Unequal Error Protection Based on Multidimensional Coded Modulation Using Several Convolutional Encoders

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Abstract– It is essential for intelligent error control schemes to use a coding method which can adapt the error–correcting capability to the changing importance of the information. This paper proposes and investigates a multidimensional coded modulation scheme to achieve unequal error protection using convolutional codes which have different error–correcting capability. An appropriate encoder is selected every frame, which consists of a constant number of data symbols, according to the importance of each frame. In decoding, however, there is a problem of decoder–selection–error, which is an error that results when the decoder that is selected is not the same as the encoder used in the transmitter. In order to reduce the decoder–selection–errors, the proposed scheme assigns a signal constellation and encoder to each frame according to its importance, because these constellations can be used to determine the correct decoder. Computer simulation is employed to evaluate the bit error rate performance of the proposed scheme. The performance is compared with a conventional error control scheme and it is found that the proposed scheme can outperform the conventional one.

I. Introduction

Recently, a lot of research has been carried out in the area of intelligent communication, in which the content of the information is taken into account so when information is transmitted[1]. To human users, not all the information is necessary to understand the information, so this naturally results in information with different importance[2][3]. Therefore, it is more efficient for intelligent error control schemes to use a coding method which assigns error protection based on the importance of the information.

Unequal error protection (UEP) codes have been studied previously [5], [6], [7], [8]. In these papers, the importance of input data is divided into 2 levels; important or less important. It is assumed that there are regular changes between the important bits and the less important bits or that there are two parallel data streams consisting of important or less important data [7]. However, when we consider the contents or meaning of the information, the importance of the bits changes irregularly.

In this paper, we consider UEP codes for use with a serial data stream which contains a random mixture of several importance information. Encoding uses several convolutional codes which have different error–correcting capability, and the encoder is selected according to the importance of the bits. The symbols are assigned an encoder and a signal constellation depending on their importance, so extra information about which code was used is not necessary. This method can achieve more than two levels of unequal error protection.

II. Multidimensional Coded Modulation with Unequal Error Protection

A. *The proposed system*

The proposed scheme is outlined in Fig. 1. The importance of the input data is divided into N levels, which are labeled $1, 2, \cdots, N$ in order of importance starting with the least important level. N convolutional codes which have different error-correcting capabilities are used. The codes are assigned to match the importance level so that the error correction capability of the code increases with the importance level. The codes are referred to as encoder $1, \cdots$, encoder N. These encoders have the same number of output bits but different rates.

Multidimensional coded modulation is used to encode the data in order to extend the distance between the sequences of each code. It is assumed that the importance of the input data is decided, and the importance level of the input bits do not change every bit. Since the performance of convolutional codes is degraded for short sequences, we assume that the importance level can change only every frame. According to the importance level of the data, the data is encoded by an appropriate encoder. Then, the encoded bits are mapped to modulation points of the signal constellation appropriate for that importance level.

Since it is not known which encoder was used to encode the data, the received signals are decoded by all decoders in parallel. The code that results in the smallest metric is assumed to be the code that was

