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Performance Analysis of CDMA System by using Different Interleaving and Encoding Schemes

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Abstract: IDMA (interleaved division multiple access) is one of the most developing technology in modern mobile communication. It has gained widespread international acceptance by cellular radio system operators as an upgrade that will dramatically increase both their system capacity and the service quality. The core principle of spread spectrum is the use of noise-like carrier waves, and, as the name implies, bandwidths much wider than that required for simple point-to-point communication at the same data rate. Most third generation mobile communication systems are using CDMA as their modulation technique. In CDMA interleaving is used for multiplexing of several input data over shared media. In CDMA system different type of interleaving schemes are used. In this paper we analyze the performance of these interleaving schemes in multipath fading and additive white Gaussian noise (AWGN) channels. We conclude that different interleaving schemes has different data rates and bit error rate.

Keywords: CDMA, System Model of CDMA, Interleaving, BER.

I. INTRODUCTION OF CDMA

The use of CDMA in wireless and cellular mobile communication has received considerable attention. In this paper, we consider the problem of computing the bit error rate of CDMA over multipath fading and additive white Gaussian noise channels which occur in various transmission mediums such as the indoor wireless and the cellular mobile communication environments.

The principle of CDMA is to spread a data symbol with a spreading sequence $c^{(k)}(t)$ of length L,

$$c^{(k)}(t) = \sum_{t=0}^{L-1} c_l^{(k)} P_{T_c}(t - lT_c) \qquad (1)$$

assigned to user k, k = 0, . . . , K − 1, where K is the total number of active users. The rectangular pulse $P_{Tc}(t)$ is equal to 1 for $0 \le t < T_c$ and zero otherwise. T_c is the chip duration and $c_l^{(k)}$ are the chips of the user specific spreading sequence $c^{(k)}(t)$. After spreading, the signal $x^{(k)}(t)$ of user k is given by

$$x^{(k)}(t) = d^{(k)} \sum_{l=0}^{L-1} c_l^{(k)} P_{T_c}(t - lT_c), \qquad 0 \le t < T_d \qquad (2)$$

for one data symbol duration $T_d = LT_c$, where $d^{(k)}$ is the transmitted data symbol of user k. The multiplication of the information sequence with the spreading sequence is done bit-synchronously and the overall transmitted signal $x(t)$ of all K synchronous users results in

$$x(t) = \sum_{k=0}^{K-1} x^{(k)}(t) \qquad (3)$$

The received signal y(t) obtained at the output of the radio channel with impulse response h(t) can be expressed as

$$y(t) = x(t) \otimes h(t) + n(t) = r(t) + n(t)$$

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$$= \sum_{k=0}^{K-1} r^{(k)}(t) + n(t) \quad (4)$$

where $r^{(k)}(t) = x^{(k)}(t) \otimes h(t)$ is the noise-free received signal of user k, n(t) is the additive white Gaussian noise (AWGN), and $\otimes$ denotes the convolution operation. The impulse response of the matched filter (MF) $h_{MF}^{(k)}(t)$ in the receiver of user k is adapted to both the transmitted waveform including the spreading sequence $c^{(k)}(t)$ and to the channel impulse response h(t),

$$h_{MF}^{(k)}(t) = c^{(k)*}(-t) \otimes h^{*}(-t) \quad (5)$$

The notation x^{*} denotes the conjugate of the complex value x. Finally, a threshold detection is performed to obtain the estimated information symbol.

Ideally, the matched filter receiver resolves all multipath propagation in the channel[1]. In practice a good approximation of a matched filter receiver is a rake receiver. A rake receiver has D arms to resolve D echoes where D might be limited by the implementation complexity. In each arm d, d = 0, . . . ,D − 1, the received signal y(t) is delayed and despread with the code $c^{(k)}(t)$ assigned to user k and weighted with the conjugate instantaneous value h_d^{*}, d = 0, . . . ,D − 1, of the time-varying complex channel attenuation of the assigned echo. Finally, the rake receiver combines the results obtained from each arm and makes a final decision.

