A Serial Unequal Error Protection Codes System using MMSE-FDE for Fading Channels*

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Abstract— **In our previous research, to achieve unequal error protection (UEP), we proposed a scheme which encodes the data by randomly switching between several codes which use different signal constellations and showed the effectiveness in AWGN channels. In this paper, we propose our UEP system using MMSE-FDE (frequency-domain equalization based on the minimum mean square error criterion) for fast and selective fading by using the fact that importance levels are changed every few symbols, i.e., every block, in the proposed system. We confirmed the improvement in BER performance and the effectiveness of adaptive equalization for the proposed system in fading channels. As a result, we showed that a UEP system is realizable in mobile telecommunications environments.**

Keywords ***UEP, MMSE-FDE, Fading channels, Equalization***

I. 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]-[7], [10], [11]. In previous research, we proposed an improvement of the time multiplexing approach mentioned in [4], [5]. Moreover, the effectiveness of the proposed UEP system for additive white Gaussian noise (AWGN) channels was shown using theoretical analysis and computer simulations [8].

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 fading become significant [9]. UEP systems have been evaluated in fading environments. In [10], the rate-Compatible Punctured Convolutional Code system is proposed. In [11], the multilevel Block Coded 8-PSK Modulation system using UEP is proposed. However, these systems are for slow fading and there have been few UEP systems using techniques to combat fast and selective fading aggressively. In this paper, we propose a UEP system using MMSE-FDE (frequency-domain equalization based on the minimum mean square error criterion) [12], [13] for fast and selective fading by using the fact that importance levels are changed every few symbols, i.e., every block, in the proposed system [8]. As a result, lower computational cost and better BER performance are expected for broad-band transmissions.

The rest of our paper is organized as follows. In section 2, previous UEP schemes are described. In section 3, we introduce our UEP scheme. In section 4, we present simulation results to show the performance of our system. Finally, we present our conclusions in section 5.

II. THE PREVIOUS UEP SCHEME

In [8], we describe the difference between the proposed system and previous systems in detail. In this section, we describe methods using a non-uniform signal constellation, methods using coded modulation with time multiplexing as typical previously proposed UEP schemes [4], [5]. An example of the latter for two importance levels is shown in fig.1. Information from the information source is classified as having either a level-L or a level-H, then encoded using a code corresponding to the importance level. Data-H uses a more powerful code (Encoder-H), while data-L uses a less powerful code (Encoder-L). In this system, the information source decides the importance level and information is processed in parallel.

III. THE PROPOSED UEP SCHEME

A. System model

The proposed scheme is outlined in fig.2. This scheme uses two importance levels. This is an improvement of the time multiplexing approach mentioned in previous schemes [4], [5]. In these schemes, it is assumed that the data stream is separated into two parallel data streams, consisting of data-*H* and data-*L* and periodic switching is needed. However, as the serial data

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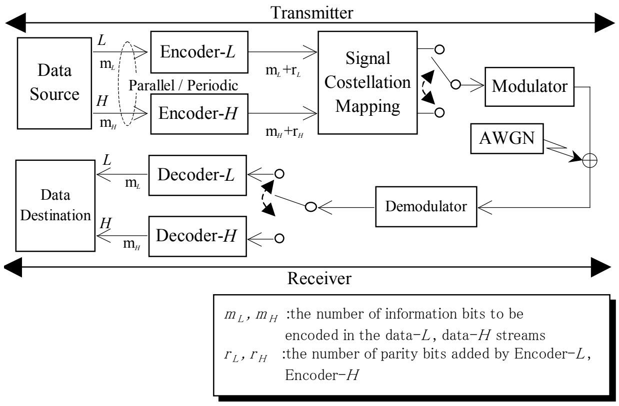


Fig. 1. Coded modulation with time multiplexing [4], [5].

stream that we consider has a random mixture of important and less important data. So, 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.3. Moreover, as mentioned above, having adaptive equalization to combat fading is different from the previous schemes [2]-[7], [10], [11].

