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# Dynamic Multi-hopping for Efficient and Reliable Transmission in Wireless Ad Hoc Networks

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***Abstract*- A dynamic multi-hop transmission method and its protocol are proposed to improve transmission quality and save radio resources in wireless ad hoc networks. By autonomously abbreviating hop path and enabling path-selection diversity between a shortcut path and normal two-hop path, transmission reliability improvement and reduction of unnecessary transmission are achieved. The enhancement method for current IEEE 802.11 MAC and AODV routing is presented to inplement the proposed method. Packet success probability with this method is analyzed for Rayleigh faded wireless links. Simulation results show that the average packet delay in hop counts is also improved.**

*Keywords:* Multi-hop, ad-hoc network, wireless transmission, routing.

## I. INTRODUCTION

In wireless ad hoc networks, multi-hop transmission is employed to send information from a source node to a destination node. Although multi-hop transmission extends communication range, packet transmission quality issues arise as the number of hops increases. They are packet error and transmission delay.

The cause of packet error and transmission delay depends on the environment where wireless ad hoc networks are oprerating. For example, mobile ad hoc network nodes are asuumed to move fast, and they are sufferd from packet errors due to fast fading of radio links. In addition, they are frequently sufferd from large delay due to missing roots because the network toporogy always changes. Thus, countermeasures for fast fading and rapid root recovery are study items.

On the other hanad, there are many ubiquitous network devices and sensor networks, which are not moving. In this case, the network topologiy is unchanged. However, their radio environments are also characterized by multipath propagation consisting of diect, reflected, and scattered waves. Thus, slow fading and shaowing occurs due to the change of the environment, such as human body move, door open and close, walls and ground becoming wet or dry. If the position of a node device falls in the dead splot for another node, they are difficult to communicate each other for a while until the environment changes. When the fading speed is slow, upper-layer reransmission is not effective. Thus the multi-hop root is temporally missed, which might initiate route reconstraction and cause large delay.

For both cases of either moving and not, mitigating the packet error due to fading is very important, because it degrades the quality of transmission, reduces throughput, increases delay, and wastes network resources by retransmission.

When a multi-hop route is created, the average packet error rate is determined by both the distance of each hop link and the number of hops [1]. By increasing the number of hops between the source and destination nodes, each hop distance can be shortened and packet error rate for each link will be improved. However, probability of errors is accumulated proportional to the number of hops. Moreover, large number of hops causes large transmission delay and needs much network resources regarding time and power. Therefore, the multi-hop transmission method that can improve transmission quality with minimum number of hops should be developed.

Since signal to noise ratio (SNR) of a wireless link widely changes due to fading, it is safe to determine the hop distance and transmitting power to satisfy a required average SNR in fading environment. However, this requires large fading margin for a link budget. It results in either shortning hop distance or requiring much transmitting power.

Many methods in different approaches have been studied to improve tolerance of the ad-hoc networks to unstable wireless transmission. In the network layer, multipath routing [2] is a solution. It creates multiple routes at the beginning of communication and route redundancy improves reliability. However, it consumes much network resources such as power and spectrum and even though, it cannot adapt to fast fading in each route. Thus, this method is not cost-effective in the wireless environments.

In the physical layer, cooperative diversity [3-5] has attracted much attention. Reliability improvement with the method is very large with reasonable spectrum efficiency. However, physical layer signal processing in the receiver for the metod is heavy for small power-source devices. In addition, relay nodes determination is not yet coordinated with multi-hop routing mechanism.

In this paper, a different approach is proposed, which is called dynamic multi-hopping. Since link propagation losses change due to fading, the optimum route path also changes dynamically at a fading speed. The proposed method enables temporary shortcut paths in a multihop network, and improves transmission quality with a smart and fast hop-path selection combining protocol to optimize the route. By choosing a minumum hop path in an autonomous way, the proposed method enables path diversity, improves reliability, reduces transmission delay, and achieves efficient use of power and wireless resources. The enhancement method for current IEEE 802.11 MAC and AODV routing is presented to inplement the proposed method, and its performance is analyzed.

