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A Serial Unequal Error Protection Code System using Trellis Coded Modulation and an Adaptive Equalizer for Fading Channels

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***Abstract*— We propose a serial unequal error protection (UEP) scheme using trellis coded modulation and an adaptive equalizer for use in mobile fading channel communication environments. We propose two types of signal constellations, TRAP and RING, to realize unequal error protection and show their performance in fading channels using computer simulations.**

Keywords: Unequal Error Protection (UEP), Fading Channels, trellis-coded modulation (TCM),Adaptive equalizer, Normalized Least Mean Square (NLMS) algorithm

I. INTRODUCTION

In order to protect information with different levels of importance, unequal error protection (UEP) is useful. The advantage of using UEP codes rather than equal error protection codes is that bits that are deemed to be important can be protected more than bits of lesser importance. This research was motivated by our work in human communication systems [1]-[3]. Also, in many other communication applications, data with different levels of importance occurs. The data cell used in ATM (asynchronous transfer mode) communication systems is one example [4]. In the 53 bytes ATM cell, 5 bytes are used for the header information. The ATM header contains various control information and therefore should be protected more than the other 48 bytes. By employing UEP, an increase in reliability and performance can be achieved. To this end, we have studied a trellis coded modulation (TCM) approach to UEP for additive white Gaussian noise channels in previous work [5]. In recent years the demand for wireless digital communication systems such as mobile phones has increased significantly. However, in wireless communication systems, signal degradation due to the effects of multi-path fading must be compensated for. Techniques to accomplish this include diversity, adaptive equalization and adaptive array antennas [6]. In this paper, we propose a UEP system using trellis coded modulation and an adaptive equalizer for a mobile communication environment and show how it can improve system performance.

The rest of our paper is organized as follows. In section 2, previous UEP schemes are described. In section 3, we introduce our UEP scheme and discuss the adaptive equalizer used. In section 4 and 5 we present simulation results to show the performance of our system. Finally, we present our conclusions in section 6.

II. PREVIOUS UEP SCHEMES

UEP has been studied by several authors [4]-[12]. After the first practical application was presented in [7], other UEP schemes using image and channel codes [8] and UEP schemes using a combination of voice and channel coding have been proposed [9]. Since these schemes use block or convolutional codes, the coding gain obtained is proportional to the available bandwidth. In order to create UEP characteristics, these schemes use multi-level codes. The source encoder divides the information sequence into M parallel sequences in decreasing order of importance. The channel encoder encodes these sequences using M codes with decreasing error correcting ability, $C_1,\ldots,C_M$, to create the desired UEP characteristics. Although encoding is simple, the disadvantage of this multi-level encoder is that the decoding process is complex. For example, the multi-stage decoder introduced in [7] requires a large amount of computation. Also, multi-level encoders must send extra bits to achieve coding gain which results in a loss in bandwidth efficiency. To correct this, unequally spaced signals are used with a modification of the time multiplexing in [10]-[11]. An example of a UEP system is shown in Fig.1 [11]. This scheme uses only two importance levels: high and low. The high importance data uses a more powerful code (Encoder-H), while the low importance data uses a less powerful code (Encoder-L). In the system shown in Fig.2, the outputs of Encoder-H and Encoder-L are mapped to signal points, so the following equation must be satisfied.

$$m_1 + r_1 = m_2 + r_2 \qquad (1)$$

Here, m_1 and m_2 are the number of information bits to be encoded in the high and low importance data streams respectively, while r_1, and r_2 are the number of parity bits added by Encoder-H and Encoder-L respectively. At the receiver, a decoder matched to each encoder decodes the received data. In most previous work, two importance levels were considered. Also the importance level was considered to change every bit or after a special bit pattern. The channel used was an additive white Gaussian noise (AWGN) channel. Work on fading channels can be found only in [12]. Incidentally, in this paper an interleaver is used to combat fading.

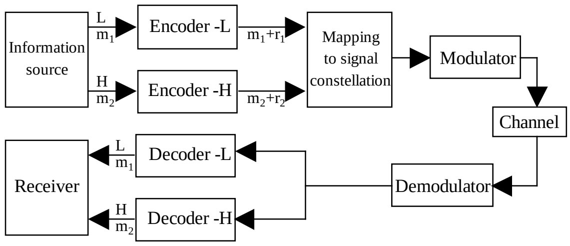

Fig. 1 A previously reported UEP system

III. PROPOSED UEP SCHEMES

A. System Model

The proposed system scheme is outlined in Fig.2. This scheme uses three importance levels. *H* is used to denote high importance, *M* is use to denote medium importance and *L* is used to denote low importance. This is a modification of the time multiplexing approach mentioned in [10]-[11]. In our scheme an adaptive equalizer is used to combat fading.

