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Forward Error Correction (FEC) Coding Techniques for Reliable Communication Systems

Jyoti Sharma[1], Sanjeev Sharma[2], Priya Sharma[3]
[1, 2, 3]Department of ECE, Sri Sai College of Engineering & Technology, Badhani, Punjab, India
Email address: [2]sanjeev.btech@gmail.com

Abstract— Due to high bit error rates (BER) of the any communication system, forward error correction (FEC) techniques are required. The error in communication system occurs due to noise. In this paper, we implement the FEC codes and evaluate the performance. The comparative comparison is done to find out the best BER performance of each of the FEC codes. We concatenate two codes to improve the BER.

Keywords— Convolutional codes (CC); reed-solomon codes (RS); concatenated codes; RS-CC; CC-RS codes.

I. Introduction

In wired/ wireless communication systems reducing error is critical. In wireless transmission, transmitted signals arrive at receiver with different power and time delay due to the reflection, diffraction and scattering effects. Therefore the Bit Error Rate (BER) value of the wireless medium is relatively high and sometimes introduces destructive effects on the wireless data transmission performance. Therefore an error control coding is necessary.

During digital data transmission and storage operations, data sent from the source picks up noise as it passes along the transmission line or through the air. There are two basic methods for handling noise induced errors in transmitted signals [1].

- Errors can be detected at the receiving end and the information re-transmitted.
- Errors can be detected at the receiving end and the information is corrected using Forward Error Correction (FEC) techniques.

Retransmission techniques require a two-way link. The error is detected at the receiving end and a signal is sent to the transmitter to retransmit the data. This causes the same data to be transmitted twice. While this is happening no new data is being sent. This causes a decrease in data throughput. Forward error correction requires only a one-way link, and its parity bits target both error detection and correction. Data can continue to be transmitted and if an error is detected encoded information sent along with the data is used to correct for the error [2].

II. Forward Error Correction (FEC)

Forward Error Correction (FEC) is a technique of error control coding for reliable data transmission. The sender or transmitters add systematically generated redundant bits to the messages. The efficiently designed redundancy provides the ability to receiver to detect and correct a limited number of errors occurring anywhere in the message but this advantage is at the cost of a fixed higher forward channel bandwidth. Therefore it is applied in applications where re-transmissions are very costly or impossible like when broadcasting to multiple receivers.

Error Correction coding is achieved by adding redundancy to the transmitted data using a predetermined algorithm. A redundant bit may be a complex function of many original information bits. The original information may or may not appear literally in the encoded output; codes that include the unmodified input in the output are systematic, while those that do not are non-systematic. FEC could be said to work by "averaging noise", since each data bit affects many transmitted symbols, the corruption of some symbols by noise usually allows the original user data to be extracted from the other, uncorrupted received symbols that also depend on the same user data [3]. With FEC techniques for the same power, we can now achieve a lower error rate. The communication in this case remains simplex and all the burden of detecting and correcting errors falls on the receiver. The transmitter complexity is avoided but is now placed on the receiver instead.

In telecommunication & information theory, forward error correction (FEC) (also called channel coding) is a system of error control for data transmission, whereby the sender adds systematically generated redundant data to its messages, also known as an error-correcting code (ECC). The American mathematician Richard Hamming pioneered this field in the 1940s and invented the first FEC code, the Hamming (7, 4) code, in 1950 [4].

III. Convolutional Codes (CC)

Convolutional codes (CC) are extensively used for real time error detection and correction. Convolutional coding is achieved by combining the fixed number of input bits. The input bits are stored in fixed length shift register and they are combined with the help of mod-2 adders. This function is equivalent to binary convolution and hence it is known as convolutional coding (CC). The ratio R=k/n is called the code rate for a convolutional code where k is the number of parallel input bits and n is the number of parallel decoded output bits, m is the symbolized number of shift registers. Shift registers store the state information of convolutional encoder, and

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constraint length (K) relates the number of bits upon which the output depends [5].

A simple convolutional code having code rate of 1/2 with constraint length K=3 is shown in figure 1. Here m represent the current message bit and m1, m2 represent the previous two successive message bits stored which represent the state of shift register. Here k is the number of input information bits and n is the number of parallel output encoded bits at one time interval. Whenever a particular message bit enters a shift register, it remains in the shift register for three shifts.

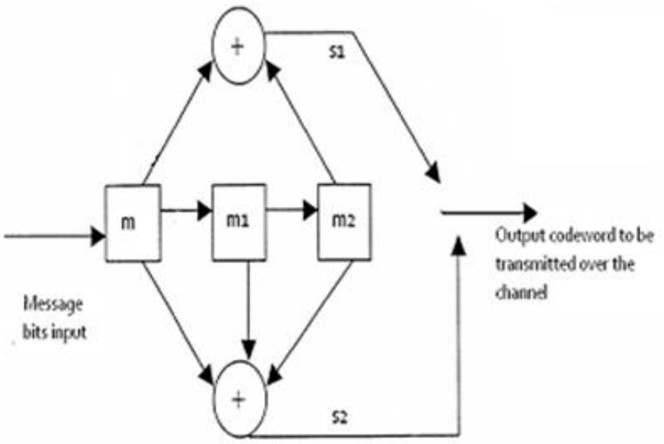

Fig. 1. Convolutional encoder with rate ½, k=1, n=2, K= 4, m= 3.

Viterbi decoding algorithm is mostly applied to convolutional encoder and it uses maximum likelihood decoding technique [4]. Viterbi algorithm estimates actual bit sequence using trellis diagram. Commonly, its decoding algorithm is used in two different forms. This difference results from the receiving form of the bits in the receiver. Decoded information is received with hard decision or soft decision.

