Performance Evaluation of Route Coding Scheme in Wireless Multi-hop Networks

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***Abstract*— Wireless multi-hop networks have been much attention for the future generation mobile communication systems. Due to the possibility of flexible construction in the wireless multi-hop networks, multiple routes from a source node to a destination node can be established. In this paper, we propose the route coding scheme in the wireless multi-hop networks. In the proposed scheme, a packeted data sequence is encoded by the convolutional code at the source node. Each digit of the code word is assigned to sub-packets on multiple routes. At the intermediate nodes, the sub-packets are regenerated-relayed to the next node. The sub-packets transmitted via multiple routes are decoded by the Viterbi decoder with the modified metric computation at the destination node. We also evaluate the system performance, and clarify the improvement of the packet error rate by the proposed scheme. Furthermore, we investigate the influence of the route loss due to topological change or recognizing failure.**

I. Introduction

Wireless multi-hop networks have been much attention for the future generation mobile communication systems[1], [2]. In wireless multi-hop networks, a packet is transmitted from a source node to a destination node via intermediate nodes. Wireless multi-hop networks can be constructed flexibly by various ways to select intermediate nodes. So, multiple routes from a source node to a destination node can be established by using the multi-path routing[3]–[7]. They are used for several purposes such as maintaining alternative routes, load balancing, and diminishing the effect of frequent topological changes.

For reduction in bit errors on wireless channels, we proposed the diversity combiner scheme on multiple routes for wireless multi-hop networks[8]. In the multi-hop networks, regenerative relay is usually employed because a header of a packet has to be demodulated. Then a packet is demodulated to a binary sequence, regenerated and relayed at intermediate nodes. The destination node can make use of the only hard (binary) value of a bit in the packet transmitted via multiple routes since a soft value cannot be transmitted beyond the intermediate nodes. Therefore, we have to develop a hard-input diversity combiner scheme on multiple routes in multi-hop networks. In the proposed scheme, a transmitter at a source node copies a packet and transmits it to the next nodes on multiple routes. A receiver at a destination node combines the received packets to get the diversity gain. This scheme is, however, corresponding to a repetition code on multiple routes, so it could be improved if the coding on multiple routes is employed.

In the multi-hop networks, the route loss due to topological change or recognizing failure may happen. The route loss does not become a big problem when multiple copies of a packet are transmitted. If a packet is encoded on multiple routes, however, the route loss results in reducing a part of the encoded packet and this influence could not be ignored.

In this paper, we propose the route coding scheme in the wireless multi-hop networks. In the proposed scheme, a packeted data is encoded on the multiple routes. We employ a simple convolutional code as the route coding scheme because the aim of this paper is to evaluate the effect of the coding on multiple routes. We evaluate the packet error rate performance, and clarify the effectiveness of the proposed scheme. Furthermore, we investigate the influence of the route loss due to topological change or recognizing failure.

II. Route Coding Scheme

A. Network Model

The wireless multi-hop network model is shown in Figure 1. A packet is transmitted from a source node to a destination

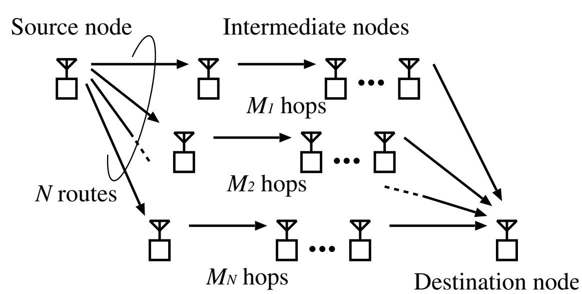

Fig. 1. Wireless multi-hop network model.

