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Utilisation of Multipath Phenomenon to Improve the Performance of BCH and RS Codes

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Abstract—In wireless communication, there exists a phenomenon known as ‘multipath’. This phenomenon is considered as a disadvantage because it causes interference. The multipath phenomenon results in an antenna receiving two or more signals from the same sent signal from different paths. This paper considers them as redundant copies of the transmitted data and utilises them to improve the performance of forward error correction (FEC) codes without extra redundancy, in order to improve data transmission reliability and increase the bit rate over wireless communication channels. The system was evaluated in bit error rate (BER) and used Bose, Ray-Chaudhuri and Hocquenghem (BCH) and Reed-Solomon (RS) codes as FEC. The results showed that the utilisation of the multipath improves the performance of FEC. Furthermore, the performance of FEC codes had $t_1$ error correction capability and employed the multipath is better than FEC codes have $t_2$ error correction capability and without the multipath, where $t_1 < t_2$. Consequently, the bit rate is increased, and communication reliability is improved without extra redundancy.

Keywords: Multipath, propagation, Phenomenon, FEC, BCH, Reed-Solomon, Hamming weight Combiner, SNR.

I. INTRODUCTION

The past decade or so has witnessed remarkable growth in the demand for providing reliable communication links and high transmission rates. A reliable digital communication system involves the sending and receiving of data with no error [1] [2]. The wireless communication system is prone to a certain level of noise, reflection, diffraction, shadowing and fading. Furthermore, the signal that is transmitted through wireless channel arrives at the receiver via a number of different paths, called multipath, and this leads to fading (signal distortion and burst errors) [3]. Therefore, transmission reliability is very challenging on wireless channels. One of the most widely used techniques to provide reliable communication is Forward Error Correction (FEC). The investment of FEC requires either increasing channel bandwidth or the rate of the transmission must be decreased [4]. Therefore, the high transmission rate and transmission reliability need high bandwidth, but the bandwidth is a substantial issue for communication. This means that the increasing of the bandwidth it’s not a wise decision [5]. In contrast, the multipath phenomenon can be utilised to improve communication reliability and increases transmission rate without increasing bandwidth. In this paper effectiveness of multipath phenomenon in order to improve the error correction capability (transmission reliability) with less redundancy as much as possible is considered. So in this paper, Reed-Solomon (RS) and Bose, Ray-Chaudhuri (BCH) codes with different parameters are used to provide high data rate transmission and analysis the communication performance with and without multipath propagation.

The paper is organised as follows. Related work is given in section II. A brief overview of FEC is presented in section III. Multipath phenomenon is described in section IV. The methodology is explained in section V. In section VI the proposed combiner is described. Simulation parameters and results and discussion are presented in section VII with the conclusions in section VIII.

II. RELATED WORK

Recently, research has shown intense interest towards analysing the performance of various FEC techniques rather than how to improve it without extra redundancy. The researchers did not take into consideration the positive effect of the multipath phenomenon on the performance of FEC and how it could be utilised to improve FEC capability. Some authors have compared the performance regarding bit error rate (BER) of different forward error correction codes such as RS, convolutional code (CC), RS-CC, and CC-RS codes [5]. They evaluated the BER of CC at various code rate. Likewise, they evaluated performance for RS codes for different code rate as well as block length. Furthermore, they compared the performance of both CC-RS and RS-CC concatenated codes with the individual codes and with encoded data transmission. There are authors examined the performance of RS codes with Binary Phase-shift keying (BPSK) and Quadrature Phase-Shift Keying (QPSK) modulation over Additive White Gaussian Noise (AWGN) channel [6]. Additionally, they compared the performance of RS codes with the BCH codes. After examining the results, they found the RS codes performance is better than the BCH code. While some authors performed RS codes for Phase-Shift Keying (PSK) modulation in a
communication noisy channel (AWGN). They performed the simulation of RS codes for the same code rates. They showed that the BER performance is poor for lower Eb/N0. On the other hand, the BER performance improved for large block lengths [7]. Moreover, other authors have simulated RS and BCH code in the presence of a Rayleigh fading channel and have shown that the BCH code exceeds RS code in the binary environment [1].

While this paper investigates the possibility of utilising the multipath phenomenon to improve the performance of FEC. Also, analysis the effectiveness of utilisation multipath propagation on the error correction capability of FEC with low redundancy. Furthermore, proposed a combiner based on Hamming weight to combine the selected paths (redundant copies of transmitted signal) in one strong signal to decode it.

