Performance of Intercode Interleaving in the Indoor Portable Radio Channel

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ABSTRACT This paper examines the performance by simulation of an *intercode interleaving* technique, for indoor portable radio channels. The intercode interleaving technique is implemented by placing a bit interleaver between two concatenated BCH codes. The modulation used is $\pi/4$-shifted DQPSK, with differential detection. The envelope and phase fading in the quasi-static indoor radio channel is modeled by SIRCIM [1]. The cochannel interference is modeled by independently faded $\pi/4$-shifted DQPSK interferences. For the power-limited channel, it is observed that intercode interleaving offers significant gains over uncoded modulation in terms of block error rate.

I. INTRODUCTION

The choice of channel coding and interleaving schemes for indoor portable communications depends on their robustness to the severe degradation effects of the short-term slow fading (causing lengthy burst errors) and cochannel interference. The long interleaver depth required for efficient forward error correction at portable speeds causes unacceptable delays. For portable speech communications, simplicity and delay are important design parameters.

The performance of convolutional codes in the slow fading channel has been examined in [2,3], and it is concluded that at low mobile speeds and in the interference-limited channels, coding gains are not observed. Trellis coding techniques examined in frequency non-selective Rayleigh and Rician slow fading channels [4] are observed to provide small or no gains over uncoded modulation, at low mobile speeds.

Concatenated coding with interleaving [5] finds application in the deep space communications channel [6], where the demand for power efficiency supersedes that for bandwidth efficiency. The deep space channel is modeled by AWGN characteristics. The outer code in this configuration is usually a powerful block code, while the inner code after the interleaver is a convolutional code. The errors at the output of the inner decoder occur in bursts. The deinterleaver decorrelates the burst errors and presents randomized errors to the outer block decoder. Concatenated codes (without interleaving) using Reed-Solomon and convolutional codes are examined in [6], for the fading dispersive channel.

In this paper, the performance of *intercode interleaving* is examined by simulation for the quasi-static flat fading indoor portable TDMA radio channel. The intercode interleaving is implemented by placing a bit interleaver between two concatenated BCH codes. The modulation used is $\pi/4$-shifted DQPSK, with differential detection.

The concatenation of the BCH codes and interleaver is examined for both the power-limited and the interference-limited indoor radio channels. The power-limited channel is one in which the system performance is mainly limited by the transmitted power, i.e., by the AWGN and slow frequency non-selective fading; in such a channel the cochannel interference caused by frequency reuse is not so strong and only introduces some additional degradation (e.g., in rural and suburban areas). In the interference-limited channel, the performance is mainly limited by the cochannel interference (CCI) generated by the system itself rather than thermal noise, because of the dense frequency reuse (e.g., in urban areas).

Section II of this paper presents the simulation model. Section III contains the simulation results, presented as curves of average BER vs. E_b/N_o and Block Error Rate vs. E_b/N_o for the power-limited channels, and BER vs. CIR and Block Error Rate vs. CIR for the interference-limited channels, respectively. Section IV contains the conclusions.

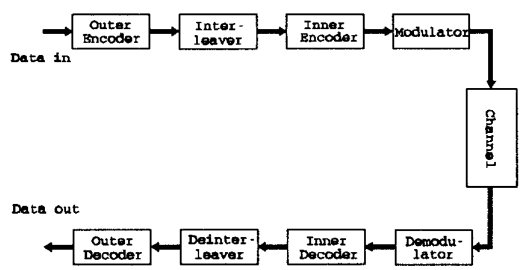

Figure 1: System block diagram of radio link employing intercode interleaving

II. SYSTEM MODEL

The system block diagram is shown in Figure 1. A portable indoor TDMA radio link is assumed, operating at a data rate of 500 kb/sec, and a carrier frequency of 1GHz. It is assumed that timing recovery is perfect, and that the delay spread (in the order of nanoseconds) is negligible for the data rate under consideration.

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At the transmitter, the intercode interleaving system consists of an outer (n_1, k_1) BCH encoder and an inner (n_2, k_2) BCH encoder with a bit interleaver of degree $\times\, n_1$ between them. The coded bits at the output of the inner encoder are modulated into $\pi/4$-shifted DQPSK symbols. The overall coding rate is $R = (k_1/n_1)(k_2/n_2)$.

