CONVOLUTIONAL INTERLEAVING FOR DIGITAL RADIO COMMUNICATIONS

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Abstract

Interleaving enhances the quality of digital transmission over the radio fading channel. This enhancement comes at the cost of introducing additional time-delay, memory space requirements, and system complexity. This paper describes commonly used interleaving techniques. It addresses the realization and performance of a convolutional interleaver that cuts down time-delay and memory space increase considerably. Base-band computer simulations are presented for convolutionally coded and interleaved QPSK transmission over Rayleigh and Rician flat-fading channels at different interference levels.

Introduction

Interleaving is a form of time diversity that mitigates the effects of error bursts over the radio fading channel. Several diversity techniques aim at reducing channel effects either by supplying the receiver with independent replicas of the transmitted sequence or by randomizing channel errors.

Diversity techniques can be divided into three broad classes [Jakes 74]: frequency diversity, space diversity, and time diversity. In frequency diversity, redundant channels carry the signal between transmitter and receiver using different carrier frequencies. In space diversity, a number of antenna elements are placed sufficiently apart such that the received signal on each antenna element degrades independently. A special case of space diversity is polarization diversity in which the signal is transmitted over two orthogonal polarizations. In time diversity, symbols of the coded sequence are either transmitted a number of times or scrambled using interleaving techniques.

This paper describes two commonly used periodic interleaving techniques. The focus is on convolutional interleaving, its realization, advantages and performance in conjunction with coded transmission under different channel conditions.

1. Interleaving Techniques

Interleaving techniques are traditionally used to enhance the quality of digital transmission over the bursty radio channel. This is usually accomplished by scrambling successive symbols of the transmitted sequence into different time slots. A channel is considered fully interleaved when consecutive symbols of the

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received sequence appear to be independent, i.e., not affected by the same error burst. This is achieved when adjacent symbols of the transmitted sequence are separated by more than the average duration of an error burst. A channel is considered partially interleaved when consecutive symbols of the received sequence are affected by the same error burst.

Interleaving improves the performance of digital radio systems at the cost of increasing memory space requirements, system complexity, and time-delay. The memory space increase is normally tolerable. The complexity issue is relative and it is always decreasing due to advances in technology. However, time-delay increase may render interleaving impractical in certain applications (e.g. voice communications). The factors that control the quality of digital communications over the radio fading channel include: The transmission and fading rates, coding and modulation techniques, antenna gain and directivity, and the interleaver depth and type.

Interleavers are classified into two broad types: periodic interleavers, and pseudo-random interleavers. In a periodic interleaver, symbols of the transmitted sequence are scrambled as a periodic function of time. The two main classes of periodic interleaving are: block interleaving, and convolutional interleaving.

2. Block Interleaving

A B-by-N block interleaver consists of a rectangular array of B rows and N columns. The vertical dimension, B, of the array is called the interleaving degree. The transmitted sequence is usually fed into the array row by row and shifted out column by column. Successive symbols of the transmitted sequence appear over the channel B-1 symbols apart. The structure of the received sequence is restored by an inverse operation using a B-by-N array as a deinterleaver. The block interleaver-deinterleaver memory space requirements and time-delay is 2BN symbols for both.

Block interleaving is usually used to improve the performance of random error correction codes over the radio fading channel [Forney 71, Lutz 84]. A channel error burst of length N symbols will affect a single symbol in a row of a B-by-N block interleaved sequence. Thus if the error correction code corrects a single error, then the interleaved code corrects bursts of length N symbols or less. Similarly, if the code corrects τ symbols, then the interleaved code corrects any combinations of bursts of length τN symbols or less.

3. Convolutional Interleaving

A convolutional interleaver can be created as shown in Figure-1 by splitting diagonally the B-by-N rectangular array of a block interleaver into two halves (two triangular arrays). The first half is the interleaver which is inserted between the channel encoder and the modulator. The second half is the convolutional deinterleaver which is inserted between the demodulator and the channel decoder. This structure is referred to as the B-by-N or (B,N) convolutional interleaver, and a shift-register realization of it is shown in Figure-1 [Clark 81].

At the transmitter, the coded sequence is fed into a B-by-N triangular array of shift-registers. The i-th ($1 \leq i \leq B$) shift-register has a length of $(i-1)M$ stages, where $M = N/B$. The registers are clocked once every B symbols, and the oldest symbols in the registers are shifted out to the channel. The received sequence is restored to its original ordering using an inverse structure of shift-registers. Symbols that are delayed by $(i-1)M$ stages at the transmitter are delayed by $(B-i)M$ stages at the receiver.

Convolutional interleaving possesses the following advantages [Clark 81]: 1) All symbols receive a total delay of $(B-1)M$ stages. For a clocking rate equal to B, this results in $B(B-1)M$ or $N(B-1)$ symbol times. This delay is less than half the delay required in a B-by-N block interleaver. 2) The total memory space requirements is $N(B-1)$ symbols. This is also less than half of the memory required by a B-by-N block interleaver.