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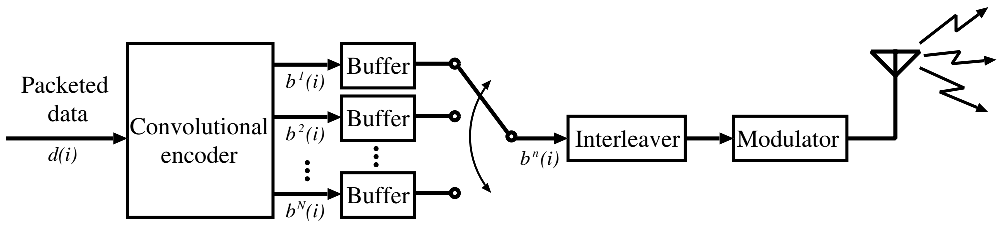
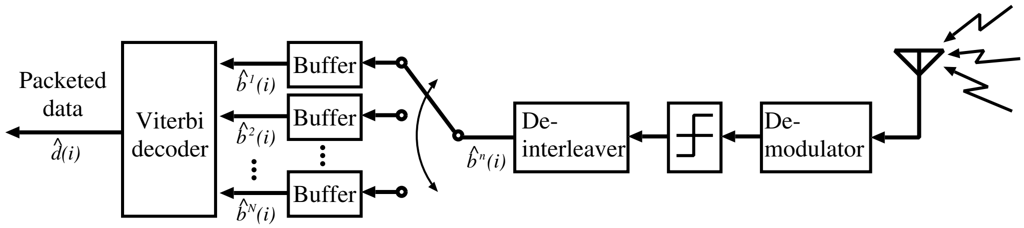


(a) Transmitter structure at source node.



(b) Receiver structure at destination node.

Fig. 2. Transmitter and receiver structure.

node via this network. Intermediate nodes relay the transmitted packet. By using a certain routing algorithm, N routes from the source node to the destination node are established. The number of hops from the source node to the destination node on the nth route is denoted by M_n. In each hop, the packet transmission is according to a certain access control protocol such as IEEE802.11.

B. Transmitter and Receiver Structure

Figure 2(a) shows the transmitter structure at the source node. It consists of a convolutional encoder, buffers, a switch, an interleaver and a modulator. A packeted data sequence, $d(i) \in \{+1, -1\}^L$, is encoded by the convolutional code with a rate $1/N$, where L is the data length. Note that the reciprocal of the code rate is equal to the number of routes. Each digit of the code word, $b^n(i) \in \{+1, -1\}$, is assigned to a sub-packet for each route in order to mitigate the influence of route loss. Then, the sub-packet is stored at the buffer. Each stored sub-packet is interleaved, and after modulation, it is transmitted to the next node on the nth route. This operation is repeated until all sub-packets are transmitted to the 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_n hops, the sub-packet arrives at the destination node. The receiver structure of the destination node is shown in Figure 2(b). It consists of a demodulator, a deinterleaver, a switch, buffers, and a Viterbi decoder. The received signal via the nth route is demodulated, hard-decided and deinterleaved to the estimated sub-packet, $\hat{b}^n(i)$. It is stored at the buffer. After receiving all N sub-packets, they are decoded to the decided data sequence, $\hat{d}(i)$, by the Viterbi decoder. In the following section, we describe the metric computation at the Viterbi decoder.

C. Metric Computation

In the wireless multi-hop network, the sub-packet is regenerated-relayed at the intermediate nodes. The destination node can make use of the only hard value of the bit in the sub-packet. Therefore, the metric is computed based on the hard-decision value, $\hat{b}^n(i)$.

A path metric is generally computed as a Hamming metric for a hard-decision value[9]. It may be expressed as,

$$PM^{(j)} = -\sum_{i=1}^{L} H_i^{(j)} = -\sum_{i=1}^{L}\sum_{n=1}^{N} -\frac{1}{2}\left\{\hat{b}^n(i)c_{in}^{(j)} - 1\right\}, \quad (1)$$

where j denotes any one of the competing paths, $H_i^{(j)}$ is the Hamming distance for the ith data sequence, and $c_{in}^{(j)} \in \{+1, -1\}$ is the coded binary digit of the nth route for the ith data sequence.

In the proposed scheme, each sub-packet is transmitted via the different route. This wireless link condition will be different among routes. Then, the reliability of each digit of the received code word will be different. To consider the reliability of each digit, we modify the computation of the path metric in (1).