B. Processing Details

In this section, we describe the main processing steps used in the proposed scheme shown in fig.2 in detail. Specially, the processing steps that are different from [8] for AWGN channels are Steps 3, 5, 7, 8, 9 and 11. The numbers in the explanation, for example #1, correspond to the numbers in fig.2.

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* bits (#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.4, 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 TCM (Trellis coded modulation) with four states [1] at the same time (#4).

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

Step5. A block consists of Nc symbols, and a cyclic-prefix (CP) consisting of a part of the end of the block (size: N_g symbols) is inserted at the beginning of the block (#6).

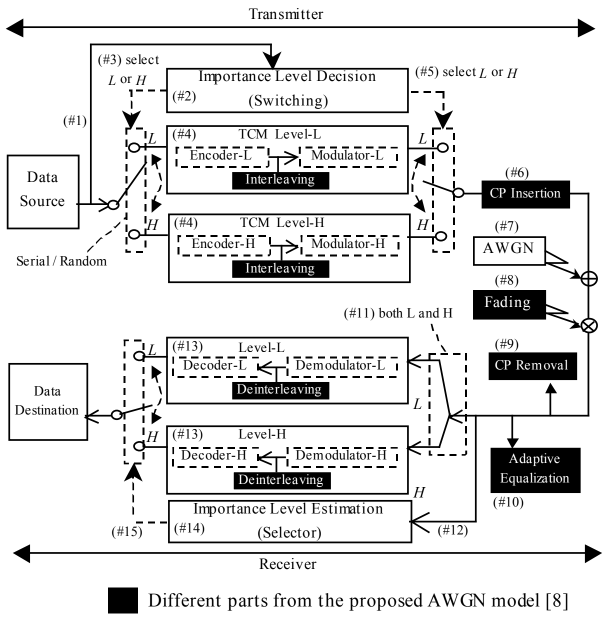


Fig. 2. The proposed UEP scheme in fading channels for two levels of importance.

Step6. AWGN affects the transmitted signal in the channel (#7). Fading in multi-path channels affects the transmitted signal in the channel (#8).

Step7. The CP is removed (#9).The MMSE-FDE [12], [13] 1is done to combat fading (#10). We describe the MMSE-FDE in section 3.3.

Step8. The channel output is sent to all the decoders regardless of the importance (#11). Also, the data is transmitted into the importance level estimator (#12). In parallel with the decoding (#13), the encoder used in the transmitter, i.e., the importance level, is estimated every Nc symbols using an importance level estimation algorithm [8] based on maximum likelihood detection (MLD [9]) (#14). Processing #13 and #14 are done in parallel to prevent throughput degradation. The output data is decided based on the estimated result (#11). In this way, the receiver can determine the importance of the information.

C. MMSE-FDE

In fig.4(a), we show the outline of MMSE-FDE including the parts mentioned in section 3.B. In the time-domain (TD) and frequency-domain (FD), the transmitted signal, the channel model, and the received signal are as follows. Here, it is noted that n denotes the time in the TD and k denotes the frequency
point in the FD.
The transmitted signal:

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k W_N^{-nk}, \quad X_k = \sum_{n=0}^{N-1} x_n W_N^{nk} \qquad (1)$$

Here, W_N is a rotation operator.

the channel model:

$$h_n = \sum_{l=0}^{L-1} h_l \delta(n-\tau_l), \quad H_k = \sum_{l=0}^{L-1} h_l W_N^{n^{\tau_l}} \qquad (2)$$

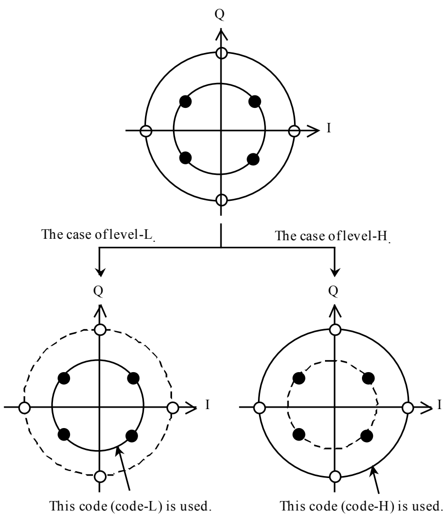


Fig. 3. The proposed concept to realize UEP for 2 levels of importance.

the received signal:

$$r_n = \sum_{l=0}^{L-1} h_l \otimes x_{n-l} + n_n, \quad R_k = H_k X_k + N_k \tag{3}$$

In fig.4(b), we show the main processing done in the MMSE-FDE. The following three parts are consisted. The following three parts are consisted.

