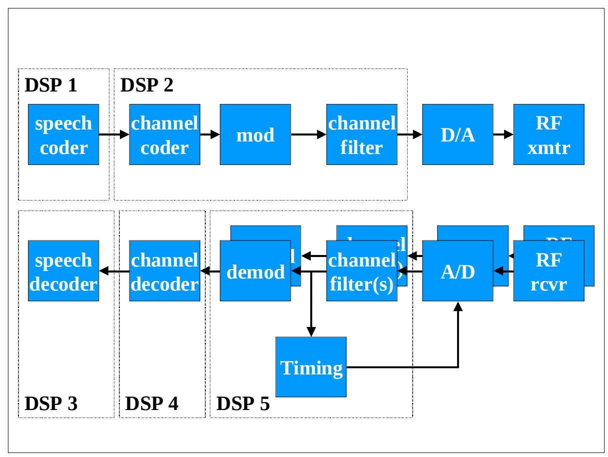

Figure 3 - Experimental System Architecture

The mobile terminal in a wireless system must lock its clock to the base station to receive symbols with the proper timing. The base station, on the other hand, has multiple terminals with which it must communicate. In the case of IS-136, this means that each of three terminals (or even six with single slot operation) will be sending data with a slightly different delay and timing clock frequency offset. For this investigation, the base station sampled at four times the symbol rate (97.2 ksamples/sec) and used four interpolated copies of the channel-shaping filter. By correlating the received IS-136 sync word against several shifted copies of the expected pattern, the base receivers were able to estimate the terminal timing phase to within 1/16th of a symbol. Figure 4 illustrates this approach.

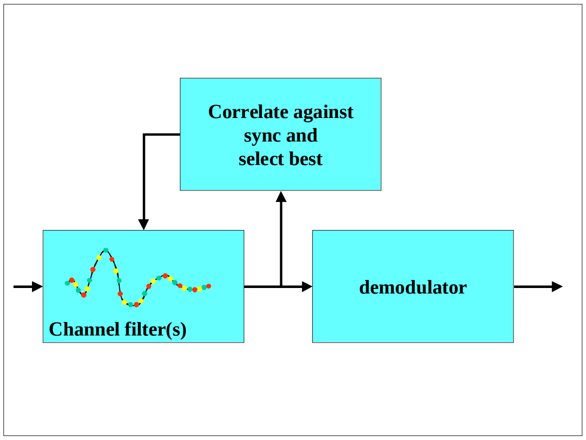

Figure 4 - Base station receiver interpolating filter

The interpolating channel filters were generated by calculating the square root raised cosine filter impulse response, sampling at 16 times the baud. Every fourth tap was used in each of the final filters, with each filter shifted by one T/16 tap. Thus, after the best filter was chosen for the slot, there was no additional computational overhead in using it for the rest of the frame.

IV. EXPERIMENTAL PROTOTYPE

Figure 5 illustrates the experimental prototype used for these investigations. The system shown is the terminal unit – the base station was essentially identical. The prototyping platform is comprised of three components: a 900 MHz RF transceiver, a Texas Instruments TMS320C40-based digital signal processing (DSP) baseband unit, and a set of analog interfaces. Speech coding and decoding, error control coding and decoding, modulation and demodulation, timing estimation and control, and overall terminal display and control were implemented as C language programs on the DSPs. The use of a fully programmable platform, programmed in a high level language, made it easy to try out a variety of system options quickly. By modularizing the signal processing functions (e.g., the speech coding functions were in a separate DSPs from the modulation and demodulation functions) and standardizing interprocessor communications, it was possible to redesign and test the subcomponents of the system independently.

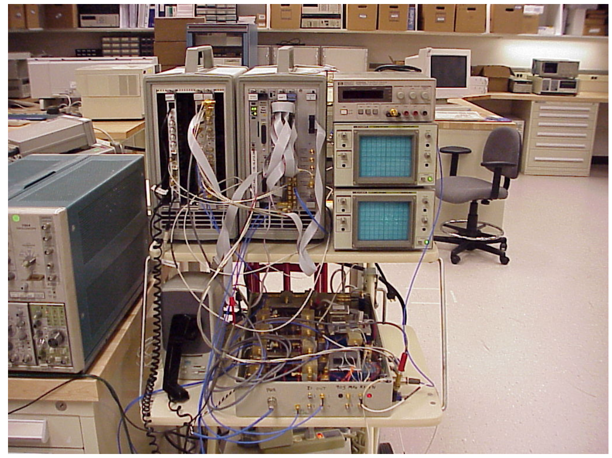

Figure 5 - Experimental Prototype "Handset"

V. OPTIONS INVESTIGATED

As indicated above, there was a tradeoff to be investigated between G.728 and GSM-EFR. While the 16 kb/s G.728 speech coder provided better speech quality over a good channel, the 12 kb/s GSM-EFR coder, with stronger coding of the most important bits, provided better performance over poorer channels. This investigation focused on the raw block error rates, dealing with the radio system performance and not the perceived speech quality. Separate subjective listener experiments evaluated the Mean Opinion Scores for the various coders under a variety of channel conditions.

