Performance Comparison of Different Forward Error Correction Coding Techniques for Wireless Communication Systems

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Abstract
High bit error rates of the wireless communication system require employing forward error correction (FEC) methods on the data transferred. In this paper, we investigate the performance of convolutional, block as well as concatenated coding schemes that are used to encode the data stream in wireless communications. In this paper we performed various simulations to find out the best BER performance of each of the Convolutional and Reed-Solomon codes and used these best outcomes to model the RS-CC and CC-RS concatenated codes. By concatenating two different codes we can get the effect of improving the total BER due to benefits of RS codes correcting burst errors while convolutional codes are good for correcting random errors that are caused due to a noisy channel.

Keywords
Convolutional codes (CC), Reed-Solomon codes (RS), Concatenated codes, RS-CC, CC-RS codes.

I. Introduction
In wireless, satellite, and space communication systems, reducing error is critical. Wireless medium is quite different from the counterpart using wires and provides several advantages, for example; mobility, better productivity, low cost, easy installation facility and scalability. On the other hand, there are some restrictions and disadvantages of various transmission channels in wireless medium between receiver and transmitter where transmitted signals arrive at receiver with different power and time delay due to the reflection, diffraction and scattering effects. Besides the BER (Bit Error Rate) value of the wireless medium is relatively high. These drawbacks sometimes introduce destructive effects on the wireless data transmission performance. As a result, error control is necessary in these applications. During digital data transmission and storage operations, performance criterion is commonly determined by BER which is simply: Number of error bits / Number of total bits. Noise in transmission medium disturbs the signal and causes data corruptions. Relation between signal and noise is described with SNR (signal-to-noise ratio). Generally, SNR is explained with signal power / noise power and is inversely proportional with BER. It means, the less the BER result is the higher the SNR and the better communication quality [1]. There are two different types of FEC techniques, namely block codes and convolutional codes [2]. The Viterbi algorithm is a method for decoding convolutional codes proposed in 1967 by A. J. Viterbi. It has been counted as one of good decoding scheme up to date. This algorithm, however, is vulnerable to burst error which means a series of consecutive errors [3]. Since most physical channels make burst errors, it can be a serious problem. Furthermore, the complexity increases as the number of memories in the encoder increases, and the increase of the memory causes the increase of computation. To compensate these problems, a new solution can be applied: a concatenation of a Reed-Solomon (RS) code and a convolutional code (CC) i.e., RS-CC or CC-RS concatenated codes. Since RS code is very strong to the burst error, the RS-CC concatenated codes can have good performance than CC and RS itself. RS-CC is widely used in various systems such as Digital Video Broadcasting-Satellite Systems,[7] Consultative committee for Space Data Systems [8] and WiMAX systems.[6] [9] The rest of this paper shows the basic concept of CC, RS, CC-RS and RS-CC codes and various simulations that are performed to find out the best BER performance of the individual CC and RS codes and the simulations for their concatenated codes which shows that RS-CC code has better performance than CC, RS, CC-RS concatenated codes in bit error rate (BER). All the simulations are performed using MATLAB Software.

II. Convolutional Codes (CC)
Convolutional codes are extensively used for real time error correction. Convolutional coding is done 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. An input sequence and contents of shift registers perform modulo-two addition after information sequence is sent to shift registers, so that an output sequence is obtained. This operation is equivalent to binary convolution and hence it is called convolutional coding. 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 constraint length (K) relates the number of bits upon which the output depends. A convolutional code can become very complicated with various code rates and constraint lengths. A simple convolutional code with ½ code rate is shown in fig.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. This is a rate (k/n) = 1/2, with constraint length K=3 convolutional encoder. Here k is the number of input information bits and n is the number of parallel output encoded bits at one time interval. In the encoder we observe that whenever a particular message bit enters a shift register, it remains in the shift register for three shifts. And at the fourth shift the message bit is discarded or simply lost by overwriting.