(1) Equalization filter part

The filter output, i.e. the equalized wave D^, is as follows using the received signal Y_k and the weight W_k in the FD.

$$\hat{d}_n = \frac{1}{N}\sum_{k=0}^{N-1} \hat{D}_k W_N^{-kn}, \quad \hat{D}_k = W_k Y_k \tag{4}$$

(2) Equalization error estimation part

The error signal is as follows using the expression of the TD.

$$\begin{aligned} e_n &= \hat{d}_n - d_n \\ &= \frac{1}{N}\sum_{k=0}^{N-1}(W_k Y_k - X_k) W_N^{-kn}, \quad E_k = \sum_{n=0}^{N-1} e_n W_N^{kn} \end{aligned} \tag{5}$$

(3) Tap gain control part

In the FD as well as the TD, we calculated suitable tap gains W_{MMSE} by minimizing the MMSE of the error signal.

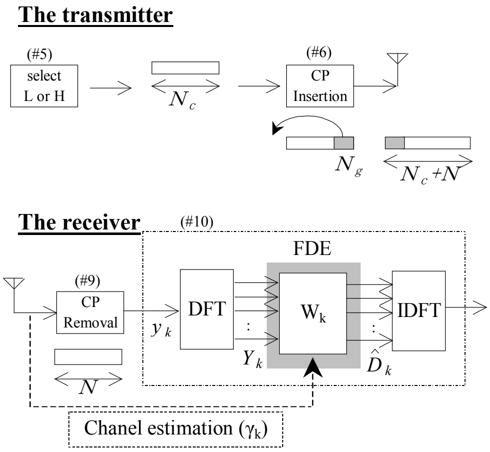
The optimal tap gain vector W_{MMSE} is as follows [12].

$$W_{MMSE} = \frac{H_k^*}{|H_k|^2 + 1/\gamma_k} \tag{6}$$

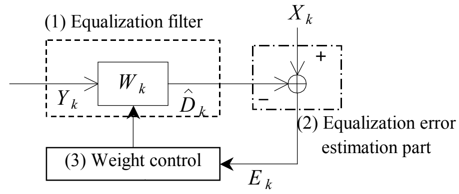
Here * denotes complex conjugation and γ_k is the signal to noise. In practice, we must estimate γ_k in some way. However, in this paper, as we focus on the evaluation of equalization performance, it is assumed that we estimate it perfectly.

D. Interleaving and de Interleaving

Interleaving and deinterleaving are used for translating burst-errors into random-errors in fading channels [1]. In the proposed system, matrix-interleaving is used. A larger matrix size(M*N) is effective for longer burst errors. However, the delay time $T_d=(2M\times N)/f_b$ (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 the proposed system, (M, N)=(8, 128) is adopted [14], because in [14], better performance is shown for TCM with 8 states and 1024 symbols.



(a) Outline



(b) Main processing

Fig.4 MMSE-FDE.

E. Relationship between the Signal Constellation and the Error Rate [8]

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 d_c. To evaluate the relationship between the signal constellation and the error rate, we introduce the following minimum squared Euclidean distances normalized by the average energy: $d_H^2/\overline{E}$, $d_L^2/\overline{E}$, $d_C^2/\overline{E}$. In fig.5, $d_H^2/\overline{E}$ (level-*H*) and $d_L^2/\overline{E}$ (level-*L*) are shown versus $d_C^2/\overline{E}$ as a function of β (ring ratio d_L/d_H) for $0 < \beta < 1$. From fig.5, if we use a smaller β, d_c is larger, so the importance level estimation error rate for the 2RING type constellations decreases. Also, d_H is larger and the average bit error rate for the code-*H* decreases. Similarly, d_L is smaller and the average bit error rate for the code-*L* increases. If we use a larger β, the opposite is true. Therefore, since the value of 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 among them.