In [9], the logarithm of the path metric for binary symmetric channel is computed as,

$$PM^{(j)} = -\sum_{i=1}^{L}\left\{H_i^{(j)} \ln\left(\frac{1-p}{p}\right) - N\ln(1-p)\right\}, \quad (2)$$

where p is a bit error rate. In the proposed scheme, the bit error rate on each route is different. So we replace p in (2) with the bit error rate on each route. Let p_n be the bit error rate on the nth route from the source node to the destination node. From (2), the modified path metric for the different wireless

TABLE I

SIMULATION PARAMETERS.

data length L	500 bits
code rate	1/2 ($N = 2$), 1/4 ($N = 4$), 1/6 ($N = 6$)
constraint length	7
modulation scheme	BPSK
wireless link model	fast/slow Rayleigh fading
the number of hops M_n	2–5

link condition can be derived as,

$$PM^{(j)} = -\sum_{i=1}^{L}\sum_{n=1}^{N}\left\{H_{in}^{(j)}\ln\left(\frac{1-p_n}{p_n}\right) - N\ln(1-p_n)\right\}$$
$$= -\sum_{i=1}^{L}\sum_{n=1}^{N}H_{in}^{(j)}\ln\left(\frac{1-p_n}{p_n}\right)+\alpha, \quad (3)$$

where α is a constant and $H_{in}^{(j)}$ is the Hamming distance of the nth route for the ith data sequence, may be expressed as,

$$H_{in}^{(j)} = -\frac{1}{2}\left\{\hat{b}^n(i)c_{in}^{(j)} - 1\right\}. \quad (4)$$

To calculate the modified path metric, the bit error rate on the nth route, p_n, has to be known. This estimation method is discussed in [10].

III. NUMERICAL RESULTS

A. Simulation Model

The system performance of the proposed scheme is evaluated by Monte Carlo simulation. The operating parameters are shown in Table I. The code rate is 1/2, 1/4 and 1/6. The constraint length for all code rates is 7. The fast/slow Rayleigh fading environment is assumed on each wireless link. In the fast Rayleigh fading, fading speed is fast and fading loss fluctuates during a sub-packet transmission. We assume that the interleaver performs ideally, that is, each bit in the sub-packet is independently affected by Rayleigh fading. In the slow Rayleigh fading, fading loss is constant during a sub-packet transmission, and independently varies at each wireless link. So the sub-packet transmitted via each route has the different bit error rate. For simplification, the number of hops from the source node to the destination node is identical on each route.

B. Comparison with Repetition Coding

In this section, we evaluate the system performance of the proposed scheme in terms of a packet error rate. For comparison, the packet error rate of the repetition coding[8] is also evaluated. In this scheme, the data sequence is encoded by convolutional code with rate $1/2$, copied to N sub-packets, and transmitted via N routes. Note that the total code rate becomes $1/2N$. At the destination node, the received sub-packets are combined by averaging each bit, and decoded by the Viterbi decoder.

Figure 3 shows the packet error rate versus E_b/N_0 with $M_n = 2$ in the fast Rayleigh fading environment, where E_b is bit energy and $N_0/2$ is two side power spectral density. From

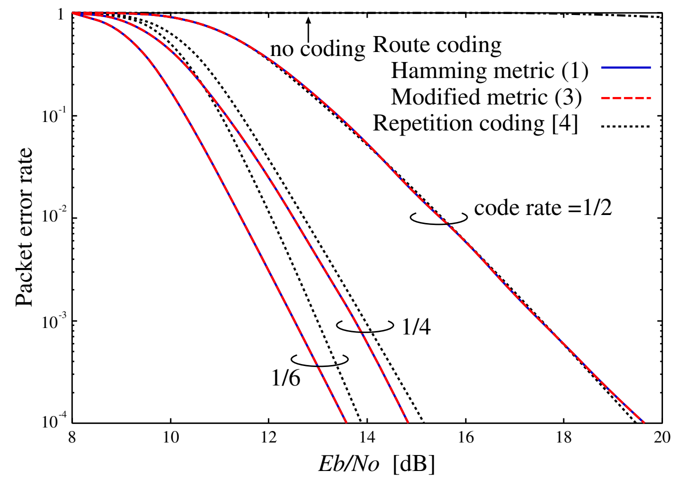


Fig. 3. Packet error rate versus E_b/N_0 ($M_n = 2$, fast Rayleigh fading).

