No. IC-5

A Serial Unequal Error Protection Codes System using AEPF-DFE for Fading Channels

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Abstract

In our previous research, we proposed a serial unequal error protection (UEP) code system for use with information sources that contain a mixture of both important and less important data. Previously, theoretical analyses were presented, and the effectiveness and the validity of the system for additive white Gaussian noise (AWGN) channels was confirmed using theoretical analyses and computer simulations. On the other hand, we proposed an adaptive error prediction filter with a decision feedback equalizer (AEPF-DFE) to achieve faster convergence and lower computational cost during the tracking period. In this paper, we propose our UEP system using AEPF-DFE for time and frequency selective fading channels. We confirm the improvement in BER performance and the effectiveness of adaptive equalization for the proposed system in fading channels. Also, we confirm the predominance of the proposed system by comparing the previous scheme, that is, the case using a simple DFE.

Keywords: Unequal error protection (UEP), Time-multiplexing Signal Constellations, adaptive error prediction filter with a decision feedback equalizer (AEPF-DFE), time and frequency selective fading channels

1. INTRODUCTION

In certain communication systems an information sequence may consist of several parts that have different degrees of significance and hence require different levels of protection against noise. Codes that are designed to provide different levels of data protection are known as unequal error protection (UEP) codes [1]. For example, in packet communications, the header must be protected more than the payload, because in the worst case, if the destination address is lost the entire packet will be lost. Similarly, UEP is useful for protecting the unique word in data frame transmission and for protecting data in the layered coding schemes used in digital terrestrial broadcasting systems. UEP codes were first studied by B. Masnick and J. K. Wolf [2] and later have been studied by several authors [3]-[10]. Previously, we proposed an improvement of the time multiplexing approach mentioned in [4], [5] and confirmed the effectiveness for additive white Gaussian noise (AWGN) channels using theoretical analysis and computer simulations [10].

In recent years, the demand for wireless digital communication systems such as mobile phones has increased significantly. However, in wireless communication environments, in addition to the influence of AWGN, the effects of time and frequency selective fading become significant [11]. However, these UEP systems are for AWGN or slow fading channels and there have been few UEP systems using techniques to combat selective fading aggressively.

Previously, we proposed an adaptive error prediction filter with a decision feedback equalizer (AEPF-DFE) to achieve faster convergence and lower computational cost during the tracking period. An AEPF is a linear predictive filter that updates its coefficients using an adaptive algorithm. We got the basic characteristic about an AEPF-DFE and the effectiveness was shown using computer simulations [12].

In this paper, we propose our UEP system using AEPF-DFE for fast and selective fading channels. We confirm the improvement in BER performance and the effectiveness of adaptive equalization for the proposed system in fading channels. Also, we confirm the predominance of the proposed system by comparing the previous scheme, that is, the case using a simple DFE.

2. The Proposed Scheme

Previously in [10], we described the proposed scheme and the difference between it and previous schemes in detail. In this section, the enhancements to the proposed system for fading environments are described by showing the differences between it and the proposed system for AWGN channels. Hereafter, high importance is denoted by “H” and low importance is denoted by “L”. For example, the low importance level is denoted by “level-L”, low importance data is denoted by “data-L” and the high importance code is denoted by “code-H”.

2.1 System model

The proposed scheme is outlined in Fig.1. As we consider a serial data stream that has a random mixture of important and less important data, the proposed scheme encodes the data by randomly switching between two codes which use different signal constellations, i.e., we use multilevel trellis coding to realize UEP. No extra information about which code was used is added to denote importance. This method has the advantage of not reducing the information rate. As more important information should be more strongly protected from errors, it’s allocated to a large ring. The opposite can be said about less important information. We show this concept for two importance levels in Fig.2. Moreover, as mentioned above, having adaptive equalization to combat fading is different from the previous schemes [2]-[10].

2.2 Processing Details

In this section, we describe the main processing steps used in the proposed scheme shown in Fig.1 in detail. Specially, the processing steps that are different from [10] for AWGN channels are Steps 3, 6, 8 and 10. The numbers in the explanation, for example #1, correspond to the numbers in Fig.1.

