Design and Implementation of FEC for CDMA System

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Abstract. In every wireless communication the data that is transferred is at a high risk of falling under the clutches of various types of disturbances termed as noise, there are various types of noises which are thermal noise, shot noise, IF noise, burst noise, avalanche noise etc. they occur due to a number of factors it can be due to temperature, device malfunctioning and frequency interference. Due to this, the data being transferred in the wireless communication channel gets corrupted resulting in data loss. This problem is rectified by employing FEC (Forward Error Correction) method on the data being transferred. This research focuses on the implementation of various FEC codes in CDMA system to study its detailed performance analysis with the help of MATLAB Software.

1. Introduction
The major highlight of the current century is study and focus which is concerned with increasing the stability of interaction on the digital programs, is the Error Correction coding. There is no doubt that even the CDMA system needs to be protected and at the same time it should be able to detect and correct the errors when the data of information is being transferred in different types of environments, an effective and better way is included via research carried out recently [1]. In the forward channel of CDMA [2] the existence of repetition of a symbol normally occurred is changed using an algorithm which is new and used for encoding. The new algorithm is named as a logic symbol repetition called "Memorizing" an encoding scheme where this new logic symbol repetition is having the capacity of making the right corrections to the bits having errors. The performance of the error correction is studied using a simulation program which was developed, it studies the bit rate of the information bits that were received.

Spread spectrum systems [3] especially CDMA systems counterpart well by applying the methods of forward error correction. This research will cover a few viewpoints of CDMA systems with coding of FEC channel. FEC/CDMA arrangements could be believed as schemes that were integrated, besides inward and decoding beyond it. In an iteration, the soft benefits of the beyond program bits are next utilized as a priori benefits for the inner CDMA decode/de-spreader [4]. This could be formulated by decoded bits (soft) obtained from the supplementary users beyond a decoder which could be compared to a scheme used for the cancellation of interference [5]. IS 95 arrangements requests display a significant gain from the repetitions and the soft output. This is believed to be spread to CDMA [19] arrangements alongside PN spreading sequences whereas the coding of FEC in 1-Dimension is given during the periods association as well as FEC coding during the supplementary dimension which is given by a logical program in the direction of CDMA program. The supplementary CDMA codes send the parity bits of this particular program. The supplementary interference [6] deterioration is hereby provoked and is outweighed by the supplementary gain of FEC coding attained by decoding iteratively [7].
2. Forward error correction.
Forward Error correction is a channel coding method which is used to control the extent of errors that take place during transmission through a communication channel. The main idea is that the sender keeps adding extra bits (redundant bits) to his/her message, this is done by using the technique of ECC (Error Correcting Code) [8].

In telecommunication and information theory, forward error correction (FEC) is termed as a system of error control for data transmission, in this case the sender will add redundant data to its message, and this is also known as an error correction code [9]. This ensures that the receiver need not depend on the sender to send any further information after the transmission, it creates the opportunity to detect the errors as well as correct them. The requirement of a back-channel is avoided in forward error correction and it proves to be greatest plus point but it requires a higher bandwidth. Due to this reason FEC is mainly used in circumstances where retransmission of data is difficult or it is difficult to incorporate any other error correcting method.

In digital signal processing, it is used as the first step and located close to the receiver. It is also observed that FEC circuit are found as in most of the analog-to-digital converting process, it is also sued for modulation and line encoding. The Bit error rate that is given by the FEC is used for fine tuning in the analog signal receiving device.

2.1 How it works.
Forward Error Correction [10] can be achieved by adding redundancy bits to the transmitted information which can be done by using a predetermined algorithm. The redundant bit used is actually an invariable complex function of many original information bits. The original information may or may not appear in the encoded output, in order to identify which codes originally belong to the output the codes are classified into two, those which are a part of unmodified input in the output are systematic, while those are not are termed as non-systematic [11].

