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A TCM–based Unequal Error Protection Scheme for Intelligent Communication†

David K. Asano[1] and Ryuji Kohno[2]
[1]Communications Research Laboratory, Ministry of Posts & Telecommunications,
4-2-1 Nukui-kitamachi, Koganei, Tokyo 184, Japan
Email: david@kohnolab.dnj.ynu.ac.jp
[2]Division of Electrical & Computer Engineering, Yokohama National University,
156 Tokiwadai, Hodogaya-ku, Yokohama 240, Japan

Abstract — **Unequal error protection codes that are designed using trellis coded modulation are proposed for use with intelligent communication systems, where the transmitted data consists of a random mixture of important and less important information. To achieve unequal error protection, the proposed scheme encodes the data by randomly switching between two codes which use different signal constellations. No extra information about which code was used is added. The receiver decides which code was used by examining the received signal points. Using simple trellis codes, it is shown that the error rate of the important information can be made lower than the error rate for an equivalent equal error protection scheme.**

I. Introduction

Recently, there has been interest in unequal error protection codes based on Trellis Coded Modulation (TCM) for broadcast systems [1] [2], because of the occurrence of information with different levels of importance. In these papers, it is assumed that there are two parallel data streams, consisting of important and less important data. These schemes transmit both kinds of data at the same time by choosing the transmitted signal appropriately.

In this paper, we consider unequal error protection codes for use with intelligent communication systems [3] [4] [5], where the transmitted data contains a random mixture of important and less important information. 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. On a word level, not all the words are necessary to understand the sentence. We can see that in these communication scenarios, information of varying importance naturally occurs.

One possible approach to unequal error protection for this kind of data stream is to use the parallel approach mentioned above by separating the data stream into two parallel data streams. However, in order to implement the parallel method, extra information must be sent so that the original data can be reconstructed by the receiver in the correct order. A periodically time varying code is also not appropriate. Therefore, we propose a scheme where the code is switched randomly between two codes of differing error protection capability, i.e., the code is a randomly time varying one. In this way, we can achieve unequal error protection for intelligent communication systems.

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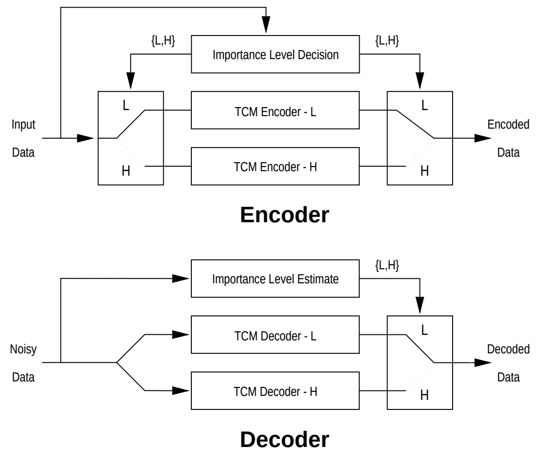

Fig. 1: The proposed UEP encoder.

II. UEP Coding Scheme

The proposed coding scheme is outlined in Fig. 1. The input data is assumed to consist of equiprobable bits. The importance level of the data is evaluated by a decision block, whose output controls the code that is used to encode the data.

Since Trellis Coded Modulation (TCM) is used to encode the data, we assume that the importance level of the input bits do not change every bit. If the importance changed every bit, then a block code would be more appropriate, since the performance of convolutional codes, such as those used in TCM, is degraded for short sequences. Therefore, we assume that the importance level can change only every NT, where T is the transmitted symbol period. We also assume that the two importance levels are equiprobable.

The decoding method for the proposed UEP scheme is also shown in Fig. 1. In a randomly time varying code, such as we are considering here, the code that was used must be estimated from the received data sequence. Once the code that was used is estimated, the switch is used to output the decoded data from the appropriate decoder.

In order for the receiver to estimate the code, the transmitter must produce sequences of data that are in some way different for each code used. One way is to have the transmitter add extra information to the transmitted data to inform the receiver of which code was used. This method is not desirable because the added data causes a reduction in the information rate. Also, the added data must be protected against errors, which results in a further reduction in the information rate.