Note that, for the most part, this paper reports block error rate statistics for coded operation. Due to the different nature of coding G.728 (equal error protection) vs. GSM-EFR (multiple levels of error protection within the block), it is difficult to compare bit error performance between the two frame structures in a meaningful way. Bit error statistics were only found useful to understand the interaction between the coder, the detection mechanism, and the channel. Frame error rates generally provide a better indication of overall speech coder performance. A 1% frame error rate was generally considered to be the target performance level where different schemes were compared.

Next, while the initial system design focused on indoor operation, the investigation here was moving more towards the possibility of outdoor operation, where handset preselection diversity might not be as effective. To regain the loss of system margin, coherent detection of the 8-PSK symbols was studied. In addition, vehicular speed fading rates were studied in addition to the earlier pedestrian speed investigations.

VI. RESULTS

Figure 6 compares the performance of the system downlink using the coding designed for G.728 (16 kb/s) versus that for GSM-EFR. In addition, the figure shows the system operation with and without preselection diversity. It can be seen that there is a considerable difference in performance between the two systems. The G.728 system uniformly protected all speech coder bits with a coding rate of approximately 5/6^{ths}. For the GSM-EFR system, a rate ½ coder was used for less than half the speech bits with the majority of the bits left uncoded. The difference in frame error rates reflects the additional power of the rate ½ code.

As previously observed [2], at low fading rates, preselection diversity tends to make the channel look more like an AWGN channel, improving the operation of the channel coder. As the fading rate increases, the reliability of the antenna selection degrades, resulting in less diversity improvement at higher fading rates.

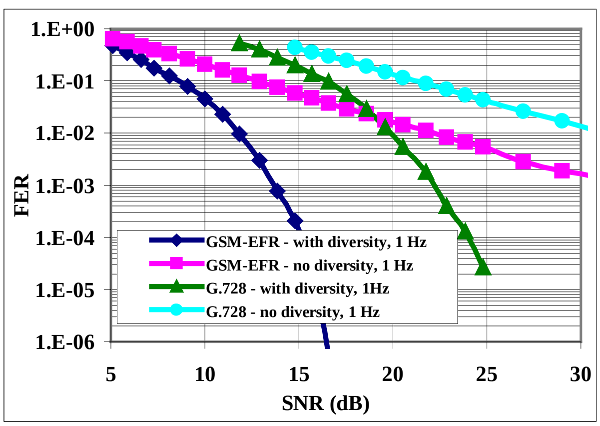

Figure 6 - Frame Error Rates - G.728 vs. GSM-EFR downlink with/without diversity, 1 Hz fading, differential detection

While Figure 6 shows downlink results for a preselection diversity combining technique,
Figure 7 shows the performance of the uplink, where equal gain combining is used. Here, it can be seen that at higher fading rates, the diversity improvement changes less.

These performance results were with differential detection to test the effectiveness of the coders and various combining techniques. Each diversity technique had its own hardware requirements – a second antenna for both and a complete second receiver for equal gain combining. To reduce the hardware complexity of the handset, coherent detection was considered as an alternate to diversity.

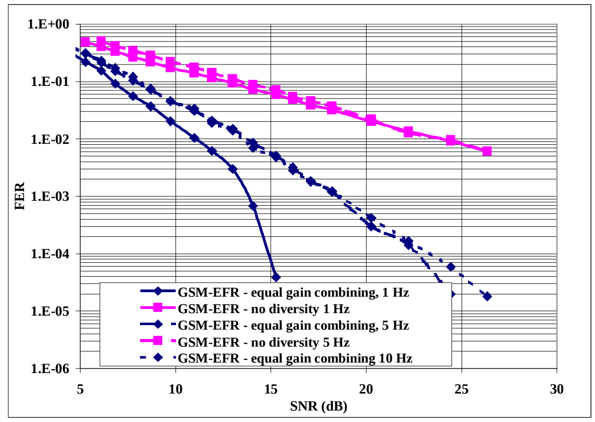

Figure 7 - Frame Error Rates - GSM-EFR uplink with/without diversity; 1, 5, 10 Hz fading, differential detection

To assess the efficacy of coherent detection as a replacement for receive diversity, the advantage of coherent versus differential detection as a function of the fading rate on the channel was measured. Figure 8 illustrates the bit error rate and frame error rates for both differential and coherent detection of the GSM-EFR system as a function of fading rate at a constant signal to noise ratio, without diversity.