II. SYSTEM MODEL OF CDMA

This paper is concerned with the calculation of the bit error rate of a CDMA in a multipath fading and additive white Gaussian noise channels that is modeled by a discrete set of Rayleigh faded paths. Figure 1 shows a CDMA transmitter. It consists of a forward error correction (FEC) encoder, mapping, spreader, pulse shaper, and analog front-end. Channel coding is required to protect the transmitted data against channel errors. The encoded and mapped data are spread with the code $c^{(k)}(t)$ over a much wider bandwidth than the bandwidth of the information signal. As the power of the output signal is distributed over a wide bandwidth, the power density of the output signal is much lower than that of the input signal. Note that the multiplication process is done with a spreading sequence with no DC component.

The chip rate directly influences the bandwidth and with that the processing gain[2]. The wider the bandwidth, the better the resolution in multipath detection. Since the total transmission bandwidth is limited, a pulse shaping filtering is employed (e.g., a root Nyquist filter) so that the frequency spectrum is used efficiently.

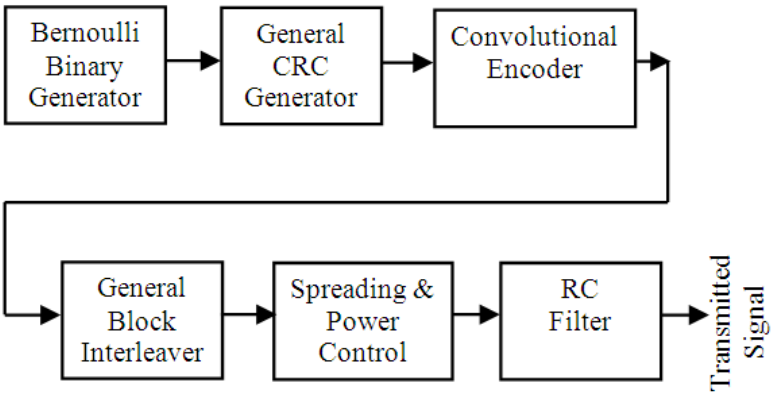

Figure 1. CDMA Transmitter

Convolutional codes are one of the most widely used channel codes in practical communication systems. These codes are developed with a separate strong mathematical structure and are primarily used for real time error correction. Convolutional codes convert the entire data stream into one single codeword. It is a type of forward error correction (FEC) which its function is to improve the capacity of a channel by adding redundant information to the data being transmitted through the channel[3].

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Convolutional codes are usually described using two parameters: the code rate and the constraint length. The code rate, *k/n*, is expressed as a ratio of the number of bits into the convolutional encoder (k) to the number of channel symbols output by the convolutional encoder (n) in a given encoder cycle. The difference between convolutional code and block code is that it has memory which is categorized by the constraint length, K. Constraint length denotes how many k-bit stages are available to feed the combinatorial logic that produces the output symbols.

In Figure 2, the receiver block-diagram of a CDMA signal is plotted. The received signal is first filtered and then digitally converted with a sampling rate of $1/T_c$. It is followed by a rake receiver. The rake receiver is necessary to combat multipath, i.e., to combine the power of each received echo path. The echo paths are detected with a resolution of T_c. Therefore, each received signal of each path is delayed by lT_c and correlated with the assigned code sequence. The total number of resolution paths depends on the processing gain. Usually in practice 3–4 arms are used. After correlation, the power of all detected paths are combined and, finally, the demapping and FEC decoding are performed to assure the data integrity.

