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Soft Decision Decoding for Binary Linear Block Codes in Communication Systems

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Abstract

In this paper, a new soft decision decoding method for channel codes is proposed. The proposed method uses soft decision information in communication systems. The refined and efficient algorithm reduces the number of required operations. It is shown that the proposed method has significant performance gain over conventional decision based decoding algorithms. The upper bound on the size of covering radius is derived and verified.

Keywords*: Soft decision decoding, Channel coding, Error correcting codes, communication engineering, electronics*

1. Introduction

In channel coding systems, the problem of designing efficient decoding algorithm is a fundamental one that arises in innumerable applications. The design of such a decoder is tantamount to the selection of candidate code words. [1-2]

The classical approach is the finite length linear code design [3] that requires the maximum entropy fitting. For soft decision decoding, the arithmetic structures have not been sufficiently helpful. Because the costs for installation of a buried land coaxial system are a major part of the total system cost, there has been a strong motivation to upgrade existing routes with the addition of more sophisticated code design. Typically, the required noise performance in communication system is difficult to achieve at the transmitted frequencies where the loss of the medium is maximum. It is common in the early design stages to concentrate on the top channel performance.

In this paper, we provide the classical derivation of optimal receivers for the channel using the framework of hypothesis testing, and describe techniques for obtaining quick performance estimates. Hypothesis testing is the process of deciding which of a fixed number of hypotheses best explains an observation. In our application, the observation is the received signal, while the hypotheses are the set of possible signals that could have been transmitted. We begin with a quick review of Gaussian random variables, vectors and processes. The basic ingredients and concepts of hypothesis testing are developed in this paper. We then show that, for signaling in AWGN, the receiver can restrict attention to the signal space spanned by the signals without loss of optimality.

Land and undersea cable systems share certain technical constraints. For optimum performance, coding gain must exactly match cable loss which increases with frequency. It doubles in decibels with each doubling in length. There is a practical limit to how much gain can be put into a code. [4-7] Repeaters must be spaced at precise intervals. Equalizers must be used to make up for small differences between the coding gain and cable loss.

We deduce the optimal decoding algorithm, and present the method for searching the candidate code words. Based on these, we propose a soft decision decoding method for

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binary linear block codes. If the multiplexed signal is assumed to be represented by a band of noise, it is possible to compute the intermodulation spectrum using the power spectral density of the signal. As a result, with the assumption of flat transmission levels and amplifier noise figure, the noise performance of the low frequency channels will be better than required.

Even though each code may meet stringent linearity requirements, the totality of the modulation noise produced by broad band system is an interference that is subjectively in distinguishable from white noise and often the controlling factor in the layout of a system. It is of interest to determine the way in which the modulation has an influence on the channel code. The decrease in average power leads to the increase in the transmission of digital data on the network. It represents a small fraction of the total network load. The creation of specialized data transmission services apart from the normal toll network should keep the impact of data transmission on the analog network relatively small.

2. Soft Decision Decoding for Binary Linear Block Codes

A communication system uses a binary linear code with generator matrix. The minimum Hamming distance is used for error control over the channel.

For BPSK transmission, the code word is mapped into the bipolar sequence. If a hard decision is performed independently, the natural choice for measure of reliability is made for bipolar signaling.

From the channel, we get the hard decision vector [8]

$$\mathbf{y} = (y_1, y_2, \cdots, y_n) \tag{1}$$

and the reliability information vector [9-11]

$$\mathbf{r} = (r_1, r_2, \cdots, r_n) . \tag{2}$$

The component of hard decision vector is binary number and that of the reliability information vector is non-negative real number. [12-13] Principal factors under the second order products combine according to their respective phase angles.

The radially directed power density at any point on the surface of the sphere passes outward through the surface. White Gaussian noise has infinite power, whereas receiver noise power in any practical system is always finite. However, since receiver processing always involves some form of integration, it is convenient to assume that the input to the system is infinite-power white Gaussian noise. In its elementary form, the central limit theorem states that the sum of a number of independent and identically distributed random variables is well approximated as a Gaussian random variable. However, the central limit theorem holds in far more general settings. It holds as long as dependencies or correlations among the random variables involved in the sum die off rapidly enough, and no one random variable contributes too greatly to the sum. The characteristic of receiver thermal noise can be attributed to its arising from the movement of a large number of electrons. However, because the central limit theorem kicks in with a relatively small number of random variables, we shall see the central limit theorem invoked in a number of other contexts, including performance analysis of equalizers in the presence of ISI as well as AWGN, and the modeling of multipath wireless channels.