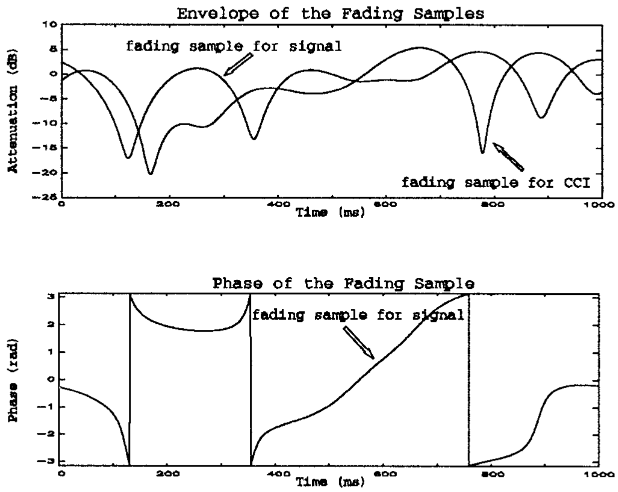

Figure 2: Envelope and phase of the fading sample for the signal and for the CCI in the power-limited channel generated by SIRCIM

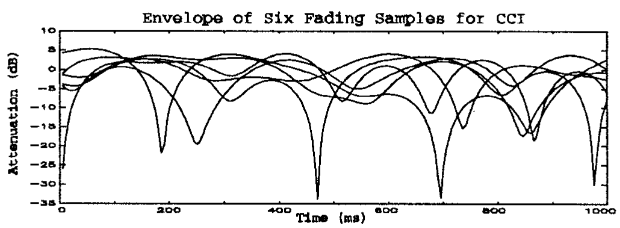

Figure 3: Envelope of the six fading samples for CCI in the interference-limited channel model generated by SIRCIM

In modeling the channel, the transmitted symbols are multiplied by a fading sample. The fading sample is generated by SIRCIM [1] over a one-meter course of the hand-held receiver movement containing slow envelope and phase variations to simulate the frequency non-selective (flat) fading. A portable speed of 1 m/sec is chosen for the simulation. A single independently faded $\pi/4$-shifted DQPSK interference signal is added at different average CIR levels to simulate the cochannel interference in the power-limited channel, and six such independently faded interfering sources are added to simulate the CCI in the interference-limited channel. For the power-limited channel, the signal is also perturbed by AWGN at different average signal-to-noise ratio levels. For the interference-limited channel, the average signal-to-noise ratio is assumed high. The fading samples used in this study for the signal and for the interference(s) are shown in Figures 2 and 3.

At the receiver, the received symbols are differentially demodulated, decoded by the inner decoder, deinterleaved, and subsequently decoded by the outer decoder. Hard-decision algebraic decoding is used for both codes. Differential detection is considered because of its simplicity compared to coherent detection which requires fast tracking carrier recovery for TDMA systems.

For speech communications over burst error channels, the speech quality is related more to the block error rate than to the average bit error rate. Therefore, the block error rate is chosen as the main criterion in this study and the average BER is used as a supplementary criterion. The block size chosen for evaluating the block error rate is 512 bits.

For interference-limited channels, because of the reduced frequency reuse distance within a given location, caused by the bandwidth expansion of coding, the performance of the intercode interleaved scheme is assessed in terms of the coding gains in CIR obtained after compensating the tradeoff in bandwidth expansion. The bandwidth expansion factor is $20\log_{10}(1/R)$ dB in average received CIR [3]. For the power-limited channels, however, as the performance is not mainly limited by CCI, the performance is evaluated by coding gains in E_b/N_0.

In the next section, the results are presented as plots of Block Error Rate vs. average E_b/N_0, and average BER vs. average E_b/N_0 for the power-limited channel; and Block Error Rate vs. average CIR, and average BER vs. average CIR for the interference-limited channel.

III. RESULTS

The intercode interleaved BCH code combinations considered in this study are listed in Table I below, along with the overall code rate R and the bandwidth expansion factor $20\log_{10}(1/R)$ for the interference-limited channel. For the first two code combinations in the table, the interleaver used between the two BCH codes is a degree×63 matrix, and for the last code combination, it is a degree×31 matrix. Various degrees of interleaving are examined.