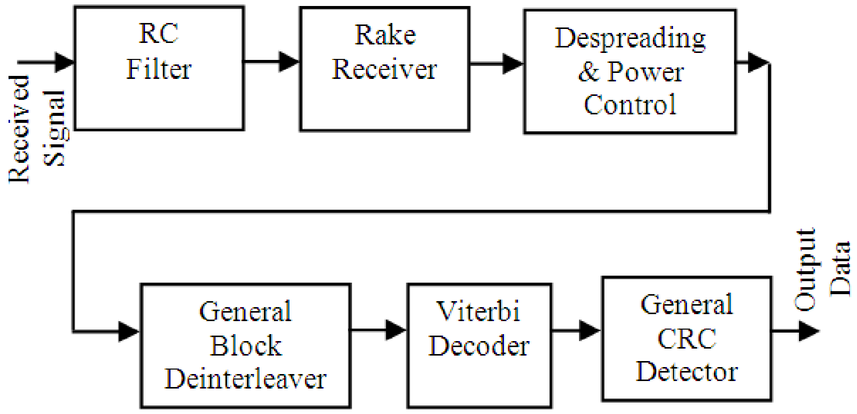

Figure 2. CDMA Receiver

Viterbi decoding is one of two types of decoding algorithms used with convolutional encoding. The other type is sequential decoding. Sequential decoding has the advantage that it can perform very well with long constraint length convolutional codes, but it has a variable decoding time. Viterbi decoding has the advantage that it has a fixed decoding time. It is well suited to hardware decoder implementation. But its computational requirements grow exponentially as a function of the constraint length. Viterbi decoding is essentially performs the maximum likelihood decoding. It reduces the computational load by taking advantage of special structure in code trellis. The Viterbi decoder examines an entire received sequence of a given length[4]. The decoder computes a metric for each path and makes a decision based on this metric. All paths are followed until two paths converge on one node. Then the path with the higher metric is kept and the one with lower metric is discarded. The paths selected are called the survivors.

In order for Viterbi algorithm to work properly, several requirements have to be met which are that the transmitter has to make sure that the encoder starts and stops in the zero state. Zero state means that all the shift registers contains all zeros and no ones. Thus the transmitter will appends m zeros at the end of the information bits to flush the encoder and the receiver can always assume that it is safe to start and end in the zero state of the trellis. Since the decoding procedure will make decision based on the most probable sequence thus the depth of the decoding trellis must also be specified. The general idea is the depth is not exceeding five times the constraint length.

III. CDMA ENCODING SCHEMES

To achieve satisfactory performance in application of CDMA, the addition of some form of coding is needed. High signal to noise ratio are required to achieve reasonable bit error rate in the presence of fading channel. Wireline systems usually use large constellation size to achieve high bit rates. Coding in this case is essential for achieving the highest possible rates in the presence of noise and interference. Proper coding is very important for CDMA[5]. There are several factors should be taken into account, such as the required coding gain, channel characteristics, source coding requirement, modulation. An encoder is a device, software program, algorithm or person that converts information from one format or code to another, for the purposes of standardization, speed, secrecy, security, or saving space by shrinking size. In this system for analysis of different encoding schemes Cyclic Redundancy Code (CRC) and Reed – Solomon (RS) encoding schemes are used.

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Cyclic Redundancy Code (CRC) Encoding

The General CRC Generator block generates cyclic redundancy code (CRC) bits for each input data frame and appends them to the frame. You specify the generator polynomial for the CRC algorithm using the Generator polynomial parameter. This block is general in the sense that the degree of the polynomial does not need to be a power of two. Representation of the polynomial can be done in one of these ways:

(a). As a binary row vector containing the coefficients in descending order of powers. For example, [1 1 0 1] represents the polynomial $x^3 + x^2 + 1$.
(b). As an integer row vector containing the powers of nonzero terms in the polynomial, in descending order. For example, [3 2 0] represents the polynomial $x^3 + x^2 + 1$.

