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Hierarchical Transmission of Huffman Code Using Multi-Code/Multi-Rate DS/SS Modulation with Appropriate Power Control

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SUMMARY For transmission of video signals, it is important that the system allows a certain degree of flexibility in bit rate as well as quality, depending upon the requirements of media and channel conditions. In this paper, we discuss the hierarchical transmission of Huffman code using multi-code/multi-rate DS/SS system to realize flexible transmission. We first discuss and show that the structure of Huffman code tree directly expresses hierarchical structure, and that parallel transmission of Huffman code can achieve hierarchical transmission. By assigning different transmission data rate to the bits in each stratum, it is possible to transmit different amount of information from each stratum. Further, we show the quality of each of the stratum can easily controlled by an appropriate power distribution to each parallel transmission branch.

key words: *Huffman code, multi-code SS, parallel transmission, hierarchical transmission*

1. Introduction

With a success of the cellular mobile phone, demand for wireless transmission of video signals is increasing. To realize a reliable video transmission system in a wireless environment, studies on an efficient source coding are drawing much attention. Video coding, especially for low bit-rate coding such as MPEG-4, H.263, and so forth, have been well studied. Huffman code is employed in such source coding scheme for transform coefficient coding, or motion vector coding [1], [2].

A difficulty in transmission of a video stream over the wireless channel arises from the fact that the reliability of the channel is not good enough for satisfactory video quality at receiver end. As video coding scheme achieves drastic reduction in bits by efficient but complicated algorithms, it results in weakness against channel noise. In fact, even a single error may cause the whole video sequence to vanish. This is mainly due to the loss of synchronization. Variable length feature of Huffman code can easily loose its code synchronization. For designing a transmission scheme for video signals, therefore, one should design under the worst channel conditions [3].

One proposal to realize an efficient transmission is a hierarchical transmission. If video stream is divided into a number of stratum according to its quality, flexibility in quality of video can be controlled by selection of the appropriate stratum. Such a transmission system has been considered for a satellite-based broadcast system that brings high-quality digital HDTV using multi-resolution 64-quadrature amplitude modulation (QAM) [4].

In this paper, we consider an alternate approach of a hierarchical transmission using multi-code/multi-rate DS/SS system. We introduce Huffman code as an example of input to our scheme and show the quality control of our system in terms of "received entropy."

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2. Hierarchical Transmission

Figure 1 shows the concept of our hierarchical transmission. Hierarchical coder separates the incoming bit stream according to the importance of each message. In this procedure the bit stream is divided into several number of strata.

From communication point of view, we characterize the stratum with required transmission rate quality, and bit error rate. It is apparent that parallel transmission scheme is one of the appropriate candidates. Adopting parallel transmission, we can easily control the information quality in each stratum. Further transmission rate and quality can be controlled according to the conditions of given channel. So the divided bits into each strata are to be transmitted in parallel form. The

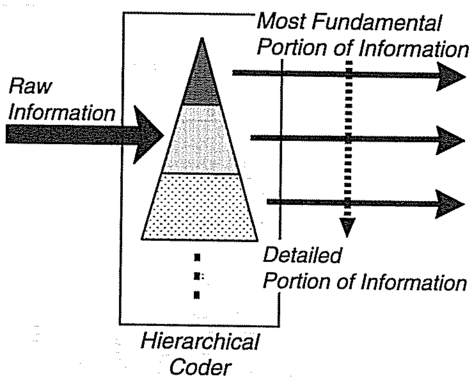

Fig. 1 Concept of hierarchical transmission.

signals transmitted from the upper branches contribute to the fundamental portion and those from the lower branches contribute to the detail. Assuming that each of strata does not contain the information of the others, then quality control can be achieved by selection of the number of strata.

In this paper, we realize a parallel transmission by adopting multi-code/multi-rate DS/SS system. The rate control is managed with assigning appropriate processing gain and quality is controlled with appropriate distribution of transmission power.

To clarify our hierarchical transmission system, we are going to consider transmission of Huffman code.

2.1 Huffman Code

Huffman code is employed in the final process of coding such as MPEG and H.263. It contributes to additional reduction of bit streams. It is well known that Huffman code achieves loss-less compression of the source message by a variable-length bit-assignment algorithm based on the probabilities of occurrence of each message. However, length variability of Huffman code shows weakness against channel errors. Even a single error can turn one code into another, creating additional errors.