The efficiency of a random error correction code can be increased using a B-by-N convolutional interleaver. Any single channel burst of a length γ M symbols affects no more than γ of the B register output sequences at a time. The deinterleaver output commutators space these sequences to give bursts of γ symbols spaced by $(B-\gamma)M$ error free symbols.

4. Computer Simulations

Base-band computer simulations are aimed at studying the impact of the convolutional interleaver of Figure-1 on the quality of coded transmission over different types of flat-fading channels. All current simulations are for QPSK modulation, a 10-by-90 convolutional interleaver, and a rate 1/2 convolutional code that has: a constraint length $\nu = 3$; a free distance $\delta = 5$; and the generator polynomials $g_1 = [101]$ and $g_2 = [111]$. Soft-decision Viterbi decoding is employed at the receiver with a trellis depth of 30 symbols.

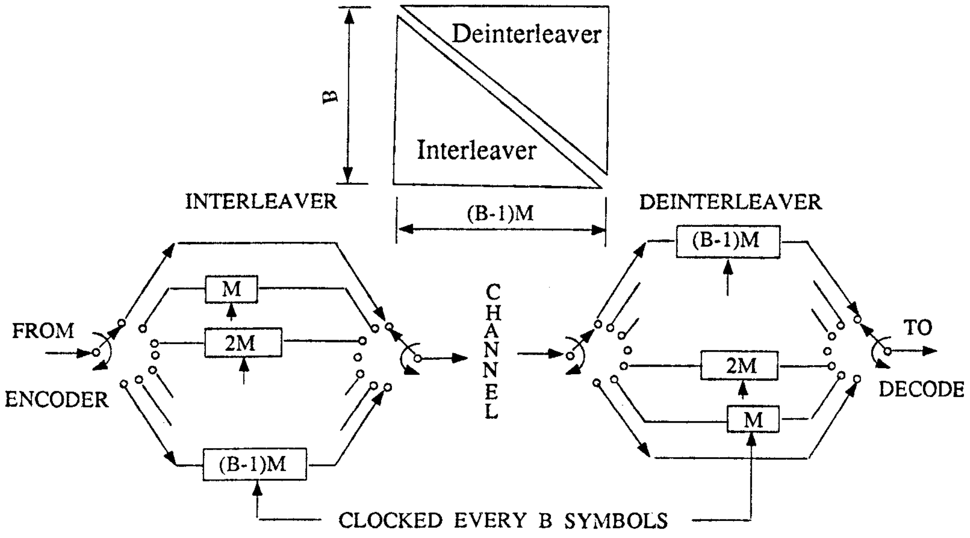

Figure-1. A realization of a B-by-N convolutional interleaver.

Current simulations are for a transmission rate of 400 kilo symbols/second (ksps). Perfect synchronization and carrier recovery are assumed.

Figure-2 shows the effect of convolutional interleaving on bit-error-rate (BER) curves for a Rayleigh flat-fading channel at a Doppler frequency f_d =60 Hz and a Carrier to Interference Ratio CIR = ∞. For a given BER, convolutional interleaving enables significant reduction in the required signal to noise ratio. Figure-3 shows BER curves for a Rician flat-fading channel with a line-of-sight to diffuse components ratio K =10 dB (f_d =60 Hz, and CIR = ∞). Figure-4 shows BER curves for convolutionally coded and interleaved transmissions over a Rayleigh flat-fading channel (f_d =60 Hz). These curves are derived for a single interferer at different CIR values. The interferer is an independent Rayleigh flat-fading signal at a 400 ksps and a f_d =60 Hz.

5. Conclusions

The advantages of using convolutional interleaving for digital coded transmission over Rayleigh and Rician flat-fading channel is established through base-band computer simulations. Convolutional interleaving reduces the effects of both fading and interference. At the same time it cuts down delay and memory space increase by more than 50 % in comparison to block interleaving.

References

Clark G. C., and Cain J. B., 1981, "Error correction coding for digital communications," Plenum Press, New York.

Forney G. D., October 1971, "Burst-correcting codes for the classic bursty channel," IEEE Trans. on Commun., vol. COM-19, no. 5, pp. 772-781.

Jakes W. C., 1974, "Microwave mobile communications," Wiley, New York.

Lutz E., November 1984, "Code and interleaving design for data transmission over fading channels," Proc. Globecomm 84, Atlanta, GA.

Ramsey J. L., May 1970, "Realization of optimum interleavers," IEEE Trans. on Inform. Theory, vol. IT-16, no. 3, pp. 338-345.

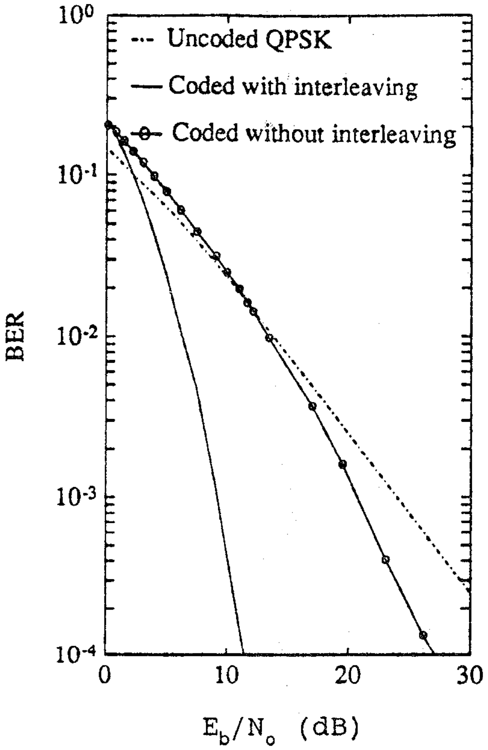

Figure-2. Performance over a Rayleigh flat-fading channel.