After filtering, the noise statistics obtained with this simplified description are the same as those obtained by limiting the noise upfront. The real-valued WGN can serve as a model for receiver noise in a system, as well as for each of the noise components after conversion.

It can model the receiver noise in a physical baseband system, which is analogous to using only the component in a system. Complex-valued WGN, on the other hand, models the complex envelope of WGN. Its spectrum is double that of real-valued WGN because the PSDs of the real and imaginary parts of the noise, modeled as real-valued WGN, add up.

The PSD is double that of the noise model for the noise. This is consistent with the relations developed in this paper between the PSD of a random process and its complex envelope. The power density is therefore

$$\text{Power density} = \frac{P_T}{4\pi d^2}\ . \tag{3}$$

If a receiving antenna with an effective area is located on the surface of the sphere, the total power is equal to the power density times the area of the antenna. That is

$$P_R = \frac{P_T}{4\pi d^2} A_R\ . \tag{4}$$

It can be shown [14] that a transmitting antenna of effective area which concentrates its radiation within a small solid angle or beam has a transmitting antenna gain with respect to an isotropic radiator of

$$g_T = \frac{4\pi A_T}{\lambda^2}\ . \tag{5}$$

Antenna heights should be such that transmission performance objectives for obstruction fading are met. Let

$$d_E(S(\mathbf{x}_m), \mathbf{r}) \tag{6}$$

Be the Euclidean distance. The larger the reliability information is, the more reliable the hard decision is.

3. External Code

Maximum likelihood decoding using the Viterbi algorithm chooses the most likely code word. If all code words are equally likely to be sent, this also minimizes the probability of choosing the wrong code word. In contrast, the algorithm provides estimates of the posterior distribution of each bit in the code word. The method applies to both the information bits and coded bits for all classes of convolutional codes that we have discussed so far. The major part of the computation is in running two conventional algorithms, one forward and one backward, through the trellis. The complexity of the algorithm is therefore somewhat higher than that of the algorithm. For any given bit, the output of the algorithm can be summarized by the log likelihood ratio. Note that computation of the posterior distribution requires knowledge of the prior distribution. These provide soft information, with our confidence on our knowledge increasing with their magnitude.

The idea in this paper is to take advantage of the ordering the information bits in error. The maximum entropy fitting reduces the number of possible changes and the remaining discarded changes do not significantly affect the error performance.

Exhaustive search test of the candidate code words in the first positions of (1) and selecting the code word with smallest distance will provide the optimum solution. The distortion signal contains both linear and nonlinear components of the desired signal. The permutation sequence

$$\mathbf{p} = (p_1, p_2, \cdots, p_m p_{m+1}, \cdots, r_n) \tag{7}$$

is obtained such that

$$d_E(S(\mathbf{y}_m), \mathbf{r}) = | C | \tag{8}$$

with

$$p_1 > p_2 > \cdots > p_m\ . \tag{9}$$

The validity of equating the power of a broad band signal with power of a single frequency signal requires that overload be independent of frequency. And

$$| p_{m+1} | > \cdots > | p_n | . \qquad (10)$$

If (9) represents the parity check components, the optimum solution is clearly the parity check matrix. Then the elementary binary additions are now required to transform the entropy fitting into the reliability information. [15-16]

The baseband noise spectra produced by transmission deviations and by AM to PM conversion have the property of being functions of the baseband signal. Hence, they are correlated to some degree.

It is important to mention that seed does not need to be fixed during the decoding. When seed is allowed to change, we have an adaptive decoding procedure. In order to avoid increasing computation time when the seed is changed at some stage of the decoding procedure, we may not want to recalculate the values of function with respect to this new seed.

