Serial Unequal Error-Protection Codes based on Trellis-Coded Modulation

David K. Asano and Ryuji Kohno

Abstract— **Unequal error-protection (UEP) codes that are designed using trellis-coded modulation (TCM) are proposed for use with a single data stream consisting of information with two levels of importance. To achieve UEP, the proposed scheme encodes the data according to the importance of the information by switching between two codes which use different signal constellations. Using simple trellis codes, it is shown that the error rate of the important information is lower than the error rate for an equivalent equal error-protection scheme.**

Index Terms— **Human communication, trellis-coded modulation (TCM), unequal error protection (UEP).**

I. Introduction

Unequal error-protection codes (UEP) have been studied by several authors [1]–[7]. 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. These papers generally consider UEP codes for cases when information of different importance is available at the same time.

In this paper, we consider UEP codes for use with a serial data stream which contains a random mixture of important and less important information, i.e., the information changes importance in an irregular way. This research was motivated by our work in human communication systems [8]–[10], where the meaning of information is taken into account as well as its statistical properties. In these communication scenarios, information of varying importance is transmitted in a single data stream. For example, when two people communicate using a natural language, not all the information is necessary to understand the message. On a character level, if some of the letters are missing or incorrect, the word can still be recognized by a human receiver. We can see that in these communication scenarios, information of varying importance naturally occurs.

Since human communication systems are still under study, the application of the proposed coding scheme may not be apparent. Since the meaning of the message can be understood even without the less important information, the message as a whole can be transmitted more efficiently through a noisy channel by taking this fact into consideration.

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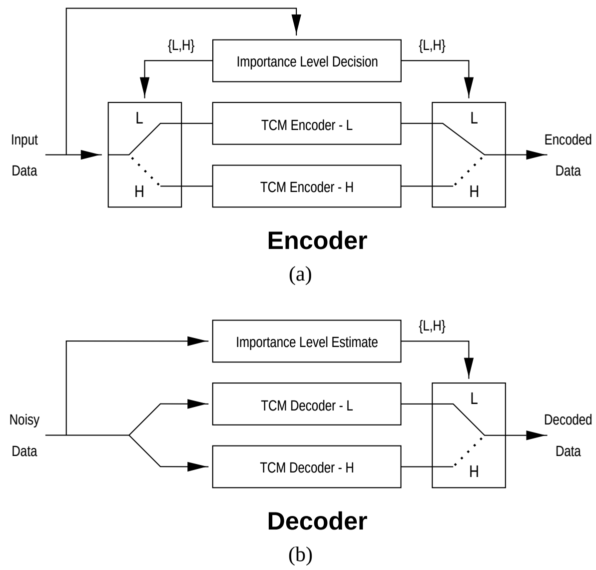

Fig. 1. The proposed serial UEP (a) encoder and (b) decoder.

The importance of the information depends upon the actual source considered. For facial image transmission, the parts of the face that often move (e.g., the mouth) are more important, while the parts that do not move much (e.g., the forehead) are less important. Details of the importance decision algorithm can be found in [10] for this application. An algorithm for natural language is given in [8].

II. Serial UEP Coding Scheme

The proposed coding scheme outlined in Fig. 1, is a modification of the time multiplexing approach mentioned in [6], [7]. The input data is assumed to consist of equiprobable bits $\{0, 1\}$. The importance level of the data is evaluated by a decision block, whose output controls the code that is used to encode the data. The L is used to denote low importance and the H is used to denote high importance. To achieve unequal error protection, 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.

Since the performance of TCM is degraded for short sequences, we assume that the importance levels of the input bits do not change every bit. Therefore, we assume that the importance level can change only every frame of length N bits. 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.