IV. Reed-Solomon Codes (RS)

The RS code is one of linear block codes which were proposed in 1960 [5] and vulnerable to the random errors but strong to burst errors. In coding theory Reed Solomon (RS) codes are cyclic codes invented by Irving S. Reed and Gustave Solomon. They described a systematic way of building codes that could detect and correct multiple random symbol errors. By adding t check symbols to the data, an RS code can detect any combination of up to t erroneous symbols, and correct up to [t/2] symbols. As an erasure code, it can correct up to t known erasures or it can detect and correct combinations of errors and erasures. Furthermore, RS codes are suitable as multiple-burst bit-error correcting codes, since a sequence of b+1 consecutive bit errors can affect at most two symbols of size b.

Reed-Solomon codes have found important applications from deep-space communication to consumer electronics. They are prominently used in consumer electronics such as CDs, DVDs, Blu-ray Discs, in data transmission technologies such as DSL & WiMAX, in broadcast systems like ATSC, and in computer applications such as RAID 6 systems. The Reed-Solomon code is a [n,k,n-k+1] code, in other words, it is a linear block code of length n with dimension k and minimum Hamming distance n-k+1.

The Reed-Solomon code is optimal in the sense that the minimum distance has the maximum value possible for a linear code of size (n, k), this is known as the Singleton bound. Such a code is also called a maximum distance separable code [6]. The error-correcting ability of a Reed–Solomon code is determined by its minimum distance, or equivalently, by n−k, the measure of redundancy in the block. If the locations of the error symbols are not known in advance, then a Reed–Solomon code can correct up to (n − k) / 2 erroneous symbols, i.e., it can correct half as many errors as there are redundant symbols added to the block. A Reed–Solomon code is able to correct twice as many erasures as errors, and any combination of errors and erasures can be corrected as long as the relation $2Er + S \leq n - k$ is satisfied, where Er is the number of errors and S is the number of erasures in the block.

For practical uses of Reed–Solomon codes, it is common to use a finite field F with 2^m elements. In this case, each symbol can be represented as an m-bit value. The sender sends the data points as encoded blocks, and the number of symbols in the encoded block is $n = 2^m - 1$. Thus a Reed–Solomon code operating on 8-bit symbols has $n = 2^8 - 1 = 255$ symbols per block. The number k, with k < n, of data symbols in the block is a design parameter [7].

V. Simulation Results

A system model with FEC was developed and implemented in Matlab. Performance evaluation in terms of BER is measured with varying code rate.

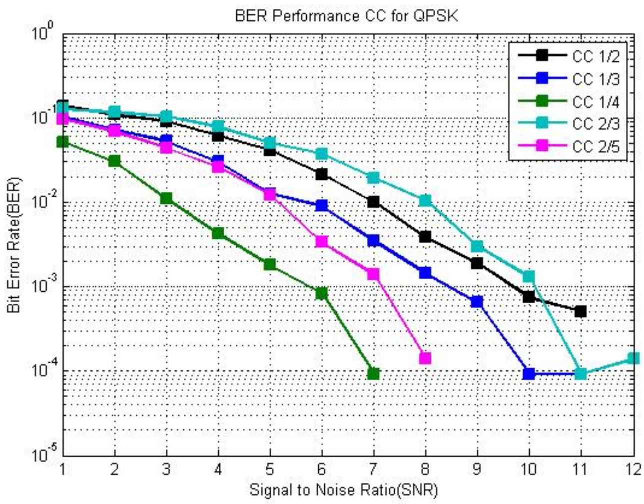

Fig. 2. Bit Error Rate of CC Codes under various code rates.

The implemented and simulated performance of concatenated Convolution code with RS code is shown in figure 2. The concatenated model CC-RS has the outer code CC and the inner code RS whereas outer code is RS and inner code is CC for RS-CC concatenation.

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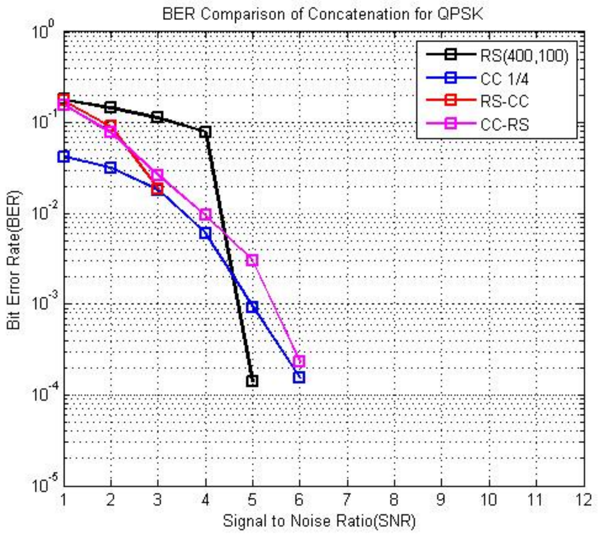

Fig. 3. Bit Error Rate Comparison of concatenated CC-RS and RS-CC Codes.

VI. CONCLUSION

In this paper we compare the performance in terms of BER of different Forward Error Correction codes. We evaluate Bit Error Rate of convolutional codes at different code rates. Lastly, we compared the performance of both RS-CC as well as CC-RS concatenated codes with the individual codes and with un-coded data transmission. BER performance of CC codes increases as the code rate decreases and gives high coding gain for 0.25 (1/4) code rate. Figure 3 reveal that the performance of RS-CC concatenated code gives better results and provides better gain.

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