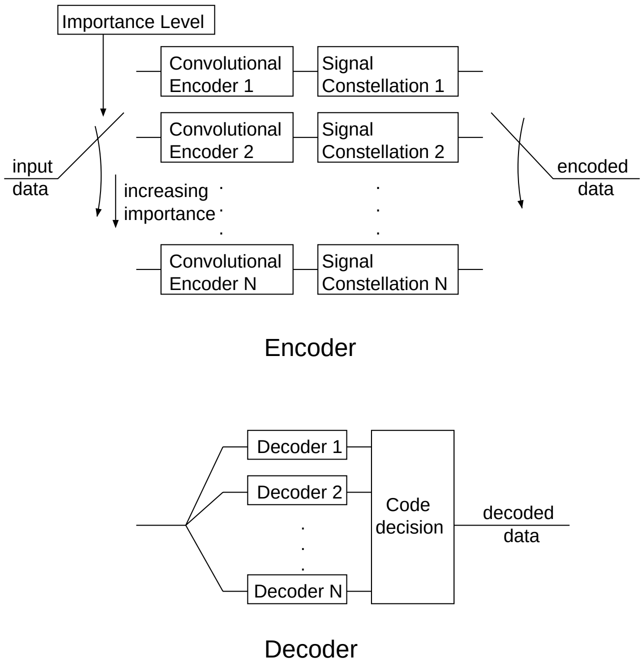

Fig. 1: The proposed system

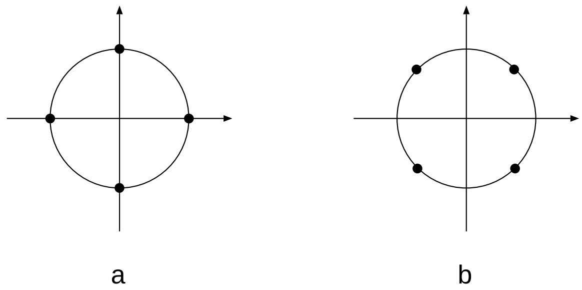

Fig. 2: An example of signal constellations

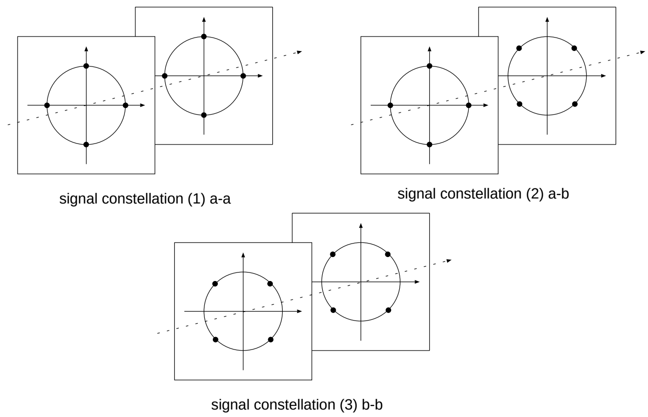

Fig. 3: An example of four–dimensional signal constellations for use with three importance levels

used to encode the data. However, there are "decoder–selection–errors". This happens when the wrong decoder is used to decode the data. In order to reduce "decoder–selection–errors", in the proposed method a different signal constellation is used for each encoder.

B. *Signal constellations*

The encoder changes randomly, so there are "decoder–selection–errors". If a "decoder–selection–error" takes place, the decoded data gets longer or shorter, because the encoders that are used have different code rates. Therefore, a different signal constellation for each code is used in order to reduce the "decoder–selection–errors". In this paper, we use multidimensional coded modulation because more distinguishable signal constellations can be made.

An example of a set of signal constellations is shown in Fig. 2. For example, when we use these signal constellations in four–dimensional coded modulation, we can make four combinations of signal constellations a–a, b–b, a–b and b–a. In this way, many combinations can be made with limited signal constellations.

In Fig. 2, all signal points have the same energy, but it is also possible to change the energy depending on the code. If important bits are transmitted with larger energy, the difference in error protection capability between less important and more important bits increases.

C. *Average Code Rate*

In the proposed method, it does not matter how many times each encoder is used. The rate of the proposed system varies according to the ratio of each importance level in the input data. Therefore, the rate of the system is the average rate of the individual encoders. The average rate is given by

$$R_{ave} = R_1 P_1 + R_2 P_2 + \cdots + R_N P_N, \qquad (1)$$

where $R_1, \cdots, R_N$ are the rates of encoders $1, \cdots, N$ and $P_1, \cdots, P_N$ are the probability that encoders $1, \cdots, N$ are used, respectively.