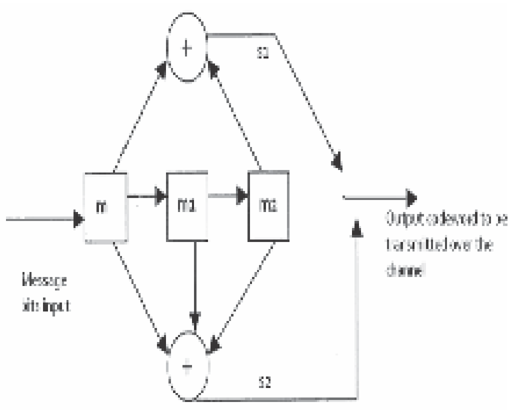

Fig.1 : Convolutional encoder with rate ½, k=1, n=2, K= 4, m= 3

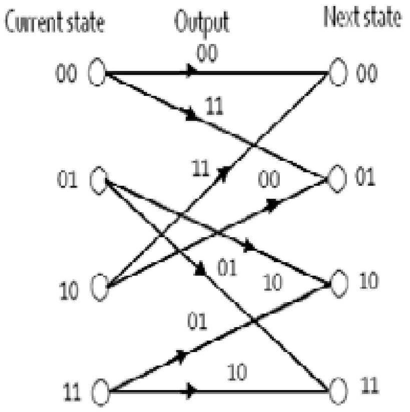

Fig. 2 : Code trellis of convolutional encoder of fig.1

The constraint length, K, of the convolutional encoder is defined by K= m+1, where m is the maximum number of memories in any convolutional encoder. The right side of fig.2 denotes the bits which are input to the encoder and denote the current state and the left side shows the next state of the shift registers.

A. Viterbi Decoding

Viterbi decoding algorithm is mostly applied to convolutional encoder and it uses maximum likelihood decoding technique [4]. Noisy channels cause bit errors at receiver. 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. Decoded information is explained with ±1 on hard decision operation while soft decision decoding uses multi bit quantization [4]. Hard decision and soft decision decoding refer to the type of quantization used on the received bits. Hard decision decoding uses 1 bit quantization on the received channel values while soft decision decoding uses multi bit quantization on the received channel values. For hard decision decoding, the symbols are quantized to one bit precision while for soft decision decoding, data bits are quantized to three or four bits of precision. The selection of quantization levels is an important design decision because of its significant effect on the performance of the link [10].

III. Reed-Solomon Codes (RS)

The RS code is one of linear block codes which were proposed in 1960 [5]. It is vulnerable to the random errors but strong to burst errors. Hence, it has good performance in fading channel which have more burst errors. In coding theory Reed–Solomon (RS) codes are cyclic error correcting 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. 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 [12].