Table I. Code combinations considered in this paper.

Outer Code	Inner Code	Code rate R	20log(1/R)
BCH (63,51)	BCH (63,45)	0.58	4.76 dB
BCH (63,51)	BCH (63,39)	0.50	6.00 dB
BCH (31,26)	BCH (63,45)	0.60	4.45 dB

First, we consider the performance for the power-limited channel.

The block error rate, which is closely related to outage probability and received speech quality, is of particular interest for the quasi-static indoor fading channel. The block error rate is defined as the ratio of the number of blocks in error to the total number of blocks transmitted. An block in error is identified by at least one bit error in a block of 512 bits.

Figures 4 to 6 contain plots of block error rate vs. average E_b/N_0 for the three intercode interleaved schemes, in AWGN and flat fading. The performance of the uncoded DQPSK scheme is also plotted for comparison. In terms of block error rates, a distinct improvement in performance is observed over uncoded modulation for all three codes. For the BCH(63,51)-BCH(63,45) code in Figure 4, the coding gain is observed to be 2.5 dB over uncoded DQPSK for an interleaving degree of 5 and block

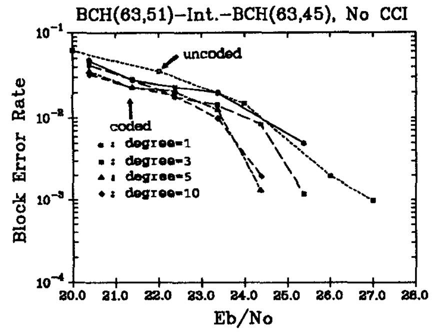

Figure 4: Block error rate vs. average E_b/N_0 for BCH(63,51)-BCH(63,45) intercode interleaved scheme in the power-limited channel with AWGN and fading.

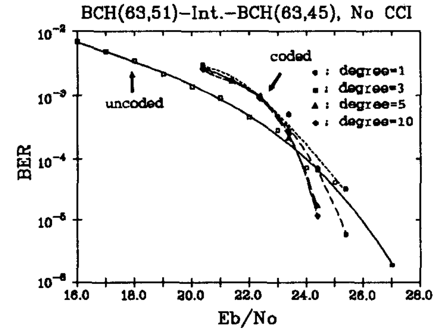

Figure 7: Average BER vs. average E_b/N_0 for BCH(63,51)-BCH(63,45) intercode interleaved scheme in the power-limited channel with AWGN and fading.

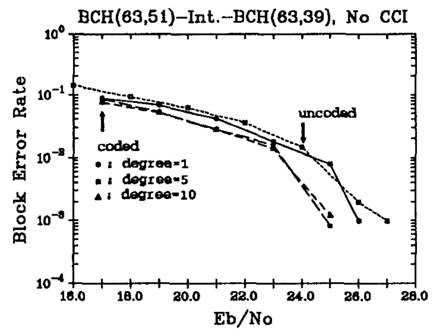

Figure 5: Block error rate vs. average E_b/N_0 for BCH(63,51)-BCH(63,39) intercode interleaved scheme in the power-limited channel with AWGN and fading.

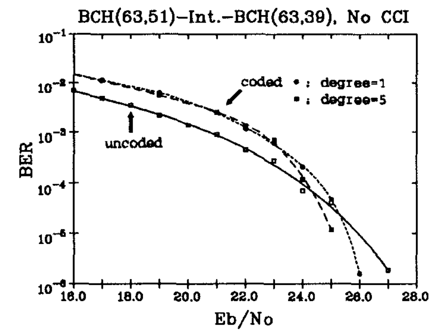

Figure 8: Average BER vs. average E_b/N_0 for BCH(63,51)-BCH(63,39) intercode interleaved scheme in the power-limited channel with AWGN and fading.

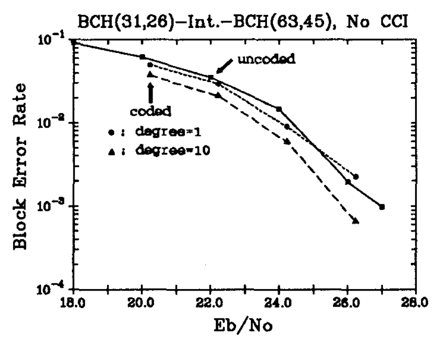

Figure 6: Block error rate vs. average E_b/N_0 for BCH(31,26)-BCH(63,45) intercode interleaved scheme in the power-limited channel with AWGN and fading.

