



A Novel Unequal Error Protection scheme employing binary BCH codes and Hierarchical 8PSK modulation for wireless channels.

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Abstract: In several applications of digital transmission such as video, images, voice and data, the importance of different bits in the input sequence of the channel encoder often varies and certain blocks of this sequence need higher protection level than other blocks, when this sequence is transmitted through a wireless channel. An error-correcting code which provides a selective level of protection to the information bits possesses a property called unequal error protection (UEP). UEP can be obtained either by using separate coding schemes with distinct error-correction capability for each level of protection or by using a hierarchical modulation with UEP capability. In this paper, a novel class of UEP for wireless Rayleigh fading channels is introduced which uses binary BCH codes together with hierarchical 8PSK modulation. The UEP scheme is designed and implemented using MATLAB R2013a.

It is shown that the UEP scheme employing 1/2-rate BCH codes and hierarchical 8PSK modulation outperform the corresponding scheme based on uniform 8PSK modulation. Simulation results reveal that for the overall 1/2-rate UEP scheme and at a BER of 10^{-5} , the hierarchical 8PSK modulator with modulation parameter $\beta=0.30$ yields a gain of around 6 dB in E_b/N_0 over the non-hierarchical 8PSK modulation case. Furthermore, it is shown that the novel UEP design is better than that of Yamazaki et al.[1] and at a BER of 10^{-5} this design gives a gain of around 3 dB over the latter.

Keywords: Unequal error protection, Linear Block codes, BCH codes, Hierarchical 8PSK modulation, wireless Rayleigh channel.

I. Introduction

In recent years conveying multiple types of data with different priorities are being studied. For example, due to the fruitful and diversified contents of multimedia traffic and the vulnerable environment of wireless communications, applying unequal error protection (UEP) is now an active research topic. Almost all algebraic codes previously considered in the literature have the property that their error-correction capabilities are described in terms of correcting errors in code words rather than in correcting errors in individual digits of a code word. For example, a t error correcting code will decode to the correct code word if t or fewer errors occur in the transmitted word [2-4].

In some circumstances it may be advisable to vary the amount, of error protection from block of digits to block of digits. Consider the problem of an observer transmitting the results of many simultaneous experiments (as from a satellite). Some of the experiments may be more important than others and therefore may be deserving of higher-error protection. While this could be accomplished by using a separate code for each experiment, it would usually be more efficient, and more desirable to use one code, and thus one encoder and one decoder.

One of the UEP is performed through Rate Compatible Puncture Convolution codes (RCPC) [5,6], with rate chosen according to the perceived importance of bits. Another well known UEP technique is based on the hierarchical modulation approach [7-10], in which the more important data are mapped to the most significant bits (MSB) of the modulation constellation points and the less important data is mapped to the least significant bits (LSB) of the PSK constellation. They are aimed at improving quality through decreasing the BER(Bit Error Rate) of the more important data.

From another study, it is found that UEP can also achieve significant improvement by combining non-uniform QAM with TCM (Trellis Coded Modulation) [11-15]. TCM is a combined coding and modulation technique for digital transmission over band-limited channel. Results show that it will further improve the overall BER once we employ the Convolutional Codes to the degrading bits due to differentiating grade of quality. In [16] DVB-T2 standard employed a combination of LDPC and BCH (Bose-Chaudhuri-Hocquenghem) code for unequal error protection of terrestrial broadcast data.

In this paper, UEP codes are investigated in which certain digits of a code word are protected against a greater number of errors than other digits in the code word. Specifically, assigned to each digit of the code words is an

error protection level. This research aims at designing and implementing UEP codes with 3 levels of protection namely High, Medium and Low. As mentioned above the literatures for UEP employing convolutional codes, TCM and LDPC codes have been widely studied. In this work a novel UEP scheme employing binary BCH codes and Hierarchical 8 PSK modulation is presented. To reduce complexity of the new design low-complexity syndrome decoding at the BCH decoder is used.

Section 2 describes the basic encoding and decoding principles of binary BCH codes. In section 3 the concept of Hierarchical 8 PSK modulation and how it will be used in this propose work to achieve unequal error protection is described. The UEP scheme is designed and its details are fully explained in section 4. The experimental set-up and simulation results with all system parameters are given in section 5 as well as discussions of the results are presented in this section. Section 6 concludes the paper.

II. Binary BCH Codes

The BCH code is an amazing generalization of the hamming code for more than one error detection and correction. The BCH codes have been subject to lots of attention and studies since it was invented. The BCH code allows the user to control the block length and the acceptable number of errors. Therefore the BCH code can be custom built for given specification [4].