- The transmitter

Step1. The input data comes from an information source which outputs random data {0,1}. Also, the input data is transmitted to the importance level decision block (#1).

Step2. The importance level of the data is evaluated by the importance level decision block every N_c symbols (#2). This decision controls the switch ahead. In this paper, in order to focus on the UEP implementation itself, we decide the importance level randomly. In Fig.1, if the output of the importance level decision block is “L”, then the switches will be in the “up” position. If the output is “H”, then the switches will be in the “down” position (#3).

Step3. We prepare codes which have different signal constellations according to the importance level. Moreover, we combine coding and modulation using Trellis coded modulation (TCM) [14] with four states at the same time (#4). Here, interleaving in units of symbols is done after coding. We describe this interleaving in section 2.4. Information bits are allocated to signal points based on Gray coding. The distance between the signal points is larger for data-H, resulting in stronger error protection. Moreover, we encode the data differently according to the importance level to create UEP characteristics.

Step4. The data is selected by changing the switches according to the importance level decision performed in step 2 every N_c symbols (#5).

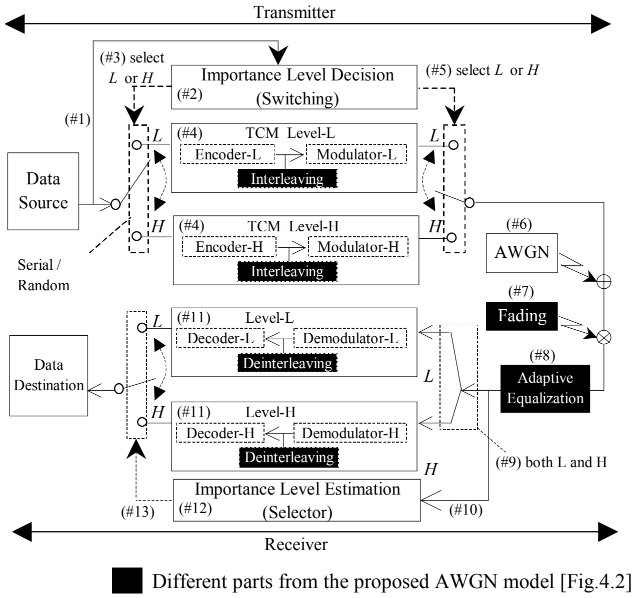

Fig. 1 The proposed UEP scheme in fading channels for two levels of importance.

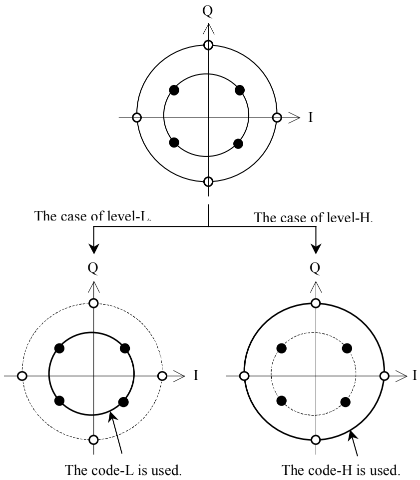

Fig. 2 The proposed concept to realize UEP for two levels of importance.

- The channel

Step5. AWGN affects the transmitted signal in the channel (#6).

Step6. Multi-path fading affects the transmitted signal in the channel (#7).

- The receiver

Step7. Adaptive equalization in the time domain is done to combat fading (#8). In section 2.3, we describe the processing in detail.

Step8. The equalized output is sent to all the decoders regardless of the importance (#9).

Step9. Also, the data is transmitted into the importance level estimator (#10). In parallel with the decoding (#11), the encoder used in the transmitter, i.e., the importance level, is estimated every N_c symbols using an importance level estimation algorithm [10] based on maximum likelihood detection (MLD) (#12). Processing #11 and #12 are done in parallel to prevent throughput degradation.

Step10. The output data is decided based on the estimated result (#13). In this way, the receiver can determine the importance of the information.