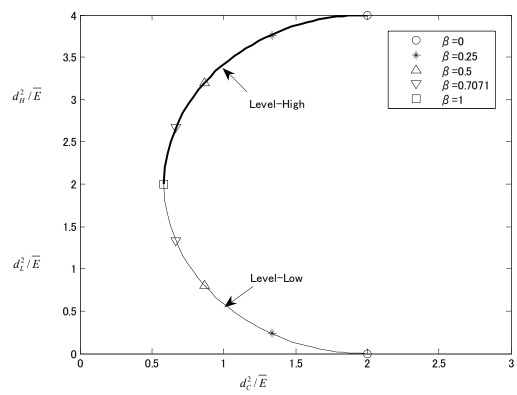


Fig. 5. $d_C^2/\overline{E}$ versus $d_H^2/\overline{E}$ (level-*H*), $d_L^2/\overline{E}$ (level-*L*)
(The values on the vertical axis: $0 < d_L^2/\overline{E} < 2$, $2 < d_H^2/\overline{E} < 4$).

IV. PERFORMANCE EVALUATION

We examine the performance of our system by using computer simulations. In this section, we evaluate the same items in [8] using the main parameters that determine the proposed system's performance, that is, the ring ration β and the importance switching ratio N_C. In table.1, the simulation parameters are shown. Here, the length of CP is designed in the length of maximum-delay time.

A. 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 factor showing whether code-*L* and code-*H* are distinguished correctly based on the proposed method. In fig.6, the importance level estimation error rate versus E_b/N_0 is shown for the two cases fdTs =0.001 and 0.01 under a fixed importance switching rate N_c=64 symbols. In fig.7, 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 fdTs =0.001 and a ring ratio β=0.25. Also, in fig.6 and fig.7, the performance without equalization is shown for the comparison. The following conclusions can be drawn.

1. Regardless of the ring ration β, if f_dT_s is larger, the performance is degraded because of fading effects. However, great performance improvement is achieved by using FDE.
2. Regardless of f_dT_s, if β is larger, the performance is degraded. The fact is due to the analysis mentioned in III.E.
3. 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 2 and 3 are similar to the results in AWGN channels [8].

B. Average Bit Error Rate

In fig.8, the average bit error rate versus E_b/N_0 of the individual codes is shown for β = 0.25, 0.5 and 0.7071 for N=64 and f_dT_s =0.001. Also, the performance without equalization and the proposed UEP schemes with equal error protection (EEP), i.e., QPSK combined with code-*H*, are shown. The following conclusions can be drawn.

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. Specially, 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 ration 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 cannot be found. As a result, we could confirm the effectiveness of adaptive equalization.

C. Equalization Effect

For reference, in fig.9, we show the signal arrangement at the transmitter, before equalization (a) and after equalization (b). Before equalization the signal points whose phase and amplitude are changed converge into their original positions after equalization. In addition of these results, we can check qualitatively the effectiveness of adaptive equalization.

V. CONCLUSIONS

In our previous research [8], to achieve UEP, we proposed a scheme which encodes the data by randomly switching between several codes which use different signal constellations and showed the effectiveness in AWGN channels. In this paper, we propose our UEP system using MMSE-FDE for fast and selective fading by using the fact that importance levels are changed every few symbols, i.e., every block, in the proposed system. We confirmed the improvement in BER performance and the effectiveness of adaptive equalization for the proposed system in fading channels. As a result, we showed that a UEP system is realizable in mobile telecommunications environments. Now, we are analyzing the proposed system in fading channels theoretically.

REFERENCES

[1] S. Lin and D. Costello, Jr., Error Correcting Coding, 2nd ed.,Prentice Hall, 2004.

