Efficient Convolutional Code Algorithm for Concatenated RS-CC Codes in Multipath Environment

Jyoti Dogra

Abstract—In the wireless communication, the error detection and correction techniques are widely used to achieve higher transmission efficiency. While transmitting the data, some coding techniques are deployed that provides the coding gain depending on its error correcting capability. Coding gain allows the wireless communication at lower transmit power level while maintaining low BER. Reed Solomon – Convolution concatenated coding technique provides significant improvement in case of burst and bit errors. In a convolutional encoder, for a constraint length of 7 and code rate of \( \frac{1}{2} \), the generator polynomial mentioned in the available literature are given by \( G_1 = 171_{\text{OCT}} \), \( G_2 = 133_{\text{OCT}} \). The aim of the paper is to design an efficient algorithm for convolution encoder that offers better error correcting capability, leading to lower BER. For the purpose a set of generator polynomial has been proposed and bit error rate has been simulated for different channels and different modulation techniques.

Keywords—BER, code rate, constraint length, Convolution, error correction, reed solomon

I. INTRODUCTION

With the current development, the wireless networks are supplementing or replacing the wired networks at enterprise, homes, campuses etc. The gigantic growth of wireless communicating devices is further pushing the demand for reliable and high data rate wireless communication networks. Design of wireless networks differs fundamentally from wired network design as a wireless channel is unpredictable in its behaviour and this effect becomes more significant at higher bit rates. Practically, low error rates can be achieved simply by increasing the transmitted power, but in mobile devices continuous power sources are not available, so alternative approach need to be devised to reduce the bit error rate in transmission to significantly lower values. Fading is a prominent cause for fading in a wireless communication system. Fading refers to the distortion that a modulated telecommunication signal experiences over a specific medium of propagation. In wireless communication, fading is primarily due to multipath components and is sometimes called as multipath induced fluctuations. Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by multiple paths. [1] Atmospheric ducting, scattering, refraction and reflection from terrestrial surrounding objects such as mountains and buildings are among causes of multipath propagation. Multipath propagation leads to constructive and destructive interference and phase shifting of the signal. This distortion or amplitude fluctuation of signals caused by multipath environment is named as fading.

II. AWGN CHANNEL

Additive White Gaussian Noise channel considers addition of wideband Gaussian distributed noise of constant spectral density. It doesn’t consider fading, dispersion or frequency selectivity and simply presents a mathematical model representing behavior of a communication channel in presence of white noise. Wideband Gaussian noise is inherent to the system and primarily arises due to thermal vibration. AWGN channel is of great importance for many satellite and deep space communication links but it is not as good model for most terrestrial links because of multipath, LOS blocking, interferences in the system. However, for terrestrial path simulations, AWGN is commonly used to simulate background noise in a communication system under study. The probability distribution function of random gaussian distribution is expressed as [2]

\[
f(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]

III. RICIAN CHANNEL

The Rician distribution is considered when; there exist a direct path between transmitter and receiver in addition to the multipath components. Such a direct path is also known as line-of-sight component. In the presence of such a path, the transmitted signal is given as:
\[
s(t) = \sum_{i=1}^{N} a_i \cos(\omega_d t + \omega_{dl} t + \phi_i) + k_d \cos(\omega_t + \omega_{dt})
\]

where the constant \( k_d \) is the strength of the direct component, \( \omega_{dl} \) is the Doppler shift along the LOS path, and \( \omega_{di} \) are the Doppler shifts along the indirect paths. The envelope in such a case has a Rician density function given by

\[
f(r) = \frac{r}{\sigma^2} \exp \left( -\frac{r^2 + k_d^2}{2\sigma^2} \right) I_0 \left( \frac{rk_d}{\sigma^2} \right), \quad r \geq 0
\]

where \( I_0 (\cdot) \) is the 0th order modified Bessel function of the first kind. The distribution of the Rician random variable is given as

\[
F(r) = 1 - Q \left( \frac{r}{\sigma}, \frac{k_d}{\sigma} \right), \quad r \geq 0
\]

where \( Q(\cdot, \cdot) \) is the Marcum’s \( Q \) function. The Rician factor \( k \), is often used to describe the Rician distribution. Here, \( k \) defined as the ratio between direct path and the indirect path. The Rician factor is generally expressed in decibels as

\[
K(dB) = 10 \log_{10} \left( \frac{k_d^2}{2\sigma^2} \right)
\]