Suppose that we have M different and independent messages, $X = \{x_1, x_2, \ldots, x_M\}$, with probabilities of occurrence $p_1, p_2, \ldots, p_M$. For simplicity, we assume $p_1 \geq p_2 \geq \ldots \geq p_M$ and each of $p_1, p_2, \ldots, p_M$ is the multiple of 1/2. Under this condition we can look upon the length of Huffman code as self-information of each message. The average length $\bar{I}$, or equivalently, average information (entropy) H, is

$$\bar{I} = H = \sum_{i=1}^{M} p_i \log_2 \frac{1}{p_i}. \tag{1}$$

2.2 Making Hierarchical Structure from Huffman Code Tree

Suppose that a source has eight messages with probability distribution given as Table 1. And we have Huffman code tree shown as the left side in Fig. 2.

We notice that the branches of Huffman tree diverge from a node according to the probability of the code. In other words, source information is divided into subsets according to the Huffman tree.

We define probability $p_{tr,k}$ as the sum of the probabilities of the nodes at the depth of k. For the Huffman code shown in Fig. 2, $p_{tr,k}$ is $\{1, 1/2, 1/4, 1/4, 1/8\}$, respectively. If we regard each bit at the same depth as one stratum, then this probability $p_{tr,k}$ can be taken as the probability that a bit occurs in the k-th strata.

The depth of the Huffman tree M_{tr} is equal to the maximum number of bits of the Huffman code word, which gives the lowest occurrence probability. For the case of Fig. 2, the depth is 5 and it requires 5 bits to represent Q_4 to Q_7.

What is the average amount of information at each depth? From the figure, we observe that each node contains either 0 or 1 with equal probability. If we consider the transmission of a sequence over a long period of time, each of 0 or 1 would appear with the probability

Table 1 Example of Huffman code.

symbol	p_k	code word	length l_k
Q_0	2^{-1}	1	1
Q_1	2^{-2}	01	2
Q_2	2^{-4}	0011	4
Q_3	2^{-4}	0010	4
Q_4	2^{-5}	00011	5
Q_5	2^{-5}	00010	5
Q_6	2^{-5}	00001	5
Q_7	2^{-5}	00000	5

(H = 2.125)

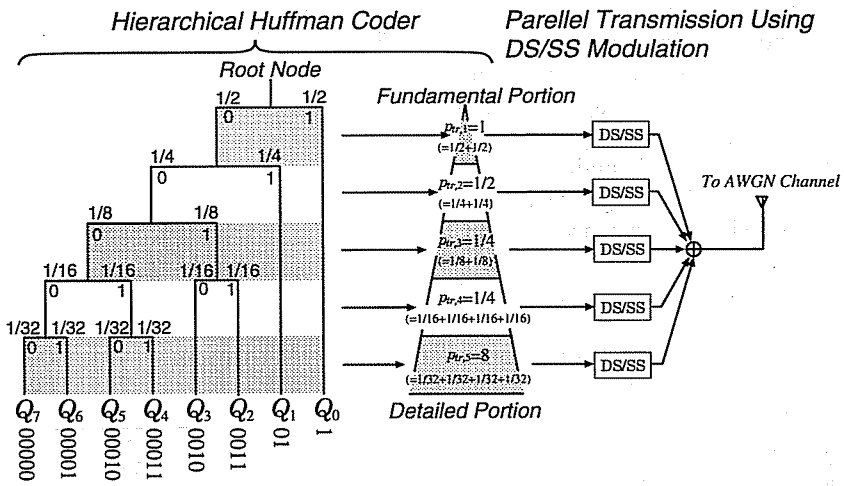

Fig. 2 Example of Huffman code tree and its hierarchical structure.

of 1/2. This implies that the amount of information is 1 ($= \log_2 2$). Further, as the sum of the probabilities of the depth of k is $p_{tr,k}$, we obtain the average information in a certain depth as same as the probability $p_{tr,k}$. From the figure, we observe that higher the node is larger the average information is.