[2] B. Masnick and J. K. Wolf, “On linear unequal error protection codes,” IEEE Trans. Inform. Theory, vol. 3, pp. 600-607, 1967.

[3] H. Imai and S. Hirakawa, “A new multilevel coding method using error correcting codes,” IEEE Trans. Inform. Theory, pp. 371-377, 1977.

[4] L. -F. Wei, “Coded modulation with unequal error protection,” IEEE Trans. Commun., vol. 41, pp. 1439-1449, 1993.

[5] A. R. Calderbank and N. Seshadri, “Multilevel codes for un-equal error protection,” IEEE Trans. Inform. Theory, vol. 39, pp. 1234-1248, 1993.

[6] M. Isaka et al., “Multilevel Coded Modulation for Unequal Error Protection and Multistage Decoding - Part II: Asymmetric Constellations,” IEEE Transactions on Commun., vol. 48, no. 5, pp. 774 -786, 2000.

[7] N.Rahnavard and F.Fekri, “New result on unequal error protection using LDPC codes,” IEEE Comm. Lett., vol.10, No.1, 2006.

[8] S. Yamazaki and D. K. Asano, “A Serial Unequal Error Protection Code System using Multilevel Trellis Coded Modulation with Ring Type Signal Constellations for AWGN Channels,” IEEJ Transactions on Electrics and Electronics, vol.5, No.6, pp. 708-716, 2010.

[9] J. G. Proakis, Digital Communications, Mc Graw-Hill, 1983.

[10] J.Hagenauer, N.Seshadri and C.-E. W. Sunderg, “The performance of Rate-Compatible Punctured Convolutional Codes for Digtal Mobile Radio,” IEEE Trans. Communication, vol. Com-38, No.7, pp.966-980, July 1990.

[11] R. Morelos-Zaragoza, T.Kasami and S.Lin, “Multilevel Block Coded 8-PSK Modulation Using Unequal Error Protection, and Low Delay for the Rayleigh Fading Channels,” 1st conferenece on universal Personal Communications, Conf. Rec., pp.283-287, Dallas, Texas, Sept. 1992.

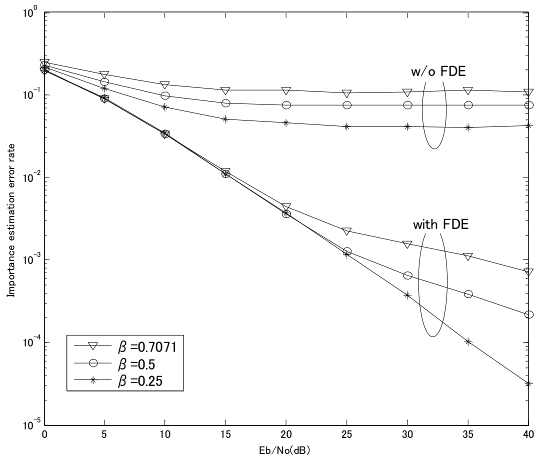
[12] D. Falconer, S. L. Ariyavistakul, A. Benyamin-Seeyar, and B. Eidson “Frequency domain equalization for single-carrier broad-band wireless systems,” IEEE Commun. Mag., vol. 40, pp.58-66, Apr. 2002.

[13] F. Adachi, H. Tomeba, and Kazuki Takeda, “Introduction of frequency-domain signal processing to broadband single-carrier transmissions in a wireless channel,” IEICE Trans. Commun., Vol.E92-B, No.09, pp. 2789-2808, Sep. 2009.