The complexity of decoding convolutional codes (Viterbi) increases exponentially as the constraint length increases [4]. The main advantage using the BCH code is the decoding process called the syndrome decoding algorithm [4]. The syndrome decoding is implemented using simple electronic devices and can easily be done without the help of PC's. The decoding device can be made very compact and operating on low power batteries. For any positive integers $m(m \geq 3)$ and t ($t < 2^{m-1}$), there exists a binary BCH code with the following parameters:

The block length: $N=2^m -1$
 Number of parity check: $N-K \leq mt$
 Minimum distance: $d_{\min} \geq 2t+1$

The BCH code can correct up to t errors and is commonly called as t -errors-correcting BCH code [4]. The encoding of such a code begins by defining a Galois field. The Galois field is also called the finite field. A Galois field containing q elements is denoted as $GF(q)$. The generator polynomial $g(X)$ has the following roots: $\alpha, \alpha^2, \alpha^3, \dots, \alpha^{2t}$. Also its conjugates are also roots.

The non-zero elements of the $GF(2^m)$ are roots of $X^{2^m-1} + 1$ and all the roots of $g(X)$ are elements of $GF(2^m)$. Therefore it can be said that $g(X)$ divides $X^{2^m-1} + 1$ ($g(X)$ is a factor of $X^{2^m-1} + 1$) this can be used to generate a cyclic code of length $2^m - 1$. Therefore the generator polynomial for a t -error-correcting binary BCH code of length $2^m - 1$ is given by

$$g(X) = \text{LCM}\{\phi_1(X), \phi_2(X), \dots, \phi_{2t}(X)\}$$

For $1 \leq i \leq 2t$, let Φ_i be the minimal polynomial of α^i . If i is an even integer, it can be termed as $i=i'2^L$, where L is a positive integer. Then α^i is a conjugate of $\alpha^{i'}$ and hence they have the same minimal polynomial.

$$\phi_i(X) = \phi_{i'}(X)$$

Every even power of α is a sequence of $\alpha, \alpha^2, \alpha^3, \dots, \alpha^{2t}$ and has the same minimal polynomial as odd power α in the sequence. Therefore the generator polynomial can be reduced to:

$$g(X) = \text{LCM}\{\phi_1(X), \phi_3(X), \dots, \phi_{2t-1}(X)\}$$

There are only t minimal polynomials in the above equation, the degree in $GF(2^m)$ is at most m and the degree of $g(X)$ is at most mt .

Therefore the t -error-correcting binary BCH code generated by $g(X)$ has at most mt parity check bits and its dimension at least $2^m - mt - 1$. The BCH codes generated are called as primitive or narrow sense BCH codes since they are constructed from primitive elements α in $GF(2^m)$.

The BCH decoding procedure is simple and fast and can be done in the following steps [4]:

1. Compute the syndrome $S = (S_1, S_2, \dots, S_{2t})$ of the received polynomial $r(X)$.
2. Determine the error location polynomial $\sigma(X)$ from the Newton identities.
3. Determine the roots $\beta_1^{-1}, \beta_2^{-1}, \dots, \beta_\nu^{-1}$ of $\sigma(X)$ and take the inverses of these roots to obtain the error location numbers $\beta_1 = \alpha^{j_1}, \beta_2 = \alpha^{j_2}, \dots, \beta_\nu = \alpha^{j_\nu}$.
4. Form the error pattern $e(X) = X^{j_1} + X^{j_2} + \dots + X^{j_\nu}$.
5. Error correction is performed by adding(modulo-2) $e(X)$ to $r(X)$ to give the code polynomial $v(X)=r(X)+e(X)$.

III. Hierarchical 8-PSK modulation

Non-Hierarchical or uniform 8 Phase Shift Keying (PSK) uses 8 different possible phases to send 3 bits per symbol. The data rate is therefore doubled compared to the QPSK for the same bandwidth. Non-uniform 8PSK consists of mapping the 8 constellation points at different angles rather than uniform angle separation between points [9,10]. The angle between the points can be represented as follows:

