HIERARCHICAL TRANSMISSION SYSTEM USING MULTI-CODE/MULTI-RATE DS/SS MODULATION

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Abstract— **For transmission of video signals, it is important that system allows certain degree of flexibility in bit rate as well as quality depending upon a requirement of media and channel conditions.**

In this paper, we discuss a hierarchical transmission of Huffman code using multi-code/multi-rate DS/SS system to realize flexible transmission.

We first discuss and show that structure of Huffman code tree directly expresses hierarchical structure and parallel transmission of Huffman code can achieve hierarchical transmission. By assigning different transmission data rate, it is possible to transmit different amount of transmitted information from each of stratum. Further, we show a quality of each of stratum can easily controlled by an appropriate power distribution to each parallel transmission branch.

I. Introduction

In accord with a success of the cellular mobile phone, demand for wireless transmission of video signal is increasing. To realize a reliable video transmission system in a wireless environment, the studies on an efficient source coding are drawing much attentions. For source video coding, low bit-rate coding of MPEG4, 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 resulting waste of channel resources [3].

One proposal to realize an efficient transmission is a hierarchical transmission of video stream. If video stream is divided into a number of stratum according to its video 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."

II. Hierarchical transmission

Figure 1 shows concept of hierarchical transmission of information. Hierarchical coder separates the incoming bit stream according to the importance of each message. This divide the bit stream into stratum.

From communication point of view, we charac-

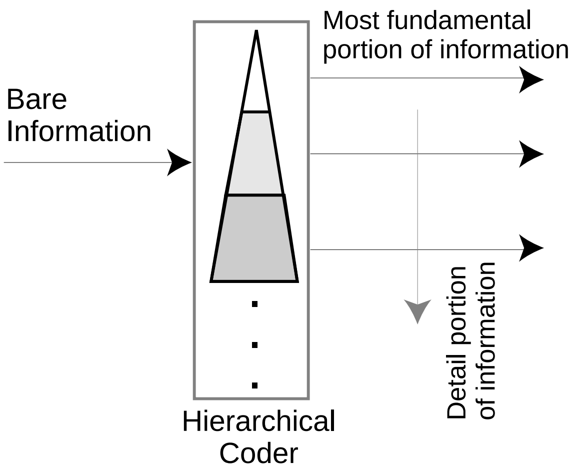

Fig. 1. Concept of hierarchical transmission

terize the stratum with the required transmission rate and quality. The signal transmitted from the upper branch contributes to the fundamental portion and that from the lower branch contributes to detail. Assuming that each of strata does not contain the informations of the others, then quality control can be achieved by selection of the number of strata.

In this paper, we consider a parallel transmission using 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 understand our hierarchical transmission system, we consider transmission of Huffman code.

A. Huffman Code

Huffman code achieves loss-less compression of the source message by a variable-length bit-assignment algorithm based on the probabilities of each message.

Suppose that we have M different and independent message of $X = \{x_1, x_2, \dots, x_M\}$ with probabilities of occurrence $p_1, p_2, \dots, p_M$. For simplicity, we assume $p_1 \geq p_2 \geq \dots \geq p_M$ and each of $p_1, p_2, \dots, p_M$ is the multiple of $1/2$. In this case, we have the length of Huffman code or equivalently self-information of each message.

The average length $\bar{I}$, or equivalently average

TABLE I

EXAMPLE OF HUFFMAN CODE (H = 2.125)