D. *Coding gain*

The coding gain, G, of a code, relative to a comparison code, is given by

$$G = 10 \log_{10} \frac{(d^2_{min}/\overline{E})_{proposed}}{(d^2_{min}/\overline{E})_{comparison}} \ (dB), \qquad (2)$$

where d^2_{min} is the minimum Euclidean distance of the code and $\overline{E}$ is the average energy of the signal constellation. In this paper, the difference in the code rate is taken into account when the coding gain is calculated. Therefore, the coding gain is given by

$$G = 10\log_{10}\frac{(d_{min}^2/\overline{E})_{proposed}}{(d_{min}^2/\overline{E})_{comparison}} + 10\log_{10}\frac{R_{ave}}{R_{comparison}}, \quad (3)$$

where $R_{comparison}$ is the code rate of the comparison system.

III. Simulation Results

A. *Two Importance Levels*

In this section, it is assumed that the input data has two importance levels: low (level 1) and high (level 2), and they are mixed in a one–to–one ratio. The low importance bits are not encoded and the high importance bits are coded with a rate 3/4 encoder. This results in an average rate of

$$P_{ave} = 1 \times 0.5 + 3/4 \times 0.5 = 7/8 \quad (4)$$

Four–dimensional coded modulation is used to encode the data. To achieve this, signal constellation (1) in Fig. 3 is used for level 1 and signal constellation (2) is used for level 2. The channel that is used is an additive white Gaussian noise (AWGN) one. The metric for the Viterbi algorithm is the Euclidean distance between the received signal and the signal constellation point. We assume that the importance level can change only every frame of 30 channel symbols.

A.1 *Decoder Error Performance*

If decoder–selection–errors occur, the number of decoded data bits is not the same as the number of original input bits. Therefore, the performance of the proposed UEP scheme depends on the decoder–selection–errors.

In Fig. 4 the decoder–selection–error rate is shown. We can see that using a different signal constellation for each code has better performance than using the same signal constellation for every code. This is because the distance between the codes is extended by using different signal constellations for each code.

A.2 *Coding Gain*

The proposed system is compared with a conventional equal error protection scheme which uses the same code as code B. The coding gain of the high importance bits is

$$G = 0 + 10\log_{10}\frac{7/8}{3/4} \simeq 0.67dB \quad (5)$$

and the coding gain of the low importance bits is

$$G = 10\log_{10}\frac{2}{4} + 10\log_{10}\frac{7/8}{3/4} \simeq -2.34dB. \quad (6)$$

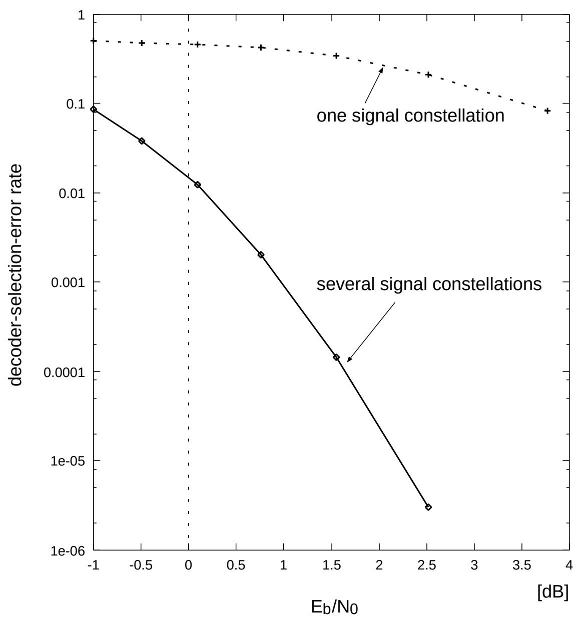

Fig. 4: Decoder–selection–error rate

A.3 *UEP Code Performance*

The performance of the proposed UEP system is shown in Fig. 5. In Fig. 5, the proposed system is compared with a conventional equal error protection scheme which uses the same code as code 2. As we can see in the figure, the performance of the important bits is better than the conventional scheme.

In this case, the average rate is 7/8. Taking into account the difference in the code rate between the proposed system and the equal error protection system, the important bits have achieved better performance than the 3/4 code.