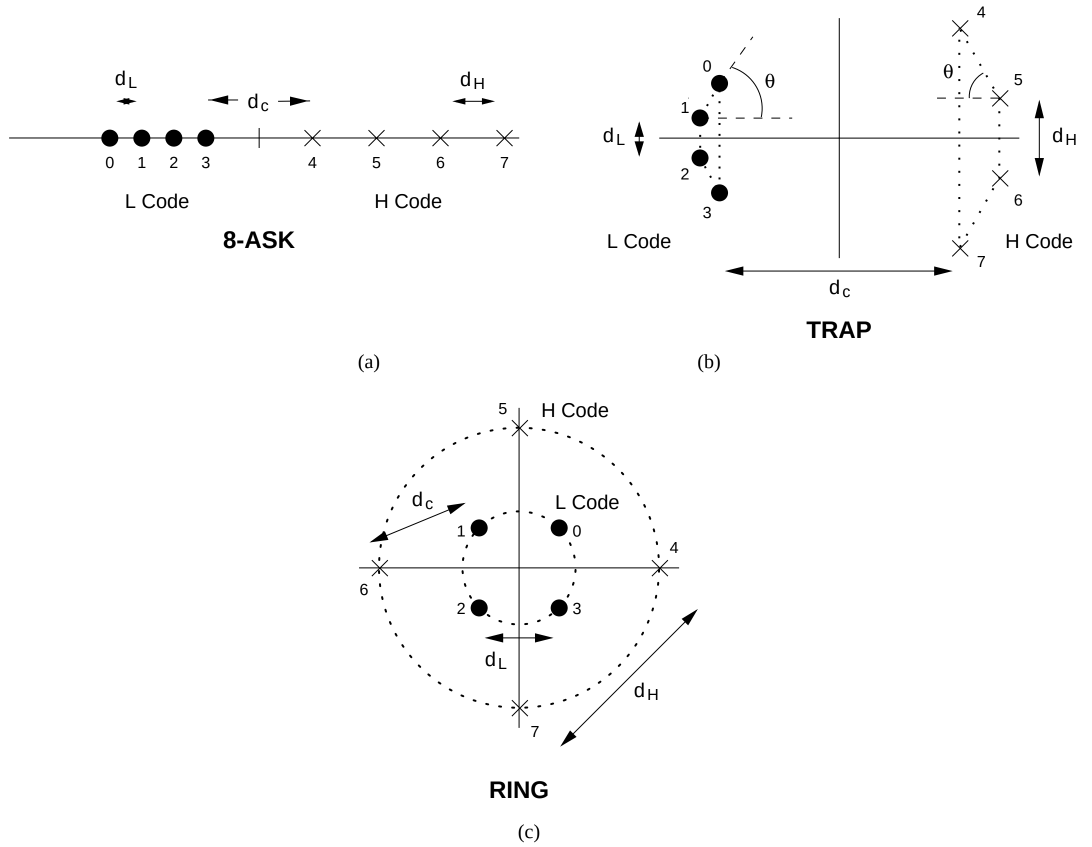

Fig. 2. Signal constellations: (a) 8-ASK, (b) TRAP and (c) RING.

The decoding method for the proposed serial UEP scheme is also shown in Fig. 1. 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, considered here, the code that was used must be estimated from the received data sequence. In order to distinguish between 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.

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. Since, we assume that the code can change only every N transmitted symbols, the estimate of which code was used can be performed using N received signals. The code decision can be improved by increasing N. Specific details of the code estimation process is given in [11].

In this paper, an additive white Gaussian noise (AWGN) channel with power spectral density equal to $N_0/2$ is used.

III. Signal Constellations

In order to achieve UEP for our randomly time varying coding scheme, different signal constellations must be used to transmit each code. The performance of the coding scheme will depend on which signal constellation is used. The signal constellations considered in this paper, called 8-ASK, TRAP and RING, are shown in Fig. 2(a)-(c). The RING constellation was examined in [6], but for a different UEP system. 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.

For the 8-ASK and TRAP constellations, the points are positioned so that the horizontal distance from the y-axis to the closest point in the L or H code is $d_c/2$. For the TRAP constellation, the parameter θ can have any value between 0 and π. The RING constellation can also be thought of as two QPSK constellations that have different energy.

Since each transmitted signal has a different energy, the average energy is used to calculate the SNR. In terms of the signal constellation, the energy of each signal is just the squared Euclidean distance of the signal point from the origin. In this paper, we use equiprobable signals, so each signal energy is given the same weight in the calculation of the average energy.

The performance of the UEP code will depend on the three distances d_c, d_L and d_H. The code separation distance d_c controls the code decision performance, while d_L and d_H control the performance of the L and H codes, respectively. Since these distances are related to one another, they cannot be independently varied. Therefore, a tradeoff among the performance of the three decisions exists. To reduce the number of parameters, we introduce β

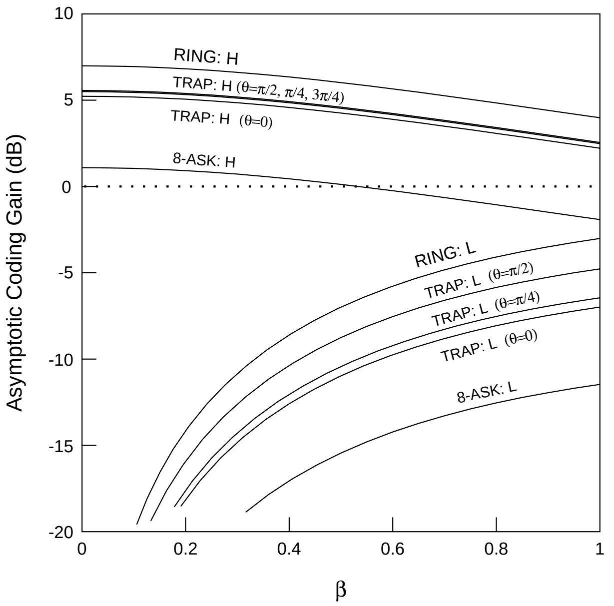

Fig. 3. The asymptotic coding gain as a function of β. For the TRAP and 8-ASK constellations, the maximum asymptotic coding gain is shown. The H indicates the important bits, while the L indicates the less important bits.

