I J C T A, 9(32), 2016, pp. 73-78
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ISSN: 0974-5572

Error Resilience: A Distinct Approach for Comparative Analysis of Error Correcting Codes

P. Ratna Kamala* and R.V.S. Satyanarayana**

ABSTRACT

In the era of wireless communication, prime criterion to develop channel coding techniques is to maintain data integrity. To achieve this, several coding techniques are applied to the data that get transmitted over a channel which involves the use of Error correcting codes. This paper deals with evaluation of a distinct performance metric, called Error decoding probability or Error Resilience for codes to decide the usability of a code in diverse applications of wireless communications. It is observed that, code words with large distance can be decoded perfectly and the best code is determined with error decoding probability as the performance measure. Performance evaluations show that at a high signal to noise ratio (SNR), Reed Solomon code outperforms the other block codes and at low SNR, the Convolutional code outperforms the RS code thus making it for use in deep space communications. Utilizing the performance of both the codes, a concatenated code is developed to meet the stringent target low bit error rate (BER) requirement for space mission applications.

Keywords: Block codes, Bit error probability, Error resilience, SNR, BER, concatenated codes

1. INTRODUCTION

Wireless channel carrying data is prone to bit errors and burst errors because of channel degradations. Because of several environmental conditions affecting the channel characteristics, designing of reliable systems with guaranteed performance has become a complex task. Thus, data integrity and reliability has to be given the utmost importance in wireless transmission of data. The technique involved in attaining data reliability while transmission over a wireless channel is to use Coding Methods. These methods aids in detecting and correcting bit errors that occur due to channel impairments and is accomplished by placing a decoder in the receiver.

In this paper, our preliminary work of [1], [2] is extended. The paper is outlined as follows: Section II explains the concept of error resilience and its significance. Section-III explains the analytical results obtained by error resilience for considered block codes and convolutional codes. Section IV gives the discussion and conclusions.

2. ERROR RESILIENCE

2.1. Introduction

By transmission over a wireless channel, received data exhibits different types of errors. The capability of the decoder is to continue decoding of data in the presence of errors without degradation in transmitted data quality. In wireless transmission of data, where channel is varying in time, error resilient decoders requires to handle random bit errors and burst errors and continue to decode the data. In this scenario, two systems are to be considered. One is transmission system with a transparent mode, that guarantees error-free

* Professor, Department of ECE, Siddharth Institute of Engineering and Technology, Puttur, AP, India, *Email: ratnapkamala@gmail.com*
** Professor, Department of ECE, Sri Venkateswara University, Tirupati, AP, India.

transmission by using the Automatic Repeat Request (ARQ) protocol, and the second one is non-transparent mode where channels exhibit residual errors in the bit stream provided to the decoder. Thus Error resilience tool provide a decoder mode where residual bit errors are tolerated and their effect is concealed by a robust decoding algorithm.

The method used to evaluate the error decoding probability for error correcting codes is discussed in succeeding topics. For unique decodability, this mapping should be one-to-one. In minimum distance decoding technique used in error resilience, the received codeword and the probable closest codeword are matched and checked for Hamming distance. Channel codes with code distance, d are developed to offer reliability.

2.2. Minimum codeword Length

Let M, d, p_{max} and X represent the number of codewords, code distance, the maximum probability of any discrete distribution and the source random variable, respectively.

Let the code with weight enumerator C_i, $W_{C_i}(z)$ is given by

$$W_{Ci}(z) = z\left(\left\lceil \frac{d}{2} - i \right\rceil\right) + (M-1)z\left(\left\lceil \frac{d}{2} \right\rceil + i\right) \tag{1}$$

Where a single codeword with weight $\left\lceil \frac{d}{2} - i \right\rceil$ is Ci and others have $\left\lceil \frac{d}{2} \right\rceil + i$. The source symbol with maximum probability ie., p_{max} be assigned to the codeword with weight $\left\lceil \frac{d}{2} - i \right\rceil$.

Let n_{min} and $W_C(z)$ represent the minimum codeword length and weight enumerator of a code respectively for given M and d. A(n, d, w) is the maximum number of code words of length 'n' with code distance 'd' and fixed code weight 'w'. The minimum codeword length n_{min} is evaluated using eqns. (2), (3) and (4). For,

1. $p_{max} < 0.5$, d even: $W_C(z) = zd/2$.