(1) Transmitter

Random data (0 or 1) is used for the input data. The importance level of the data is assumed to change every N bits. In this paper, we do not consider methods to determine the importance level. We merely assume that the importance level has been decided and changes every N bits. To achieve unequal error protection (UEP), trellis-coded modulation (TCM) encoders that have different error-protection capability are used. Of course, the *L* encoder provides less error protection than the *H* encoder. In the previously proposed scheme shown in Fig.2, coding and modulation are done separately, but in our proposed scheme we combine the coding and modulation using trellis coded modulation. This results in a performance improvement without bandwidth expansion and removes the restriction of (1) required in the system shown in Fig.1. In this paper, we also focus on the case when the important information and the less important information occur with equal probability. This can be generalized easily to the case when one importance level occurs more frequently than the other. In a periodically time-varying code, if some initial synchronization takes place, the code that was used to transmit the data will be known at the receiver. However, in a randomly time-varying code, such as considered here, the code that was used must be estimated from received data sequence. In order to estimate the codes, we use different signal constellations for each code. This is equivalent to using the importance level to select the transmitted signal constellation. This method has the advantage of not reducing the information rate. At the receiver, we use the algorithm described in section C.(Importance Level Estimation Algorithm) to estimate the code used. The code used only depends on the importance level, so the transmitted signal can be selected using a switch as shown in Fig.2.

(2) Channel Model

In such multi-path communication environments inter-symbol interference (ISI) results from the suppression of high frequency signal components and causes amplitude

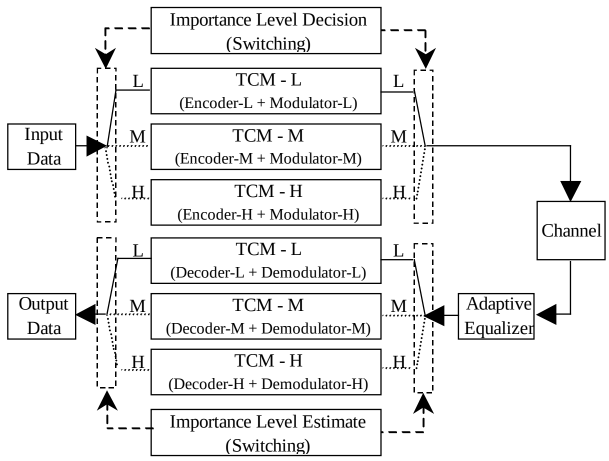

Fig.2 The proposed UEP scheme

and phase distortion, resulting in a performance loss. We considered a Rician fading channel model as the communication environment. A single frequency carrier signal is transmitted, but two signals are received at the mobile receiver: the direct wave and one reflected wave. The ratio of the power of the direct wave, $A^2/2$, to the average power of the reflected waves, σ_s^2, is called the rice parameter and is given by the following equation.

$$K = A^2 / 2\sigma_s^2 \qquad (2)$$

In this paper, we mainly consider the case when K=0, corresponding to Rayleigh Fading, but for the TRAP signal constellation, we also consider K=5. We mentioned about the reason in section V (B.TRAP constellation performance).

(3) Receiver

To reduce ISI, an adaptive equalizer is used in the receiver. This compensates for the distortion caused by fading. In our proposed scheme, we use a switch to change between training and tracking modes. Details are given in section 4. The output of the adaptive equalizer is decoded by each decoder, after which the output data is chosen according to the importance level estimate.

B. Signal Constellations

In section A, we stated that we use different signal constellations to change the importance level. The signal constellations considered in this paper, called 2-RING, 3-RING and TRAP, are shown in Fig.3 (a)-(c).

(a) 2-RING type

This signal constellation is the combination of two QPSK constellations of different energy. This constellation can support two importance levels: high and low. High importance data is assigned to the outer ring and low importance data to the inner ring. In order to separate the rings as much as possible, the phase difference of the two QPSK constellations is $\pi/4$.

The distance between signal points in the *L* code is d_L, while the distance between those in the *H* code is d_H. The minimum distance between signals in the *L* code and signals in the *H* code is given by d_c.

(b) 3-RING type

This constellation is created by adding one more importance level to the 2RING constellation, i. e. , one more QPSK constellation of different energy is added. This results in the three importance levels: high, middle and low. The phase of the third ring is also shifted by $\pi/4$ to separate the signal points as much as possible.