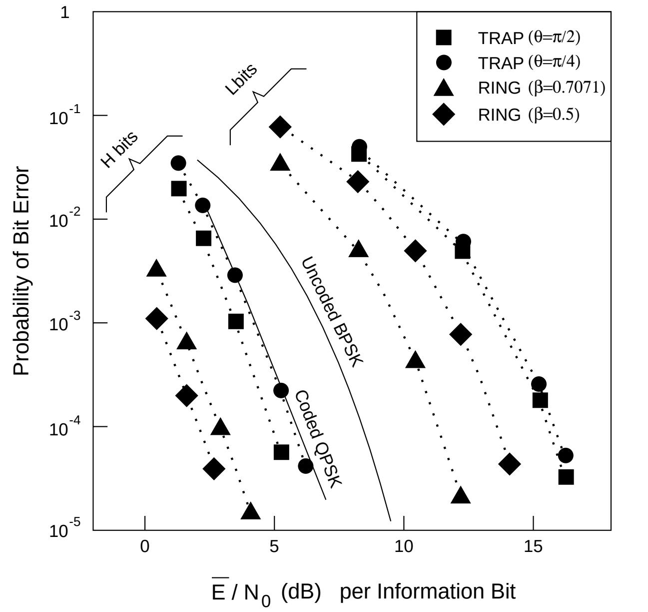

Fig. 4. The performance of the proposed UEP scheme. The TRAP constellation has $d_c^2/\overline{E} = 0.3$ and $\beta = 1\sqrt{2}$. The coded QPSK scheme uses equal error protection.

as the ratio of d_L and d_H, i.e., $d_L = \beta d_H$, where $0 \leq \beta < 1$, because d_H is larger than d_L.

IV. UEP Code Performance

As a sample implementation of the proposed UEP system, we use a rate-1/2, four-state trellis code given in [12] for the H code. Since the rate of the code is $1/2$ and there are four points in the H code signal sub-constellation, the information rate for the important bits is 1 bit/T.

To achieve less error protection for the less important bits, we do not use any encoding. This also increases the information rate for the less important bits to 2 $bits/T$. Since we are considering the case when the important and less important bits are equiprobable, the average information rate for this implementation of the proposed UEP scheme is 1.5 $bits/T$.

In Fig. 3, the asymptotic coding gain for the RING constellation is shown together with the maximum asymptotic coding that is possible, i.e., when $d_c = 0$, for the 8-ASK and TRAP constellations, as a function of β. Uncoded BPSK is used as a reference. We can see that the RING constellation achieves the best performance for both the important and less important bits, while the 8-ASK constellation is the worst.

Using our UEP scheme, the coding gain for all constellations is achieved with an average information rate of 1.5 $bits/T$, while the coding gain of the uncoded BPSK scheme is 1 bit/T. If the coding gain is adjusted by this difference, the coding gain of the UEP scheme increases by 1.8 dB.

If we compare the proposed UEP scheme with an equal error protection scheme, i.e., QPSK combined with the H code, the important bits still have a larger coding gain, since the gain of the coded QPSK scheme is 4.0 dB relative to uncoded BPSK.

As for the actual bit-error-rate (BER) performance, by using computer simulations, we compare the constellations in Fig. 4 when no code-decision errors occur. For comparison, the coded QPSK scheme using equal error protection and the uncoded BPSK scheme is shown. As expected, the RING constellation achieves the best performance for both important and less important bits. All the UEP schemes shown achieve better performance for the important bits than the coded QPSK scheme.

Of course, this is just one implementation. Other codes can improve the performance more. Here, we show that even with a simple code, an improvement in performance for the important bits can be realized. In exchange, the less important bits have an increased information rate, but more errors.

When the important and less important information do not occur with equal probability, the performance of the system becomes closer to an equal error protection scheme. For example, if the important bits occur with high probability, the energy used to transmit the important bits will have to be lower than the equiprobable case in order to keep the average energy constant. This will result in a higher error rate for the important bits. In the extreme case when only important bits are transmitted, the proposed system is an equal error protection system and therefore the performance is the same as the equal error protection scheme.

V. Conclusions

In this paper, we proposed an UEP scheme based on TCM for use with information sources that contain a random mixture of both important and less important data.

The proposed scheme is basically a random code-switching scheme that uses a more powerful code for the important information. It is necessary at the receiver to decide which code was used before final decoding of the bits is possible.

The asymptotic coding gains and BER's when various constellations had been used were compared with an uncoded scheme and an equal error-protection scheme. We found that the proposed UEP scheme achieves better performance for the important bits than the equal error-protection scheme. The less important bits could be transmitted with a higher rate than the important bits but had a higher BER.

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