A Study on Error Correcting and Diversity Combiner Scheme on Multiple Routes in Wireless Multi-hop Networks

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***Abstract*— Wireless multi-hop networks have been much attention for the possibility of flexible construction of the network topology. One of the important and interesting techniques for multi-hop networks is a multi-path routing. By using the multi-path routing, multiple routes from a source node to a destination node can be established. In this paper, we propose the error correcting and diversity combiner scheme on multiple routes in wireless multi-hop networks to reduce bit errors. The diversity combiner outputs the likelihood information from the packets transmitted via multiple routes. By feeding the likelihood information into the Viterbi decoder, the diversity gain can be obtained. We evaluate the packet error rate and the total traffic. As a result, the packet error rate can be improved. Furthermore, the total traffic can be reduced in the low E_b/N_0 in spite of the traffic increase due to transmission via redundant routes.**

I. INTRODUCTION

Wireless multi-hop networks have been much attention for the possibility of flexible construction of the network topology[1]–[3]. One of the important and interesting techniques for multi-hop networks is a multi-path routing[4]–[8]. By using the multi-path routing, multiple routes from a source node to a destination node can be established. It is used for various purposes such as maintaining alternative routes, load balancing, and diminishing the effect of frequent topological changes. But it has been hardly employed for the reduction in bit errors on wireless channels.

If a packet is transmitted via multiple routes and diversity-combined effectively at a destination node, it is expected to get the diversity gain and reduce bit errors. There are various diversity combiner schemes; selection combiner, equal gain combiner, maximal ratio combiner, and so on. Many of them make use of a physical soft (non-binary) value such as signal to noise ratio. In multi-hop networks, a packet is demodulated to the binary sequence, regenerated and relayed at intermediate nodes. A destination node can make use of the only hard (binary) value of a bit in the packet transmitted via multiple routes since a physical value cannot be transmitted beyond the intermediate nodes. Therefore, we have to develop a hard-input diversity combiner scheme for multiple routes in multi-hop networks.

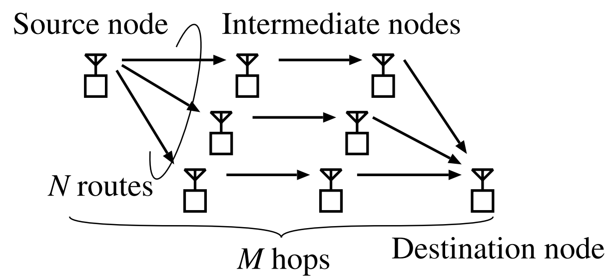

Fig. 1. Wireless multi-hop network model.

In this paper, we propose the error correcting and diversity combiner scheme on the multiple routes in wireless multi-hop networks. The input of the proposed combiner is hard-valued bit in the packets transmitted via multiple routes. The combiner outputs the likelihood information from this input. By feeding it into the Viterbi decoder, the diversity gain can be obtained. We also evaluate the system performance, and clarify the effectiveness of the proposed error correcting and diversity combiner scheme.

In Section II, we describe the wireless multi-hop network model. In Section III, the proposed error correcting and diversity combiner scheme is described. We evaluate the system performance and discuss the results in Section IV. Finally some conclusions are presented in Section V.

II. NETWORK MODEL

Figure 1 shows the wireless multi-hop network model. A packet is transmitted from a source node to a destination node via this network. Intermediate nodes relay the transmitted packet. By using a certain multi-path routing algorithm, N routes from the source node to the destination node are established. For simplification, the number of hops from the

Fig. 2. Transmitter structure.