(c) Trap type

This constellation is created by placing signal points around a circle, but with the high importance points clustered on the right and the low importance points clustered on the left. The point spacing is chosen so that $d_L : d_H = 1:2$. Since each transmitted signal has a different energy, the average energy is used to calculate the SNR. In terms of the signal constellations, the energy of each signal is just the squared Euclidean distance of the signal point from the origin. In this paper, we use equally probable signals, so each signal's energy is given the same weight in the calculation of the average energy.

C. Importance Level Estimation Algorithm

In order to estimate the code that was used, the receiver looks at the received signal and determines which signal constellation it is closer to. We assume that the code can change only every *N* bits, so we can observe the received signal for *N* bits before making a decision. Below, we describe our estimation algorithm using the 2RING constellation.

(Step1) Compute the distance d_{ij} from the *i*th received signal to each high importance signal point *j* (0〜3).

(Step2) Select the smallest of the distances computed in Step1: min(d_{ij}).

(Step3) Repeat Steps 1 and 2 *N* times and add the resulting smallest distances to obtain the total distance H_{min} for the currently used importance level

$$H_{\min} = \sum_{i=1}^{N} \min(d_{ij}, j = 0〜3) \tag{3}$$

(Step4) In the same way, compute the total distance L_{min} to the low importance signal points from the smallest distances d_{ik} to each low importance signal point *k* (4〜7)

$$L_{\min} = \sum_{i=1}^{N} \min(d_{ik}, k = 4〜7) \tag{4}$$

(Step5) Compare H_{min} and L_{min}.

if $H_{min} < L_{min}$ then
the high importance level was used
elseif $H_{min} > L_{min}$ then
the low importance level was used

D. Adaptive Equalizer

In this paper, we adopt an adaptive equalizer as a counter-measure for multi-path fading. Other methods such as diversity and array antennae require extra hardware, but an adaptive equalizer can be implemented using digital signal processing and can therefore be used in mobile devices. Adaptive equalizers are also useful in frequency selective fading environments.

In the proposal system, we consider an FIR adaptive equalizer based on the NLMS (Normalized Least Mean Square) algorithm [13]. In the NLMS algorithm, the

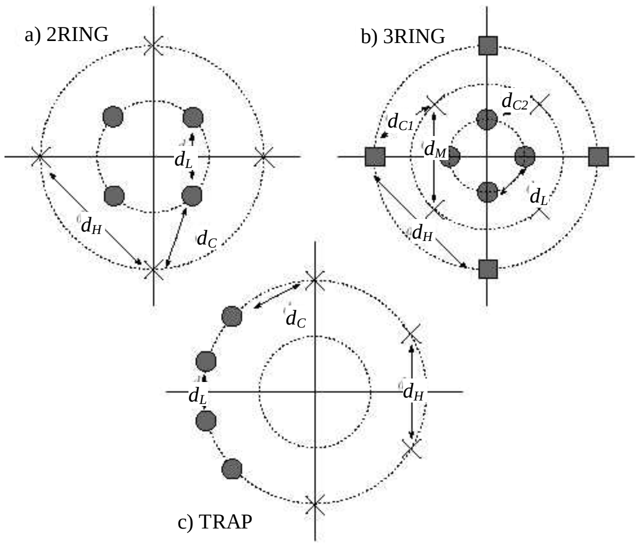

Fig.3 Signal Constellations

$$W(k+1) = W(k) + \beta \frac{\varepsilon(k) + n(k)}{X^T(k) X(k)} X(k) \tag{5}$$

$$\varepsilon(k) = r(k) - y(k) \tag{6}$$

$$y(k) = W^T(k) X(k) \tag{7}$$

$$X(k) = \{x(k), x(k-1), \ldots, x(k-L+1)\} \tag{8}$$

adaptation of the weight vector of the adaptive equalizer is given by where *x(k)* is the input sample at discrete time *k*, *W(k)* is the weight vector, *X(k)* is the input sample vector, $X^T(k)$ is the transpose of *X(k)*, *r(k)* is the output of the known system, *n(k)* is the noise signal, *L* is the number of filter weights and β is the gain constant.

Also, we use an adaptive equalizer that operates in both training and tracking modes. In training mode, a training signal known at the receiver is transmitted. After a certain training period, the equalizer is switched to tracking mode, during which actual data is transmitted. In tracking mode, the result of the data decision based on the output of the equalizer is used as the desired signal input to the equalizer [14].