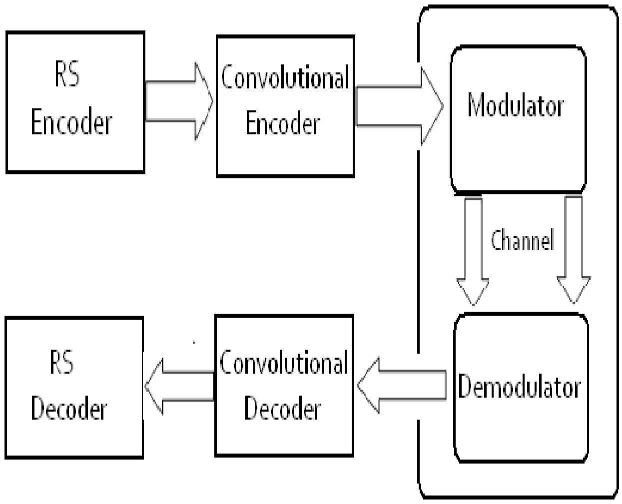

Fig. 3: Basic block structure of RS-CC codes

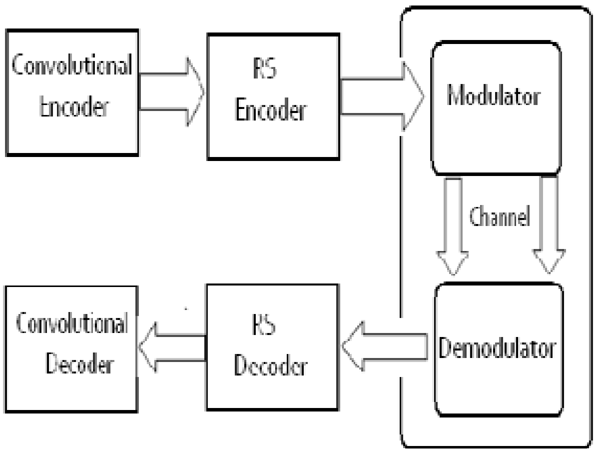

Fig. 4 : Basic block structure of CC-RS codes

IV. Concatenated Codes

Since the two codes i.e. Convoluional codes and Reed Solomon codes have different characteristic in terms of handling the errors, so their concatenation lead to give benefits in BER performance. More specifically, the CC is good for correcting random errors that is caused due to a noisy channel and RS codes can combat burst errors which is caused by convolutional decoder. This is main reason for using concatenated scheme because it reduces overall error rate than single coding scheme. It has been used in deep space communications and digital video broadcasting systems. RS-CC code is a concatenated code of RS code as the outer code and Convolutional code as the inner code [11]. The basic structure for RS-CC concatenated codes is shown in fig. 3. Fig. 4 shows the basic block structure of CC-RS codes. CC-RS code is a concatenated code of Convolutional code as the outer code and RS code as the inner code. The basic structure for CC-RS concatenated codes is shown in fig.4.

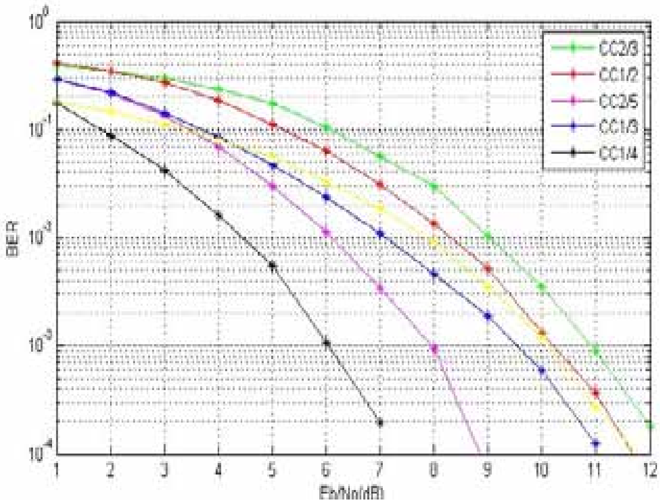

Fig. 5 : The BER performance comparison of convolutional codes for different code rates

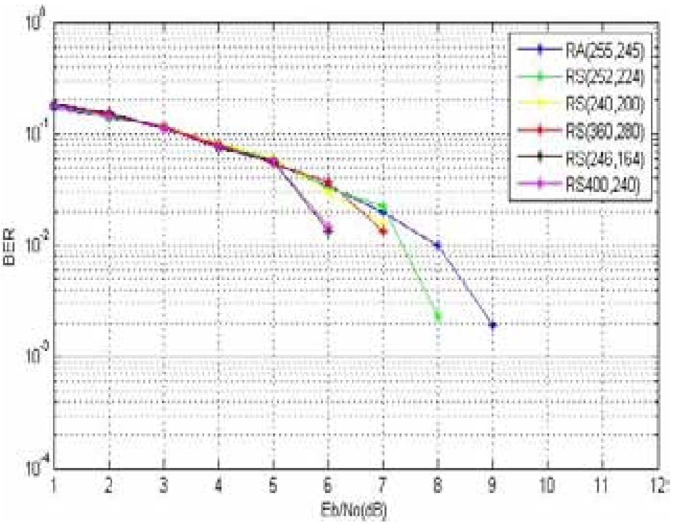

Fig. 6 : The BER performance of different RS codes

V. Simulation Results

A full system model was implemented in Matlab according to the above described system for different coding techniques. Performance analysis is done for different code rates by taking random data stream of defined length for each of the coding techniques. Here we have used QPSK (Quadrature Phase Shift Keying) modulation and demodulation for all the simulations. The encoded data is then passed through Gaussian channel which adds additive white Gaussian noise (AWGN) to the channel symbols produced by the encoder. In the following fig.s, Eb/No dB denotes the information bit energy to noise power density ratio and at the y-axis we plot the bit error rate (BER). First we run the simulations for convolutional codes with different code rates i.e.2/3,2/5,1/2,1/3,1,4. The block length (n) taken is 2400 and traceback length as 2. From fig.5, it can be seen, as we decrease the code rate the BER performance improves and the best result comes for rate 1/4, for this the absolute BER performance is approx. 5dB better than code rate 2/3 at BER of 10-³.