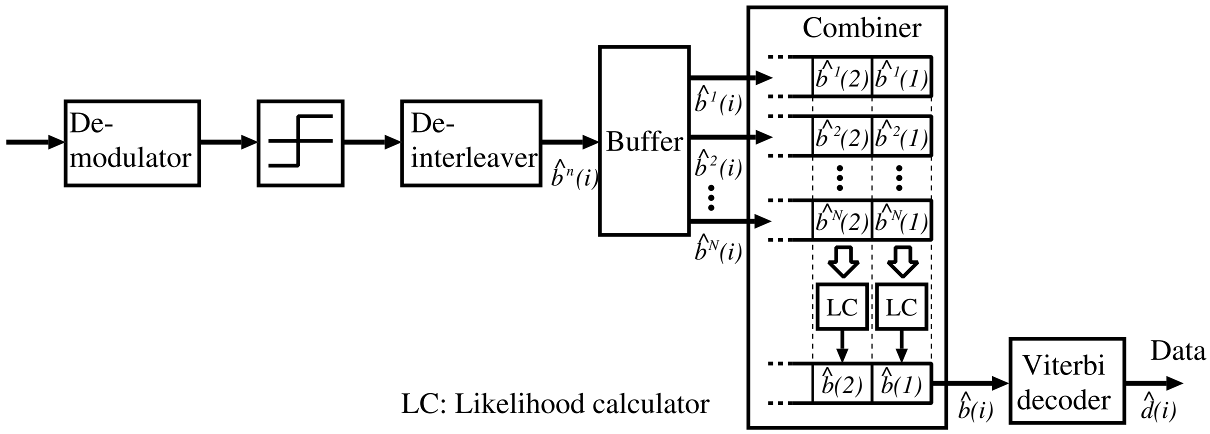

Fig. 3. Receiver structure.

source node to destination node is the same at each route, and it is denoted by M.

III. Error Correcting and Diversity Combiner Scheme

A. Transmitter and Receiver Structure

Figure 2 shows the transmitter structure of the source node. The transmitter consists of a convolutional encoder, an interleaver, a buffer, and a modulator. A packeted data sequence, $d(i) \in \{+1, -1\}^L$, is encoded by convolutional code, where L is the data length. Then, the encoded packet $b(i)$ is interleaved and stored at the buffer. The stored packet is copied, and after modulation, it is transmitted to the next node on the nth route. This operation is repeated until the packet is transmitted to all next nodes on N routes.

At the intermediate nodes, the received signal is demodulated to the binary sequence, remodulated, and transmitted to the next node. Note that decoding is not performed at the intermediate nodes.

After M hops, the packet arrives at the destination node. The receiver structure of the destination node is shown in Figure 3. It consists of a demodulator, a threshold device, a deinterleaver, a buffer, a diversity combiner, and a Viterbi decoder. The received signal via the nth route is demodulated and deinterleaved to the encoded packet $\hat{b}^n(i)$. It is stored at the buffer. After receiving all N packets, the stored packets are fed into the combiner. In order to get the diversity gain, the N packets are combined to a packet $\hat{b}(i)$ which contains likelihood information of the ith bit in a packet. The likelihood information is calculated by a likelihood calculator (LC), which is described in the following section. The output $\hat{b}(i)$ of the combiner is decoded to the decided data sequence $\hat{d}(i)$ by the Viterbi decoder. Note that the combined packet $\hat{b}(i)$ is not necessary to be hard value. If it is soft value, only the soft-input Viterbi decoder is employed.

B. Diversity Combiner Scheme

In this paper, two types of the diversity combiner schemes are proposed; one is a hard-output combiner scheme and the other is a soft-output combiner scheme. Both schemes calculate the likelihood information from N packets transmitted via different routes.

Hard-output Combiner: The hard-output combiner outputs a hard value as the likelihood information. At first, the ith bit of the N packets, $\hat{b}^n(i)$, is summed up. When this sum is larger than 0, a combiner output $\hat{b}(i) = +1$. Otherwise, $\hat{b}(i) = -1$. That is,

$$\hat{b}(i) = \begin{cases} 1 & \text{if } \sum_{n=1}^{N} \hat{b}^n(i) > 0 \\ -1 & \text{if } \sum_{n=1}^{N} \hat{b}^n(i) < 0 \end{cases}. \tag{1}$$

The hard-valued output is fed into the hard-input Viterbi decoder, and decoded by using a Hamming metric.

Note that this method corresponds to a majority decision. So the hard-output combiner requires N to be odd.