IV. COMPUTER SIMULATION

We evaluate the performance of our proposed scheme using computer simulations. The simulation model for two importance levels is shown in Fig.4. The part shown inside the dotted box is the newly introduced adaptive equalizer, which was not part of the model for the AWGN communication channel considered in [5].

The simulation parameters are shown in Table 1. The high importance information is protected by a convolutional code, but the low importance information is uncoded. A matrix interleaver is also used in the transmitter to improve the error rate by spreading the bit errors. In the receiver, the digital clock is used to change the Adaptive Equalizer from training mode to tracking mode. The received data is deinterleaved, after which the Viterbi algorithm is used to decode the data. Additive white Gaussian noise is also added to the transmitted

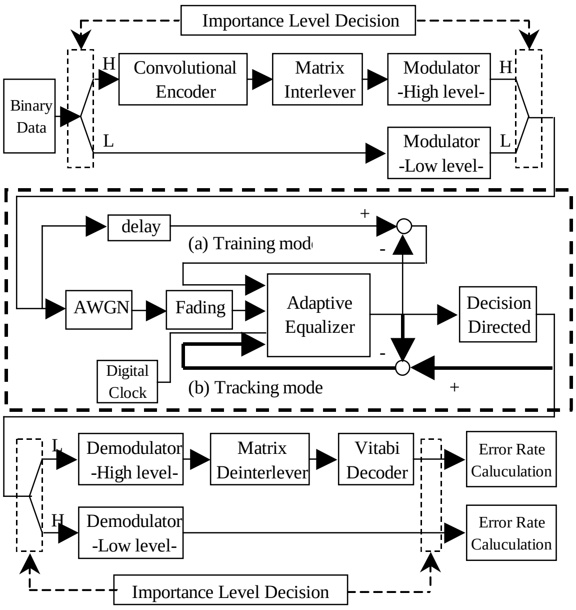

Fig. 4 Simulation model

Table 1 Simulation Parameters

Receiver Speed	0.1km/h, 10km/h, 50km/h
Matrix Interlever Size	1024 (32*32)
Signal Constellations	2RING, 3RING, TRAP
Importance Level	2 (2RING, TRAP), 3 (3RING)
Encoding	Convolutional code (high and medium importance levels)
Encoding rate	3/4 (middle importance level) 1/2 (high importance level)
Constraint length	2
Channel	Rician fading
Rician Parameter	K=0 (2RING, 3RING) K=0, 5 (TRAP)
Decoding	hard-decision Viterbi decoder
Trace back length	10
Equalizer structure	FIR transversal filter
Equalizer algorithm	NLMS
Number of filter weights	11
Equalizer step size	0. 01
Equalizer gain constant	0. 05

signal. The noise level is taken relative to the average power of the transmitted signal points. Also, the SNR is calculated on a per information bit basis to make the performance comparisons fair. For example, if a rate 1/2 code is used, there are twice as many information bits in the uncoded data stream as the code one. In this paper, we evaluate the error rate of the codes and the error rate of the importance level estimate separately. We consider three mobile receiver speeds: 0.1 km/h, 10 km/h and 50 km/h.

V. PERFORMANCE EVALUATION

The error performance for the 2RING, 3RING and TRAP constellations is shown in Figs.5-8. In the figures, the lines with a circle show the performance for the high importance data, those with a square are for medium importance data and those with a triangle are for low importance data. Lines with no symbol show the performance for a scheme with equal error protection, i. e. , QPSK combined with the *H* code.

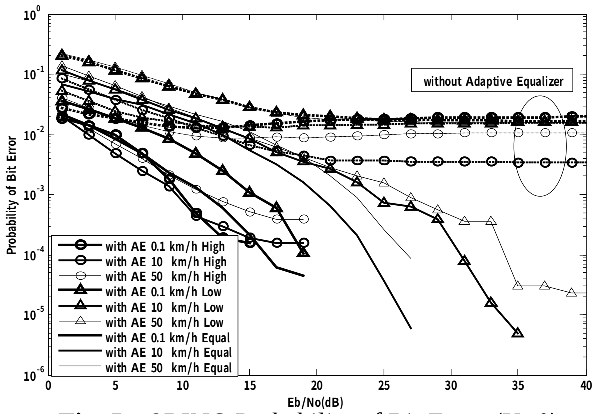

Fig. 5 2RING Probability of Bit Error (K=0)

