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Concatenation of Coded OFDM Communications System over AWGN and Rayleigh Fading Channels

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Abstract: The high bit error rate of the wireless communications system requires Forward Error Correction (FEC) methods to be implemented on the data to be transmitted. Orthogonal Frequency Division Multiplexing (OFDM) technique exhibits some challenges which are Inter Carrier Interference (ICI), high Peak to Average Power Ratio (PAPR), and inadequate spectral efficiency at higher subcarrier channels. Many researchers have attempted to mitigate these mentioned challenges by using different error coding techniques but there is still room for further improvement. Therefore, this paper evaluated the performance of convolutional, Reed-Solomon, and Concatenated Convolutional with Reed-Solomon (CC-RS) coding schemes over AWGN and Rayleigh fading channels in order to improve the spectral efficiency at higher subcarriers. These schemes were implemented in MATLAB R2015b environment and simulation results were validated by comparing these coding techniques with the non-coded OFDM scheme using Bit Error Rate (BER) and Signal to Interference Ratio (SIR) as performance metrics.

Keywords: CC-RS, AWGN, SIR, BER

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1. INTRODUCTION

The OFDM is a combination of both modulation and multiplexing techniques, where the main carrier signal is splitted into independent channels (sub-carriers). These sub-channels are modulated by data signals and then re-multiplexed into a single carrier known as an OFDM carrier. The OFDM is sometimes called the multi-carrier FDM. These carriers (sub-carriers) in OFDM are made orthogonal with the help of Fourier transform to permit simultaneous transmission of many sub-carriers without interference as well as to increase the capacity and spectrum utilization of the whole system. Therefore, in OFDM, a large number of parallel narrow based subcarriers are used for information transmission instead of a single wide based carrier [17].

In OFDM, a large number of closely spaced orthogonal sub-carriers are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation technique (such as quadrature amplitude modulation or phase-shift keying) at a very low symbol rate and maintaining data rates similar to conventional single-carrier modulation scheme using the same bandwidth. Mostly, in a single carrier system, the whole available spectrum is used for transmission of a single message signal. The small time duration of message signal leads to ISI due to the multipath nature of the signals. While in a multicarrier system, the available spectrum is divided into many narrow subbands and data is divided into parallel data streams each transmitted in a separate band [19].

The OFDM is an example of a multicarrier system in which each carrier has a very narrow bandwidth of lower symbol rate. This results in the signal having a high tolerance to multipath delay spread, as the delay spread is very long to cause significant ISI. The OFDM overcomes the problem of Inter-Symbol Interference (ISI) by transmitting a number of narrow band subcarriers together with guard intervals between them. This in turn gives rise to another problem, that is, all subcarriers arrive at the receiver with different amplitudes. Some carriers are detected without errors but the errors are distributed among the few weak subcarriers with small amplitudes and are corrected using channel coding [25].

In OFDM systems, error correction has a significant role since it helps to deal with fading channel problem along the link. The error correction helps in the recovery of faded information by providing a relation between information and transmitted code such that errors occurring within the channel can be removed at the receiver end. In the proposed research work, the performance of two well-known error correction techniques, such as Reed-Solomon coding and convolutional coding are implemented in a 64 carrier OFDM system [21].

In convolutional coding, the principle involve is the weighted sum of the various input message symbols of the resultant codeword symbol. The information sequences are not grouped into distinct blocks and encoded, instead a continuous sequence of information bits is mapped onto a continuous sequence of encoder output bits. The convolutional code is generated by passing the information sequence through a finite state shift register. Some of the advantages of the convolutional coding scheme include very good performance in lower noise environments, flexibility to achieving different coding rates, and its encoder having memory [3]. On the one hand, its disadvantages include very complex decoding procedures and inadequate protection against noise [8]. Convolutional codes are different from the block codes whose information sequences are grouped into distinct blocks and encoded. Convolutional coding can achieve a larger coding gain than can be achieved using block coding with the same code rate [3].