Soft-output Combiner: The soft-output combiner outputs a soft value as the likelihood information. In this combiner, the average value of the ith bit of N packets is calculated. Therefore, a combiner output $\hat{b}(i)$ may be expressed as,

$$\hat{b}(i) = \frac{1}{N} \sum_{n=1}^{N} \hat{b}^n(i). \tag{2}$$

TABLE I

OPERATING PARAMETERS

data length	500 bits
code rate	1/2
constraint length	7
interleaving	ideal
modulation scheme	BPSK
channel model	fast/slow Rayleigh fading

The output of this combiner is $N+1$ levels; $+1$, $(N-2)/N$, $(N-4)/N$, $\cdots$, and -1. When all bits from the N routes are the same value, the output becomes $+1$ or -1. In the other case, the output is decided in proportion to the number of disagreements. The N-level output is fed into the soft-input Viterbi decoder. By calculating a euclidean metric, decoding is performed.

The soft-output combiner can be used whether N is odd or even.

IV. PERFORMANCE EVALUATION

In this section, the system performance of the proposed scheme is evaluated by Monte Carlo simulation.

A. Simulation Model

The operating parameters are shown in Table I. The code rate is $1/2$ and the constraint length is 7. The data length is 500 bits, and encoded packet length becomes 1012 bits which include termination bits. The BPSK is employed as the modulation scheme. The wireless channel model of each wireless link is fast/slow Rayleigh fading environment. In the fast Rayleigh fading, fading speed is fast and fading loss fluctuates during a packet transmission. We assume that the interleaver performs ideally, that is, each bit in the packet is independently affected by Rayleigh fading. It is also assume that the packet transmitted at each wireless link has the same average received power. In the slow Rayleigh fading, fading loss is constant during a packet transmission, and independently varies at each wireless link. So the packet transmitted via each route has the different average received power.

We evaluate the system performance in terms of the packet error rate and the total traffic. The total traffic is introduced to evaluate the influence of the traffic increase due to transmissions via multiple routes. It is defined as the total number of transmissions when the packet is retransmitted until it is received correctly at the destination node. The packet retransmission is done between the source node to the destination node, and we assume no error of an ACK/NAK message. Then, the total traffic T normalized by the number of hops may be expressed as,

$$\begin{aligned} T &= \frac{1}{M}\{NM(1-PER) + 2NM\cdot PER(1-PER) \\ &\quad + \cdots\} \\ &= \frac{N}{1-PER} \quad , \end{aligned} \tag{3}$$

where PER is the packet error rate.

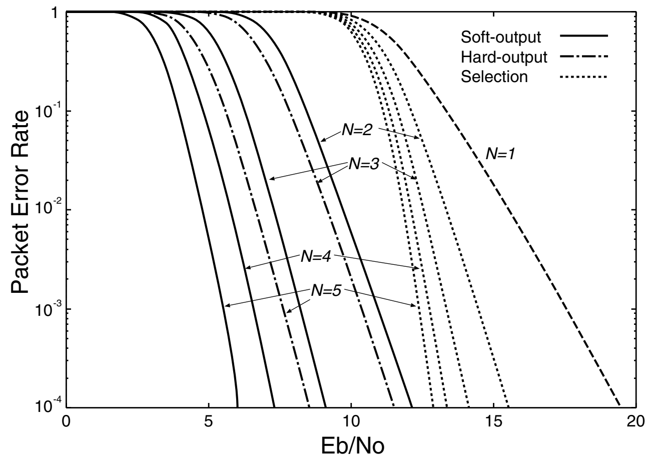

Fig. 4. Packet error rate versus E_b/N_0 ($M = 2$, fast Rayleigh fading).

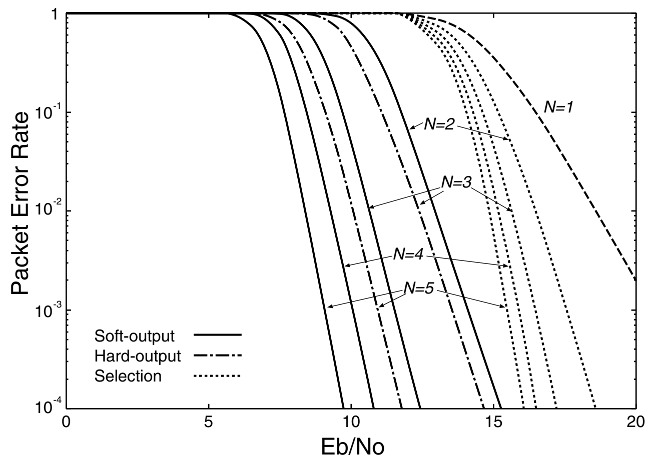

Fig. 5. Packet error rate versus E_b/N_0 ($M = 4$, fast Rayleigh fading).