B. *Three Importance Levels*

It is assumed that the three importance levels are: low (level 1), middle (level 2) and high (level 3), and that they have the same probability of occurrence . The level 1 bits are not coded, while the level 2 and 3 bits are coded by the rate 3/4 code and 2/4 code, respectively. This results in an average rate of 3/4. The signal constellations that are used are constellation (1) (Fig. 3) for level 1, constellation (2) for level 2 and constellation (3) for level 3. In this section we also evaluate the performance in an AWGN channel.

B.1 *Three Level UEP Code Performance*

The performance of the proposed UEP system when there are three importance levels is shown in Fig. 6. The proposed scheme is compared with a conventional

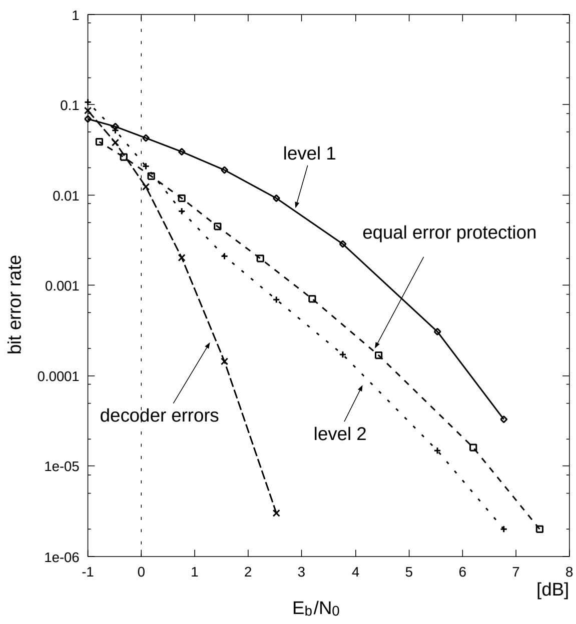

Fig. 5: The bit error rate performance of the proposed system

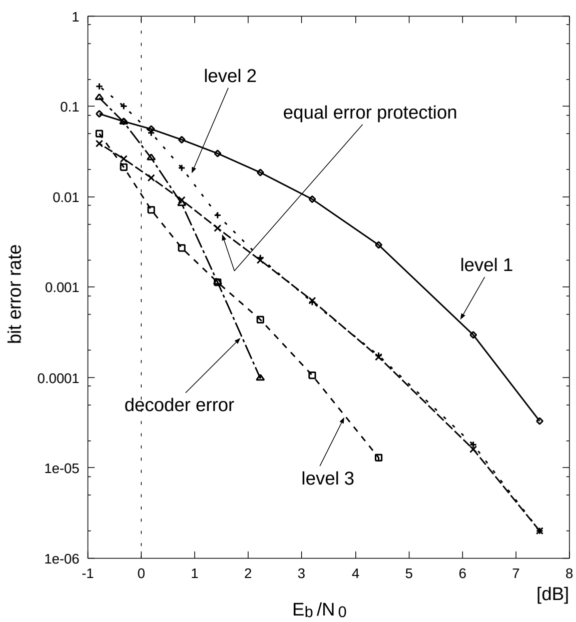

Fig. 6: The performance of the 3 level UEP code

error protection scheme whose rate is the same as the average rate of 3/4. The code that is used for the conventional error protection scheme is also code 2.

In Fig. 6, we can see that this UEP scheme achieves three levels of error protection. The most important bits are protected more strongly than the conventional equal error protection scheme.

IV. Conclusion

In this paper, we proposed an unequal error protection scheme based on multidimensional trellis coded modulation for use with information sources that contain a mixture of data with various importance. In this method, the bits are encoded with different codes depending on their importance. The signal constellations that are used are also different for each importance level, so no extra information about which code was used is added to the transmitted signal.

The bit error rates were compared with an equal error protection scheme using computer simulations. We found that the proposed unequal error protection scheme achieves better performance for the important bits than the equal error protection scheme.

We will evaluate the complexity of the proposed scheme and optimize the combination of the encoders in future work.

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