You specify the number of checksums that the block calculates for each input frame by the Checksums per frame parameter. The Checksums per frame value must evenly divide the size of the input frame. If the value of Checksums per frame is k, the block does the following:

(a). Divides each input frame into k subframes of equal size
(b). Prefixes the Initial states vector to each of the k subframes
(c). Applies the CRC algorithm to each augmented subframe
(d). Appends the resulting checksums at the end of each subframe
(e). Outputs concatenated subframes

If the size of the input frame is m and the degree of the generator polynomial is r, the output frame has size m + k * r [7]. For Example: Suppose the size of input frame is 10, the degree of the generator polynomial is 3, Initial states is [0], and Checksums per frame is 2. The block divides each input frame into two subframes of size 5 and appends a checksum of size 3 to each subframe, as shown below. The initial states are not shown in this example, because an initial state of [0] does not affect the output of the CRC algorithm. The output frame then has size 5 + 3 + 5 + 3 = 16.

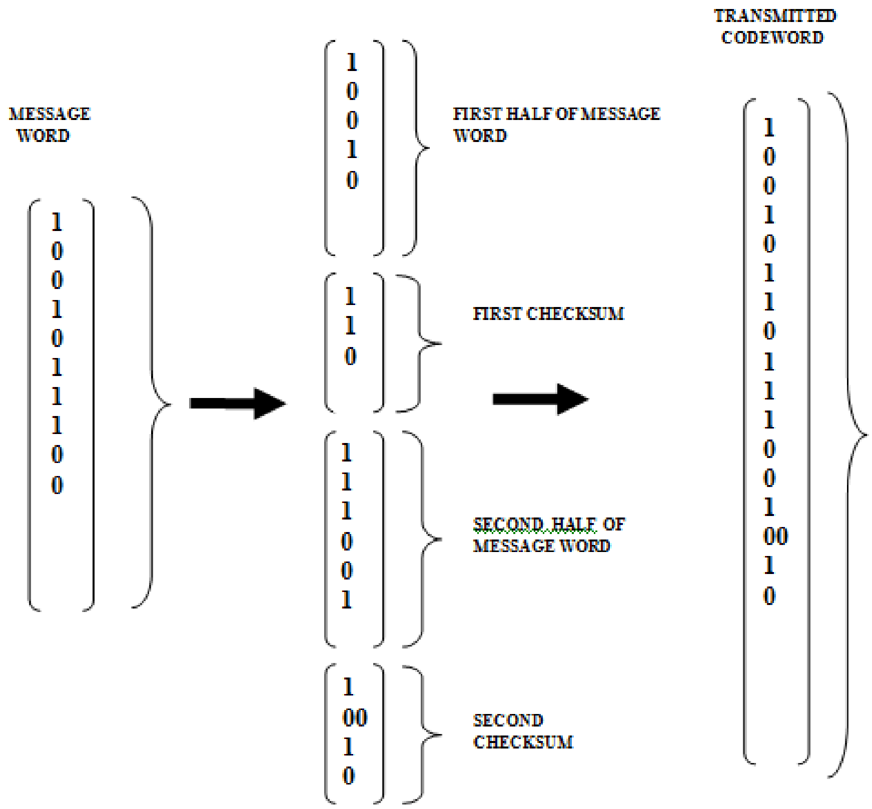

Figure 3. Algorithm Of Cyclic Redundancy Coding

In this model cyclic redundancy code is an encoding software program or algorithm that converts information from one format or code to another, for the purposes of standardization, speed, secrecy, security, or saving space by shrinking size.

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3.4.2.2. Reed – Solomon (RS) Encoding

The Binary-Input RS Encoder block creates a Reed-Solomon code with message length K and codeword length N by specifying both N and K directly in the dialog box. The symbols for the code are binary sequences of length M, corresponding to elements of the Galois field GF (2^M), where the first bit in each sequence is the most significant bit[8]. The restrictions on the degree M of the primitive polynomial and the codeword length N are as follows:

(a). If you do not select Specify primitive polynomial, N must lie in the range $3 < N < 2^{16}–1$.
(b). If you do select Specify primitive polynomial, N must lie in the range $3 \le N < 2^{16}–1$ and M must lie in the range $3 \le M \le 16$.

Suppose M = 3, N = 2^3-1 =7, and K = 5. Then a message is a binary vector of length 15 that represents 5 three-bit integers. A corresponding codeword is a binary vector of length 21 that represents 7 three-bit integers. The following figure shows the codeword that would result from a particular message word. The integer format equivalents illustrate that the highest order bit is at the left.