We begin with an exposition of the original algorithm, followed by a detailed discussion of its logarithmic version, which is preferred in practice because of its numerical stability. The logarithmic implementation also provides more insight into the nature of the different kinds of information being used by the algorithm. This is important in our later discussion of how to use the algorithm as a building block for iterative decoding.

Under these circumstances, nodes on list may have values of function h calculated with respect to different seeds. We cannot assure that when a node is selected for expansion the decoding algorithm has already found a minimum cost path from the start node to this node. Therefore, the decoding algorithm may not find an optimal path, but by not checking for repeated nodes it is ensured that the decoding algorithm will find an optimal path.

This can easily be seen, since the procedure will now generate a decision tree. As the procedure is now generating a decision tree, the cost of the minimum cost path from the start node to the goal node.

If we do not check for repeated nodes, then the adaptive version will never delete all optimal paths during the search procedure.

The same permutation is determined when dependent columns are present. Note that the ordering is realized with respect to the dual code. We need to evaluate the convergence statistics. From these statistics, we then evaluate the probability that the hard decisions of any group of information bits are jointly in error.

4. Simulation Result

We present the performance of the proposed soft decision decoding algorithm and that of maximum entropy fitting (MEF) decoding algorithm. [17] Figure 1 to 5 show the bit error probability of the proposed algorithm and MEF decoding algorithm. Figure 6 to 10 show the computational complexity of the proposed algorithm and MEF decoding algorithm. Figure 11 to 15 show the average reduction rate of the proposed algorithm and MEF decoding algorithm. The fundamental assumption is that the information passed from one decoder to another is a Gaussian distributed random variable. The metric of a priori input for the information is modelled as mutual information for extrinsic output.

Simulation results for these codes show that a drastic reduction on the search space was achieved for most practical communication systems. In order to verify the contribution of our heuristic function to the efficiency of our decoding algorithm, we implemented decoding algorithms. Simulation results for 7 dB show that for the samples that satisfy the criterion in the codes, the nodes need to be stored. On the other hand, the proposed algorithm need to store the nodes to decode the samples. Simulation results showed that our adaptive decoding algorithm described in this paper is at least one order of magnitude more efficient in time and space than that proposed in the conventional method, where the seed is 0 during the entire decoding procedure.

The classical approach is the finite length linear code design that requires the maximum entropy fitting. For soft decision decoding, the arithmetic structures have not been sufficiently helpful. Because the costs for installation of a buried land coaxial system are a major part of the total system cost, there has been a strong motivation to upgrade existing routes with the addition of more sophisticated code design.

Typically, the required noise performance in communication system is difficult to achieve at the transmitted frequencies where the loss of the medium is maximum. It is common in the early design stages to concentrate on the top channel performance

The normalized threshold algorithm changes the range of candidate code words according to SNR of the channel. The adaptive change improves the performance. Soft decision decoding improves the reliability of the coding systems by using more information than that of hard decision decoding. Over the additive white Gaussian noise channel, the (15, 11) RS code is used. The energy per information bit is E_b, and the single-sided noise spectral density is N_o. When a transmitted signal goes through a channel, at the very least, it gets attenuated and delayed, and undergoes a change of carrier phase. Thus, the model considered here applies to a receiver that can estimate the effects of the channel, and produce a noiseless copy of the received signal corresponding to each possible transmitted signal. Such a receiver is termed a coherent receiver.