   $n_{min} = \min\{\bar{n} : A(n, d, d/2) \geq M\}$. Since 1's in each codeword are disjoint,

$$n_{\min} = \frac{Md}{2} \tag{2}$$

2. $p_{max} < 0.5$, d odd: The weight enumerator is $W_c(Z) = Z^{[d/2]} + (M-1) Z^{[d/2]}$ and

$$n_{min} = [d/2] + \min\{\tilde{n} : A(\tilde{n}, 2m+1, m+1) \geq M-1\} \tag{3}$$

3. $p_{max} > 0.5$: The code has the weight enumerator $W_c(Z) = Z^0 + (M-1)Z^d$ and

$$n_{min} = \min\{n: A(n, d, d) \geq M - 1\} \tag{4}$$

For $p_{max} < 0.5$ and d-even, blocks of 1s are shifted by proper amounts to satisfy the Hamming distance with the previous codeword. The minimum codeword length with this scheme is given by,

$$n_{min} = d + (M - 2) |d/2| \tag{5}$$

For numerical analysis of error performance and to obtain valid results for all the values of p_{max} and d, eqn.(5) is used. On increasing of minimum Hamming distance between the code words more codeword errors can be corrected.

3. ANALYTICAL RESULTS FOR ERROR RESILIENCE

In a communication system, when data is transmitted over a wireless channel there is always a chance for the data to get corrupted. This may lead to several problems especially when data reliability plays a key role. So there is always a need to determine the correctness of received data. To ensure this as already discussed in section III forward error correcting codes are used. But the performance of these codes can be assessed using several parameters [8]. One such important parameter used in this paper is Error decoding probability, ξ_d. The probability that a codeword is correctly decoded is given by eqn.(6).

$$\xi_d = \sum_{o=0}^{\left\lfloor \frac{d-1}{2} \right\rfloor} \binom{n_{\min}}{i} p_s^i \left(1-p_s\right) n_{\min} - i \tag{6}$$

The code words are exactly decoded with maximum probability, if p_s is less than the inverse of M and with sufficiently large distance.

$$\xi = \lim_{d \to \alpha} \varepsilon_d = \begin{cases} 1, & p_s < 1/M \\ 0, & p_s > 1/M \end{cases} \tag{7}$$

To determine the decoding probability for any code, minimum codeword length, n_{min} is determined using eqns. (2), (3), (4) or (5). Choosing of the equation for calculating n_{min} depends on the hamming distance, d to be either even or odd.

$M = 2^k$ is going to vary according to the type of code [9] chosen. The symbol error probability, p_s is varied from 0 to 10 and is represented on logarithmic scale. The plots for Error decoding probability versus symbol error probability are obtained by writing MATLAB programs for eqn. (6) and are shown from Fig.1 through Fig.6.

- For (8, 1), (16, 1) Parity code and (12, 8) Hamming code, the hamming distance, d = 3 and M = 8/16/256. For (15, 7) BCH code, M = 128 with d = 7 and for CRC-8 and CRC-16 codes, d = 3 and M = 7/16 are chosen respectively. Eqn. (10) is used to determine $n_{min.}$ for all the codes specified. With this n_{min} and varying symbol probability error, p_s the plot for error resilience of (8, 1) and (16, 1) Parity code, (12,8) Hamming code, (15,7) BCH code, CRC-8 and CRC-16 codes is shown