$$\theta_i = \frac{\pi}{2} \beta^i \text{ for } i=1, 2, 3, \dots, m-1$$

m : number of bits used for one symbol

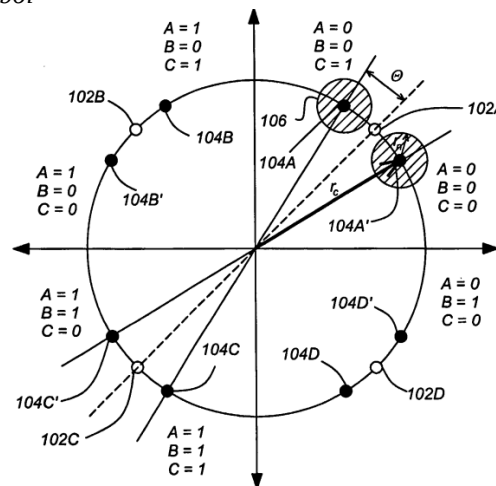


Fig. 1: Hierarchical or non-uniform 8PSK constellation

Fig. 1 shows how the points are represented on the constellation diagram. The phase angles vary according to the Beta (β). The reason for fixing the ratio of the angles for any subsequent levels of the signal constellation hierarchy β to a constant is to facilitate the phase offset optimization (i.e., only a single parameter needs to be optimized rather than manipulating $(m-1)$ variables[10]). Non uniform 8PSK has shown better performance than uniform PSK [9,10]. When Beta (β)=0.5, the constellation becomes similar to a uniform 8PSK constellation. For this research work, beta is varied from 0.3 to 0.5 in steps of 0.05. Also, the modulator is designed and implemented based on the mapping rules given next.

Phase Angle	Signal	Symbol
$\left(\frac{\beta\pi}{2}\right) + \left(\frac{\beta^2\pi}{2}\right)$	S_0	000
$\left(\frac{\beta\pi}{2}\right) - \left(\frac{\beta^2\pi}{2}\right)$	S_1	001
$2\pi - \left[\left(\frac{\beta\pi}{2}\right) + \left(\frac{\beta^2\pi}{2}\right)\right]$	S_2	010
$2\pi - \left[\left(\frac{\beta\pi}{2}\right) - \left(\frac{\beta^2\pi}{2}\right)\right]$	S_3	011
$\pi - \left[\left(\frac{\beta\pi}{2}\right) + \left(\frac{\beta^2\pi}{2}\right)\right]$	S_4	100
$\pi - \left[\left(\frac{\beta\pi}{2}\right) - \left(\frac{\beta^2\pi}{2}\right)\right]$	S_5	101

$$\pi + \left[\left(\frac{\beta\pi}{2} \right) + \left(\frac{\beta^2\pi}{2} \right) \right] \quad S_6 \quad 110$$

$$\pi - \left[\left(\frac{\beta\pi}{2} \right) - \left(\frac{\beta^2\pi}{2} \right) \right] \quad S_7 \quad 111$$

IV. Proposed UEP System Design

In this work, MATLAB R2013^R Simulink^R is used to design the UEP scheme. Fig. 2 below shows the complete UEP model with 3 levels of protection. It is proposed to divide the bitstream into three priorities and apply equal BCH coderate encoders to each priority for different packets based on their importance. UEP is achieved by applying Hierarchical 8PSK modulation where the most significant bit (MSB) is given more protection than the least significant bit (LSB), thus creating unequal error protection at bit level.

From the design of Fig. 2 the Bernoulli Binary Generator generates a bitstream and a demultiplexer is used to split the bitstream into 3 priorities which are fed to BCH encoders of rate 64/127. To exploit unequal error protection hierarchical 8PSK modulation is used which accepts one bit from each priority and maps them onto the non-uniform 8PSK constellation diagram of Fig. 1 with signal coordinates given in section II.

The modulated signal is then fed to the wireless baseband multipath Rayleigh fading channel with Doppler frequency of 500 Hz. The Jakes model is chosen because it is a deterministic model and the signal scatters uniformly across the medium and emerge uniformly at the receiver side. The Rayleigh Multipath Fading includes complex path gains which need to be removed from the signal. The block consists of a circuit which removes the gain occurred during multipath and converge all signal onto one resulting signal. Additive White Gaussian Noise (AWGN) is then added to the faded signal resulting in a corrupted one. The Signal to Noise Ratio per bit or E_b/N_0 in this block is varied to measure the performance of our UEP design. At the receiver side demodulation of the signal is carried out using hard decision and the value of beta followed by the syndrome decoding of the BCH decoder.