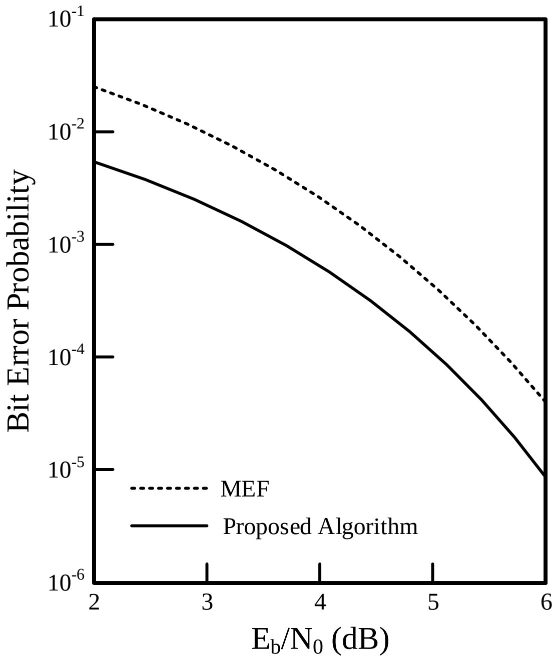

Figure 1. Bit Error Probability of (15, 11) RS Code

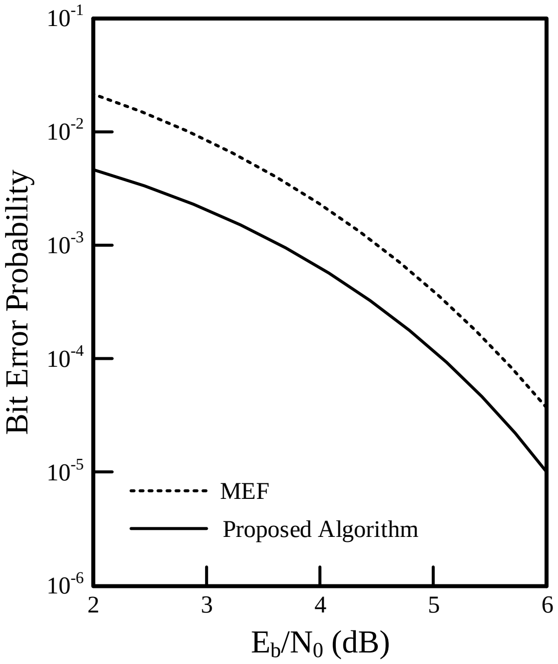

Figure 2. Bit Error Probability of (24, 12, 8) Extended Golay Code

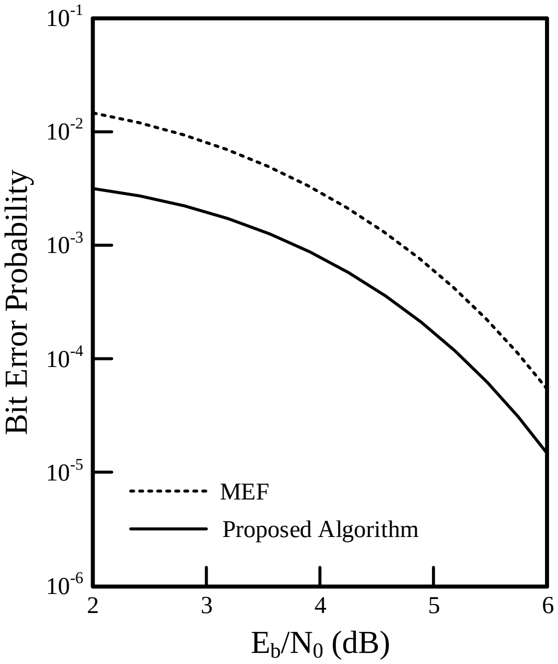

Figure 3. Bit Error Probability of (64, 42, 8) Reed-Muller Code

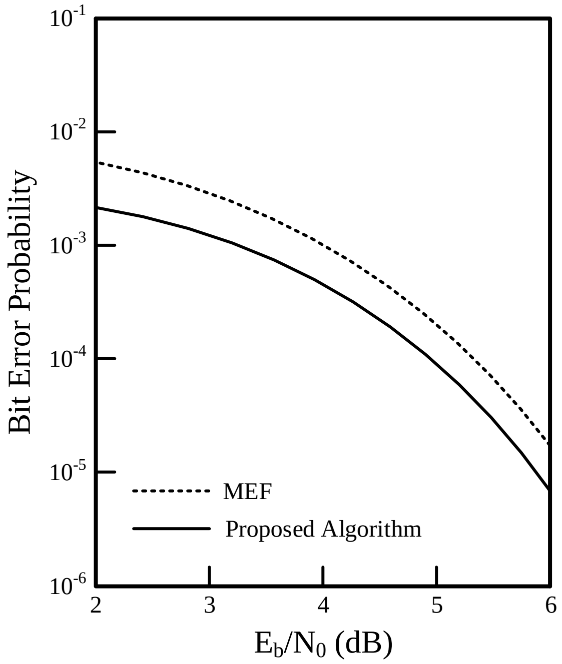

Figure 4. Bit Error Probability of (128, 99, 10) Extended BCH Code

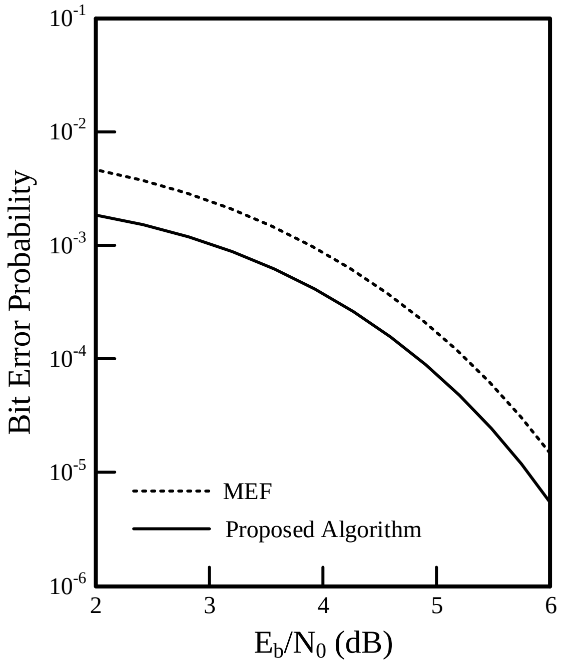

Figure 5. Bit Error Probability of (128, 64, 22) Extended BCH Code

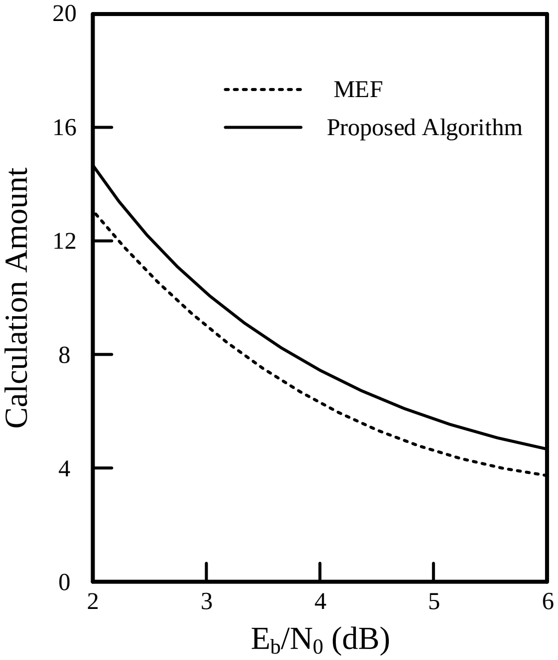

Figure 6. Calculation Amount of (15, 11) RS Code

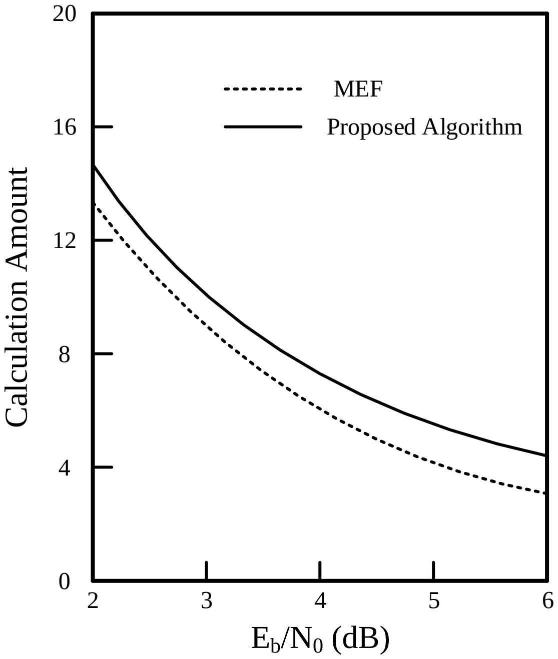

Figure 7. Calculation Amount of (24, 12, 8) Extended Golay Code

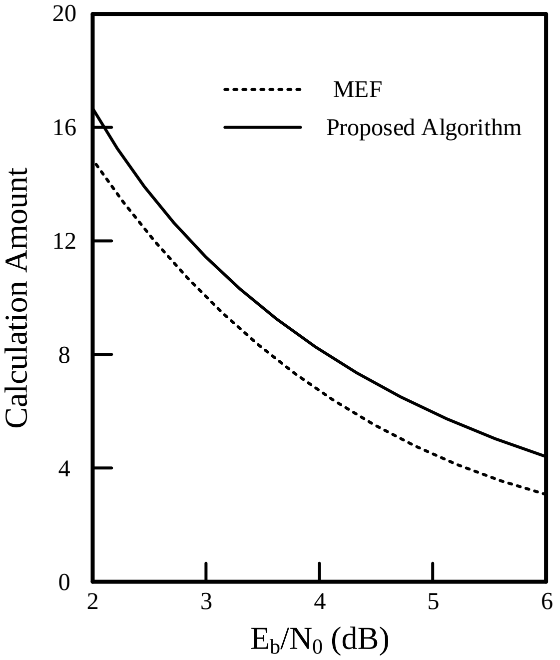