For comparison, the performance of a selection combiner scheme is also evaluated. In the selection combiner scheme, the transmitter at the source node is the same structure with that of the proposed scheme, that is, a packeted data sequence is encoded, interleaved, and transmitted to the N next nodes. The receiver at the destination node demodulates and decodes the packet transmitted via each route. Assume that packet error is perfectly detected by using a certain error detection code. Then, the correctly decoded packet is selected. So, in the selection combiner scheme, a packet transmission succeeds if any of N packets are demodulated and decoded correctly.

B. Results

Figures 4 and 5 show the packet error rate versus E_b/N_0 for $M = 2, 4$ in the fast Rayleigh fading environment, where E_b is bit energy and $N_0/2$ is two side power spectral density. The curve of $N = 1$ is the packet error rate performance when the diversity combiner on multiple routes is not employed. From these figures, it is found that all diversity combiner schemes can improve the packet error rate performance, and

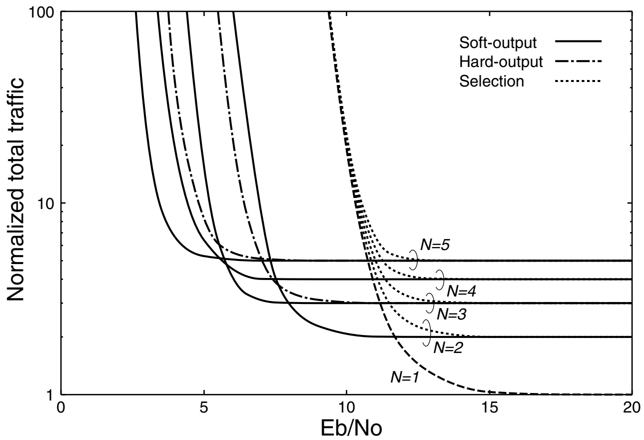

Fig. 6. Total traffic versus E_b/N_0 ($M = 2$, fast Rayleigh fading).

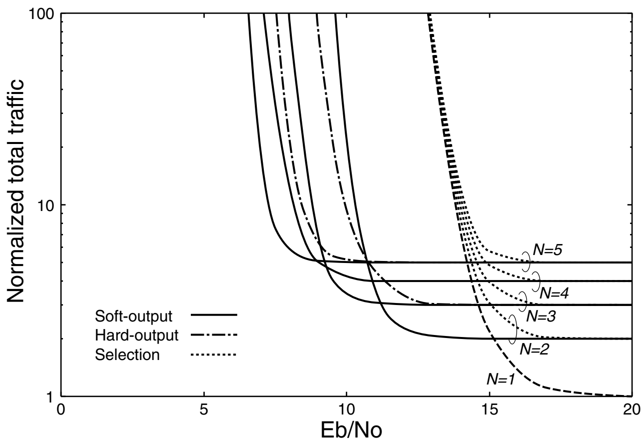

Fig. 7. Total traffic versus E_b/N_0 ($M = 4$, fast Rayleigh fading).

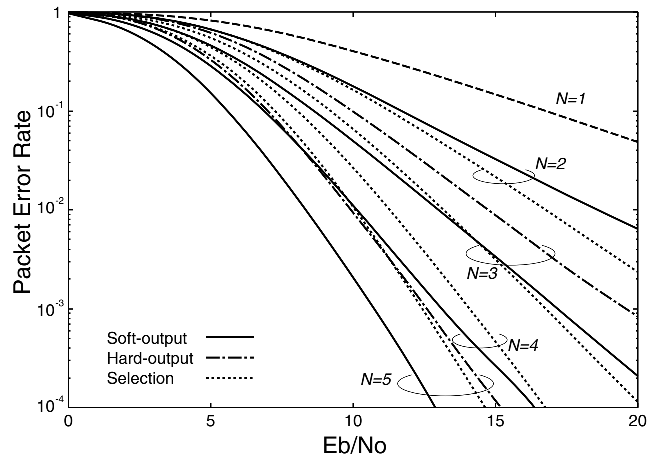

Fig. 8. Packet error rate versus E_b/N_0 ($M = 2$, slow Rayleigh fading).