It is interesting to compare the system performance at various fading rates for the two detection techniques. First, consider the raw uncoded BER for differential vs. coherent detection. At low fading rates, coherent detection has a small advantage over differential detection. However, as the fading rate starts to exceed the frame rate, there is degradation in the coherent system's performance. This appears to be due to the difficulty in maintaining an accurate estimate of the channel phase. Differential detection, on the other hand, maintains about the same performance at all fading rates, since it is only the phase of the previous symbol that matters for detection.

Next, consider the performance of the coded system. (Recognize that the frame error rates measured only captured uncorrectable errors on the rate ½ coded bits.) Here, it can be seen that the slight BER advantage of coherent detection translates into a greater FER advantage at low fading rates. Near the point where the coherent system's BER starts to degrade, the FER of the coherent system begins to lose its advantage over the differential system. Meanwhile, the FER of the differential system continues to improve, albeit more slowly. It appears that the continuing improvement of the differential system is due to the fact that error events are becoming less correlated. Slow, deep fades create bursty errors that the coder has trouble correcting while faster, shorter duration fades damage fewer symbols. Correspondingly, it appears that the degradation in the advantage of the coherent system is due to loss of good phase estimates of the pilot symbols. With increasing fading rates, the probability that more than one pilot symbol in a frame will be lost increases.

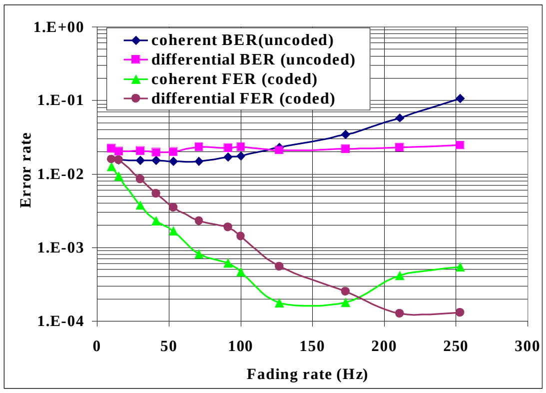

Figure 8 – BER/FER versus fading rate, 22.7 dB SNR, no diversity

It is difficult to state a single value that represents the performance gain of a practical coherent system, given that the advantage of coherent versus differential detection varies with the fading rate on the channel. Figure 9 shows FER versus SNR for differential versus coherent detection at 100 Hz - one particular fading rate in the range of interest for vehicular speeds. It can be seen that under these conditions (which Figure 8 shows the greatest advantage of coherent over differential detection), the performance advantage is actually 1.5 to 2 dB, not the 3 dB that one might expect.

VII. CONCLUSIONS

These experiments illustrated some of the complex tradeoffs between channel coding, modulation, speech coding, channel impairments and system performance. In particular, with a practical implementation of coherent detection, a best case improvement of 2 dB was observed.

Previous work had shown the advantage of preselection diversity on a slowly fading channel. This investigation showed that antenna diversity remains a powerful technique to mitigate the effects of a fading channel under a variety of scenarios

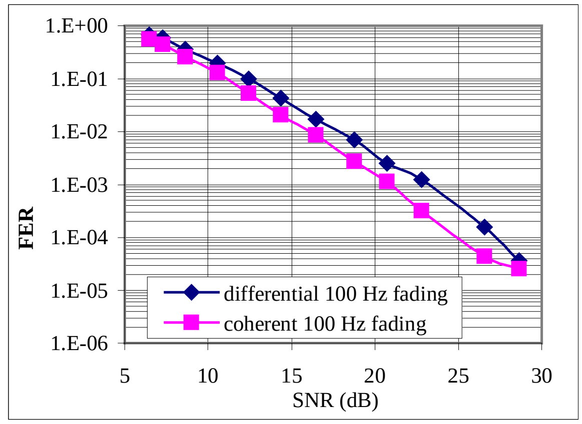

Figure 9 - FER vs. SNR for differential vs coherent detection at 100 Hz fading

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