Figure 8. Calculation Amount of (64, 42, 8) Reed-Muller Code

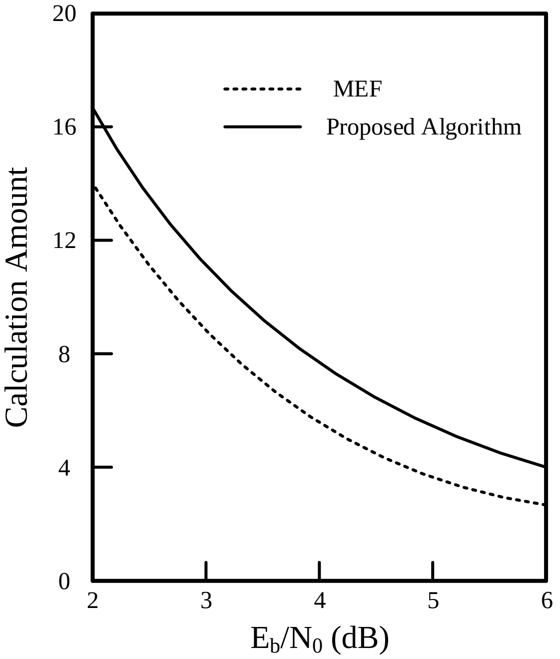

Figure 9. Calculation Amount of (128, 99, 10) Extended BCH Code

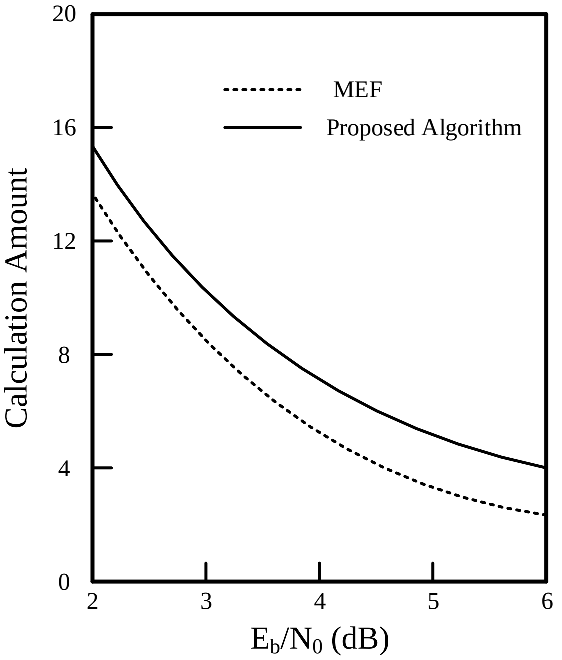

Figure 10. Calculation Amount of (128, 64, 22) Extended BCH Code

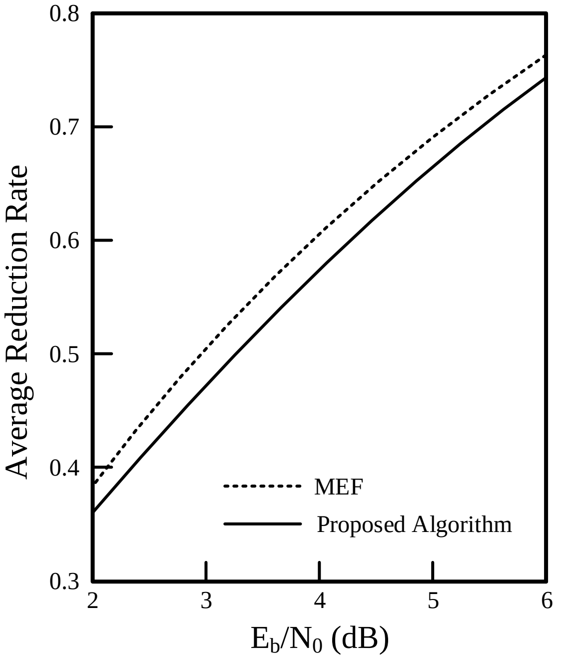

Figure 11. Reduction Rate of (15, 11) RS Code

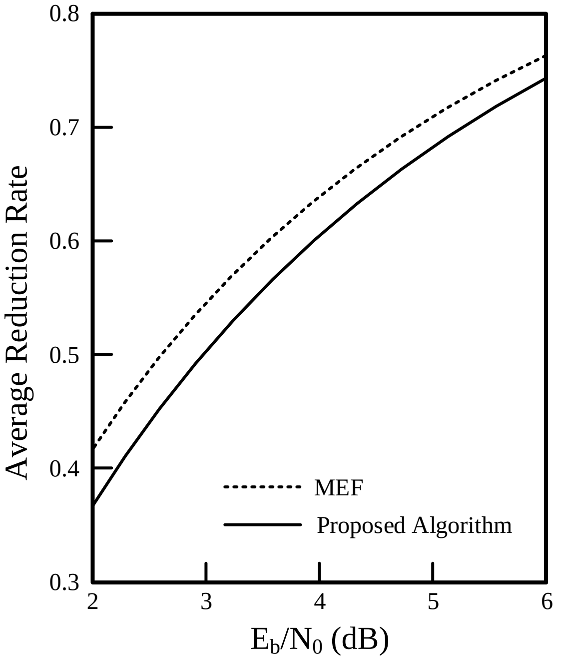

Figure 12. Reduction Rate of (24, 12, 8) Extended Golay Code

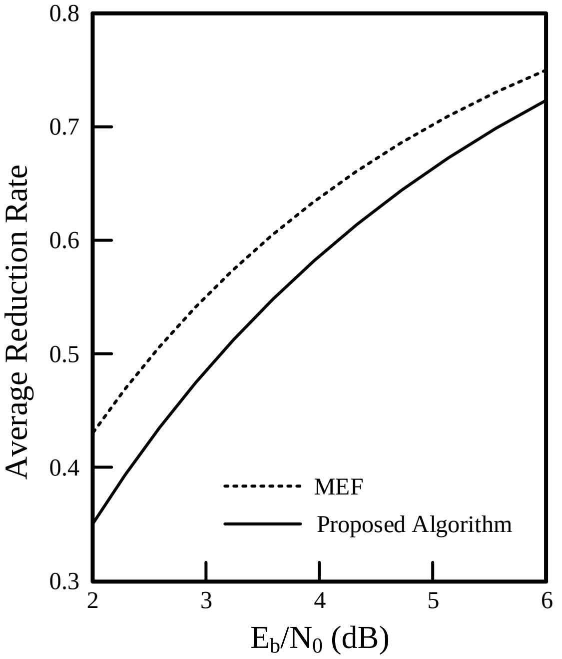

Figure 13. Reduction Rate of (64, 42, 8) Reed-Muller Code

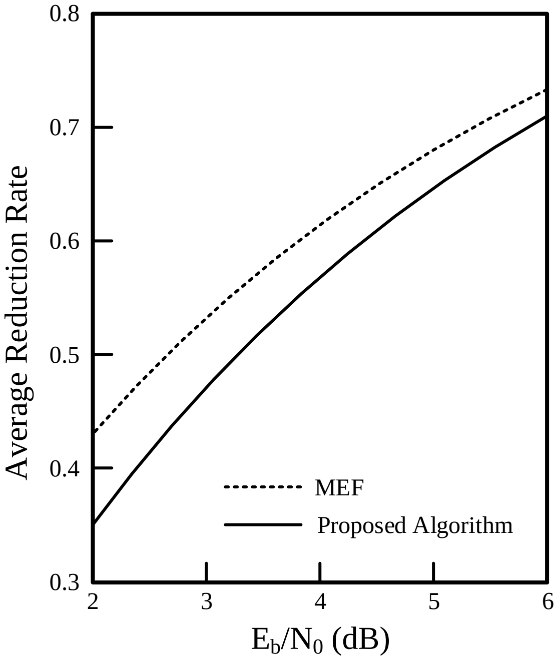

Figure 14. Reduction Rate of (128, 99, 10) Extended BCH Code

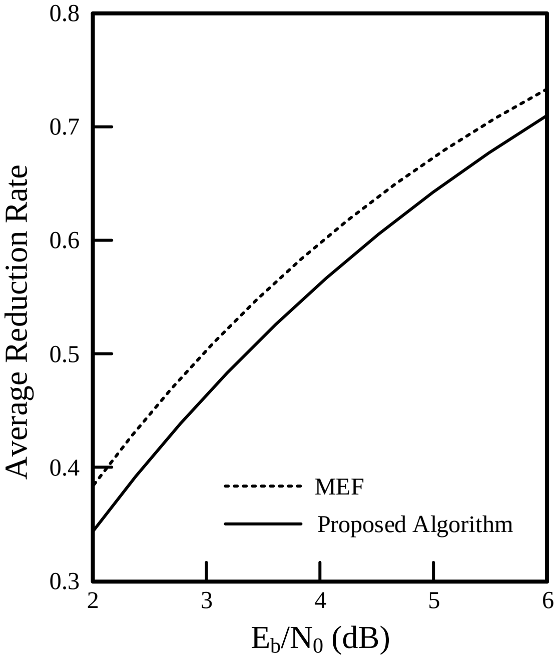

Figure 15. Reduction Rate of (128, 64, 22) Extended BCH Code