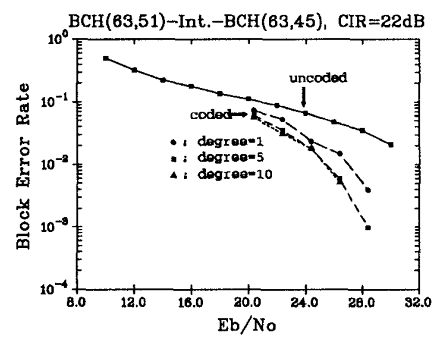

Figure 9: Block error rate vs. average E_b/N_0 for intercode interleaved BCH(63,51)-BCH(63,45) in channel with AWGN, fading and CCI (average CIR=22 dB).

error rate of 10^{-3}. In Figure 5, the BCH(63,51)-BCH(63,39) code has approximately 2 dB gain over uncoded modulation for degree=5 and block error rate near 10^{-3}. The performance of the BCH(31,26)-BCH(63,45) code shown in Figure 6 indicates coding gain of about 1 dB for degree=10 and 10^{-3} block error rate. For all the three codes examined in Figures 4 to 6, intercode interleaving contributes an improvement in block error performance of at least 1 dB in the high average E_b/N_0 range over the concatenated codes without interleaving (i.e., the degree=1 case). And without the intercode interleaving, the concatenated codes provide very little gains or even some losses. Again, simulations show that interleaving depths greater than 5×63 (or 10×31) provide little further gains.

In comparison, the best code is the BCH(63,51)-BCH(63,45) code combination. The outer code is a two-error correcting code, while the inner code is a three-error correcting code. This code yields a coding gain of 2.5 dB (when interleaving is considered).

As another measure of performance, Figures 7 and 8 contain plots of the average BER vs. average E_b/N_0 for the first two intercode interleaved schemes, in AWGN and flat fading. The codes show gains in the sense of average BER only at high SNR range. Increasing the degree of interleaving helps to asymptotically improve the code performance over that of

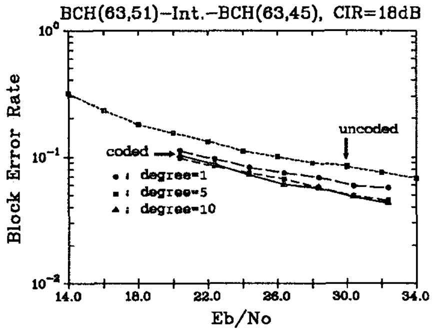

Figure 10: Block error rate vs. average E_b/N_0 for intercode interleaved BCH(63,51) - BCH(63,45) in channel with AWGN, fading and CCI (average CIR=18 dB).

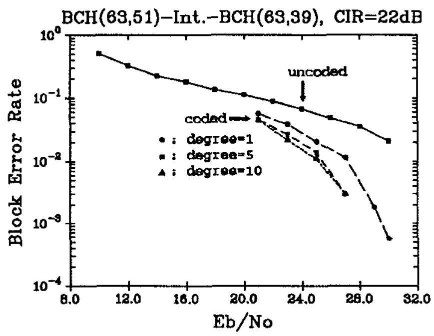

Figure 11: Block error rate vs. average E_b/N_0 for intercode interleaved BCH(63,51) - BCH(63,39) in channel with AWGN, fading and CCI (average CIR=22 dB).

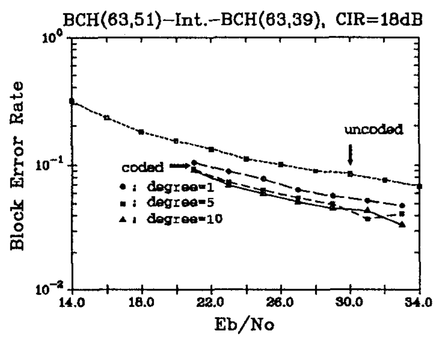

Figure 12: Block error rate vs. average E_b/N_0 for intercode interleaved BCH(63,51) - BCH(63,39) in channel with AWGN, fading and CCI (average CIR=18 dB).

uncoded modulation.