Taking sum of all the average information of node, we obtain average amount of information, H_{tr} as

$$H_{tr} = \sum_{k=1}^{M_{tr}} p_{tr,k} \tag{2}$$

where M_{tr} is the depth of the tree. For the case of Fig. 2, we obtain $H_{tr} = 2.125$. We observe that the amount is equal to the source entropy H.

As each leaf of the Huffman tree represents each of Huffman code word, it is possible to represent the code by the nodes. Therefore, instead of transmitting a Huffman code word, transmission of node information can convey exactly the same amount of information.

In this way, we can achieve hierarchical transmission and we observe that the structure of Huffman tree directly expresses a hierarchical structure of source information.

2.3 Parallel Transmission of Huffman Code

Now consider a simultaneous transmission of information representing each depth according to Huffman code. Then this equivalently transmits Huffman code in parallel. As the Huffman code is transmitted code-by-code, the code synchronization can be kept which results no error propagation [6]–[8]. In our system the head of the code word corresponds to one stratum, so code synchronization is easily achieved.

Figure 2 shows the hierarchical transmission of Huffman code. The probabilities of occurrence of each transmission branch $p_{tr,k}$ is $\{1, 1/2, 1/4, 1/4, 1/8\}$, respectively. Different probabilities mean that each transmission branch conveys different information with a different data rate. This is why we consider parallel transmission using multi-code/multi-rate DS/SS system.

3. Hierarchical Transmission of Huffman Code Using Multi-Code/Multi-Rate DS/SS System

Figure 3 shows the block diagram for the proposed system. Information is first fed to the Huffman encoder. The parallel outputs from the encoder are transmitted in the form of DS/SS signal [5].

Let $a_1(t), a_2(t), \cdots, a_{M_{tr}}(t)$ be the spreading signal assigned to the m-th bit signal of $b_{1,m}(t), b_{2,m}(t), \cdots, b_{M_{tr},m}(t)$, respectively.

The data signal $b_k(t)$ and spreading signal $a_k(t)$ are written as

$$b_k(t) = \sum_{m=-\infty}^{\infty} b_{k,m}\psi_{T_{b,k}}(t - mT_{b,k}) \tag{3}$$

$$a_k(t) = \sum_{\iota=-\infty}^{\infty} \sum_{l=0}^{L_k-1} a_{k,l}\psi_{T_c}(t - lT_c - \iota L_k T_c)$$

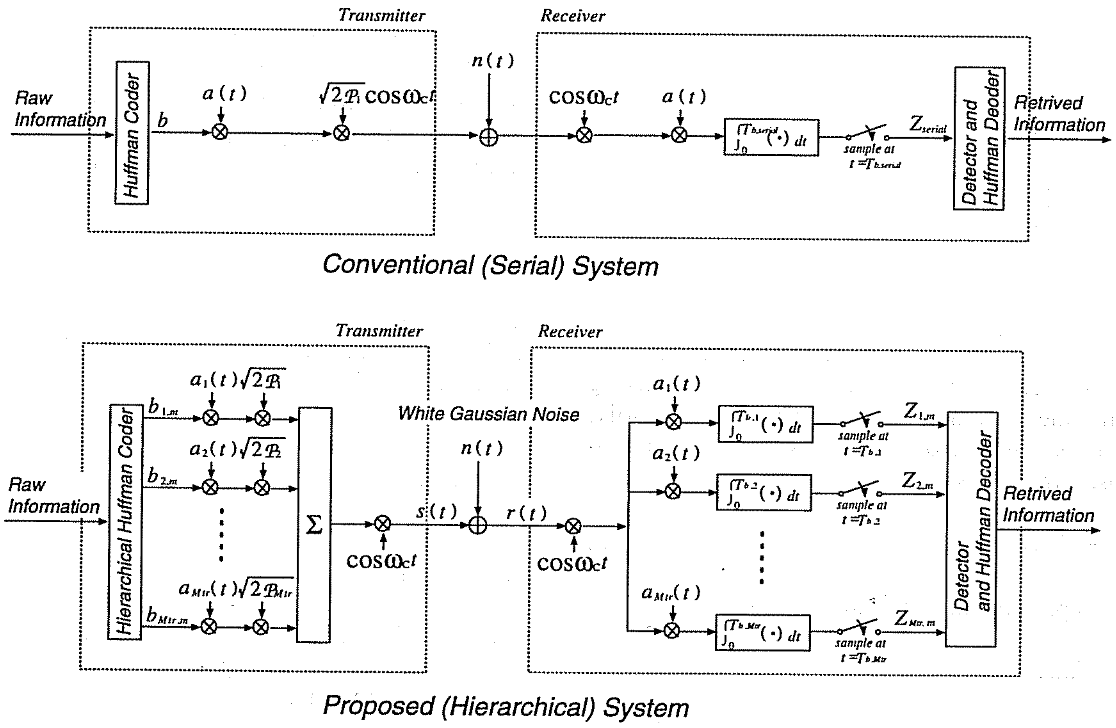

Fig. 3 System model.