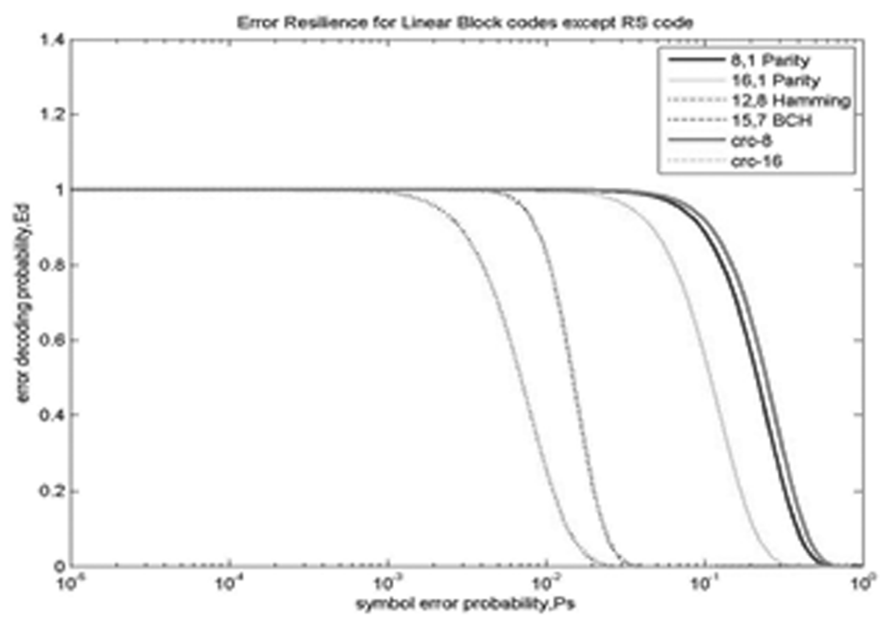

Figure 1: Error resilience curves for Block codes except RS code

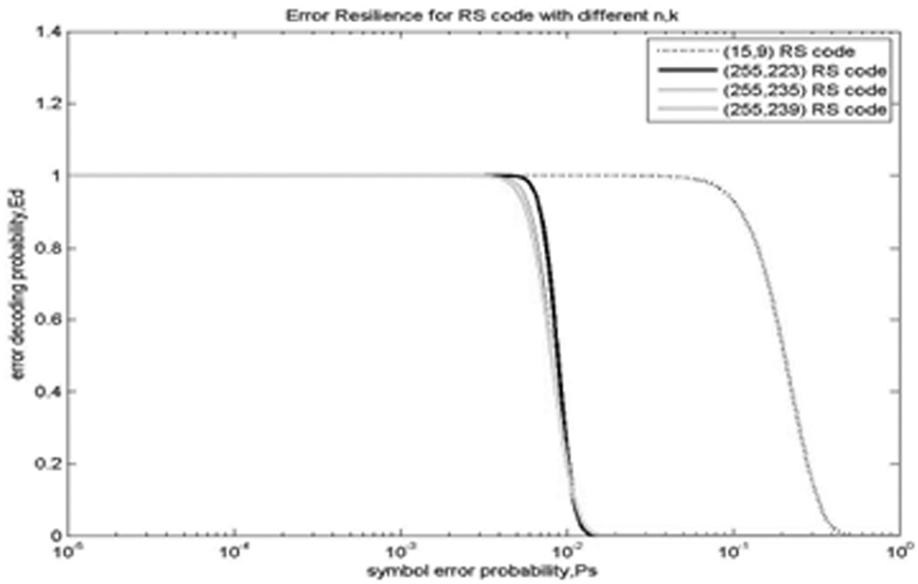

Figure 2: Error resilience curves for RS (n, k) code

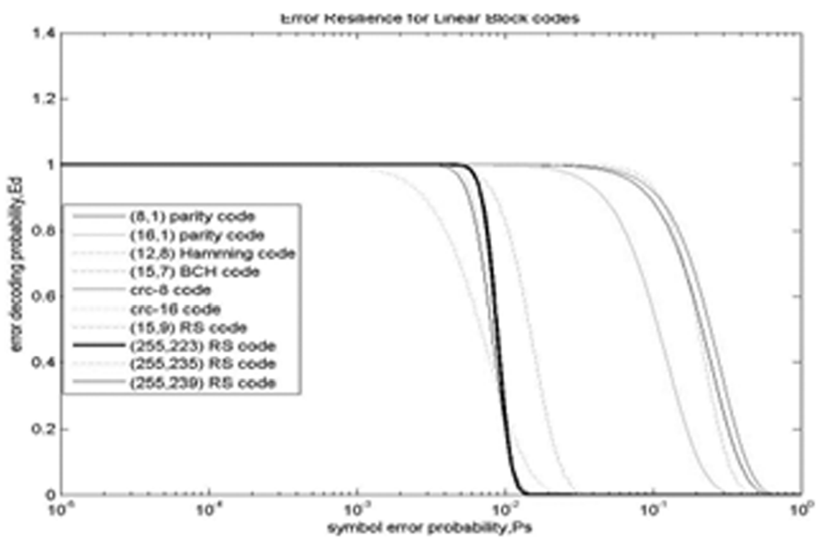

Figure 3: Error resilience curves for various Linear Block Codes

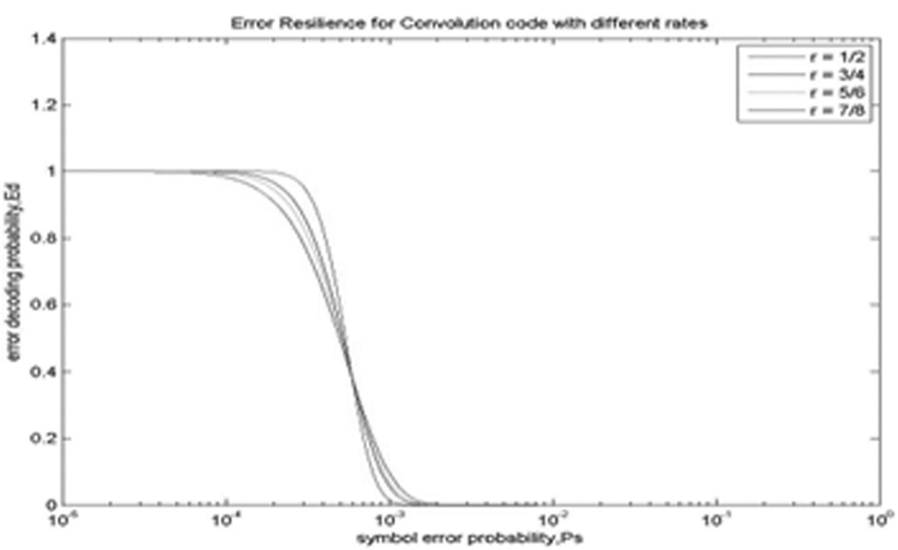

Figure 4: Error resilience curves for Convolutional code

in Fig.1. From the plot, it is observed that among these codes (12, 8) Hamming code is giving better decoding probability.

- Another important error correcting code is the Reed Solomon (RS) code that plays a vital role in correcting burst errors. This RS code with 'n' and 'k' varying is considered. In this paper, among the several values of 'n' and 'k', 4 variants are chosen according to their applications in wireless communications. They are RS(15,9), RS(255,223), RS(255,235) and RS(255,239) [10]. For these codes, n_{min} and thereby ξ_d is calculated and the plot is shown in Fig.2. It is observed that RS code with n=255 and k=223 is giving the better decoding probability and is indicated by a curve black in color.
- Combining all the linear block codes discussed above, a plot is shown in Fig.3 from which it can be concluded that RS (255,223) code is offering the best error decoding probability among the class of existing Linear Block codes thus making it an optimal code even with respect to the parameter ξ_d.