2.3 AEPF-DFE[12]

We describe the operation of the proposed scheme. During the training period, we use the RLS (Recursive Least Square)[11] algorithm which has a higher convergence speed to focus on transmission efficiency. On the other hand, during the tracking period the LMS (Least Mean Square) algorithm[11], which is not computationally intensive, is used to reduce the computational load. However, as the LMS algorithm has a slower convergence speed, we propose a decision feedback equalizer with a linear predictive filter to improve convergence properties. A linear predictive filter consists of a FIR (Finite Impulse Response) filter of order, and future sample values can be predicted from previous values sampled in a fixed time period. The predictive error is the difference between the predicted sample value and the actual sample value. By minimizing the mean square of the predictive errors adaptively using the LMS algorithm, a linear predictive filter has the effect of flattening the frequency response and we can expect an improvement in the convergence speed. Therefore, we propose an AEPF with a DFE in cascade called AEPF-DFE. The proposed DFE system is shown in Fig.3 and the structure of the proposed AEPF is shown in Fig.4. Using the proposed method, we expect faster convergence and lower computational cost during tracking. So, when the system is implemented in hardware, we can expect an advantage from the viewpoint of control.

2.4 Interleaving and Deinterleaving

Interleaving and deinterleaving are used for translating burst-errors into random-errors in fading channels [1]. In the proposed system, matrix-interleaving is used. In the transmitter, the transmitted data sequence is written to a memory table in rows and then read out in columns to implement interleaving in Fig.5 (a). On the other hand, in the receiver, the data is written in columns and then read out in rows to achieve deinterleaving in Fig.5 (b). Burst errors which occurred during transmission are made random by this operation. A larger matrix size ($L\times R$) is effective for longer burst errors. However, the delay time $T_d=(2L\times R)/f_b$ (f_b:bit rate) to read and write data is longer. So, the matrix size must be chosen based on both the allowed delay time for the system and the length of burst errors. In this letter, (L, R)=(8,128) is adopted, because in [13], better performance is shown for TCM with 8 states and 1024 symbols.

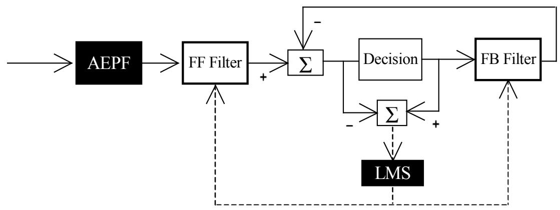

Fig.3 The proposed DFE scheme (AEPF-DFE)[12].

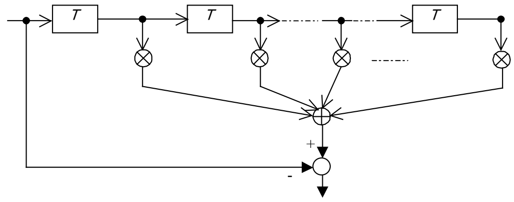

Fig.4 The structure of the proposed AEPF[12].

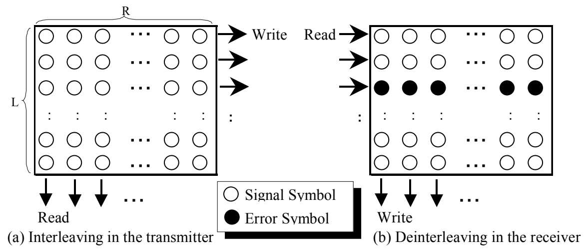

Fig.5 Interleaving and deinterleaving.

2.5 Relationship between the Signal Constellation and the Error Rate [10]

In Fig. 6, the analysis model of the RING type constellations described in section 2.1 is shown. The error rate performance largely depends on the distances between signal points. Namely, the average bit error rate for each code (code-H or code-L) is related to the distance d_H or d_L and the importance level estimation error rate for the 2RING type constellations is related to the distance dc. To evaluate the relationship between the signal constellation and the error rate, we introduced the following minimum squared Euclidean distances normalized by the average energy. As a result, we confirmed that since the value of the ring ratio β is related to both the average bit error rate for each code and the importance level estimation error rate for the 2RING type constellations, a tradeoff exists. In Fig.7, if we use a smaller β, a tradeoff exists between the average bit error rate for each code and the importance level estimation error rate for the 2RING type constellations.