In last equation, if \( k_d \) goes to zero, if the direct path is eliminated and the envelope distribution becomes Rayleigh, with \( K(dB) = -\infty \). [3]

IV. ERROR CONTROL CODING

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to interference, bit synchronization error, noise and distortion. Quantization errors also reduce BER performance, through incorrect or ambiguous reconstruction of the digital waveform. The accuracy of the modulation process and the effects of the filtering on signal and noise bandwidth also affect quantization errors. BER can also be defined as the probability of error (POE); as given in the following equation

\[
POE = \frac{(1 - \text{erf}(\sqrt{E_b/N_0}))}{2}
\]

The primary function of an error control encoder-decoder pair is to enhance the reliability of message during transmission of information carrying symbols through a communication channel. An error control code can also ease the design process of a digital transmission system by allowing lesser transmitted power, smaller antenna sizes and improved jamming margin.

The error control coding has emerged as a powerful and practical means of achieving efficient and reliable communication of information. Various error control schemes have been studied for wired as well as for wireless media. For encoding, additional bits are generally added by specific techniques so as to facilitate the decoding of a received sequence. The advantage of forward error correction techniques is that the reverse-channel is not sought and retransmission can often be avoided, at the expense of higher bandwidth. FEC is therefore preferred in circumstances where retransmissions are relatively costly or impossible.[4] The complete process of decoding is applied on the received sequence to detect error positions in the sequence and correct the erroneous symbols.

V. REED-SOLOMON CODES

Reed-Solomon codes are nonbinary cyclic codes with symbols made up of m-bit sequences. Here, \( m \) is any positive integer having value greater than 2. RS (n, k) codes on m-bit symbols exist for all n and k for which

\[
0 < k < n < 2m + 2
\]

where \( k \) is the number of data symbols that are to be encoded, and \( n \) is the total number of code symbols in the coded block. For the most conventional RS (n, k) code,

\[
(n, k) = (2m - 1, 2m - 1 - 2t)
\]

where \( t \) is the symbol-error correcting capability of the code and \( n - k = 2t \) is the number of parity symbols. Reed-Solomon codes achieve the largest possible code distance for any linear code with the same encoder input and output block lengths. Corresponding to each error, one redundant symbol is used to identify the error, and another redundant symbol is used to find its correct value. [5]

For a code to successfully combat the effects of noise, the duration of noise must be of relatively small percentage of the codeword. To ensure that this happens in most instances, the received noise should be averaged for a long time duration, reducing the effect of a freak streak of worst case. Hence, error-correcting codes become more efficient as the code block size increases, making R-S codes an attractive choice whenever long block lengths are desired.

VI. CONVOLUTIONAL ENCODER

Convolutional codes are like the block codes that involve the transmission of parity bits that are computed from message bits. Unlike block codes in systematic form, in convolution codes, the sender does not send the message bits followed by (or interspersed with) the parity bits; instead it sends only the parity bits. A sliding window approach is followed to calculate the parity bits by combining various subsets of bits in the window. The size of the window (in bits) is known as the code’s constraint length. The larger the constraint length, more are the parity
bits that are influenced by a specific given message bit. As only parity bits are sent over the channel, a longer constraint length generally implies a greater resilience to bit errors. If a convolutional code that produces “r” parity bits per window and slides the window forward by one bit at a time, its rate is 1/r. The greater the value of r, more is the resilience of errors, but at the same time larger bandwidth is devoted to coding overhead. In practice, it is preferred to pick “r” and the constraint length to be as small as possible while providing a low enough resulting probability of a bit error. [6]

A. Parity Equations

The fig1 shows one example of a set of parity equations, which govern the way in which parity bits are produced from the sequence of message bits, X. Here, the equations are as follows:

\[ p_0[n] = x[n] + x[n-1] + x[n-2] \]
\[ p_1[n] = x[n] + x[n-1] \]

In the RS-CC concatenated coding, after the Reed Solomon encoding, the data bits are further encoded by a binary convolution encoder. The generator polynomials used to derive the two output code bits, represented by X and Y, are given as:

\[ G_1 = 171_{OCT} \text{ for } X, \]
\[ G_2 = 133_{OCT} \text{ for } Y. \]

Schematically, the above mentioned convolution encoder can be described as shown in fig2.