III. FORWARD ERROR CORRECTION

Appropriate technique is necessary to overcome the problem of errors that are introduced during the transmission which occurs due to inter-symbol interference (ISI), multipath phenomenon and noise. The FEC is used for combatting this issue in a communication system. Generally, FEC techniques add some redundancy to the data which enables the receiver to detect and correct errors. BCH and RS codes are FEC techniques which work by appending extra data at the end of each message that known as a codeword, see Fig. 1. This section shows some preliminaries of BCH and RS codes.

A. BCH Codes

BCH codes is a kind of binary cyclic code discovered Bose, Ray-Chaudhuri, and Hocquenghem [9]. This code has been studied intensively due to the strict algebraic structure introduced in the codes. In the BCH codes, the codewords are created by dividing a polynomial \( m(x) \) by a generator polynomial \( g(x) \) and taking the remainder which will be presented as a parity check bits \( r(x) \). The encoded data \( C(x) \) will be constituted as:

\[
C(x) = m(x) + r(x)
\]  

(1)

The characteristics of the code are determined by the selected generator polynomial \( g(x) \). For integers \( m \) and \( t \), the BCH can correct \( \leq t \) independent errors and its possible codes are [1].

- Block length: \( n = 2^m - 1 \)
- Parity check bits: \( n - k \leq m \ t \)
- Minimum distance: \( d \geq 2t + 1 \)

Where \( m \geq 3 \), \( t < 2^{m-1} \) and the distance represents Hamming distance.

The decoding procedure of this code is more complicated and performed in three steps [9] [10].

- Calculate the syndrome from the received codeword. The syndrome vector is only a function of the error pattern.
- The error location polynomial is found by using a set of equations derived from the syndrome; and
- Erroneous bits are corrected by using the error location polynomial.

One of the most significant advantages of this code is quite simple to be encoded and easy to be decoded. The decoder can simply implement compared with modern coding technology such as turbo and Low-Density Parity-Check (LDPC). Another advantage is the BCH code can detect and correct errors up to nearly 25% [11].

B. Reed-Solomon Codes

The RS codes belong to the family of BCH codes, but the symbols in this code are nonbinary (multi-bit per symbol (integer)). RS codes are very efficient for dealing with bursts of errors [12] because, even if all bits of one symbol are in error, this counts as only one symbol error in terms of the correction capacity of the RS code.

For integers \( m \) and \( t \), the RS possible codes are:-

- Block length: \( n = 2^m - 1 \)
- Parity check bits: \( n - k = m \times 2t \)
- Minimum distance: \( d = m \times 2t + 1 \)

Where \( m \) represents the number of bits per symbol, \( n \) represents the number of symbols in each codeword and \( t \) is the number of symbol errors that can be corrected in a codeword, where:

\[
t = \begin{cases} 
\frac{n - k}{2} & \text{if } (n - k) \text{ even} \\
\frac{n - k - 1}{2} & \text{if } (n - k) \text{ odd}
\end{cases}
\]

(2)

The codewords are formatted by first multiplying the data by \( x^k \), then divide the result by the generator polynomial, \( g(x) \), to produce a quotient \( q(x) \) and a remainder \( r(x) \). The transmitted codeword \( T(x) \) will be presented as:

\[
T(x) = m(x) \times x^{n-k} + r(x)
\]

(3)

The general decoding process steps of RS code are [13] (Wicker and Bhargava, 1994):

- From the received codeword calculate the syndrome. The syndrome is about error pattern which can derive directly from the received data [14]);
- Find the error locator and error value polynomial by using 2t nonlinear equations derived from the syndrome; and
- Correct corrupted symbols by using the error location and error value polynomial.

The major advantage of the RS code is the capability of correcting both burst error and erasures. RS codes have a special attraction because its efficiency is growing with code length [15].
IV. MULTIPATH PROPAGATION

The multipath phenomenon is caused by atmospheric ducting, reflective surfaces (including water, building and mountains) and ionospheric refraction [16]. This phenomenon results in the receiver antenna receiving two or more copies of the same signal via different routes, see Fig. 2. The different path lengths cause each signal to have a different propagation delay. The first received signal is known as the Line of Sight (LoS) and the other signals are Non-Line of Sight (NLoS).