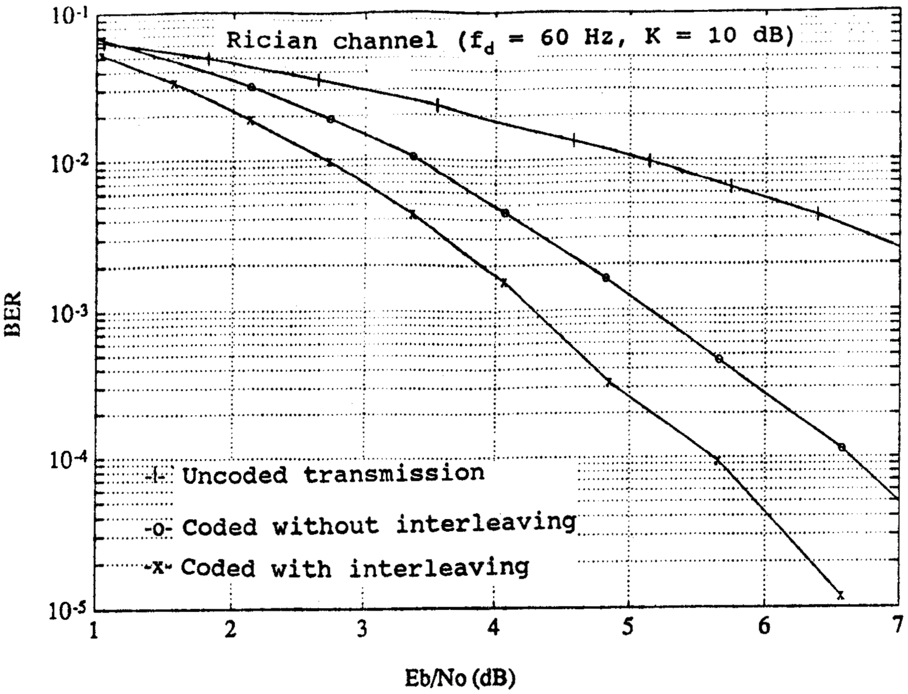

Figure-3. Performance of a convolutionally coded and interleaved QPSK transmission over a Rician flat-fading channel.

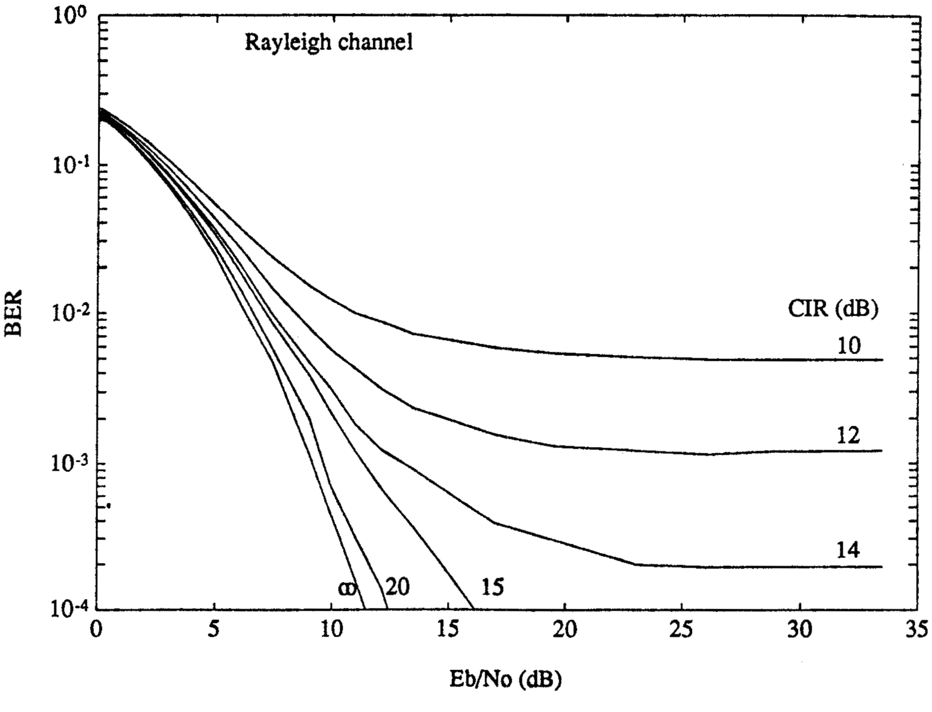

Figure-4. Performance of a convolutionally coded and interleaved QPSK transmission over a Rayleigh flat-fading channel in the presence of a single interferer.