A link from shift register feeding into the adder means a “one” in the octal representation of the polynomials, and no connection is represented by a “zero”.

VII. Methodology

Simulation results have been presented to describe the performance of Reed-Solomon Convolutional concatenated codes with the proposed algorithm considering random data source in Additive White Gaussian Noise (AWGN) and Rician channels. Further different orders of modulations have been simulated to analyze the bit error rate variations with respect to energy per bit to noise density ratio (E_b/N_0). In the presented results, MATLAB version 2008b has been used to simulate the bit error rate variation in different channels.

A. Simulation Parameters

Various parameters used in the simulation process, along with their specification have been enlisted in table1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT Size</td>
<td>64</td>
</tr>
<tr>
<td>Number of Sub Carrier</td>
<td>52</td>
</tr>
<tr>
<td>Number of Symbols</td>
<td>10^3</td>
</tr>
<tr>
<td>Sub-Carrier Index</td>
<td>{-26 to -1 to +1 to +26}</td>
</tr>
<tr>
<td>Modulation Schemes</td>
<td>16-QAM, 32-QAM, 64-QAM, BPSK, QPSK, 8PSK</td>
</tr>
<tr>
<td>Channel</td>
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</tbody>
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The design of proposed algorithm for convolution encoding is as shown in fig 5.1. The proposed set of polynomial effectively reduces the bit error rate without altering the number of connections and hence complexity remains the same. The graphical representation for the designed convolution encoder is as shown in fig 3.

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Fig. 3: Convolutional encoder for (172,135) generator polynomial
B. Performance of RS-CC encoding over AWGN channel

Two modulation schemes QAM, PSK have been simulated for AWGN channel. Arbitrarily high spectral efficiencies can be achieved with QAM by setting a suitable constellation size, depending on the noise level and linearity of the communications channel. While higher order modulation rates are able to offer much faster data rates and higher levels of spectral efficiency for the radio communications system but this comes at the cost of noise and interference i.e. the higher order modulation schemes are considerably less resilient to noise and interference. Fig 4 describes the flowchart of simulation model for RS-CC code over AWGN channel.

VIII. Results

The performance of an AWGN channel has been described in terms of the variation in BER with $E_b/N_0$. Fig 5 and Fig 6 depicts the behavior of QAM and PSK for three different modulation orders respectively.

It is evident from fig 5 that with the proposed algorithm for RS-CC encoding, the bit error rate for different orders of QAM modulation reduces to very low value, well before the limit of $E_b/N_0 = 10$. Also, it indicates the higher BER is inherently associated to higher order modulation. Despite this increase acceptable results can be obtained by encoding the transmitted signal. Similarly, fig 6 depicts the specific values of bit error rates for different order psk modulation in AWGN channel that too follows a monotonic decrease in BER.

The simulation procedure for the bit error rate analysis in rician channel is similar to AWGN channel. For the purpose different orders of QAM and PSK have been
simulated and consequently the results have been presented. The variation for BER in rician channel for various QAM modulation schemes is as shown in fig 7.

Fig. 7: Variation of BER with Eb/No in Rician Channel

All the considered modulation schemes show a significant monotonic decrease in bit error rate. Similarly the variation for various PSK modulation schemes is as shown in fig 8.

Fig.8: Variation of BER with Eb/No in Rician Channel

IX. RESULT

The research motivation for this thesis work was to develop a new algorithm providing lower bit error rate with RS-CC concatenated codes in wireless multipath environment. In this work, a new set of polynomials have been proposed by changing the algorithm for convolutional codes and lower bit error rate have been presented in results. Suggestions for the future work include analysis of the performance in other modulation techniques such as Gaussian Minimum Shift Keying (GMSK) and by considering other fading models like Nakagami fading.

References