where $\psi_\tau(t)$ is a rectangular pulse, and defined as $\psi_\tau(t) = 1$ $(0 \leqq t \leqq \tau)$, 0 $(t < 0,\ t > \tau)$. $T_{b,k}$ and T_c are bit duration of the k-th blanch and chip duration, respectively. And $a_{k,l}$ and $b_{k,l}$ are binary digits which take -1 or 1. Note that T_c is equal all over the branches. L_k is the number of chips in each period of the spreading sequence.

These signals are summed and transmitted as the form of multi-code DS/SS signals, expressed as

$$s(t) = \cos(\omega_c t) \sum_{k=1}^{M_{tr}} \sqrt{2P_k} a_k(t) b_k(t) \tag{4}$$

where P_k is the signal power of branch k and $\omega_c/2\pi$ represents the carrier frequency.

At the channel, noise $n(t)$ is added, of which we assume to be a white Gaussian process with two-sided spectral density $N_0/2$. The received signal is, therefore,

$$r(t) = \cos(\omega_c t + \phi) \sum_{k=1}^{M_{tr}} \sqrt{2P_k} a_k(t-\tau) b_k(t-\tau) + n(t) \tag{5}$$

where τ is the time delay, ϕ is the phase introduced at the receiver.

Assuming the perfect synchronization of carrier and spreading code, we set $\tau = 0$ and $\phi = 0$ to simplify the discussion.

The output of each branch for each of m-th bit is written as

$$Z_{k,m} = S_{k,m} + I_{k,m} + N_{k,m} \tag{6}$$

where

$$S_{k,m} = \sqrt{\frac{P_k}{2}} b_{k,m} T_{b,k}$$
$$I_{k,m} = \sum_{i=1(\neq k)}^{M_{tr}} \int_{mT_{b,i}}^{(m+1)T_{b,i}} \sqrt{\frac{P_i}{2}} a_i(t) b_{i,m}(t) a_i(t) dt$$
$$N_{k,m} = \int_{mT_{b,k}}^{(m+1)T_{b,k}} n(t) a_k(t) \cos \omega_c t dt. \tag{7}$$

In the above equations, $S_{k,m}$ represents the signal component of k-th branch and $I_{k,m}$ represents the interfering signal component from the other branches. the noise component $N_{k,m}$ is a zero mean Gaussian random variable, whose variance is

$$\sigma_{k,N}^2 = E[N_{k,m}^2] = \frac{N_0 T_{b,k}}{4} \tag{8}$$

where $E[\cdot]$ represents the ensemble average.

3.1 Error Rate

We invoke standard Gaussian approximation [10], to obtain the bit error rate of k-th branch.

$$P_{b_k} = \frac{1}{2} erfc \sqrt{\frac{S_{k,m}^2}{2(\sigma_{I,k}^2 + \sigma_{N,k}^2)}} \tag{9}$$

where

$$\sigma_{I,k}^2 = E[I_{k,m}^2]$$

Clearly if the spreading signals are orthogonal, the interference term vanishes, and (9) is easily expressed as

$$P_{b_k} = \frac{1}{2} erfc \sqrt{\frac{E_{b,k}}{N_0}} \tag{10}$$

where $E_{b,k} = P_k T_{b,k}$ is the bit energy per bit of the k-th branch.