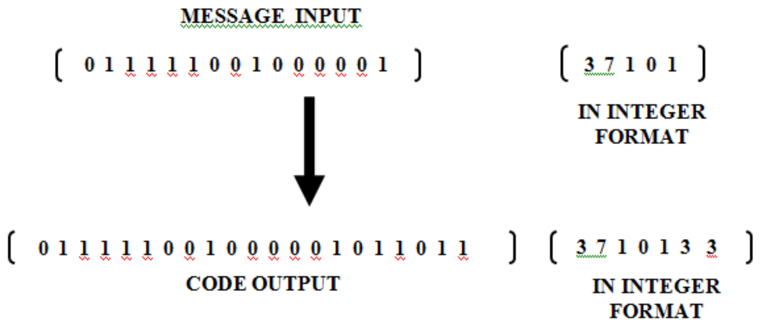

Figure 4. Algorithm of Reed-Solomon (RS) Encoding

The main parameters of RS Encoding block are codeword length, message length, primitive polynomial and generator polynomial. The Primitive polynomial represents the primitive polynomial in descending order of powers. The Generator polynomial represents the generator polynomial in descending order of powers whose entries are in the range from 0 to 2^M-1.

IV. PERFORMANCE ANALYSIS OF CDMA

CDMA performance analysis presented in this section is based on computer simulations. The basic scenario of our simulation is represented by the CDMA transmission system performing through multipath fading and AWGN transmission channel, at sample time (20e-3*1)/172 and 172 samples per frame. As the spreading sequences, Walsh codes with period of 64 chips is used. The simulation results of CDMA system is shown below:

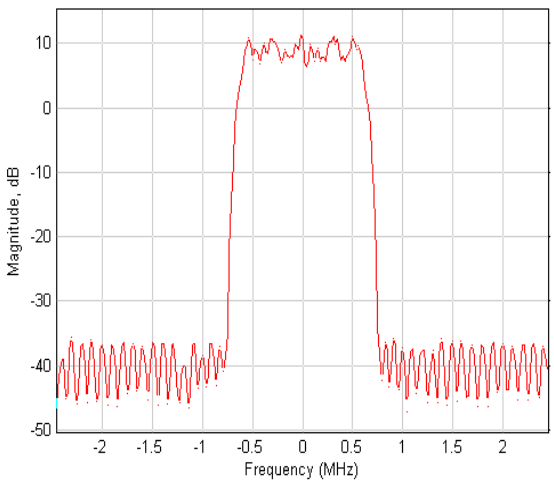

Figure 5. CDMA Transmitted Signal

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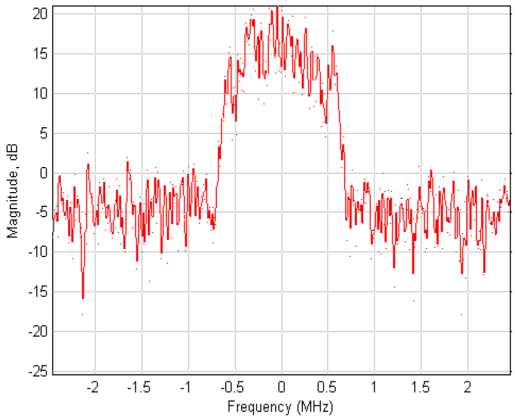