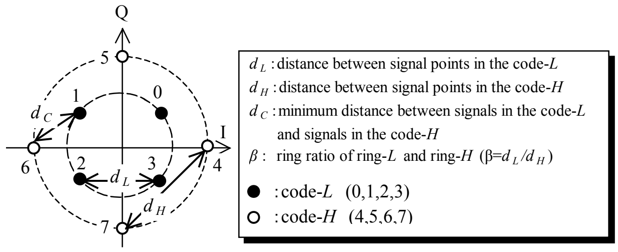

Fig.6 Analysis model of the RING type constellations.

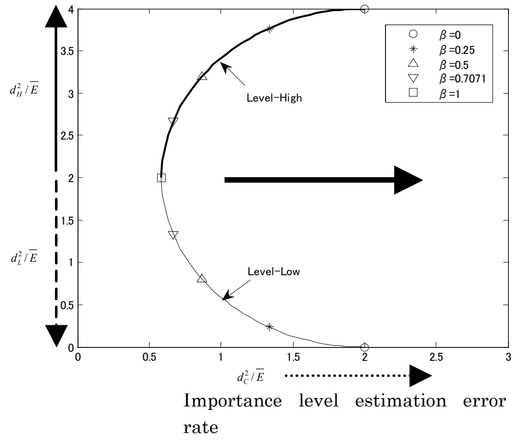

Fig.7 Tradeoff between the error rate performances [10].

3. Performance Evaluation

We examine the performance of our system by using computer simulations. In this section, we evaluate the same items in [10] using the main parameters that determine the proposed system's performance, that is, the ring ratio β and the importance switching ratio N_c. In table.1, the simulation parameters are shown.

3.1 Importance Level Estimation Error Rate

The importance level estimation error rate is the probability that code-H is estimated incorrectly to be code-L or vice-versa. This value will be a measure showing whether code-L and code-H are distinguished correctly based on the proposed method. In Fig.8 and Fig.9, the importance level estimation error rate versus E_b/N_0 is shown for the two cases f_dT_s = 0.001 and 0.01 under a fixed importance switching rate N_c = 64 symbols. In Fig.10, the importance level estimation error rate versus E_b/N_0 is shown for the importance switching rates N_c = 16, 32 and 64 for f_dT_s = 0.001 and a ring ratio β = 0.25. Also, in these figures, the performance without equalization is shown for the comparison. The following conclusions can be drawn. Also, in Fig.10, to evaluate the proposed AEPF-DFE, we compare our system and the previous DFE.

1. Regardless of the ring ratio β, error floors occur in the region around BER=10^{-1} when adaptive equalization is not used. On the other hand, when adaptive equalization is used, this situation is avoided and we confirmed the effectiveness of equalization. Otherwise the error floors occur starting at about E_b/N_0=40[dB]. One of reasons for this is as follows. Coherent demodulation is used in this system, so tracking the fading is difficult. However, we confirmed that a BER of 10^{-2} - 10^{-3}, which is considered a standard for voice communication, was obtained in fast fading.
2. Regardless of the ring ratio β, if f_dT_s is larger, the performance is degraded because of fading effects. However, a great performance improvement is achieved by using AEPF-DFE.
3. Regardless of the value of f_dT_s, if β is larger, the performance is degraded. This fact is due to the analysis mentioned in section 2.5.
4. If the importance switching rate N_c is larger, the performance is improved for a fixed value of β and f_dT_s (β = 0.25, f_dT_s = 0.001). This is due to the fact that if N_c is larger, the importance does not frequently change, so importance estimation errors do not occur frequently. Results 3 and 4 are similar to the results in AWGN channels [10].
5. In Fig.10, as the performance is improved for a fixed value of β and f_dT_s, we confirmed the excellence of the proposed scheme over the previous scheme. In our UEP system, we confirmed that the result is due to the effectiveness described in [12].