Considering a simple example mentioned in Table 1 to understand, this could be an analog to digital converter which will sample three bits of data in every transmitted signal [12]. The transmitted bit is considered to be zero if the three samples received are majorly zero and the transmitted bit is considered to be one if the transmitted bit has majorly one in the three bit sample received. In this way it can be concluded that the easiest way for correcting the error is for the receiver to look for most frequently occurring bit in the sample of three.

| Triplet Received | Interpreted as |
|------------------|---------------|
| 000              | 0             |
| 001              | 0             |
| 010              | 0             |
| 011              | 1             |
| 100              | 0             |
| 101              | 1             |
| 110              | 1             |
| 111              | 1             |

2.2 Averaging noise to reduce errors.
The corruption of some symbols due to noise ruins the original data and becomes impossible for the receiver to read the data, as he/she depends on the original uncorrupted data to be sent from the sender. The effect of risk pooling ensures that the signal to noise ratio is above a particular minimum level. This enables FEC to be used as a form of error correction technique. The method also helps to reach the limit imposed by Shannon. Hence it is m stronger than other codes which are used. The method of interleaving the FEC codes data further reduces the all or nothing properties of transmitted FEC codes [21].

Like every other method the averaging noise has got its own limit, this method can work well only in narrowband data. Majority of the telecommunication system uses fixed channel code which is designed to withhold the worst expected case of error in bits, if the error rate exceeds the limit then the
communication channel fails to work. However there are certain adaptive systems, which works on a fixed FEQ method until the error occurred is within the channel capacity once it exceeds then the FEQ method automatically gets shifted to ARQ method [11].

2.3 Type of FEC.
Block coding and Convolution coding [15] are the two main classifications under Forward Error Correction. Block coding works on the concept of blocks, where the size of the block is determined with a predetermined size of bits it can also be called as packet. Convolutional codes on the other hand deal with bits or symbol streams of a particular fixed length. It is to be noted that the convolution code can be converted into a block code if needed based on the situation. Decoding of Convolutional codes is mostly done using the Viterbi algorithm, apart from this there are other methods of decoding available.

Similarly in the case of block coding, it comes in different versions, but the most commonly used is Reed- Solomon coding. It is used on a Compact disc even found in hard drives [16].

2.4 Averaging noise to reduce errors.
In block coding the entire message that is to be sent is divided into blocks of fixed length. Each of them will be represented as ‘u’ and each block will have ‘k’ information bits. The total number of code words possible in block coding is $2^k$ and there are $2^k$ block codes. This set of $2^k$ code words of length n is called (n, k) block code. The ratio is determined by the formula stated below.

$$R = \frac{k}{n}$$

Where R is called the code rate. It is defined as the total number of information bit that is entering the encoder per each symbol that is transmitted. The transmitted ‘n’ depends only on the k-bit. This is why the encoder does not require a memory. It is to be ensured that if the binary code can be useful only if the code rate is less than 1 or in other words the value of ‘k’ is lesser tan ‘n’. How to choose these redundant bits to achieve reliable transmission over a noisy channel is the major problem in designing the encoder [17]. Block codes are referred to as (n, k) codes. A block of k information bits is coded to become a block of n bits. But before going any further with the details, let's look at an important concept in coding called Hamming distance. Let's say that 10 integers, 0 to 9 by a digital sequence is required. Sixteen unique sequences can be obtained from four-bit words. The first ten are assigned, one to each integer. Each integer is now identified by its unique sequences of bits as in the Table 2 below. The remaining six possible sequences are unassigned. Assigning 4-bit sequences to the 10 integers.

| Sequence | Integer | Sequence | Integer |
|----------|---------|----------|---------|
| 0000     | 0       | 0111     | 7       |
| 0001     | 1       | 1000     | 8       |
| 0010     | 2       | 1001     | 9       |
| 0011     | 3       | 1010     | Unassigned |
| 0100     | 4       | 1011     | Unassigned |
| 0101     | 5       | 1100     | Unassigned |
| 0110     | 6       | 1101     | Unassigned |

In the above example there are 16 different types of codes available, together they form the code space. Among these only 10 of these codes were used. The one that is not labeled or used is called as an unassigned code and if received by the receiver then it is discarded [22].