## II. PRINCIPLE

The dynamic multi-hopping method takes advantage of wireless transmission. The principle is shown in Fig. 1. In the figure, a sender node S sends packets to a destination node D. A route from S to D has determined as “S-A-B-C-D” by some routing protocol such as Ad hoc On-demand Distance Vector (AODV) [6]. Suppose that the direct link “A -C” is not selected in the hop route, because the link distance $R_{\mathrm{AC}}$ is too long for satisfying the required average SNR. Nevertheless, node C can detect certain percentage of packets transmitted from node A to node B due to good SNR which temporary occurs in the fading environment.

If this temporary shortcut link is incorporated in the multi-hop transmission, the average number of hops can be reduced. Moreover, path diversity effect is expected between the two-hop path “A-B-C” and the shortcut path “A-C”. Then packet error rate will be improved. However, a mechanism is necessary which avoids unnecessary packet transmission from node B to C, which may interrupt packet transmission from node C to D after receiving the shortcut packet from node A.

The detailed protocol sequence is shown in Fig. 2. When node A sends data packets to node B, node C simultaneously monitors and captures the packets. If node C can receive the packet successfully, the node C sends the highest priority acknowledgement message, ACK-F, to node A. Since the Ack-F has the shortest inter-frame spacing (SIFS), it is received by node B before it sends normal ACK to node A. If the ACK-F is monitored by node B, node B stops to send normal ACK and data packet. Thus, unnecessary packet transmission from node B to C is avoided.

In order to enable this protocol, two functional enhancements are necessary to current MAC and routing protocols. The first enhancemet is to add Ack-F message and avoid collision of packets sent by the two-hop and shortcut pathes. The second one is to enable next two nodes addressing for the shortcut. The enhancement methods for the current IEEE 802.11 MAC and AODV routing are presented in this paper.

Fig. 3 shows the whole process of the next two nodes addressing for the shortcut. The first step of enabling the next two nodes addressing is to inform each node on the root its two next hop node address. In order to acieve this, the AODV routing table and RREP message are modified. The enhanced routing table entry in each node has the next and two next hop node addresses as shown in Fig. 4. In order to include the next two nodes in routing table, a Route Reply (RREP) message should convey addresses of last two hop nodes. A new address field “Previous Hop IP Address” in RREP messages is created to inform a previous hop node address as shown in Fig. 5. Node B fills this address field with node C address and sends this message to node A. After receiving the RREP, node A can add this address to the “two next hop” section of the routing table.

The second step of the next two nodes addressing is to enable data packets to be decoded by the next two nodes. The “adddress3” (or “adress4”) area of the IEEE 802.11

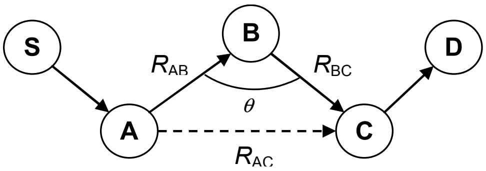

Fig. 1 Temporary shortcut in multi-hop network.

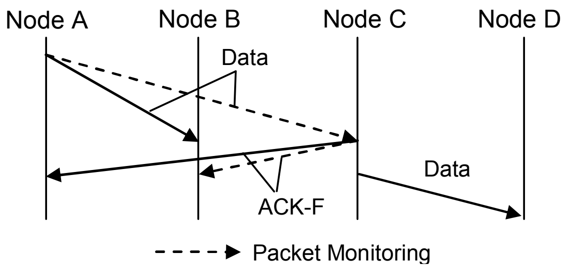

Fig. 2 Protocol sequence for the dynamic multi-hopping.