3.2 Bit Error Rate

In Fig.11, the average bit error rate versus E_b/N_0 of the individual codes (code-H, code-L) is shown for β = 0.25, 0.5 and 0.7071 for N_c= 64 and f_dT_s = 0.001. Also, the performance without equalization for code-H and the performance with equal error protection (EEP) are shown. The following conclusions can be drawn. In Fig.12, the average bit error rate versus E_b/N_0 is shown for the importance switching rates N_c = 64 for f_dT_s = 0.001 and a ring ratio β = 0.5 for comparison with the previous scheme.

1. We confirmed that the desired UEP characteristics can be obtained, in other words, the information bits that are deemed to be important can be protected more than bits of lesser importance, using the proposed method. Especially, the error rate of the important information is lower than the error rate for an EEP scheme. For example, for code-H at an error rate of 10^{-3}, we get an improvement of about 5 dB regardless of β.
2. Regardless of the ring ratio β, in the case without equalization, an error floor occurs at about BER = 10^{-1}. On the other hand, in the case with equalization, such an error floor does not appear. As a result, we could confirm the effectiveness of adaptive equalization. If we use a smaller β, the average bit error rate for code-L is worse. On the other hand, the average bit error rate for code-H is better. This fact is due to the analysis mentioned in section 2.5.

Table 1. simulation parameters

Transmitted Data	0, 1 (random)
Noise	AWGN
Pulse shaping	None
Synchronization	Ideal
Importance level M	2 (High, Low)
Occurrence Probability of importance	High: 1/2, Low: 1/2
Ring ratio β	0.25, 0.5, 0.7071
Importance switching rate N_c	16, 32, 64 [symbols]
Channel coding rate	High: 1/2, Low: 1
Demodulation	Coherent
Decoding	Viterbi decoding
Detection	Hard-decision
Fading	Time and Frequency selective Rayleigh
Channel model	10-path exponential power delay model Decay factor : 3[dB] Delay interval : 1 sysmbol interval
Channel Estimation	Perfect
Interleaving Size ($L \times R$)	(L, R) = (8,128)
Normalized Doppler Frequency $f_d T_s$	0.01, 0.001
Delay of training sequence D	8
Order of APEF filter	4
Order of FF filter	4
Order of FB filter	1
Frame structure (Training part)	20 symbols
Frame structure (Information part)	200 symbols
Step size μ on LMS algorithm	0.05
Forgetting factor λ on RLS algorithm	0.7

3. In Fig.12, as the performance is improved for a fixed value of, N_c, $f_d T_s$ and β, we confirmed the excellence of the proposed scheme over the previous scheme. In our UEP system, we confirmed that the result is due to the effectiveness described in [12].

4. Conclusions

We introduced the proposed AEPF-DFE into the proposed UEP system and showed the effectiveness of adaptive equalization, the improvement in the average bit error rate for each code and the code decision error rate for the 2RING constellation in frequency and time selective Rayleigh fading. As a result, we introduced fading compensation technology, which has not been considered in previous UEP work, into our UEP system and showed its effectiveness in fast and selective fading. Moreover, in fading channels we confirmed the validity of the theoretical tradeoff shown in static conditions. As a result, we showed that a UEP system is realizable in mobile communication environments.
Now, we are analyzing the theoretical BER performance in fading channels.

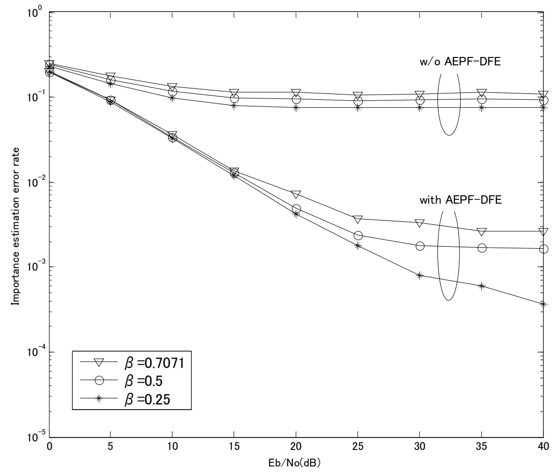

Fig. 8 (a) Importance level estimation error rate versus E_b/N_0 (The dependency on the ring ratio β for $f_d T_s$ =0.001).