2.5 Convolutional coding.
A convolutional code is a kind of code which corrects the errors in the telecommunication where. The information bit is represented as ‘m’ and is then converted to ‘n’ bit-symbol. It is to note that the code
rate is the information bit divided (m) by converted bit (n). The limit of code is ‘k’, which are the last symbol of information that is converted. Convolutional code is used in different applications including satellite and mobile communication. It is generally implemented with “Reed Solomon” which is termed to be as a hard decision code.

Before turbo code came into existence, it was used widely as it was the most closest to the Shannon Limit. Here also allows k-bits of block information series ‘u’ and generates a protected series (code word) ‘v’ of the ‘n’ symbol-block. Yet, each block-encoded relies upon not only the consequent k-bits information simultaneously, but also- on the ‘m’ prior information block. The encoder has a storage order of ‘m’ other sets of encoded series by ‘k’ input, ‘n’ output encoder of storage order ‘m’ is known as an (n, k, m) convolution code. The repetitive bit can be included by improving storage order ‘m’. The usage of the memory is to accomplish efficiently transmitting over a channel that is noisy which is a significant issue in developing encoder. The integrated codes are formed from the block codes which correct the burst errors, as the outer codes by frequently using the convolutional codes as the inner codes. In the decoding algorithms, which are Viterbi decoding for the convolution codes, the errors likely arise in bursts as it is a consequence in the trellis diagram from going in the wrong path. The correction efficiency of the burst errors in the code outer is normally used to pull through from such patterns of the burst errors while the inner codes are decoded.

3. Implementation of FEC in CDMA.
Below Figure 1 is the block diagram of given CDMA [18]. Data to be transmitted is encoded by channel coding techniques. Here in this work block code and convolution code are implemented. This encoded data is further getting spread by PN Sequence, the spreaded data is transmitted to wireless channel through BPSK modulation process. This wireless channel adds AWGN to the modulated data because of AWGN, BPSK demodulator at the receiver side detects error. This data is despreaded to get back the original data by the PN sequence at the receiver. If despread data is with error, that error is getting corrected by channel decoder and hence BER is reduced.

![Figure 1. Block diagram of implementation of FEC in CDMA](image)

3.1 Graphical results obtained after implementation in Matlab.
Figure 2 shows binary sequences to be transmitted. They are original binary sequences. They are not coded by FEC process and Spreading process. This data is applied to the input of FEC encoder to channel coding process.
The PN sequence are available in Figure 3. These PN sequences spread binary sequence to be transmitted. The details of spreaded binary data is available as shown in Figure 3. This action leads to get coded data. After the binary sequence get spreaded, the coded data gets modulated. BPSK modulation is employed. The waveform in figure shows the details of BPSK modulation of code data and transmitted through AWGN wireless channel.

Figure 2. Original Binary Sequence

Figure 3. PN Sequence generated

Figure 4 shows the output signal of circuit employed at the receiver. Because of noise in the channel, the received signal distorted wave form.
4. Output of FEC codes in CDMA using MATLAB.

4.1 Block Coding.

Figure 5 and Figure 6 shows bit error rate performance of CDMA system in hard decision and soft decision respectively when Block coding is employed as FEC. It is found that BER is getting decreased with the increase in SNR.
4.2 Block coding results in tabular form.

From the Table 3, Table 4 and Table 5, it is found that BER is better than FEC coded CDMA than encoded CDMA. If the code rate is \( \frac{1}{2} \) and \( m=2 \), BER at 5 dB for coded CDMA is \( 9.5 \times 10^{-8} \) using hard decision and for uncoded CDMA is \( 9.2 \times 10^{-7} \) using soft decision. If the code rate is changed to \( 1/3 \), BER is \( 1 \times 10^{-7} \) in the case of hard decision and \( 9.2 \times 10^{-7} \) in the case of soft decision.