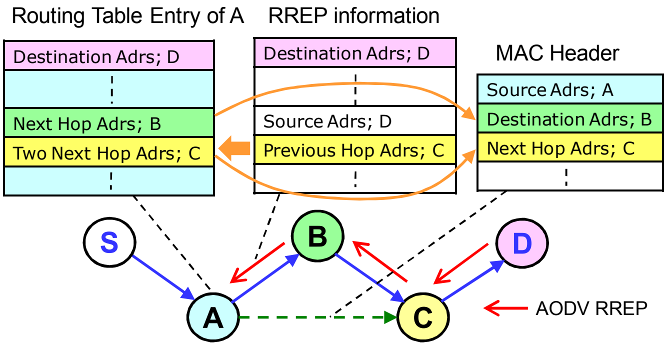

Fig. 3 Enabling next two nodes addressing for the shortcut.

| |
|---|
| Destination IP Address |
| Destination Sequence Number |
| Interface |
| Hop Count |
| Last Hop Count |
| List of Pricursors |
| Next Hop |
| 2 Next Hop |
| Lifetime |
| Routing Flags |

Fig .4 Enhanced AODV routing table.

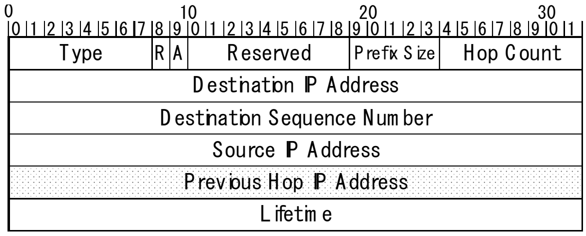

Fig .5 Enhanced AODV RREP message.

| Flame Control | Dulation / ID | Address1 | Address2 | Address3 | Sequence Control | Address4 |
|---|---|---|---|---|---|---|
| (2) | (2) | (6) | (6) | (6) | (2) | (6) |

Fig. 6 MAC header enhancement.

MAC header shwon in the Fig. 6 is used to address to the two next node. If node C receives data packet with its address in the field of adrres3, node C returns ACK-F packet for node A.

## III. PERFORMANCE ANALYSIS

### *A. Packet Error Probability*

The packet error probability for a wireless link suffered from flat Rayleigh fading can be expressed by

$$P_e = \int P_R(E)\; P_D(E)dE \qquad (1)$$

$$P_R(E) = \frac{E}{\sigma^2}\exp\left(-\frac{E^2}{2\sigma^2}\right) \qquad (2)$$

Where, $E$ is a received signal amplitude, $P_R$ is the probability density function of received signal envelope according to Rayleigh distribution with average power of $\sigma^2$, $P_D$ is the packet error rate for a receiver at an input signal power of $E^2/2$.

Packet transmission success probability $P_{2\mathrm{h}}$ and $P_{\mathrm{C}}$ for the normal two-hop and dynamic multi-hopping links can be expressed by

$$P_{2h} = P_{AB}\,P_{BC} \qquad (3)$$

$$P_C = P_{AC} + (1-P_{AC})P_{AB}P_{BC} \qquad (4)$$

$$P_{XY} = 1-\int P_{Rxy}(E)\; P_D(E)dE \qquad (5)$$

$$P_{Rxy}(E) = \frac{E}{{\sigma_{XY}}^2}\exp\left(-\frac{E^2}{2{\sigma_{XY}}^2}\right) \qquad (6)$$

Where, $P_{AC}$, $P_{AB}$ and $P_{BC}$ denote packet transmission success probabilities for the shortcut link “A-C”, two hop links “A-B”, and “B-C”, respectively. ${\sigma_{XY}}^2$ denote average received power for the link from node X to node Y.

Improvement of packet transmission success probability with the proposed method depends on the angle of the three nodes shown in Fig. 1. If the angle $\theta$ in the figure is close to 180 degrees, the shortcut distance $R_{\mathrm{AC}}$ will be the longest, reaching the sum of node distances $R_{\mathrm{AB}}$ and $R_{\mathrm{BC}}$.