Symbol	p_k	Huffman	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

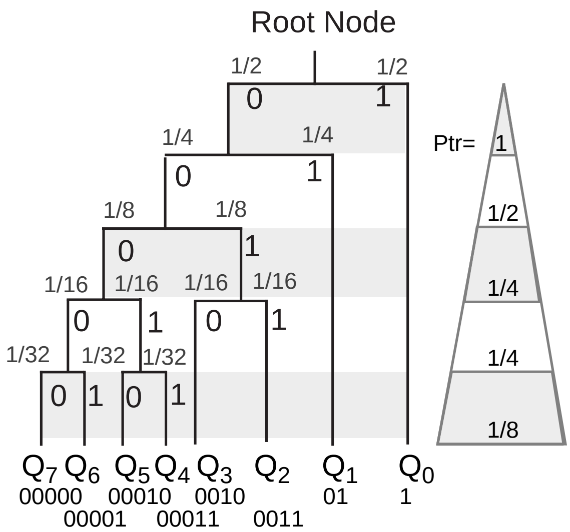

Fig. 2. Example of Huffman code tree and its hierarchical structure

information (entropy) H, is

$$
\begin{aligned}
I_i &= log_2 \frac{1}{p_i} && (1) \\
\bar{I} &= H = \sum_{i=1}^{M} p_i \; log_2 \frac{1}{p_i}
\end{aligned}
$$

Huffman code is employed in final process of MPEG and H.263. It contributes to additional reduction of bit streams. However, variable code length of Huffman code shows weakness against channel error. Even a single error can turn one code into another, creating additional errors.

B. Making Hierarchical structure from Huffman code tree

Suppose that a source has eight messages with probability distribution given as Table I. Then we have Huffman code tree as shown in Fig.2. We notice that 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.

The sum of the probabilities of the node at the same depth gives the probability of each node. If we denote it as $p_{tr,k}$, the probabilities of node is $p_{tr,k} = \{1, 1/2, 1/4, 1/4, 1/8\}$, respectively. The number of node M_{tr} equals to the maximum number of bits of the Huffman code word, which gives the lowest occurrence probability. This is also the depth of the node in Huffman tree. For the case of Fig.2, the depth is 5 and it requires 5 bits to represent Q_4 to Q_7.

What is average amount of information of each node? From the figure, we observe each node contains either 0 or 1 with equal probability. If we consider the transmission of a sequence in a long period of time, each of 0 or 1 would appear with the probability of 1/2. This implies that the amount of information is 1 $(= log_2 2)$. Further, as the probability of the node is $p_{tr,k}$, we obtain the average information of node 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 number of node. For the case of Fig.3, we obtain $H_{tr} = 2.125$ and the amount equals to 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.

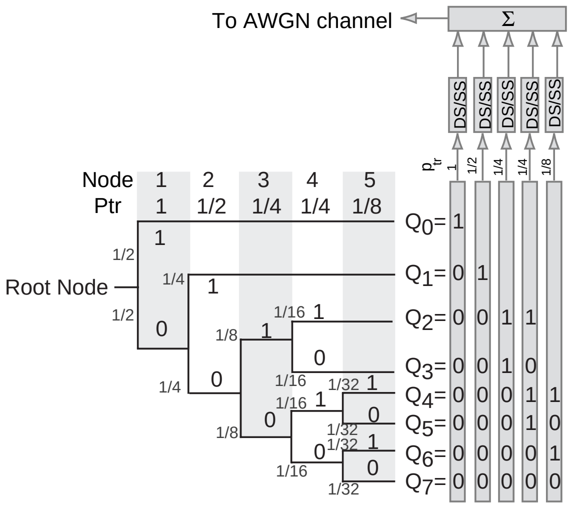

Fig. 3. Hierarchical transmission of Huffman code

C. Parallel transmission of Huffman code

Now consider a simultaneous transmission of information representing each node according to Huffman code. Then this equivalently transmit 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], [7].

Figure 3 shows the hierarchical transmission of Huffman code. The probabilities of each transmission branch is $p_{tr} = \{1, 1/2, 1/4, 1/4, 1/8\}$, respectively. Different probabilities mean that each transmission branch conveys different information with a different data rate. For this reason, we consider parallel transmission using multi-code/multi-rate DS/SS system.

III. Hierarchical Transmission of Huffman code using multi-code/multi-rate DS/SS system

Figure 4 shows the block diagram for the proposed system. Input bearing information is first fed to the Huffman encoder. The parallel outputs from the encoder are transmitted as the form of DS/SS signal [5], [6], [7].