Since all paths differ in their transmission length and propagation delay, the receiver could probably separate some of them and obtains two or more copies from the transmitted signal if the following condition satisfies [17].

\[
\frac{\text{speed of light}}{\text{chip rate}} \leq L \quad \rightarrow \quad \frac{3.0 \times 10^8 \text{ms}^{-1}}{\text{chip rate}} \leq L \tag{4}
\]

Where \( L \) is the difference in path lengths. In this case, the delay time (\( \tau \)) need it to receive uncorrelated path is:

\[
\frac{L}{\text{speed of light}} = \frac{L}{3.0 \times 10^8 \text{ms}^{-1}} \tag{5}
\]

For example, Wideband Code Division Multiple Access (WCDMA) receiver if the chip rate is 5Mcps then \( L \) will be at least 60 m and the chip duration or multipath delay \( \tau \) is equal to 0.2 \( \mu s \) which will be enough to separate the multipath components to obtain more than copies. Table 1 shows different chip rates and the delay time which need it. In order to provide a wireless communication system with a high data transmission rate, these copies are employed to increase the error correction capability of RS and BCH code without add more redundant bits.

<table>
<thead>
<tr>
<th>Chip Rate in Mcps</th>
<th>Delay ( \tau ) in ( \mu s )</th>
<th>Path Length at less ( L ) in m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>3.84</td>
<td>0.26</td>
<td>78.125</td>
</tr>
<tr>
<td>10</td>
<td>0.1</td>
<td>30</td>
</tr>
</tbody>
</table>

V. METHODOLOGY

The coding/decoding simulation of BCH and RS code is performed by simulating using Matlab. Fig. 3 shows the block diagram of coded wireless communication system using BCH and RS code with the existing of multipath propagation.

In the transmitter side, \( k \) bits sequence of a random number of 1 and 0 are generated by the random number generator block and input to the BCH/RS encoder block. The encoder block maps \( k \) bits sequence into \( n \) bits sequence. After that the \( n \) bits are passed to the modulation block (digital modulator). The modulator uses a BPSK scheme to modulate the data into a waveform signal. The AWGN channel block is designed to introduce fading effect and add AWGN noise to the modulated signal. The channel block helps to study and analyse the effect of actual signal properties.

At the receiver side, \( L \) signals are chosen (LoS and \((L-1)\) from NLoS). The threshold which is used to choose \( L \) paths was selected randomly for each transmission. It represents the minimum signal-to-noise ratio (SNR) that can be accepted to consider the received signal as a copy of the original transmitted signal. If the received signal has SNR less than the threshold, the receiver will ignore it. The threshold depends on and ranges between 40% and 75% from the SNR of LoS signal. After selected \( L \) signals (copies), the signals are first demodulated by demodulation block to get the coded signals. After that, the demodulated signals pass to the combiner block to combine them into one strong signal. The BCH/RS decoder block takes the result of the combiner block as an input and performs the appropriate decoding operation to recover the transmitted signal. The final step in the simulation is to compute the BER to analyse and study the performance of the coded communication system with and without the existing of multipath propagation. The BER calculator block is designed for this purpose.

VI. HAMMING WEIGHT COMBINER

This paper proposes a combiner based on Hamming weight (\( w_n \)) to combine the LoS and NLoS signals. This combiner receives \( L \) copies from one transmitted signal as input (\( L \) should be odd number and include the LoS signal), then arranges them in \( L \times N \) matrix:

\[
L_c = \begin{bmatrix}
C_{11} & C_{12} & \cdots & C_{1(n_2 \times n_2)} \\
C_{21} & C_{22} & \cdots & C_{2(n_2 \times n_2)} \\
\vdots & \vdots & \ddots & \vdots \\
C_{L1} & C_{L2} & \cdots & C_{Ln_2(n_2 \times n_2)}
\end{bmatrix}
\tag{6}
\]

\[
y_{ij} = \begin{cases} 
0 & \text{if } w_{hi,j}(C_{1j},C_{2j},C_{3j},\cdots,C_{Lj}) < \frac{L+i}{2} \\
1 & \text{if } w_{hi,j}(C_{1j},C_{2j},C_{3j},\cdots,C_{Lj}) \geq \frac{L+i}{2}
\end{cases}
\tag{7}
\]
Where \( i = 1, 2, \ldots, L \) and \( j = 1, 2 \ldots (n_1 \times n_2) \). For example, assume that \( L = 5 \) and \( N = 10 \), which it means that there are five codewords each one contains 10 bits, \( C_1 = [0 1 0 1 0 1 1 0 0 0] \), \( C_2 = [1 1 1 0 1 1 0 0 0] \), \( C_3 = [0 0 0 0 0 1 1 0 0 0] \), \( C_4 = [1 1 1 1 1 1 1 1 1 1] \), and \( C_5 = [0 0 0 0 0 0 0 0 0 0] \). The matrix will be like the below:

\[
L_c = \begin{bmatrix}
C_1 \\
C_2 \\
C_3 \\
C_4 \\
C_5
\end{bmatrix}
\]

After calculating \( W_{i1}, W_{i2}, \ldots, W_{i1.10} \), \( Y \) will be:

\[
Y = [0 1 0 1 1 0 0 0 0 0].
\]

Fig. 4 shows that the combined packets improved the system performance, where the improvement is increased when the number of combined paths are increased. Also, the performance improvement depends on the threshold value, see Fig. 5.