In our system we assign different processing gain for each branch. Processing gain G_k, which is equal to the length of the spreading code L_k, is defined as $G_k = T_{b,k}/T_c$. Note that as we transmit according to $p_{tr,k}$ assigned to each of k-th branch, we obtain the mean transmission rate as $R_k = 1/T_{b,k} = R_1/p_{tr,k}$. We have assumed $p_{tr,1} \geqq p_{tr,2} \geqq \ldots \geqq p_{tr,M_{tr}}$ and these values are multiple of 1/2, so the processing gain of a certain branch is multiple of the smallest one (G_1). The tree structured generation of spreading codes with different length can achieve the orthogonal multiplexing of different data rate [9].

For Huffman decoding, even a single error would vanish the whole sequence because of the error propagation. If we can achieve perfect code synchronization, then the average symbol error rate is obtained as

$$P_e = \sum_{i=1}^{n} p_i \left(1 - \prod_{k=1}^{l_i} (1 - P_{b_k})\right) \tag{11}$$

where p_i and l_i are the probability of occurrence and length of the symbol Q_i, respectively. And n is the number of the codewords. Actually, if the transmission power is controlled appropriately, we can neglect the effect of the error propagation. This problem is precisely discussed in the following section.

4. Quality Control and Error Propagation

Let us denote the total transmission energy of Huffman code as $\mathcal{E}_H$ and the expected amount of received information, H_r, with a little modification of (2). We denote it as,

$$H_r = \sum_{k=1}^{M_{tr}} p_{tr,k} (1 - P_{b_k}) \tag{12}$$

4.1 Algorithm of Branch Power Control

What we should achieve is to obtain the maximum H_r with given $\mathcal{E}_H$. Let us express β_k as the required quality to be maintained for branch k, then we introduce following power distribution procedure.

First, we set $\mathcal{P}_1$ to the minimum value that satisfies

Sequence to be transmitted / *Signal energy distribution* / *Retrived sequence*

Q_0	Q_1	Q_0	Q_0	Q_4	Q_0	Q_1	Q_6	Q_0	Q_1	Q_0	Q_0	Q_4	Q_0	Q_1	Q_6	
1	0	1	1	0	1	0	0	3	3	3	3	3/4	3	3/2	3/5	
*	1	*	*	0	*	1	0	*	3	*	*	3/4	*	3/2	3/5	
*	*	*	*	0	*	*	0	*	*	*	*	3/4	*	*	3/5	$Q_0\ Q_1\ Q_0\ Q_0\ *\ Q_0\ Q_1\ *$
*	*	*	*	1	*	*	0	*	*	*	*	3/4	*	*	3/5	
*	*	*	*	*	*	*	1	*	*	*	*	*	*	*	3/5	

TJCOM98 System (*cf. Makido et.al.* [8])

Q_0	Q_1	Q_0	Q_0	Q_4	Q_0	Q_1	Q_6	Q_0	Q_1	Q_0	Q_0	Q_4	Q_0	Q_1	Q_6	
1	0	1	1	0	1	0	0	1		1	1	1	1	1	1	
1	1	0	0	1	1	0	0	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	$Q_0\ Q_1\ Q_0\ Q_0$ (Q_4 or Q_5 or Q_6 or Q_7) $Q_0\ Q_1$ (Q_4 or Q_5 or Q_6 or Q_7)
0	0	0	0	0	0	0	0	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	
1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	

Proposed System

Fig. 4 Example of branch power control.

$$P_{b_1} \leqq \beta_1$$

Second, we set $\mathcal{P}_2$ to the minimum value that satisfies

$$P_{b_2} \leqq \beta_2 \quad \text{and} \quad \mathcal{P}_2 \leqq \frac{\mathcal{E}_H - E_{b,1}}{T_{b,2}}$$

Finally the rest is obtained similarly; we set $\mathcal{P}_k$ the minimum value that satisfy

$$P_{b_k} \leqq \beta_k \quad \text{and} \quad \mathcal{P}_k \leqq \frac{\mathcal{E}_H - \sum_{i=1}^{k-1} E_{b,i}}{T_{b,k}}$$

If we cannot assign the power, which is the case $\sum_{i=1}^{k-1} E_{b,i} \geqq \mathcal{E}_H$, we would not transmit any signals of the branches containing detailed information.

Example

Here let's see the effectiveness of the branch power control according to the example shown in Fig. 4. In Fig. 4 we show two parallel transmission system as examples. One is the system we have presented in the proceedings of TJCOM98 [8], and the other is our new proposal (hierarchical transmission).