Reed-Solomon codes are error correcting codes in which the encoder adds redundant bits to the digital input data block. They are block-based codes in which the message to be transmitted is divided up into separate blocks of data, where each block has parity protection information added to it to form a self-contained codeword [12]. The decoder attempts to correct and restore the original data by removing the errors that are introduced in transmission or storage and retrieval. Some of its advantages are that it achieves the largest possible code with minimum distance for any linear code with the same encoder input and output block lengths and very strong to burst errors. Its main drawback is that it is susceptible to random errors [5].

By concatenating these two coding schemes as Concatenated Convolutional and Reed-Solomon (CC-RS), an improved BER performance is obtained due to benefits of convolutional coding scheme that corrects random bit errors caused by a noisy channel and Reed-Solomon coding scheme that corrects burst errors [5].

2. REVIEW OF RELATED WORK

[27] discussed the performance improvement of OFDM communication system using different channel coding techniques through Additive White Gaussian Noise (AWGN) channel model. These coding techniques included Reed-Solomon coding, convolutional coding, concatenated coding (by combining convolutional with Reed-Solomon), and interleaved concatenated coding techniques. Also, a new algorithm was produced to choose a good convolutional encoder designed for a certain rate and memory registers with less complexity in its decoding technique. The performance of the non-coded versus the coded OFDM system over AWGN channel and the effects of different channel coding techniques were compared and it showed that the CC-RS coding scheme provided a better performance at earlier power level than convolutional with Reed-Solomon coding schemes in an OFDM system. This research work was prone to a high PAPR because of the lack of consideration of ther concatenation of Rayleigh fading channels. Consideration of only AWGN was not sufficient for effective OFDM analysis.

[25] investigated the performance of different error correction techniques for an OFDM system. These techniques were based on convolutional codes, linear block codes and Reed-Solomon codes for comparing Bit Error Rate (BER) versus Signal to Interference Ratio (SIR). They focused on the implementation of an OFDM system with 64 carriers such that the transmitted data was passed through Rayleigh fading channel and AWGN was added. Simulations were performed to evaluate the considered techniques for different channel conditions by comparing the three techniques over three error rates of 1/3, ½, 2/3 and the results showed that convolutional and Reed-Solomon codes had improvements for E_b⁄N_0 of 2.3dB and 2.8dB respectively at 1/3 code rate when compared to non-coded OFDM at BER of 10-3 while Reed-Solomon codes performed the best for E_b⁄N_0 of 4.7dB at 2/3 error rates as compared to non-coded OFDM at a BER of 10-3. Also, Reed-Solomon scheme was consistent in performance at both low and high code rates since it could handle long bursts of errors. Linear Block codes showed less improvement at both low and high error rates. The problem of this research was that the trade-off between performance and complexity when the number of bits to the encoder was increased for the different codes was not analyzed, which might have required an unnecessary time before the right error were corrected.

[13] analyzed the performance of a rate of 2/3 convolutional code of memory order 6 obtained by puncturing a rate of ½. Soft decision Viterbi algorithm which was used to decode the messages transmitted over an AWGN noise channel. By controlling the SIR, the BER of the convolutional coded model was compared with the non-coded BER for performance evaluation. Viterbi algorithm was also used to evaluate the free distance of the code, the first few terms of the truncated weight enumerating function which was used to find the union bound on code performance, and computed asymptotic and actual coding gain of the rate 2/3 code. It was shown from simulations that encoded convolutional model performed better. The problem of this research work was that it was prone to interference due to the lack of consideration of other fading channels such as Rayleigh fading channel because consideration of only AWGN was not sufficient for analysis to get good results.

[19] studied the effects of multipath fading on wireless communication channel in a Rayleigh and Rician multipath fading channels using convolutional coding as the Forward Error Correction (FEC) technique. The performances of convolution encoded Binary Phase Shift Keying (BPSK) and Viterbi decoding were also investigated using BER as the performance metric and by means of simulations, it was found that the improvement of BER using convolutional code in the presence of Rician fading provided a better performance than that of Rayleigh fading and the non-coded signal. The trade-off between performance and complexity when the number of bits to the encoder was increased was not analyzed which might require an unnecessary time before the right error was corrected. This was a limitation of this research.