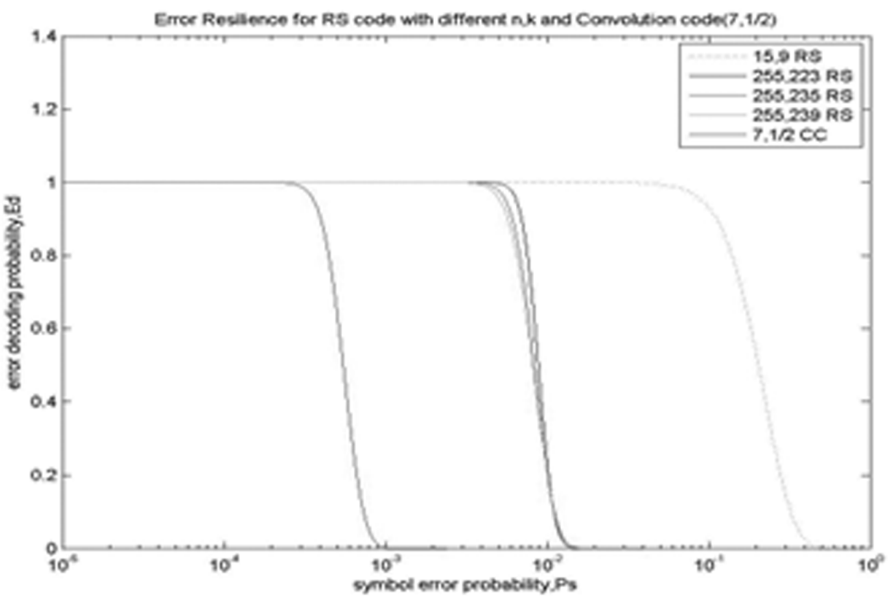

Figure 5: Error resilience curves for RS (n, k) and Convolutional code

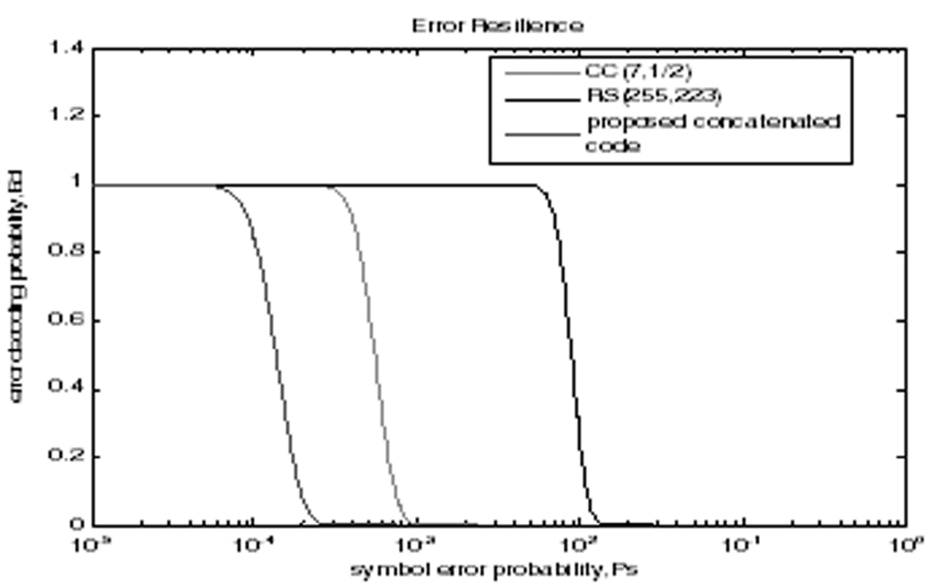

Figure 6: Curves for RS (255, 223), Convolutional code and concatenated RS (255, 223) / Convolutional code

- Convolutional code doesn't belong to a class of linear block codes. This code is important when working with low data rates. This also involves the presence of memory elements thus making the implementation of the system complex. At the cost of complexity still this is preferred because of its excellent performance at low data rates that are required in space communications. n_{min} is calculated by changing the rate, r with M=1784 and 'd = d_{free}'. The error decoding probability of this code is determined for different convolution rates, r = 1/2, 3/4, 5/6 and 7/8 and the plot is shown in Fig.4. The analysis shows that, convolution code with rate, r =1/2 is offering better error decoding probability.
- From Fig.1 to Fig.4 it is concluded that, among the linear block codes discussed RS (255,223) is found to be the optimal code in terms of error decoding probability. But this code is best used at high BER. In space communications, codes with low BER are preferred. Fig. 5 displays individually the error resilience plots for RS (n, k) with varying n and k and Convolution code.
- Codes working with further low BER are obtained by combining two or more codes. This is achieved by concatenating the Reed Solomon code of n=255 and k=223 with Convolutional code having constraint Length, K= 7 at a rate r = 1/2. These codes together are familiarly known as Concatenated codes. The error resilience plot for these codes is shown in Fig.6. This plot displays curves for optimal RS code and CC (7, 1/2) code. Finally, Concatenated RS (255,223)/ CC(7, 1/2) code, was observed to have better error decoding probability of around 10^{4} than individual codes as shown in Fig. 6. If code length increases evaluation of this parameter for such large values involves usage of a lot of memory and evaluation time. The computation of these values itself takes a lot of time and memory.

4. CONCLUSION

From the performance analysis, three important conclusions drawn are: 1. considering the discussed linear block codes it can be concluded that RS (255,223) is the optimal code. 2. From the class of non-linear codes, Convolutional code (7, 1/2) is chosen and proven to be a better code when compared to RS (255,223). 3. When these two codes are combined, called the concatenated code RS(255,223)/CC(7,1/2) it is found that much better performance is obtained than the individual codes alone that makes it to be used in diverse fields of wireless communications like space research deep space missions, Earth exploration Satellites, etc.

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