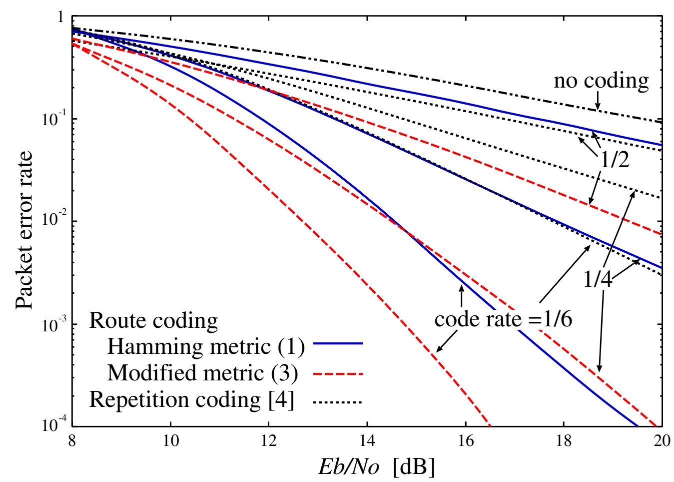


Fig. 4. Packet error rate versus E_b/N_0 ($M_n = 2$, slow Rayleigh fading).

this figure, it is found that the packet error rate of the route coding is equal or better than that of the repetition coding. So the packet error rate can be improved by the coding on multiple routes. But its improvement is not so large. The route coding with the Hamming distance metric (1) is the same performance with that with the modified metric (3). It is because the bit error rate on every route is identical in the fast Rayleigh fading environment. In the following discussions, we omit the packet error rate of the route coding with the modified metric in the fast Rayleigh fading environment.

The packet error rate in the slow Rayleigh fading environment is shown in Figure 4. The packet error rate of the rate 1/2 route coding with the Hamming metric is slightly worse than that of the repetition coding. It is because the route coding scheme with the Hamming metric does not consider different reliability on each route. Except for this case, the packet error rate of the route coding is much better than that of the repetition coding. The effect of the route coding is very large in the slow Rayleigh fading environment. By employing the

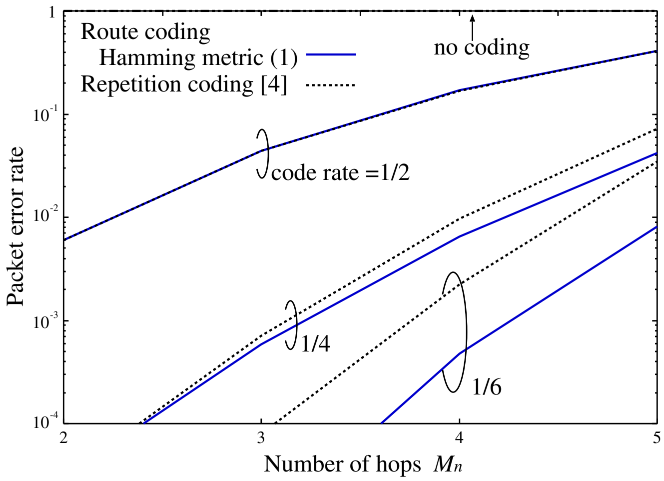


Fig. 5. Packet error rate versus the number of hops ($E_b/N_0 = 16$ dB, fast Rayleigh fading).

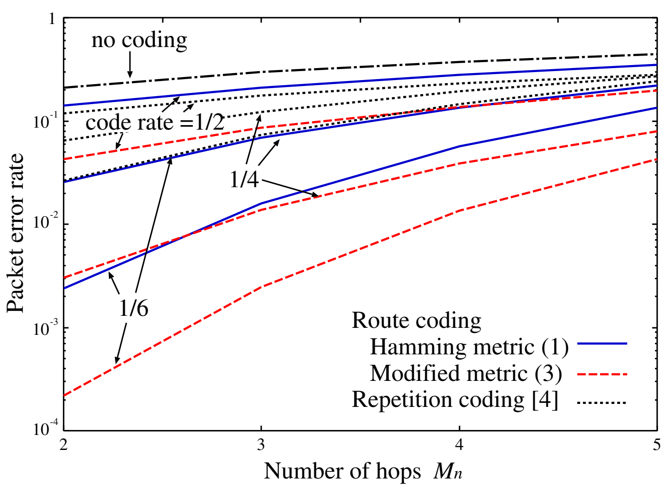


Fig. 6. Packet error rate versus the number of hops ($E_b/N_0 = 16$ dB, slow Rayleigh fading).