[1] worked on convolutional codes with different code rates of 1/3 and 1/2 and evaluated their performance. BPSK scheme and Binary Symmetric Channel (BSC) model were used in an AWGN channel. Maximum

likelihood mechanism (Vertibi Algorithm) for decoding process was used, where BER was also used as the performance metric and simulations were carried out using MATLAB tool box. It was observed that the performance of 74% and 70% for both code rates were achieved at the BER of 10¬¬-4and 10-2 respectively. The trade-off between performance and complexity was not analyzed. Also, multipath channel was not considered in order to determine its error handling capability. These were setbacks of this research work.

[12] modeled the performance of Reed-Solomon code in digital communication. The performances were evaluated by applying BPSK modulation over an AWGN channel and are assessed in terms of BER and signal energy to noise power spectral density ratio (Eb/No). It was observed from simulations that Reed-Solomon code showed a poor BER performance for lower SIR and improved performance for larger block lengths. This research work might be prone to interference and high PAPR due to the lack of consideration of other fading channels such as Rayleigh fading channel because consideration of only AWGN was not sufficient for analysis to obtained good results.

It is evident that error correcting techniques have been given significant attention and eliminating errors in OFDM system entirely is still a serious research problem for academics and individual researchers. This dissertation provided an error correcting coding technique by using a CC-RS coding scheme which integrated the advantages of convolutional coding and Reed-Solomon coding schemes with the aim of improving the original convolutional coding and Reed-Solomon coding schemes combined advantages.

3. METHODOLOGY

This work, CC-RS coding technique over AWGN and Rayleigh fading channel using code rate of 1/3. The procedures which were employed for the successful implementation of this research work are highlighted as follows:

1. Development of the OFDM model using the 64 subcarriers channel and data modulation.
2. Implementation of the convolutional channel coding model to enhance the systems error detection and correction abilities.
3. Implementation of the Reed-Solomon channel coding model to enhance the systems error detection and correction abilities.
4. Concatenation of two coding scheme using models implemented in item (2) and (3).
5. Conversion of the serial stream of data into parallel streams of data using the Fast Fourier Transform (FFT) subcarriers and also to convert data from time domain to frequency domain.
6. Applying the Inverse Fast Fourier Transform on each stream to convert the data from frequency domain to time domain.
7. Applying the orthogonal guard interval in item (6) to improve the performance of the OFDM system.
8. Validation of performance was done by comparing results of CC-RS coding scheme against the respective convolutional and Reed-Solomon coding schemes for AWGN channel at code rate of 1/3.

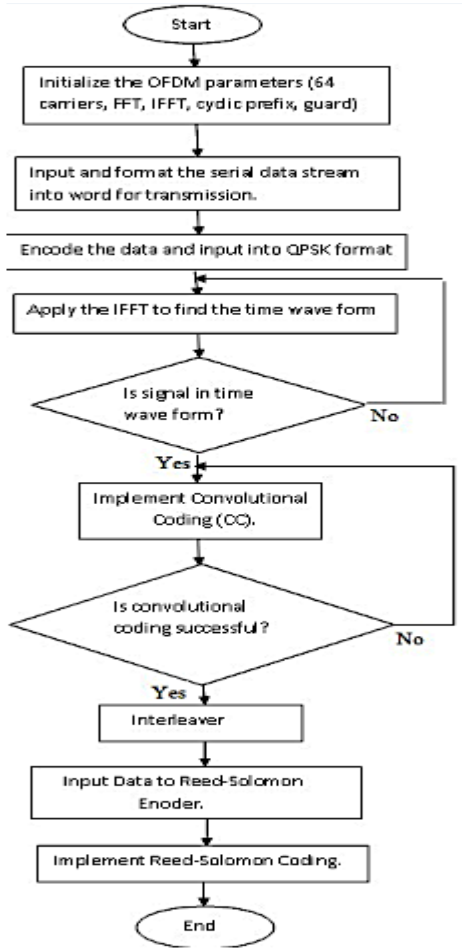

Figure 1. Flowchart of Concatenated Process

4. SIMULATION ENVIRONMENT

The simulation results in this paper were obtained using MATLAB 2015b to perform comparison between CC-RS coding, convolutional coding, Reed-Solomon coding and non-coded OFDM schemes in AWGN channel and code rate of 1/3 at BER 〖10〗^(-3)