Let $a_1(t), a_2(t), \cdots, a_{M_{tr}}(t)$ be the spreading signal assigned to the m-th bit signal of $b_{1,m}(t), b_{2,m}(t), \cdots, b_{M_{tr},m}(t)$ Huffman bit, respectively. Let $T_{b,k}$ be the bit duration of k-th branch and T_c be the chip duration, then processing gain G_k is defined as $G_k = T_{b,k}/T_c$. Note that as we

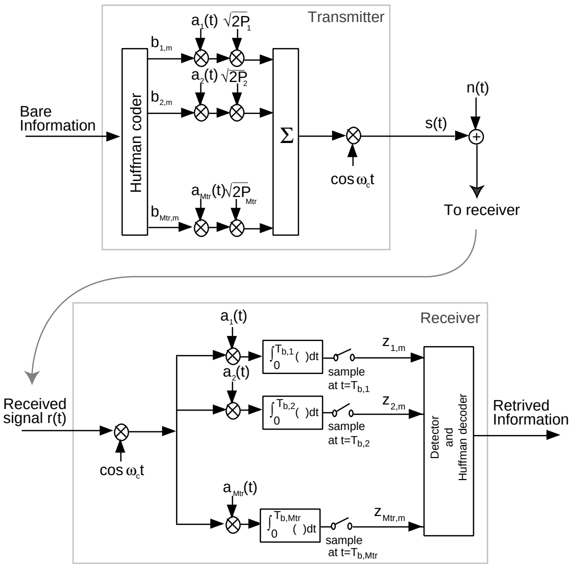

Fig. 4. System Model

transmit according to $p_{tr,k}$ assigned to each of k-th branch, we obtain the mean transmission rate as $R_k = 1/(p_{tr,k}T_b)$. We assume $p_{tr,1} \geq p_{tr,2} \geq \ldots \geq p_{tr,M_{tr}}$ to simplify the discussion.

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

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

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

where $\psi_\tau(t)$ is a rectangular pulse, and defined as $\psi_\tau(t) = 1 \ (0 \leq t \leq \tau), \quad 0 \ (t < 0, t > \tau)$ and the number of chips in each period of the spreading sequence L_k.

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

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

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,

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

where τ is the time delay and ϕ is the phase introduce 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 Huffman bit is written as

$$Z_{k,m} = S_{k,m} + I_{k,m} + N_{k,m} \quad (6)$$

where

$$S_{k,m} = \sqrt{\frac{P_k}{2}}w_k b_{k,m}T_{b,k}$$

$$I_{k,m} = \sum_{i=1(\neq k)}^{M_{tr}}\int_{mT_{b,k}}^{(m+1)T_{b,k}}\sqrt{\frac{P_i}{2}}a_i(t)b_{i,m}(t)a_k(t)dt$$

$$N_{k,m} = \int_{mT_{b,k}}^{(m+1)T_{b,k}} n(t)a_k(t)cos\omega_c t dt. \quad (7)$$

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

$$\sigma_{k,N}^2 = E[N_{k,m}^2] = \frac{N_0 T_b}{4} \quad (8)$$

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

A. Error Rate

We invoke standard Gaussian approximation [9], to obtain the bit error rate of k-th branch. Then we have

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

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

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

where $E_{b,k} = P_k T_{b,k}$ is the bit energy per bit of the k-th branch. The tree structured generation of spreading codes with different length can achieve the orthogonal multiplexing of different data rate [8].

For Huffman decoding, even a single error would vanish the whole sequence because of the error propagation. However, as Huffman code is transmitted symbol by symbol with our scheme, we can achieve perfect code synchronization. Then the symbol error rate is obtained as

$$P_e = 1 - \prod_{k=1}^{M_{tr}} (1 - p_{tr,k} P_{b_k}) \qquad (11)$$

B. Quality control

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

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

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 P_1 to the minimum value that satisfies

$$P_{b_1} \leq \beta_1$$

Second, we set P_2 to the minimum value that satisfies

$$P_{b_2} \leq \beta_2 \quad \text{and} \quad P_2 \leq \frac{\mathcal{E}_H - E_{b,1}}{T_{b,2}}$$

Finally the rest is obtained similarly; we set P_k to minimum value but satisfy

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

.