Next we performed the simulations for RS codes for different block lengths. We can see from fig. 6, as the block length increases the BER performance improves also it can be seen from the graph that the performance also improves for small values of code rate. The RS code, which is well suited for correction of burst errors, shows a poor BER performance for lower SNR values, because of the mainly random errors introduced by the AWGN. So here the best result comes out with RS (400,240) with m= 9 i.e. number of bits per symbol is 9.

A. CC-RS and RS-CC Codes Simulations

First we performed simulation for CC-RS codes. Here the outer code is CC code and the inner code is RS. The information bits go into the CC encoder and the output of CC encoder is the input of the RS encoder. Then we performed simulation for RS-CC codes. Here the outer code is RS code and the inner code is CC. The information bits go into the RS encoder and the output of RS encoder is the input of the CC encoder. For modeling both the concatenated codes we have the previous two results which we got from the RS and CC simulations done earlier in this paper. The specification of outer and inner code for the two concatenated codes is shown in Table 1

Table 1: Specification of Concatenated codes

	OUTER CODE	INNER CODE
CC-RS CODE	CC CODE (171,133,120,153) Number of memo-ries=6	RS CODE (400,240) Over GF(2^9)
RS-CC CODE	RS CODE (400,240) Over GF(2^9)	CC CODE (171,133,120,153) Number of memories=6
	Berlekamp-Massey Decoding	Viterbi decoding

The convolutional encoder we have used for the concatenated codes is the best BER result of 1/4 code rate that we got in our first simulation (shown in fig. 5) and the RS encoder used is also the best outcome result that we got after comparing the simulations for different block lengths and different code rates as shown in fig.6 of this paper. We used (400, 240) RS code in GF (2^9). It can be decoded by using Berlekamp-Massey decoding algorithm. The convolutional encoder we used is (171, 133,120,153) with 1/4 code rate and 6 memories i.e. 7 constraint length. Decoding is done by Viterbi decoding algorithm with traceback length as 2 for RS-CC code and 4 for CC-RS code.

So here we can say that we have done the concatenation with the best results that we have got for the single RS and CC codes in order to get much better simulation results.

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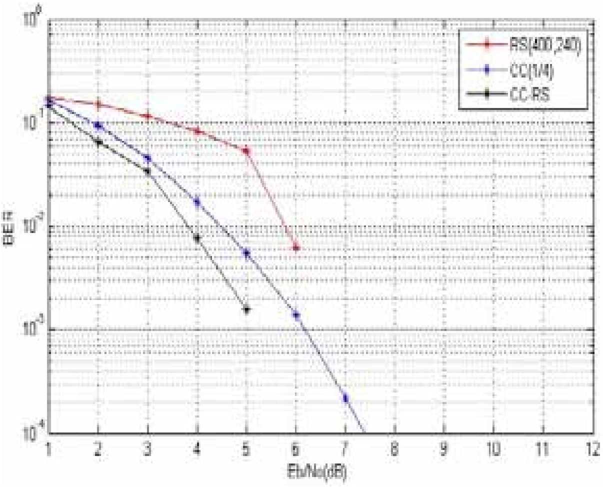

Fig.7 : BER performance comparison of RS- CC concatenated code with Single codes

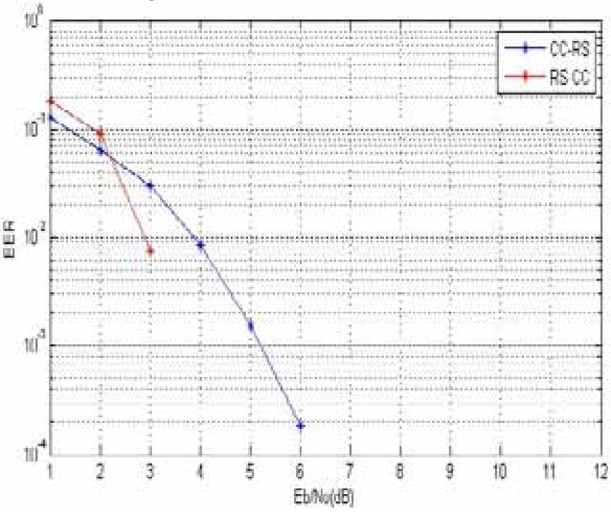

Fig. 8: BER performance comparison of CC -RS concatenated code with Single codes

From fig.7 it is clear that the performance of CC-RS concatenated code outperforms that of nonconcatenated codes. It can be seen that CC-RS curve shows less flattening effect and has a better slope than the other two codes. The absolute BER performance is about 0.5 dB better than CC code and about 2 dB better than RS code at a BER of 10-². From fig. 8 we can see the sharp improvement in the BER curve for the RS-CC concatenated code as compared to the RS and CC codes. The absolute BER performance is about 1.5 dB better than CC code and about 2.8 dB better than RS code at a BER of 10-².