5. RESULTS

Figure 2 shows the performance of the various coding techniques in AWGN channel at BER of 〖10〗^(-3). When compared to the non-coded OFDM scheme, CC-RS coding scheme had the best improvement for E_b⁄N_0 of 3dB because it integrated both advantages of convolutional coding and Reed-Solomon coding schemes. CC-RS achieved better error corrections ability in terms of random bit errors associated with AWGN channel and burst errors associated with Rayleigh fading channel. This is followed by Reed-Solomon scheme in the second place with an improvement of 2.8dB, while convolutional scheme shows the least improvement of 2.2dB.

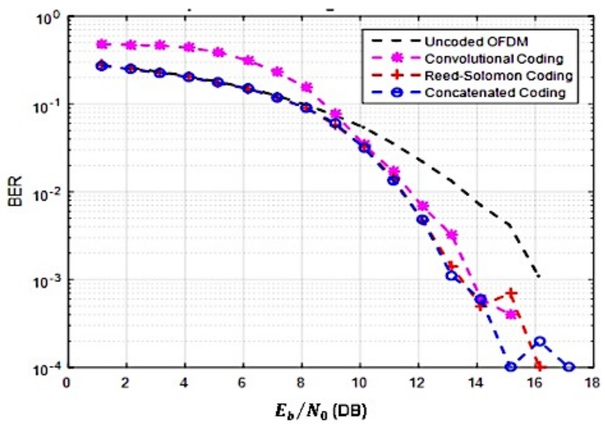

Figure 2. Coding Scheme in AWGN Channel

Figure 3 shows the performance of the various coding techniques in AWGN and Rayleigh fading channel at BER of 〖10〗^(-3). Similarly, when compared to the non-coded OFDM scheme, CC-RS coding scheme had the best improvement for E_b⁄N_0 of 4.2dB because it has the capability of correcting both random bit errors associated with AWGN channel and burst errors associated with Rayleigh fading channel, these improve the overall performance of the system. It is followed by Reed-Solomon in the second place with an improvement of 3.8 dB, while convolutional shows the least improvement of 2 dB.

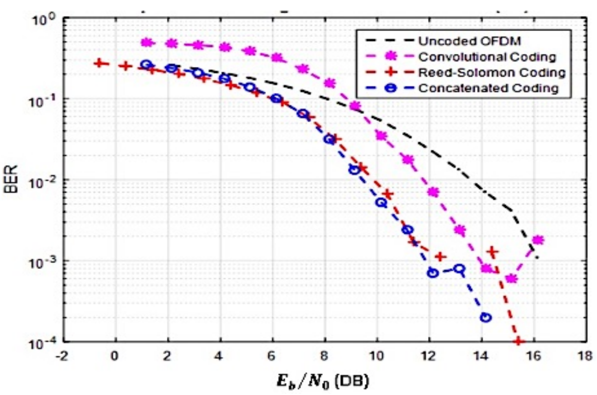

Figure 3: Coding Scheme for Code Rate of 1⁄3

6. CONCLUSION

This paper presented the results of the CC-RS coding scheme over AWGN and that of Rayleigh fading channel for the code rate of 1/3, which were represented by the plots shown. CC-RS coding scheme of the combined convolutional with Reed-Solomon coding techniques outperformed both the individual separate convolutional and the Reed-Solomon coding techniques. Due to complex decoding structure, these individual techniques are difficult to implement because of the following reasons. First, the convolutional coding technique has the problem of very complex decoding process, when the length of the input data increases. The trellis used becomes complex which results in a more complicated decoding process. On the other hand, the Reed-Solomon coding technique, though difficult to implement, has its performance much better than convolutional coding scheme. It is consistent in correcting errors than convolutional coding scheme because it can handle long bursts of errors.

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