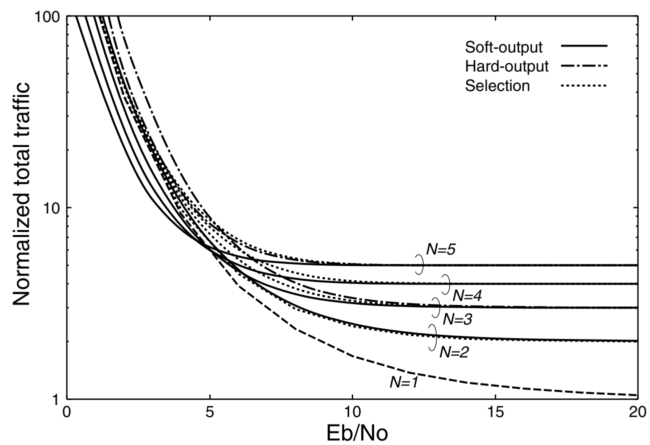

Fig. 9. Total traffic versus E_b/N_0 ($M = 2$, slow Rayleigh fading).

this improvement becomes more effective as the number of routes, N, is larger. Furthermore, the performance of the soft-output and hard-output combiner scheme is better than that of the selection combiner scheme. The selection combiner scheme cannot improve the packet error rate in the low E_b/N_0 since this scheme only select the correctly decoded packet among N transmitted packets and does not improve the packet error rate on each route before combining packets. While the soft-output and hard-output combiner schemes can improve the packet error rate not only in the high E_b/N_0 but also in the low E_b/N_0 because these schemes can get the diversity gain by combining the N packets. The soft-output combiner scheme can improve the packet error rate more than the hard-output combiner scheme. So it is concluded that the soft-value output of the combiner is more reliable than the hard-value output.

Figures 6 and 7 show the normalized total traffic versus E_b/N_0 for $M = 2, 4$ in the fast Rayleigh fading environment. In the high E_b/N_0, the packet error rate is very low even if the diversity combiner is not used. Therefore, the total traffic becomes heavy in proportion to the number of routes because of redundant routes. On the other hand, the total traffic of the proposed diversity combiner scheme can be reduced by increasing the number of routes in the low E_b/N_0 although that of the selection combiner scheme cannot be reduced. It is because the improvement in the bit error rate by the diversity combiner scheme reduces the packet retransmissions. Not only the soft-output combiner scheme but also the hard-output combiner can reduce the total traffic. Therefore, the proposed diversity combiner scheme is effective especially in the low E_b/N_0.

Figures 8 and 9 show the packet error rate and the normalized total traffic, respectively, for $M = 2$ in the slow Rayleigh fading environment. In this environment, the average received power on one route is different from that on the other routes. Despite unequal average received power on each route, the packet error rate can be improved by the proposed diversity combiner schemes. The soft-output combiner scheme can also reduce the total traffic in the low E_b/N_0 though the reduction of the total traffic is small in comparison with the case of the fast fading environment. Unfortunately, both the bit error rate and total traffic of the hard-output combiner scheme are worth than those of the selection combiner scheme.

V. Conclusions

In this paper, we have proposed the error correcting and diversity combiner scheme on multiple routes in wireless multi-hop networks. Two types of the multiple-route combiner schemes have been introduced; one is the hard-output combiner and the other is a soft-output combiner. The system performance of the proposed scheme has been evaluated. As a result, the packet error rate can be improved by employing the proposed combiner schemes not only in the high E_b/N_0 but also in the low E_b/N_0. Furthermore, the total traffic can be reduced in the low E_b/N_0 although it increases in the high E_b/N_0 because of redundant routes. Therefore, we have clarified the effectiveness of the proposed scheme on the multiple routes.

Acknowledgment

This work was supported in part by The Strategic Information and Communications R&D Promotion Programme of the Ministry of Public Management, Home Affairs, Posts and Telecommunications, and The 21st Century COE Program by the Ministry of Education, Culture, Sports, Science and Technology in Japan.

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