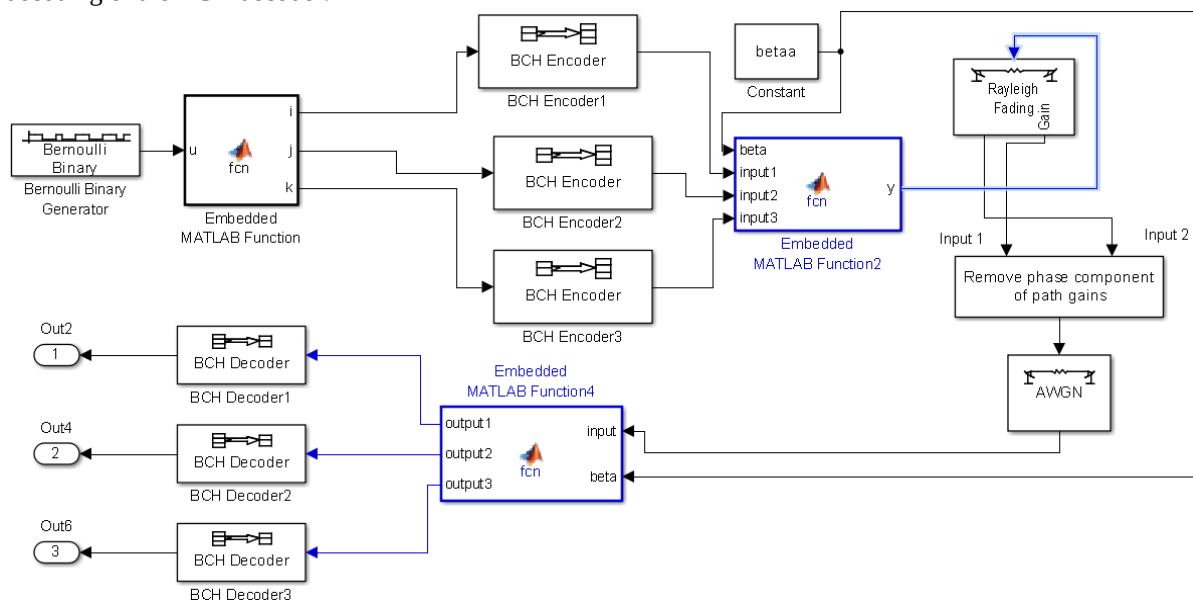


Fig. 2: Proposed UEP system design in Matlab R2013a Simulink

The UEP model is executed under the following circumstances to test its reliability and robustness

1. AWGN (E_b/N_0) is varied from -4dB to 20dB in steps of 2dB.
2. Beta is known as the priority element. Beta is varied from 0.3 to 0.5 in steps of 0.05.

The bit stream generated by the Bernoulli binary generator is recorded and also the output bit stream. This process is iterated for all the above variables (beta, AWGN) and the Bit Error Rate (BER) is calculated.

V. Simulation results and Discussions

The experiment is set up by using MATLAB R2013a, Simulink model Communication blockset. The built in Rayleigh and AWGN MATLAB R2013a Simulink channel models were used. The experiments were conducted by varying the Signal to Noise Ratio per bit (E_b/N_0) and the non-uniform 8-PSK modulation design parameter β from 0.30 to 0.50 in steps of 0.02. Figure form 3 to 7 presents the BER performance for the three levels of protection. It can be clearly seen that while the modulation parameter beta is varied UEP is perfectly achieved

by our new design. At $\beta=0.30$ and a BER of 10^{-4} the highest prioritized queue yields a gain of around 6 dB over the medium priority data. This result and the subsequent simulations confirm that UEP is efficiently achieved in the design. From the simulations of Fig. 8 it can be clearly observed that for all the designed UEP schemes and for the Highest prioritized queue, as β increases from 0.30 to 0.50 the error rates reduces, hence both the BCH code as well as the non-uniform 8PSK modulator have more UEP capabilities than the uniform case.