Instead of adding extra data, it is more efficient to modify the transmitted signal. The convolutional code used in the TCM encoder produces binary symbols, so it is difficult to create different sequences of data. Therefore, 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. This provides a form of time diversity for the code information.

In this paper, an additive white Gaussian noise (AWGN) channel with power spectral density equal to $N_0/2$ is used. The demodulator is assumed to be a perfectly coherent correlator receiver.

III. Signal Constellations

The signal constellations considered in this paper, called 8-ASK and TRAP, are shown in Fig. 2. 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. 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 values between 0 and π.

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.

Since d_H is larger than d_L, we can write d_L in terms of d_H as $d_L = \beta d_H$, where $0 \leq \beta < 1$. Now, in order

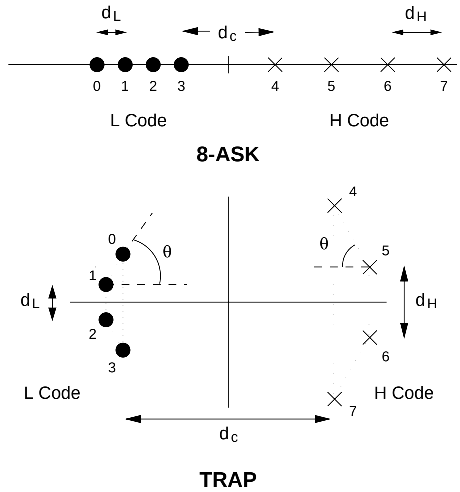

Fig. 2: Signal constellations: 8-ASK and TRAP.

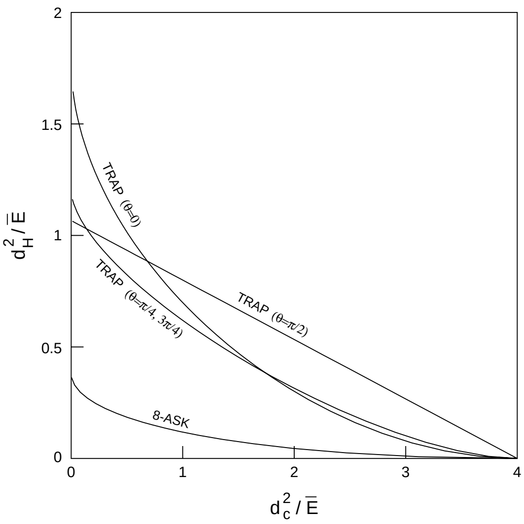

Fig. 3: The signal spacing of the H code (d_H^2) versus the minimum code spacing (d_c^2) for $\beta = 1/\sqrt{2}$.

to further parameterize the families so that d_c and d_H are related, we introduce γ such that $d_H = \gamma d_c$.

In order to compare the performance of the UEP schemes, d_H^2 is plotted versus d_c^2. An example is shown in Fig. 3, where the distances are normalized by the average energy of the constellation. From the figure, we can see that the TRAP constellation with $\theta = 0$ and $\theta = \pi/2$ result in the largest d_H^2.

IV. Code Estimation

Since the receiver does not know which code was used to encode the data, the performance of the entire UEP scheme depends heavily on the performance of the code estimation process. In this section we develop a code estimation algorithm for each signal constellation type using the time diversity of the transmitted signal and evaluate its performance in an AWGN channel.

The code estimation process is a binary decision problem. It is our goal to decide which signal sub–constellation the received signal came from. Let us begin by assuming that each signal constellation contains only one point, i.e, there are only two possible transmitted signals. Let us label the signal point for the L code l and the signal point for the H code h. In our UEP coding scheme, either l or h will be sent N times in succession. Since we are assuming an AWGN channel, the received signal point, r_k, will be either $l + n_k$ or $h + n_k$, where n_k is a zero mean Gaussian random variable with variance $N_0/2$.