**Table 3.** The plot of BER vs. SNR for the rate \( \frac{1}{2} \), \( m=2 \), encoder considering hard decision Viterbi decoder.

| SNR(Db) | CODED(BER)   | UNCODED BPSK(BER) | DECODER USED |
|---------|--------------|-------------------|--------------|
| 5       | 9.5x10^{-8}  | 9.2x10^{-3}       | Hard         |
| 7       | 7x10^{-8}    | 5x10^{-3}         | Hard         |
| 5       | 9.2x10^{-7}  | 9.5x10^{-3}       | Soft         |
| 7       | 6x10^{-7}    | 5x10^{-3}         | Soft         |

**Table 4.** The plot of BER vs. SNR for the rate \( 1/3 \), \( m=2 \), encoder considering hard and soft decision Viterbi decoder.

| SNR(Db) | CODED(BER)   | UNCODED BPSK(BER) | DECODER USED |
|---------|--------------|-------------------|--------------|
| 5       | 1x10^{-7}    | 9.2x10^{-3}       | Hard         |
| 7       | 9.5x10^{-8}  | 5x10^{-3}         | Hard         |
| 5       | 9.2x10^{-7}  | 9.5x10^{-3}       | Soft         |
| 7       | 6x10^{-7}    | 5x10^{-3}         | Soft         |
Table 5. The plot of BER vs. SNR for the rate 1/3, m=6, encoder considering hard and soft decision Viterbi decoder.

| SNR(Db) | CODED(BER) | UNCODED BPSK(BER) | DECODER USED |
|---------|------------|-------------------|--------------|
| 5       | 4x10^{-7}  | 9.2x10^{-3}       | Hard         |
| 7       | 2x10^{-7}  | 5x10^{-3}         | Hard         |
| 5       | 0.5x10^{-6} | 9.5x10^{-3}       | Soft         |
| 7       | 9.2x10^{-7} | 5x10^{-3}         | Soft         |

4.3 Convolutional coding.

Figure 7 and Figure 8 shows bit error rate performance of CDMA system in hard decision and soft decision respectively when Conventional coding is employed as FEC. It is found that BER is getting decreased with the increase in SNR.

![Figure 7. The plot of BER vs. SNR (Hard decision)](image-url)
Figure 8. The plot of BER vs. SNR (Soft decision)

4.4 Convolutional coding results.
From the Table 6, Table 7 and Table 8, it is found that BER is better than Convolutional coded CDMA than uncoded CDMA. If the code rate is ½ and m=2, BER at 5 dB for coded CDMA is $2 \times 10^{-7}$ using hard decision and for uncoded CDMA is $2 \times 10^{-6}$ using soft decision. If the code rate is changed to 1/3, BER is $9.5 \times 10^{-8}$ in the case of hard decision and $9.2 \times 10^{-7}$ in the case of soft decision.

Table 6. Plot of BER vs SNR for the rate $1/2$, m=2, encoder considering hard or soft decision Viterbi decoder.

| SNR(Db) | CODED(BER)   | UNCODED BPSK(BER) | DECODER USED |
|---------|--------------|-------------------|--------------|
| 5       | $2 \times 10^{-7}$ | $9.5 \times 10^{-3}$ | Hard         |
| 7       | $1.5 \times 10^{-7}$ | $5 \times 10^{-3}$ | Hard         |
| 5       | $2 \times 10^{-6}$ | $9.5 \times 10^{-3}$ | Soft         |
| 7       | $9.5 \times 10^{-8}$ | $5.5 \times 10^{-3}$ | Soft         |

Table 7. Plot of BER vs SNR for the rate $1/2$, m=6, encoder considering hard and soft decision Viterbi decoder.

| SNR(Db) | CODED(BER)   | UNCODED BPSK(BER) | DECODER USED |
|---------|--------------|-------------------|--------------|
| 5       | $9.5 \times 10^{-8}$ | $9.2 \times 10^{-3}$ | Hard         |
| 7       | $7 \times 10^{-8}$ | $5 \times 10^{-3}$ | Hard         |
| 5       | $9.2 \times 10^{-7}$ | $9.5 \times 10^{-3}$ | Soft         |
| 7       | $6 \times 10^{-7}$ | $5.5 \times 10^{-3}$ | Soft         |
Table 8. The plot of BER vs SNR for the rate 1/3, m=6, encoder considering hard and soft decision Viterbi decoder.