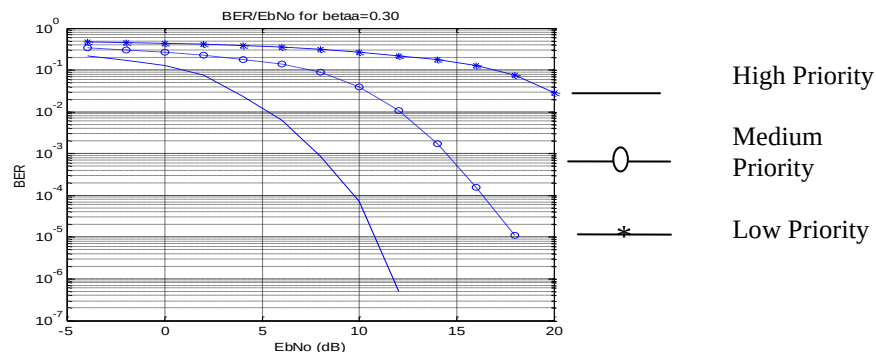


Fig. 3: Bit error performance at $\beta=0.30$

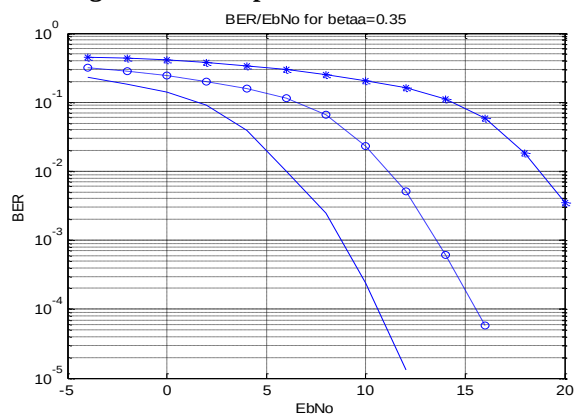


Fig. 4: Bit error performance at $\beta=0.35$

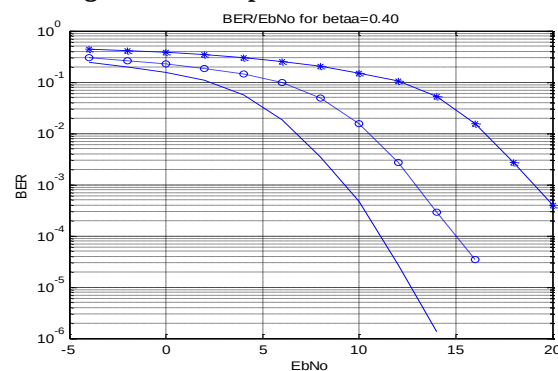


Fig. 5: Bit error performance at $\beta=0.40$

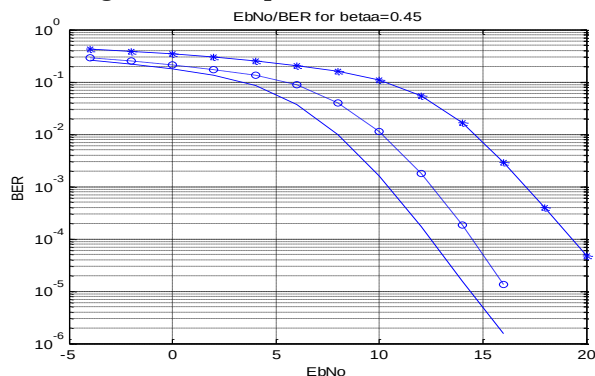


Fig. 6: Bit error performance at $\beta=0.45$

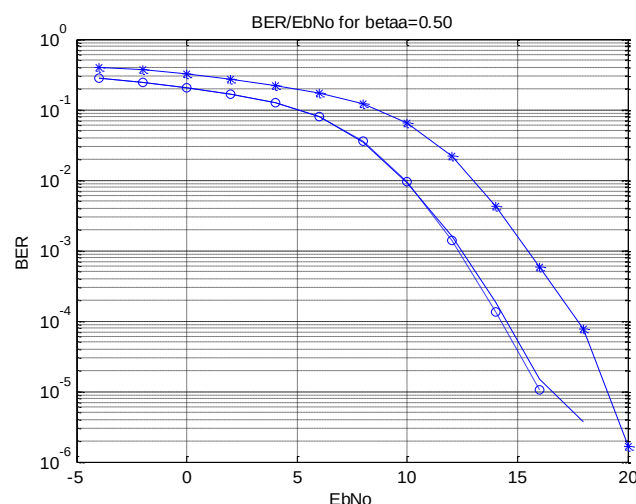


Fig. 7: Bit error performance at beta=0.50

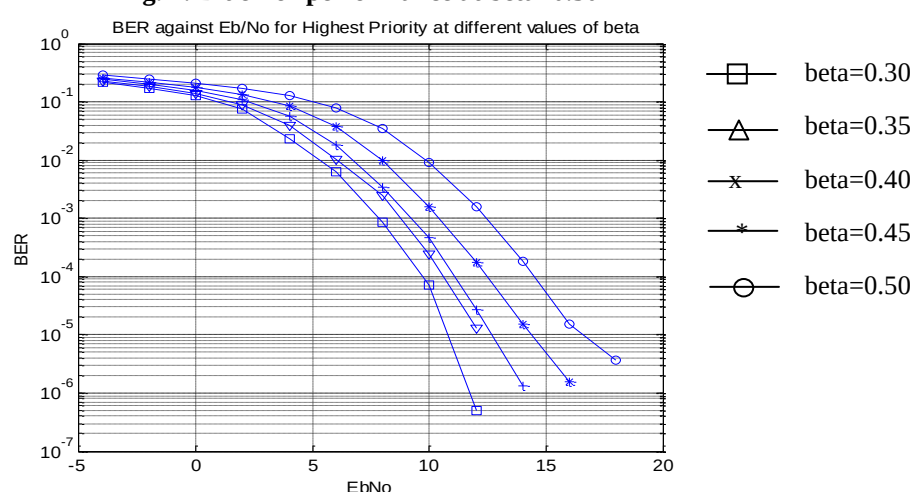


Fig. 8: Bit error performance for the Highest priority at different values of beta.

Fig. 9 compares the newly reported results at values of beta=0.30 and 0.35 with one previous work in Unequal Error Protection that has been designed in a similar way to this work. Yamazaki et al [1] used 3RING 8 PSK modulation and Trellis-Coded modulation to send prioritized data over the Rayleigh and AWGN channels. They also considered adaptive equalization in their design. Fig. 9 shows that these results are better than Yamazaki et al. [1] for values of EbNo above 8 dB. The implementation can be further extended to hierarchical 8QAM and since the average power transmitted is higher than that of 8PSK it is expected that further performance improvements will be obtained. Therefore it can be deduced that this novel UEP scheme can find several applications in multimedia communications.

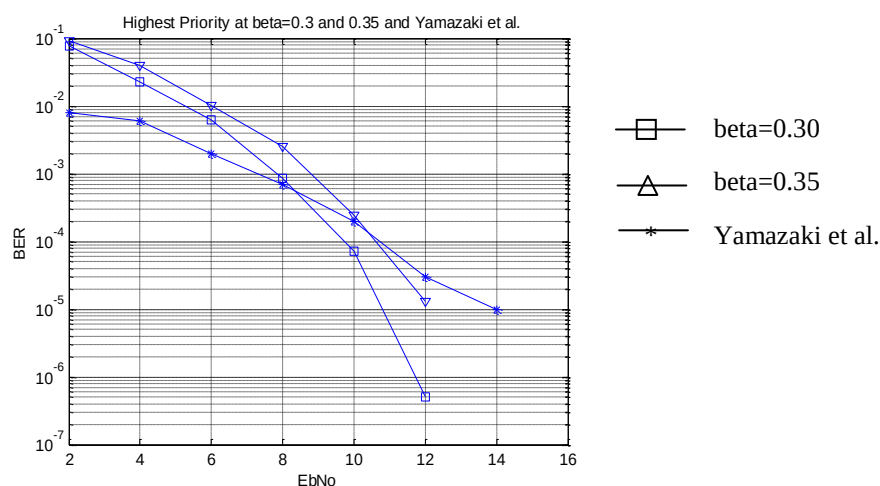


Fig. 9: Bit error performance for the proposed UEP design and Yamazaki et al.

VI. Conclusions

A novel Unequal Error Protection scheme based on 1/2-rate BCH code and non-uniform/uniform 8PSK modulation for the wireless Rayleigh fading channel has been successfully designed and implemented in this paper. In order to achieve UEP a simple modulation parameter called beta is included in our design and it has been shown through simulations that the UEP scheme suffers degradation in Eb/No when the modulation parameter increases from 0.30 to 0.50. Simulations prove that the bit error performance is improved by the use of non-uniform 8PSK modulation and this does not increase the complexity of the UEP scheme since only the parameter beta dictates the non-uniformity or uniformity of the 8PSK modulator. For the overall 1/2-rate UEP scheme and at a BER of 10^{-5} , the non-uniform 8PSK modulator with beta=0.30 yields a gain of around 6 dB in Eb/No over the uniform 8PSK modulation case. Furthermore, it is shown that the novel UEP design is better than that of Yamazaki et al. [1] and at a BER of 10^{-5} this design gives a gain of around 3 dB over the latter. This work can find direct applications to video communications such as robust transmissions of H.264/AVC video data over fading channels.

VII. Acknowledgments

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VIII. References

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