Next, the performance in presence of CCI in the power-limited channel is considered. For the relatively far frequency reuse distance in such channel, we assume there is only one major (faded) CCI source and simulate the performances vs. average E_b/N_0 with average CIR as a parameter. Figures 9 through 12 plot the block error rates of the BCH(63,51)-BCH(63,45) and the BCH(63,51)-BCH(63,39) code combinations, compared with uncoded modulation in channel perturbed by AWGN, fading and CCI of average CIR = 22 and 18 dB, respectively. Significant performance improvements are observed for all these cases. For example, the code BCH(63,51)-BCH(63,45) in Figure 9, the coding gain at an block error rate of 2×10^{-2} is in the order of 6 dB, without interleaving, and 7 dB with interleaving.

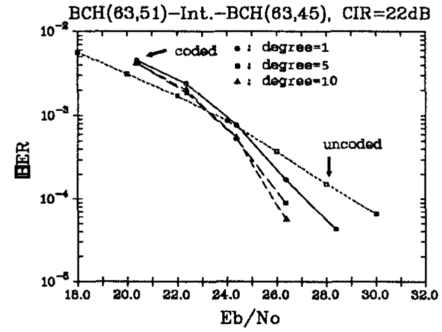

Figure 13: Average BER vs. average E_b/N_0 for intercode interleaved BCH(63,51) - BCH(63,45) in channel with AWGN, fading and CCI (average CIR=22 dB).

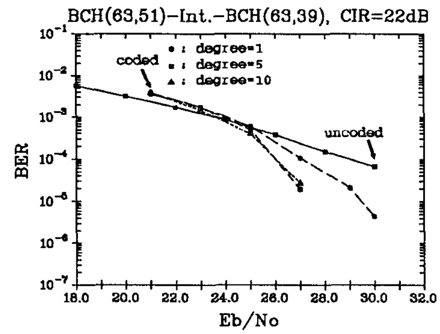

Figure 14: Average BER vs. average E_b/N_0 for intercode interleaved BCH(63,51) - BCH(63,39) in channel with AWGN, fading and CCI (average CIR=22 dB).

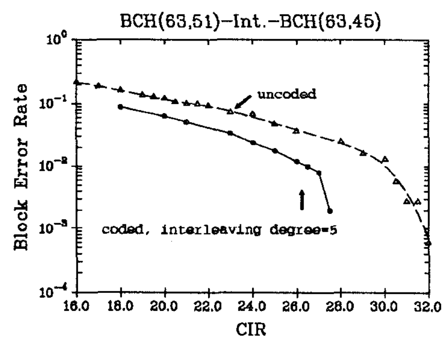

Figure 15: Block error rate vs. average CIR for intercode interleaved BCH(63,51) - BCH(63,45) in interference-limited channel with fading.

Results in terms of average BER are given in Figures 13 and 14 for CIR=22 dB. Again, for average BER, gain is observed only in the high SNR range.

Now, consider the performance of the intercode interleaved codes in the interference-limited channel, where the channel is simulated at high SNR with six faded CCI sources. To demonstrate the performance over uncoded modulation, the coding gains must be obtained by subtracting the bandwidth expansion factor listed in Table I from the raw gains in received average CIR, observed from the curves. Here results for only one code combination, the BCH(63,51)-BCH(63,45), are given as in Figures 15 and 16. It is observed that, after deducting the bandwidth expansion factor of 4.76 dB, no gains can be obtained in such CCI limited channels.

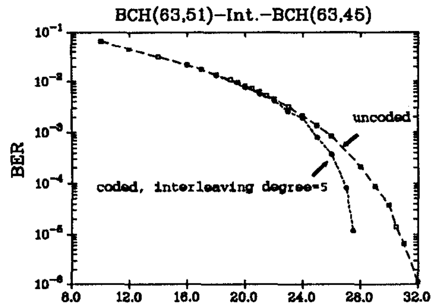

Figure 16: Average BER vs. average CIR for intercode interleaved BCH(63,51) - BCH(63,45) in interference-limited channel with fading.