| SNR(Db) | CODED(BER) | UNCODED BPSK(BER) | DECODER USED |
|---------|------------|--------------------|--------------|
| 5       | 4x10^{-7}  | 9.3x10^{-3}       | Hard         |
| 7       | 2x10^{-7}  | 5x10^{-3}         | Hard         |
| 5       | 9.2x10^{-7}| 9.5x10^{-3}       | Soft         |
| 7       | 6x10^{-7}  | 5x10^{-3}         | Soft         |

5. Conclusion.
The results were displayed accurately in MATLAB in regard to the implementation of CDMA. The program used a simple technology of CDMA. EC coding was used as the method of error correction. Forward Error Correction works very well with additive white Gaussian noise in short AWGN. This was achieved by s both convolutional and block encoding. In the receiver side Viterbi Decoder was used. The encoding process was demonstrated using a (2.1.3) convolutional encoder. A 3-bit input system stream was encoded as an example to show the working of this encoder.

The decoding process was depicting using both hard and soft Viterbi Decoder. The noise due to which the message got corrupted was encoded in a 3-bit input sequence and decoded and recovered using the concepts of Hamming distances and the Euclidean distances for the hard decision Viterbi decoder and the soft decision Viterbi decoder respectively. The performance factors which have affected the FEC were discussed. These included encoder memory size and the more significant factor of SNR.

To study how these performance factors, affect the working of the FEC technique, the encoder for the FEC technique was considered for different values of code rates and the number of memory registers. Two code rates were used in this study. They were 1/2 and 1/3. These code rates were used with each of the two values of memory. The decoder for the FEC technique was then tested with both hard and soft Viterbi decoder.

From Table 9, Table 10 and Table 11, it is seen that at a particular Bit error rate in the execution of Block and convolution codes, the Bit error rates of the convolutional coded data is comparatively low or equal to that of the block coded data. For example, at the code rate=1/3, m=6 and code rate =1/2, m=6 the convolutional code and the block code functions equally. But for the code rate=1/3, m=2 the convolutional code performs better when compared to block codes. So, since block code performance is low for a few code rate combinations it is recommended to use convolutional coding in the CDMA network.

Table 9. Comparison table between convolutional coded & block coded BER values at code rate=1/3, m=6.

| SNR(Db) | Convolutional coded BER | Block coded(BER) |
|---------|-------------------------|-----------------|
| 4       | 5x10^{-7}               | 5x10^{-7}       |
| 5       | 4x10^{-7}               | 4x10^{-7}       |
| 6       | 3x10^{-7}               | 3x10^{-7}       |
| 7       | 2x10^{-7}               | 2x10^{-7}       |
Table 10. Comparison table between convolutional coded & block coded BER values at code rate=1/3, m=2.

| SNR(Db) | Convolutional coded (BER) | Block coded(BER) |
|---------|--------------------------|-----------------|
| 4       | 5x10^{-7}                | 9x10^{-7}       |
| 5       | 4x10^{-7}                | 8x10^{-7}       |
| 6       | 3x10^{-7}                | 6x10^{-7}       |
| 7       | 2x10^{-7}                | 4x10^{-7}       |

Table 11. Comparison table between convolutional coded & block coded BER values at code rate=1/2, m=6.

| SNR(Db) | Convolutional coded (BER) | Block coded(BER) |
|---------|--------------------------|-----------------|
| 4       | 5x10^{-7}                | 5x10^{-7}       |
| 5       | 4x10^{-7}                | 4x10^{-7}       |
| 6       | 3x10^{-7}                | 3x10^{-7}       |
| 7       | 2x10^{-7}                | 2x10^{-7}       |

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