Let us assume to transmit the following sequence.

$$Q_6, Q_1, Q_0, Q_4, Q_0, Q_0, Q_1, Q_0$$

Figure 4 is the case that total transmission energy $\mathcal{E}_H = 3$ and required energy for each branch $E_{b,k} = 1$. The transmission energy is assigned to each branch according to the algorithm discussed in this section. In this case we have to note that there exists the branches that are not assigned any energy. If we assume that all of the bits have energy below the required energy level are in error, then then two symbols, Q_6 and Q_4, are not received correctly. However, the two systems are rather different. If the error occurs in TJCOM system, the symbol in error has no information at all. On the other hand, some of the information can be received in our new system. That is, the symbol Q_6's first three bits can be received correctly. So, at the receiver end, we can know the information that "One of Q_4, Q_5, Q_6, and Q_7 was transmitted."

4.2 Error Propagation

One of the difficult problems when we consider the transmission of Huffman code is error propagation. Error propagation is very serious if the channel condition is relatively bad. It is true that our proposed system has the possibility of error propagation, but this possibility is very small if the branch power is appropriately controlled. So error propagation problem is not so serious in our system.

This is firstly because the higher stratum is transmitted with higher energy in our system. More important bits of the Huffman code word, those are the bits near root node of the Huffman tree, are guaranteed their quality (BER).

Secondly, if the error propagation occurs, synchronization is easily recovered by introducing some synchronization code. In actual video coding scheme such as MPEG or H.263, synchronization code is inserted every GOP (Group Of Picture), and it contains several hundreds of thousands bits. If we select the quality parameter $\beta = 10^{-6}$, the GOP error rate is roughly 10^{-3}. This situation is not so serious. Further there exists the possibility of the backward decoding. In MPEG-4 system, reversible Huffman code is considered to achieve backward decoding [12]. Reversible Huffman code introduces about 10 to 15% of redundancies to achieve backward decoding. But in our parallel system we don't need to introduce any redundancies because the head of the code word (correspond to the highest stratum in our system) is perfectly synchronized.

5. Serial Transmission System

For comparison, we consider a serial (non-hierarchical) transmission of Huffman code. Let us assume that we transmit sequence of L bits. Since the parallel transmission scheme completes transmission after L/H-bit time, we obtain the symbol energy for serial transmission as $\mathcal{E}_H/H$ for serial transmission.

Because even a single error would cause the whole sequence to vanish, the error rate is obtained as

$$P_{e_{serial}} = 1 - \left(1 - \frac{1}{2} erfc\sqrt{\frac{\mathcal{E}_H}{HN_0}}\right)^L \tag{13}$$

The expected amount of received information for serial transmission is

$$H_{r,serial} \geqq H(1 - P_{e_{serial}}) \tag{14}$$

6. Numerical Examples

Figure 5 shows the bit error performance (BER) of each transmission branch as a function of $\mathcal{E}_H/N_0$. We consider transmission of the Huffman code of Table 1. The spreading ratio of transmission branches are $G_k = \{32, 64, 128, 128, 256\}$, respectively. Orthogonal Gold sequence codes are used as spreading code. To guarantee orthogonality between different processing gain, we make the code that has higher processing gain from the set of orthogonal Gold sequence which has the length of 32 ($= GCD(G_1, G_2, G_3, G_4, G_5)$). For instance, G_2 composes of two consecutive sequence of G_1. The required quality β is assumed to be same for all branch and we set $\beta = 10^{-6}$. [11]

The BER of serial transmission system is also plotted in the figure for the case of $L = 1000$ [bit].

From the figure, we observe the effect of quality control. It requires 13.8 dB to maintain the required qualities of all branches for our scheme while, it requires 16.0 dB for serial transmission system.

Figure 6 shows the performance of average received information calculated as a function of $\mathcal{E}_H/N_0$ and various β. We also plot the performance of the TJCOM system and the conventional (serial) one.

We observe step increase in the average received information due to the effect on quality control. Focusing on the case of $\beta = 10^{-6}$, additional 1.8 dB improves H_r from 1.00 to 1.50 and 0.6 dB improves from 1.50 to 1.75 and from 1.75 to 2.00. With 13.8 dB of $\mathcal{E}_H/N_0$, we achieve entropy transmission with qualities of $\beta = 10^{-6}$. Difference in H_r corresponds to that the transmission rate is managed with given quality, β.