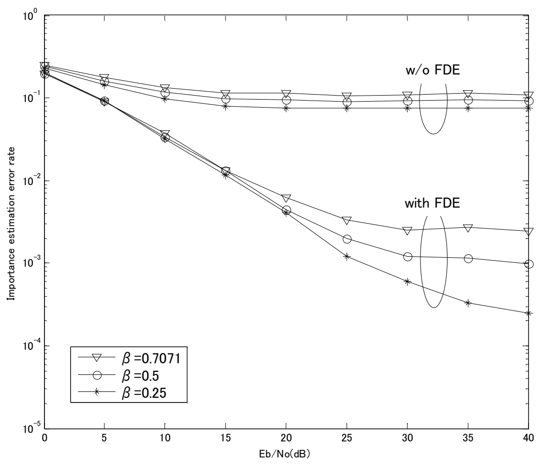
[14] Y.Kamio, “Ber performance pf trellis coding modulation in land mobile communications,” Review of the Communications Research Laboratory, Vol.37, No1, pp.117-121, Feb 1991.

Table1 Simulation parameters

Transmitted Data	0, 1 (random)
Noise	AWGN
Fading	None
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	64 [symbols]
Channel coding rate R	High: 1/2, Low: None
Demodulation	Coherent
Decoding	Viterbi decoding
Detection	Hard-decision
Fading	Time and Frequency selective
Channel model	10-path exponential model
Channel Estimation	Perfect
Interleaving Size	8×128
Normalized Doppler Frequency f_dT_s	0.01, 0.001
FFT size	64
Cyclic prefix	20[samples]



(a) f_dT_s =0.001



(b) f_dT_s =0.01

Fig. 6. Importance level estimation error rate versus E_b/N_0
(The dependency on the ring ratio β)

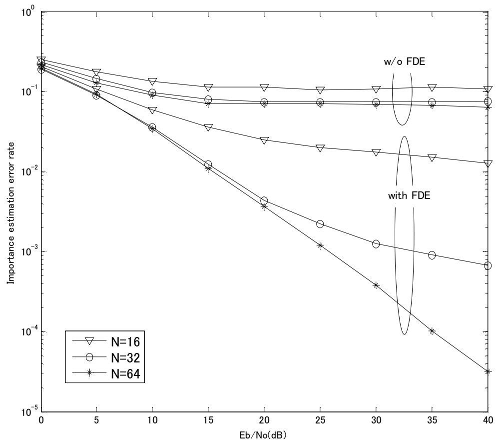


Fig. 7. Importance level estimation error rate versus E_b/N_0
(The dependency on the importance switching rate N_C; f_dT_s =0.001, β=0.25)

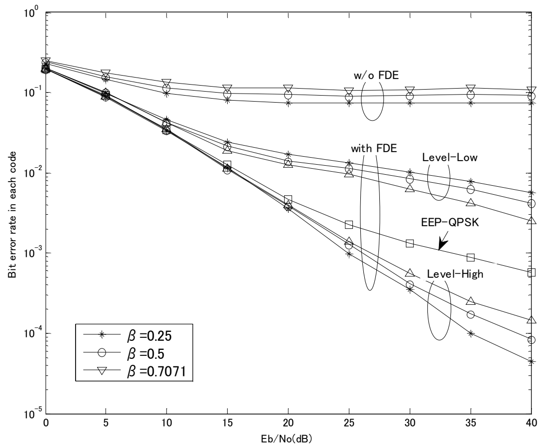
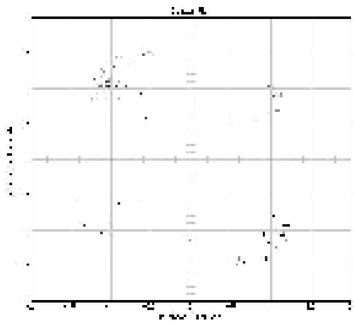
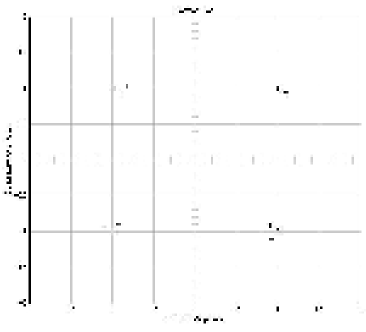


Fig.8 Average bit error rate versus E_b/N_0（f_dT_s =0.001，N_C=64）



(a) Before equalization



(b) After equalization

Fig.9 Equalization effect