To decide which code was used, we form decision variables, μ_L and μ_H, for the L and H codes respectively as

$$\mu_L = \frac{1}{N}\sum_{k=1}^{N}(r_k - l), \quad \mu_H = \frac{1}{N}\sum_{k=1}^{N}(r_k - h). \qquad (1)$$

Equal combining is used, because the noise in each received signal is independent and equally important. Our decision rule is to decide that the L code was used if $|\mu_L| < |\mu_H|$ and that the H code was used otherwise.

These decision variables are just the sample means of the distances of the received signal points from each code's signal constellation. If the L code was the one that was used, μ_L will be the sum of independent Gaussian random variables. On the other hand, μ_H will have the same variance as μ_L, but will have a mean equal to $l - h$. If the H code was the one that was used, the properties of μ_L and μ_H in the above discussion will be reversed.

If the sample mean of a sequence of N independent zero mean Gaussian random variables with variance $N_0/2$ is taken, i.e.,

$$\mu_N = \frac{1}{N}\sum_{k=1}^{N} n_k \qquad (2)$$

then μ_N will be a zero mean Gaussian random variable with variance given by

$$\mathrm{Var}[\mu_N] = \frac{N_0}{2N}. \qquad (3)$$

From this equation, we see that the variance of the noise can be reduced by taking more samples. For our code decision problem, more samples implies increasing the number of symbols that are sent between code switching times.

The probability of a code decision error (*cde*) is

$$P(cde) = P(cde|l)P(l) + P(cde|h)P(h). \qquad (4)$$

Since $P(cde|l) = P(cde|h)$ and since we are considering the case when the $P(l) = P(h)$, the code decision error probability can be reduced to

$$P(cde) = \frac{1}{2}\mathrm{erfc}\left[\sqrt{\frac{N d_c^2}{4N_0}}\right], \qquad (5)$$

which is just the binary signalling probability of error. In this case, $d_c = |h - l|$.

To extend the decision process to signal constellations with more than one point, μ_L and μ_H are redefined as

$$\mu_L = \frac{1}{N}\sum_{k=1}^{N}(r_k - l_i), \quad \mu_H = \frac{1}{N}\sum_{k=1}^{N}(r_k - h_j) \qquad (6)$$

where l_i and h_j are signal points in the L and H codes. The values of i and j that are used are the values that minimize $|r_k - l_i|$ and $|r_k - h_j|$. In other words, the point closest to the received signal is used as the reference point in the calculation of μ_L and μ_H.

In general, the code decision performance is better than (5), because the points in the L constellation are more than a distance d_c away from the points in the H constellation. Therefore, (5) is an upper bound on the code decision error performance.

The performance of the code decision scheme, obtained by using simulations, is shown in Fig. 4 for $\beta = 1/\sqrt{2}$, $d_c^2/\overline{E} = 0.3$ and $N = 30$. Also shown in the figure is the upper bound for the probability of code decision error given by (5).

As we can see in the figure, the performance of the code decision process depends on the signal constellation used. The 8–ASK constellation has the best performance, because the signals in the H code subset and the L code subset are separated from each other more than the other signal constellations. In the TRAP family with $\theta = \pi/2$, the L code signal points are all separated from the H code signal points by a horizontal distance of d_c.

The upper bound shows that the code decision performance improves rapidly as N increases. When the upper bound for $N = 1$ is roughly 0.1, the upper bound for $N = 30$ is less than 10^{-11}. Since the upper bound for $N = 1$ is also roughly the uncoded symbol error performance of the system, we can see that the code decision error rate can be made insignificant relative to the symbol error rate.

V. UEP Code Performance

As a sample implementation of the proposed UEP system, we use the rate 1/2, 4–state trellis code shown in Fig. 5 [6] for the H code. In the figure, the trellis branches are labelled with the input bit and the transmitted signal point in the H code.

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 $bits/T$.