As the case of $\beta = 10^{-2}$ does not reach H, we consider that β should be set less than 10^{-2}.

The performance for $\beta = 10^{-5}$ is similar to the serial system. We, however, observe that the quality is not enough. From Fig. 5 we realize serial system requires 15 dB to achieve BER$=10^{-5}$. So a gradual increase in H_r with serial system is the result of a sacrifice in quality.

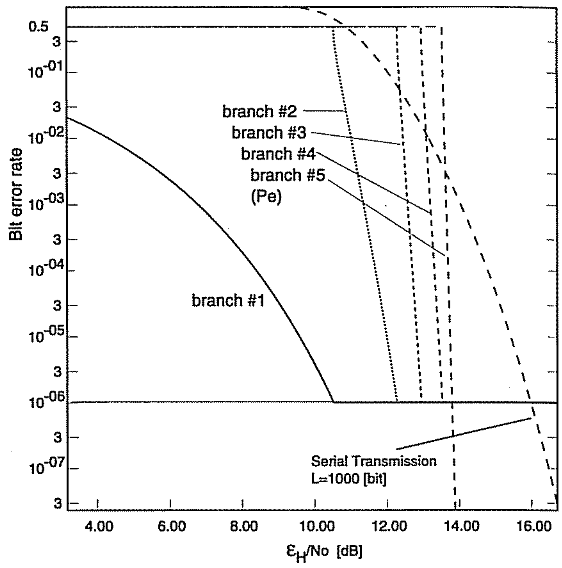

Fig. 5 Bit error performance of transmission branch.

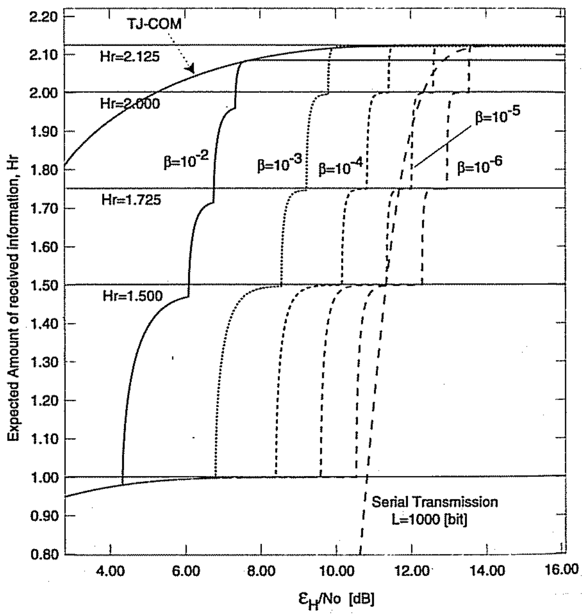

Fig. 6 Average received information.

From the Fig. 6, the performance of the TJCOM system seems to give the upper bound of the system. This is because the TJCOM system assigns transmission energy equally every branch. In other words TJCOM system gives the performance in the case that the quality parameter β goes to zero.

7. Conclusions

In this paper, we have evaluated the hierarchical transmission of Huffman code using multi-code/multi-rate DS/SS system.

We have shown that structure of Huffman code tree directly expresses hierarchical structure and parallel transmission of Huffman code can achieve hierarchical transmission. Different transmission rate can be achieved by assigning different processing gain to each of transmission branch. Quality is controlled by an appropriate distribution of power to each of parallel transmission branch.

As a results, we found that hierarchical transmission achieves superior performance in both bit error rate and average received information. We conclude that a hierarchical transmission using multi-code/multi-rate DS/SS system is a good candidate for transmission of multi-media.

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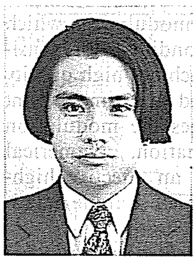

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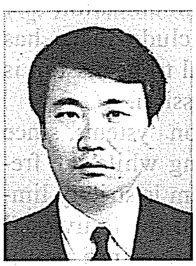

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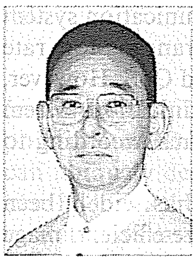

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