![Figure 4](image)

**Figure 4. BER vs. (Eb/N₀) of Hamming weight combiner. 3, 5, 7 and 9 paths are combined**

![Figure 5](image)

**Figure 5. BER vs. (Eb/N₀) of Hamming weight combiner with different threshold values.**

![Figure 6](image)

**Figure 6. BER vs. (Eb/N₀) of BCH (15, 11) code with and without multipath propagation**

![Figure 7](image)

**Figure 7. BER vs. (Eb/N₀) of RS (15, 13) code with and without multipath propagation.**

**VII. RESULTS**

In this paper, analysis of BCH and RS codes over AWGN channel has been performed. The block length of \((n_1, k_{11})\) and \((n_2, k_{12})\) for BCH code where \(k_{11} > k_{12}\), and \((n_2, k_{21})\) and \((n_2, k_{22})\) for RS code where \(k_{21} > k_{22}\) are simulated with 3, 5, and 7 paths. The threshold value was set as 75% from SNR of LoS signal to choose NLoS signals. The BER ratio was computed by changing \(E_b/N_0\) from 1 to 21.

Fig. 6 and 7 show that BCH and RS codes with multipath consistently performed better than BCH and RS codes without multipath in an AWGN channel under a binary environment. It can be seen that combining 3, 5, and 7 coded paths result in a better slope than solely the coded LoS. The absolute BER performance of BCH and RS codes is approximately 3 dB for 3 combining paths, 4 dB for 5 combining paths and 6 dB for 7 combining paths better than the coded LoS at a BER of 10\(^{-3}\).

BCH (15, 11), BCH (127, 120) and BCH (255, 247) codes have error correction capability \( t = 1 \). While the error correction capability of BCH (15, 7), BCH (127, 113) and BCH (255, 239) codes is \( t = 2 \). Fig. 8, 9, and 10 show that the combining of three paths improved the performance of BCH (15, 11), BCH (127, 120) and BCH (255, 247) codes approximately by 3dB, 2.8dB and 2.75dB respectively at a BER of 10\(^{-3}\). Furthermore, their performance is better than BCH (15, 7), BCH (127, 113) and BCH (255, 239) codes approximately by 0.75dB, 0.85dB and 1dB respectively at a BER of 10\(^{-3}\).
Similarly, the RS (15, 13), RS (127, 125) and RS (255, 253) codes have error correction capability $t_1=1$ and RS (15, 11), RS (127, 123) and RS (255, 251) codes is $t_2=2$. Fig. 11, 12 and 13 show that the performance of RS codes with $t_2$ error correction capability is better than RS with $t_1$ error correction capability after utilising three paths.

The results indicate that BCH and RS codes without multipath show poor results for lower $E_b/N_0$. But for higher values of $E_b/N_0$, BCH, and RS codes gives a good performance.

On the other hand, the BCH and RS codes with multipath show a good result for both lower and higher values of $E_b/N_0$.

The achievement is: due to combining the multipath signals at the receiver side, FEC with lower error correction capability improved to perform better than some of the FEC with higher error correction capability as shown in Fig. 8-13.

VIII. CONCLUSIONS

This paper shows that the performance of FEC codes can be improved. Furthermore, it shows that an FEC with low redundancy and low error correction capability performed better than the one with higher redundancy and higher error correction capability. The performance of BCH(15, 11) with one error correction capability is better than BCH(15, 7) with two errors correction capability. Also, the performance of RS(15, 13) with one error correction capability is better than RS(15, 11) with two errors correction capability. Moreover,
the performance of BCH codes is improved more than the performance of RS codes have the same errors correction capability. This is achieved through utilising an existing phenomenon in the wireless communication called multipath propagation and proposing a combiner known as Hamming weight combiner with low complexity. The improvement in the performance of FEC increased by increasing the number of combined paths.

In possible future work, this research could be extended by analysing and evaluating the performance of FEC techniques with high modulation schemes, multiple-input multiple-output (MIMO) systems and over different wireless channel models. As open research topics, it is recommended to take one of the following further:

- The performance of FEC codes which utilise the multipath phenomenon can be compared with turbo code performance.
- The performance of LDPC code can be compared with the performance of FEC codes which employ the multipath phenomenon.
- The performance analysis can be extended to codewords with different lengths.
- Analyse the overall system and compare it with turbo and LDPC codes in term of complexity and overhead.

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REFERENCES