The bit error rate performance was investigated by using computer simulations. The performance when no

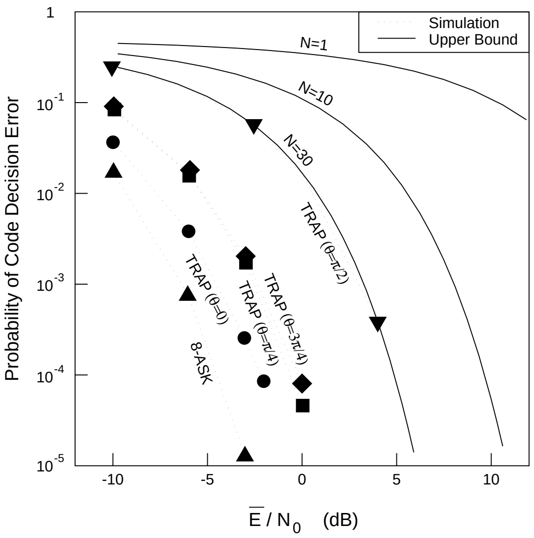

Fig. 4: The code decision performance when $\beta = 1/\sqrt{2}$, $d_c^2/\overline{E} = 0.3$ and $N = 30$.

code decision errors occur is shown in Fig. 6. For comparison, the coded QPSK scheme using equal error protection and the uncoded BPSK scheme is shown. 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.

VI. Conclusions

In this paper, we proposed an unequal error protection scheme based on trellis coded modulation for use with information sources that contain a 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. No extra information about which code was used is added to the transmitted signal, so at the receiver it is necessary to decide which code was used before final decoding of the bits is possible.

The bit error rates when various constellations were used was compared with an uncoded scheme and an equal error protection scheme. We found that the proposed unequal error protection 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 bit error rate.

References

[1] A. R. Calderbank and N. Seshadri, "Multilevel codes for unequal error protection," *IEEE Trans. Inform. Theory*, vol. 39, pp. 1234–1248, July 1993.

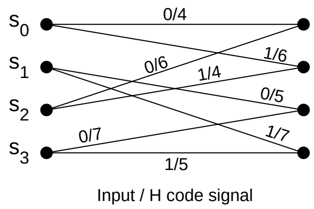

Fig. 5: A rate 1/2, 4–state trellis code.

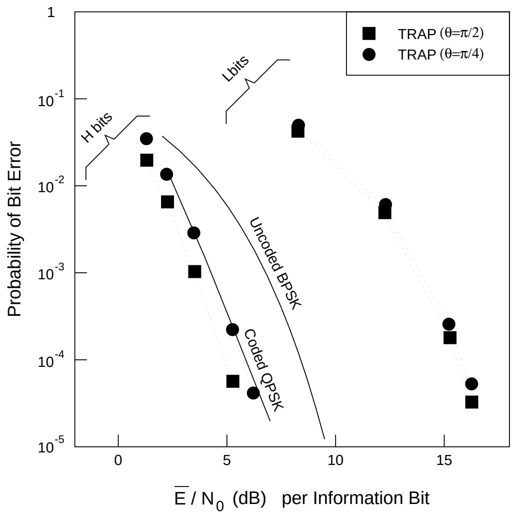

Fig. 6: The performance of the proposed UEP scheme. $d_c^2/\overline{E} = 0.3$ and $\beta = 1\sqrt{2}$.

[2] L.-F. Wei, "Coded modulation with unequal error protection," *IEEE Trans. Commun.*, vol. 41, pp. 1439–1449, Oct. 1993.

[3] T. Sasaki, R. Kohno, and H. Imai, "An error controlling scheme based on different importance of segments of a natural language," *IEICE Trans. Fundamentals*, vol. E75-A, pp. 1076–1086, Sept. 1992.

[4] T. Sasaki, R. Kohno, and H. Imai, "Variable error controlling schemes for intelligent error controlling systems," *IEICE Trans. Fundamentals*, vol. E77-A, pp. 1281–1288, Aug. 1994.

[5] N. Suzuki, T. Sasaki, R. Kohno, and H. Imai, "An error controlling scheme according to the importance of individual segments of model–based coded facial images," *IEICE Trans. Fundamentals*, vol. E77-A, pp. 1289–1297, Aug. 1994.

[6] G. Ungerboeck, "Channel coding with multilevel / phase signals," *IEEE Trans. on Information Theory*, vol. IT-28, pp. 55–67, January 1982.