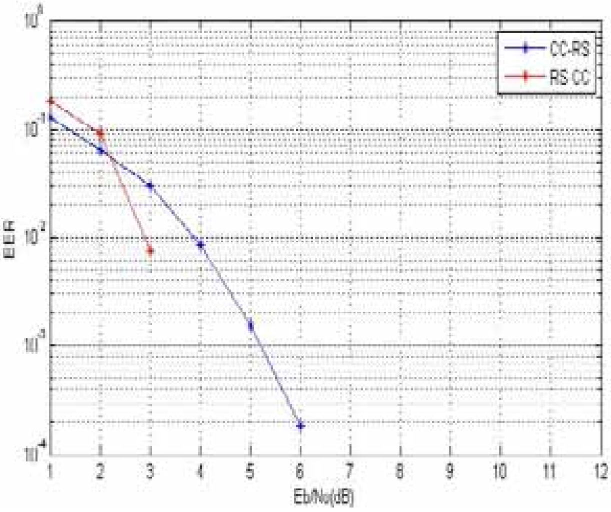

Fig. 9 : BER performance comparison within the two concatenated codes (CC-RS and RS-CC)

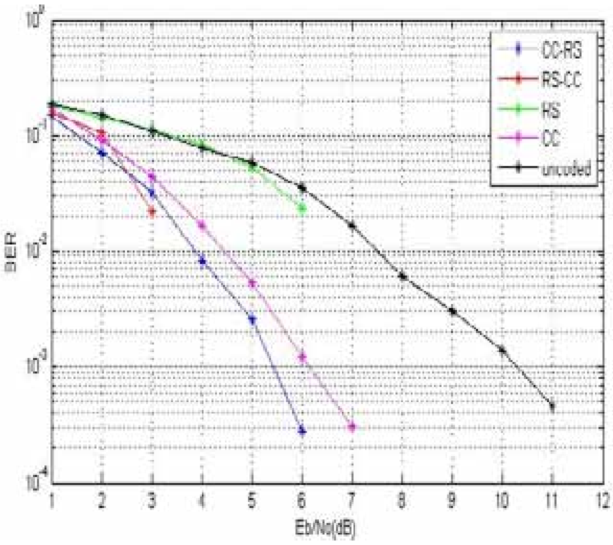

Fig.10 : BER performance comparison of all the coding techniques with the uncoded data

From the above simulation results we can see that BER performance with coding is much better than without coding. We can see from the above plot that the BER curves for concatenated codes are far better than nonconcatenated codes and too far better than the curve for uncoded data transmission. The flattening effect of the curve keeps on reducing from uncoded curve towards the RS-CC curve. The absolute BER performance for RS-CC code is about 0.9 dB better than CC code, 3dB better than RS code and 3.7 dB better than uncoded at a BER of 0.02315. From fig. 9 we can easily see that RS-CC code performs better than CC-RS code. RS-CC provides better gain, the absolute BER performance for RS-CC code is about 1 dB better than CC –RS code at a BER of 10-².

We have illustrated the gains of several decibels for different FEC coding techniques as follows:

Table 2: Gain comparison of different FEC coding techniques

Comparison	Gain/dB
Switching from uncoded curve to RS codes	1.0
Switching from RS codes to CC codes	2.2
Switching from CC codes to CC-RS codes	1.0
Switching from CC-RS to RS-CC codes	1.2

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. Similarly we evaluate performance for Reed-solomon codes for different block lengths as well as code rates. The best results of each of the two were used to model the concatenated codes. Lastly, we compared the performance of both RS-CC as well as CC-RS concatenated codes with the individual codes and with uncoded data transmission. The simulation results confirms the outperformance of the concatenated codes especially RS-CC when compared to CC and RS codes. CC-RS is no doubt much better than CC and RS codes but the simulation result shows clearly that RS-CC to be even better code than CC-RS. Due to a good burst error-correcting capability of RS codes, total BER of RS-CC has significant coding gain, and it increases as Eb/No increases. Also the slope of concatenated codes is more strong and has less flattening effect.

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