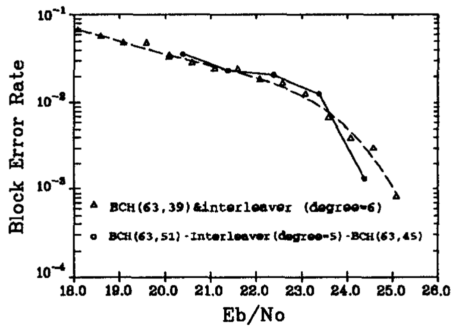

Figure 17: Block error rate vs. E_b/N_0 for the conventional coding - interleaving and the intercode interleaving scheme in the power-limited channel.

Finally, we compare the performance of the intercode interleaving scheme with conventional single code with interleaving at the same delay. A single BCH(63,39) code of coding rate 0.62 with bit interleaver 63×6, is chosen to compare to the BCH(63,51)-BCH(63,45) with intercode interleaver of 63×5. Simulated block error rates for the two types of channels are plotted in Figures 17 and 18. In the power-limited channel, the intercode interleaving scheme has about 0.5 dB gain over the single code in the high SNR range (Figure 17), and in low SNR range, the conventional scheme performs a little bit better. The two schemes perform almost the same in the interference-limited environment as in Figure 18.

IV. CONCLUSION

In this paper, the performance of intercode interleaving was investigated by simulation. The intercode interleaving was realized by placing a bit interleaver between two concatenated BCH codes, in conjunction with differential detection of the $\pi/4$-shifted DQPSK signals, and hard-decision algebraic decoding. Two types of indoor potable radio channels were investigated. The first type of channel was power-limited channel in which the performance is mainly limited by AWGN and slow fading. In terms of block error rates, significant asymptotically increasing gains in average E_b/N_0 were observed over uncoded modulation with or without CCI for this type of channel. Among the three code combinations investigated, the BCH(63,51)-BCH(63,45) code provided the best performance (2.5 dB over uncoded system without CCI and 7 dB with CCI of CIR=22 dB). Compared with conventional single code scheme with interleaving, this code combination was 0.5 dB better in the high SNR range. The second type of channel considered was the interference-limited channel in which the performance is limited by slow fading and CCI due to extensive frequency reuse. For this type of channel, after deducting the spectrum expansion factor, the intercode interleaving scheme provides no gains in average CIR.

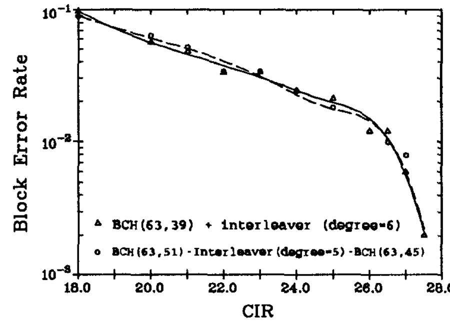

Figure 18:Average BER vs. average CIR for the conventional coding- interleaving and the intercode interleaving scheme in interference-limited channel.

A further examination of other code combinations using the intercode interleaving concept is being considered.

References:

[1] SIRCIM Ver. 2.0: Simulation of Indoor Radio Channel Impulse Response Models, (Software), Virginia Tech Intellectual Properties, Inc.

[2] C.L. Despins and D. Haccoun, Channel Coding and Antenna Diversity Trade-offs for Indoor Wireless Channels, IEEE International Conference on Selected Topics in Wireless Communications, Vancouver, B.C., Canada, 1992, pp. 402 - 405.

[3] L.F. Chang and S. Ariyavisitakul, Performance of Convolutional Codes with Interleaving in the Interference Limited Rayleigh Fading Channel, IEEE Veh. Technol. Conf., 1991, pp. 812 -816.

[4] S.S. Periyalwar, Multiple Trellis Coded Modulation for the Mobile Radio Channel, IEEE Global Communications Conference, GLOBECOM '92, Orlando, Fla., U.S.A, pp. 894 - 898 .

[5] G.C. Clark and J.B. Cain, Error Correction Coding for Digital Communications, Plenum Press, N.Y., 1981.

[6] D.C. Linne von Berg and S.G. Wilson, Improved Concatenated Coding/Decoding for Deep Space Probes, IEEE Global Communications Conference, GLOBECOM 92, Orlando, Fla., pp. 707 - 711.