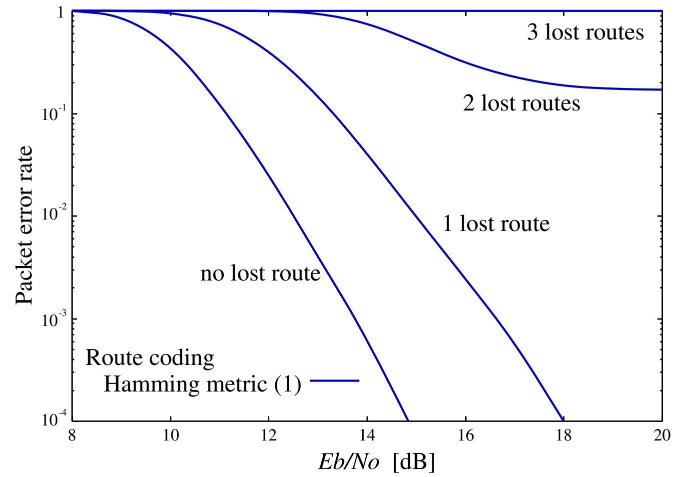


Fig. 7. Packet error rate versus E_b/N_0 as a parameter of the number of lost routes ($M_n = 2$, code rate=1/4, fast Rayleigh fading).

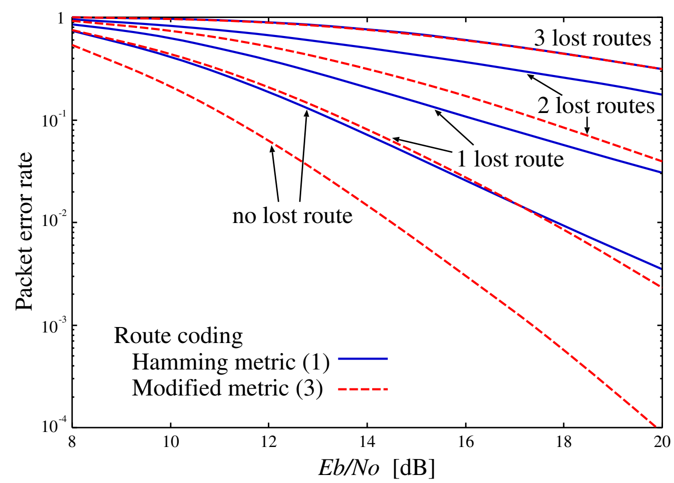


Fig. 8. Packet error rate versus E_b/N_0 as a parameter of the number of lost routes ($M_n = 2$, code rate=1/4, slow Rayleigh fading).

modified metric, the packet error rate can be further improved.

Figures 5 and 6 show the packet error rate versus the number of hops with $E_b/N_0 = 16$ dB as a parameters of the code rate. As the number of hops, M_n, increases, the packet error rate becomes worse in all cases. This reason is only the degradation of the bit error rate due to increase in the number of hops.

C. Influence of Route Loss

In this section, we investigate the influence of the route loss due to topological change or recognizing failure.

Figure 7 shows the packet error rate versus E_b/N_0 with $M_n = 2$ and code rate=1/4 in the fast Rayleigh fading environment as a parameter of the number of lost routes. The packet error rate in the case of 1 lost route is worse than that in the case of no lost route, but this degradation can be tolerable. On the other hand, when the number of lost routes is equal or larger than 2, the packet error rate cannot be improved even if E_b/N_0 increases. So we can conclude that the performance degradation is very serious when a half of sub-packets is lost.

Figure 8 shows the packet error rate versus E_b/N_0 with the same parameters in the slow Rayleigh fading environment. In this case, error floor, which is found in the fast Rayleigh fading environment, cannot be seen. It is because some sub-packets have a strong signal power and it enables us to decode the received sub-packets correctly.

IV. Conclusions

In this paper, we have proposed the route coding scheme in wireless multi-hop networks. So as to consider the different reliability each route, we have modified the metric computation. By evaluating the system performance, we can find that the packet error rate can be improved by the proposed route coding scheme. Specially, it is more effective in the unequal bit error rate environment on each route. Further improvement can be obtained by the modified path metric.

We have also investigated the influence of the route loss due to topological change or recognizing failure. As a result, performance degradation is very serious when a half of sub-packets is lost.

In this paper, we employed a simple convolutional code as the route coding scheme since we focused on the evaluation of the effect of the coding on multiple routes. In the future study, we will develop the coding scheme which can mitigate the influence of both bit errors and route loss for wireless multi-hop networks.

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