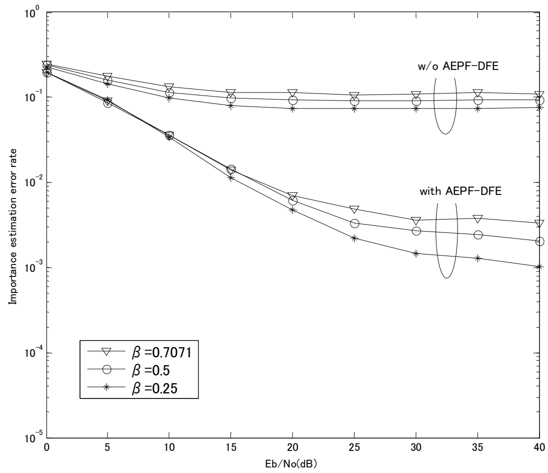

Fig. 9 (b) Importance level estimation error rate versus E_b/N_0 (The dependency on the ring ratio β for $f_d T_s$ =0.01).

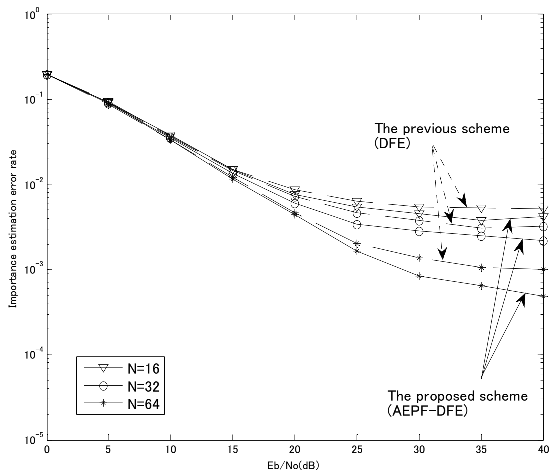

Fig. 10 Importance level estimation error rate versus E_b/N_0 (The dependency on the importance switching rate N_c for $f_d T_s$ =0.001, β=0.5)

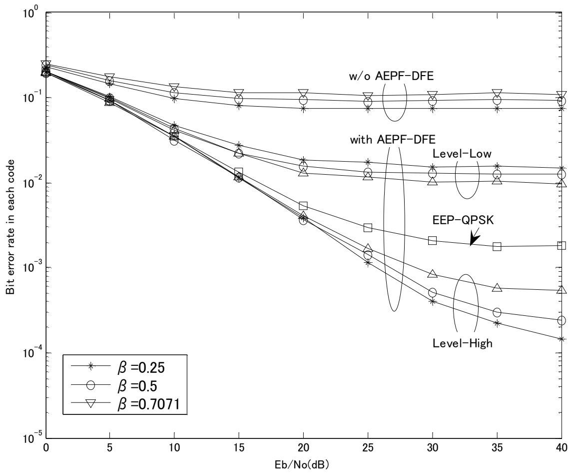

Fig. 11 Bit error rate versus E_b/N_0
(The dependency on the ring ratio β for N_c=64, f_dT_s =0.001).

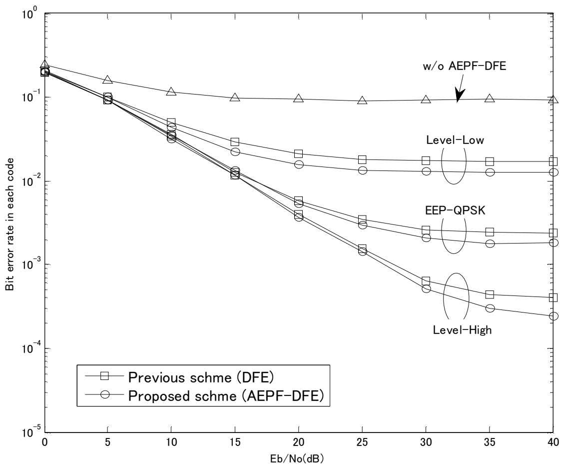

Fig. 12 Bit error rate versus E_b/N_0
(N_c=64, f_dT_s =0.001, β=0.5).

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