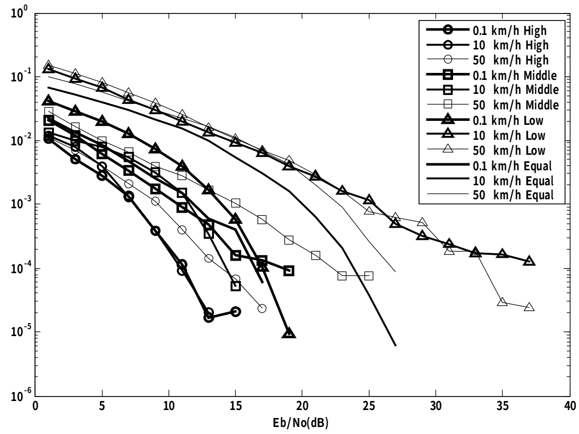

Fig. 6 3RING Probability of Bit Error (K=0)

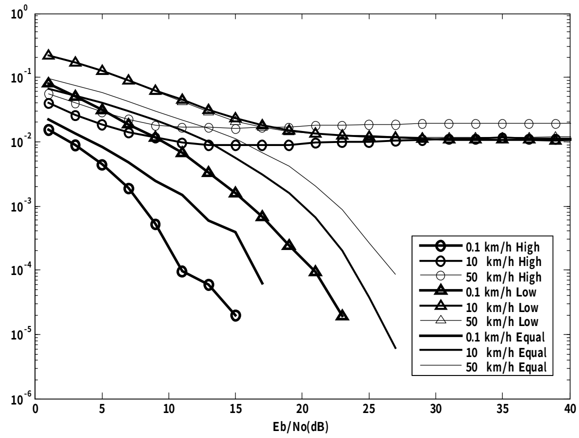

Fig. 7 TRAP Probability of Bit Error (K=0)

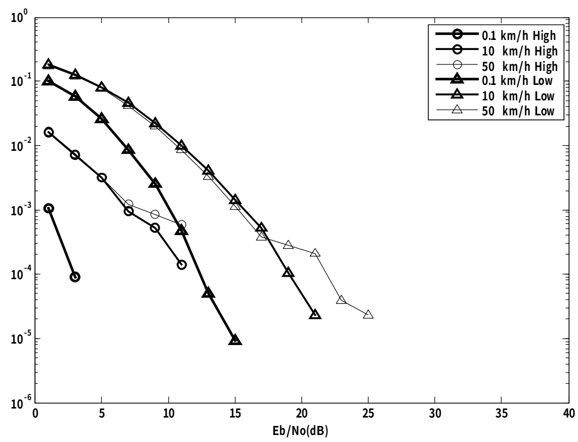

Fig. 8 TRAP Probability of Bit Error (K=5)

A) RING constellation performance

The results for the 2RING constellation (Fig.5) and the 3RING constellation (Fig.6) show that for all mobile speeds considered, the important data is protected better than an equal error protection scheme. In Figure 5, the error probability of unequally protected data (High:○, Low:□) and equally protected data (solid line) is shown. However as expected, the low importance data is not protected as well as in an equal error protection scheme. As a result, we see that by using a UEP scheme, the total system efficiency can be improved.

B) TRAP constellation performance

We see from the results for the TRAP constellation (Fig.7) that at a speed of 0. 1 km/h, the same performance trend as the RING constellation was obtained. However, at speeds of 10 and 50 km/h, an error floor appears. This is caused by the smaller distance between the signal points in the TRAP constellation, which makes the signals more susceptible to the effects of fading. In general, increasing the rice parameter K results in an improvement in performance because of the effects of the reflected waves on the amplitude and phase of the transmitted signal decrease. The results for K=5 are shown in Fig.8. For the TRAP constellation, a value of K greater than 5 is sufficient to effectively eliminate the error floor. A mobile receiver speed of less than 3 km/h is also sufficient.

VI. CONCLUSION

In this paper we proposed an unequal error protection (UEP) scheme using trellis coded modulation and an adaptive equalizer for use in mobile fading channel communication environments. We proposed two types of signal constellations, TRAP and RING, to realize unequal error protection and showed their performance using computer simulations. Our main conclusions are as follows.

(1) We showed that error protection corresponding to the importance of the information can be obtained using our proposed system in fading channels. Important information can be protected more than using an equal error protection scheme.

(2) We introduced an adaptive equalizer to counteract fading, and its effectiveness was confirmed.

(3) For the TRAP signal constellation, we found that a rice parameter of more than 5 or a mobile speed of less than 3 km/h was sufficient to effectively eliminate the error floor present in the error rate performance.

Topics of future work include a theoretical analysis of the effect of the signal constellation on error performance, evaluation of techniques to combat fading and examination of a Decision Feedback Equalizer.

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