5. Conclusion

A decoding scheme for error control codes is proposed. The scheme is a soft decision decoding algorithm for binary linear block codes in channel coding. We present the refined and efficient algorithm which reduce the number of candidate code words. Experimental results show that the proposed decoding algorithm gives high probability of correct decoding.

We deduce the optimal decoding algorithm, and present the method for searching the candidate code words. Based on these, we propose a soft decision decoding method for binary linear block codes. If the multiplexed signal is assumed to be represented by a band of noise, it is possible to compute the intermodulation spectrum using the spectral density of the signal. As a result, with the assumption of flat transmission levels and amplifier noise figure, the noise performance of the low frequency channels will be better than required.

In this paper, we provide the classical derivation of optimal receivers for the channel using the framework of hypothesis testing, and describe techniques for obtaining quick performance estimates. Hypothesis testing is the process of deciding which of a fixed number of hypotheses best explains an observation. In our application, the observation is the received signal, while the hypotheses are the set of possible signals that could have been transmitted. We begin with a quick review of Gaussian random variables, vectors and processes. The basic ingredients and concepts of hypothesis testing are developed in this paper. We then show that, for signaling in AWGN, the receiver can restrict attention to the signal space spanned by the signals without loss of optimality.

The decrease in average power leads to the increase in the transmission of digital data on the network. It represents a small fraction of the total network load. The creation of specialized data transmission services apart from the normal toll network should keep the impact of data transmission on the analog network relatively small.

We have developed an approach to obtain the upper and lower bound which can be evaluated explicitly. The proposed algorithm is asymptotically optimum for high signal to noise ratio.

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