Figure 6. CDMA Received Signal

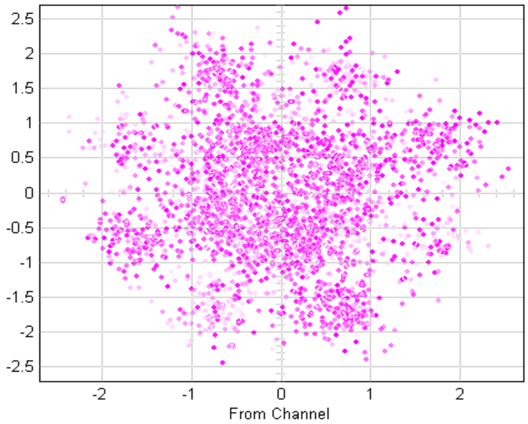

Figure 7. Scatter Plot of CDMA Transmitted Signal

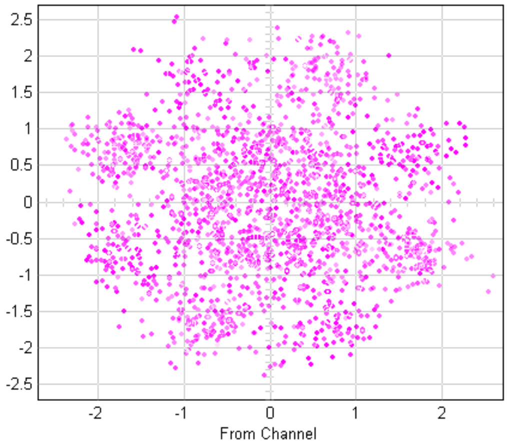

Figure 8. Scatter Plot of CDMA Received Signal

Figure 5 shows the CDMA transmitted signal to the channel. This signal is passed through the multipath fading and additive white Gaussian noise channel. After passing this signal from channel we get the CDMA received signal as shown in Figure 6 which is full of distortions. Figure 7 shows the scatter plot of transmitted signal of CDMA system. The scatter plot is used to reveal the modulation characteristics, such as pulse shaping or channel distortions of the signal. Similarly Figure 8 shows the scatter plot of CDMA received signal. The scatter plot illustrates the effect of fading on the signal constellation. For all the interleaving schemes the transmitted and received signal has same bandwidth but these schemes effect the transmission rate and bit error rate of CDMA system. These effect of interleaving schemes is shown in tabular form in Table 1.

Interleaver	Total Bits Transmitted	Bit Loss	Bit Error Rate (BER)
Block Interleaver	84280	4200	0.04983
Convolutional Interleaver	84280	3472	0.04119
Matrix Interleaver	84280	4216	0.05002
Helical Interleaver	84280	4169	0.04947
Random Interleaver	84280	4305	0.05108

On comparing these interleaving schemes we get that the transmission rate of all the interleaving schemes used in CDMA system is same but the bit error rate if different. From all these interleaving schemes convolutional interleaving scheme is best suitable for CDMA system because it has very low bit error rate as compare to other schemes. In CDMA system we generally use CRC (Cyclic Redundancy Code) and RS (Reed - Solomon) encoding schemes:

- CRC Encoding: The General CRC Generator block generates cyclic redundancy code (CRC) bits for each input data frame and appends them to the frame.
- RS Encoding: The Binary-Input RS Encoder block creates a Reed-Solomon code with message length K and codeword length N.

From all these interleaving schemes convolutional interleaving scheme is best suitable for CDMA system because it has very low bit error rate as compare to other schemes. Then compare all encoding schemes we het following results in form of BER:

Encoding Scheme	Bit Error Rate	Error Bits	Total Bits
CRC	0.06216	2662	4.283e + 004
RS	0.05861	2510	4.283e + 004

This is clear that RS encoding scheme is best for CDMA system with Covolutional interleaving scheme.

V. CONCLUSION

In CDMA interleaving is used for multiplexing of several input data over shared media. In CDMA system different type of interleaving schemes are used. The transmission bandwidth of the CDMA system with all these interleaving schemes is same. But in a transmission system main concern is on efficient transmission i.e. number of error or distortion is less. So CDMA system with convolutional interleaving is more efficient because it has less BER as compared to other interleaving schemes and by using different encoding schemes we get that RS encoding scheme is best suited for CDMA system with less BER as compare to CRC encoding scheme. So we conclude that between all these interleaving schemes CDMA system achieves better BER results with convolutional interleaving and RS encoding scheme for the same bandwidth efficiency.

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