IV. 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.

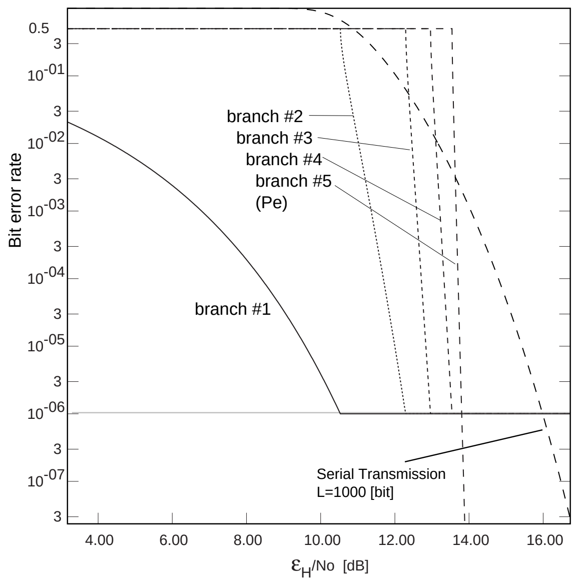

Fig. 5. Bit error performance of transmission branch

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

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

The expected amount of received information for serial transmission is

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

V. Numerical Examples

Figure 5 shows the bit error rate (BER) performance 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 the transmission branches are $G = \{32, 64, 128, 128, 256\}$, respectively. Orthogonal Gold sequence is 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 $\beta = 10^{-6}$.

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 $13.8dB$ to maintain the

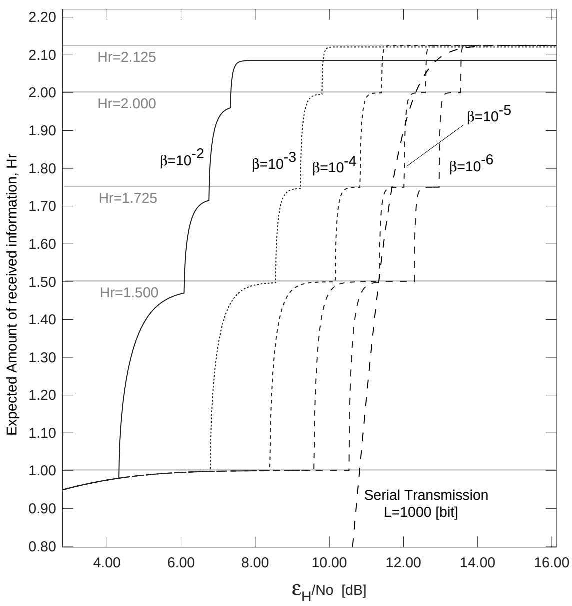

Fig. 6. Average received information

required qualities of all branches for our scheme while it requires $16.0dB$ 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 observe step increase in the average received information due to the effect of quality control. Focusing of the case of $\beta = 10^{-6}$, additional $1.8dB$ improves H_r from 1.00 to 1.50 and $0.6dB$ improves from 1.50 to 1.75 and from 1.75 to 2.00. With $13.8dB$ of $\mathcal{E}_H/N_0$, we achieve entropy transmission with qualities of $\beta = 10^{-6}$. Different in H_r corresponds to that transmission rate is managed with given quality, β.

As the case of $\beta = 10^{-2}$ does not reach H, we consider β should be set less than 10^{-2}. The performance for $\beta = 10^{-5}$ is almost similar with the serial system. We, however, observe that the quality is not enough. From Fig.5 we realize serial system requires $15dB$ to achieve BER=10^{-5}. So gradual increase in H_r with serial system is the result of a sacrifice in quality.

VI. 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 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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