### *B. Average Transmission Delay*

The average transmission delay time for a route can be expressed by the product of

1. average packet transmission time for a link and
2. average number of hops.

If we fix packet size and physical layer parameters for a link, a necessary packet transmission time is determined. The average packet transmission time for a link takes into acount MAC-layer retransmission time. If the packet success rate is low, retransmission happens frequently and the average packet transmission time increases.

The average number of hops depends on how the route is determined. For example, AODV chooses the minimum hop count route. However, each link distance of the selected route tends to be long for AODV, SNR margin for each link is not sufficient to achieve good packet success rate in fading environment.

Therefore, reducing the average number of hops involves risk of increasing average packet transmission time. By making the best use of potential shortcuts, the proposed method can improve packet success probability and reduce average number of hops at the same time. Thus, it can reduce transmission delay.

## IV. SIMULATION RESULTS

We simulated the packet success probabilities $P_{2\mathrm{h}}$ and $P_{\mathrm{C}}$ as functions of the shortcut distance and node angle $\theta$. Simulation conditions are listed in table 1. In this condition, the propagation loss exponent is 4 for the distance longer than 72 m. The distance $R_{\mathrm{AB}}$ and $R_{\mathrm{BC}}$ are set identical.

Table 1 Simulation condition.

| | |
|---|---|
| RF band | 2.4 GHz |
| Transmission rate | 11 Mbps |
| Tx Power | 15 dBm |
| Required SNR | 10 dB |
| Rx sensitivity | -83 dBm |
| Path loss model | 2 path |
| Tx/Rx antenna height | 1.5 m |
| Fading | Flat Rayleigh |

Fig. 7 and 8 show packet success probabilities for $\theta$’s of 90 and 120 degrees, respectively. The proposed method can improve packet success probabilities in both cases for the shortcut distance from 100 to 300 m. Improvement is more remarkable for the $\theta$ of 90 degrees,

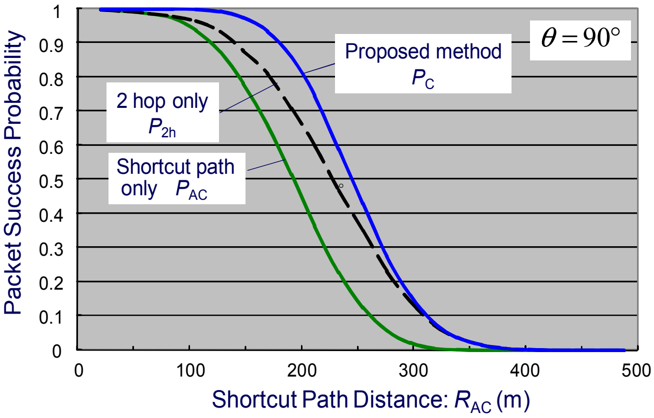

Fig. 7 Packet success probability for $\theta$ of 90 degrees.

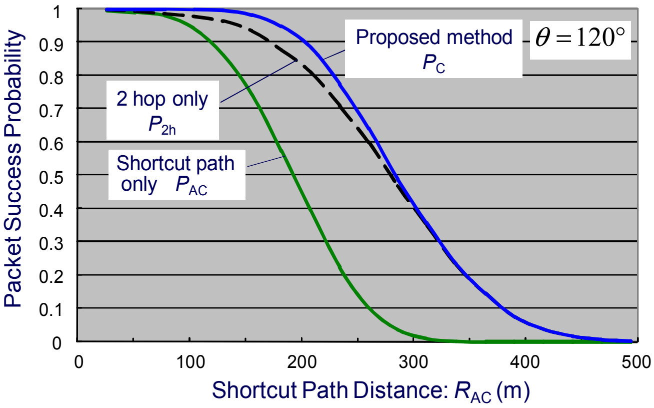

Fig. 8 Packet success probability for $\theta$ of 120 degrees.

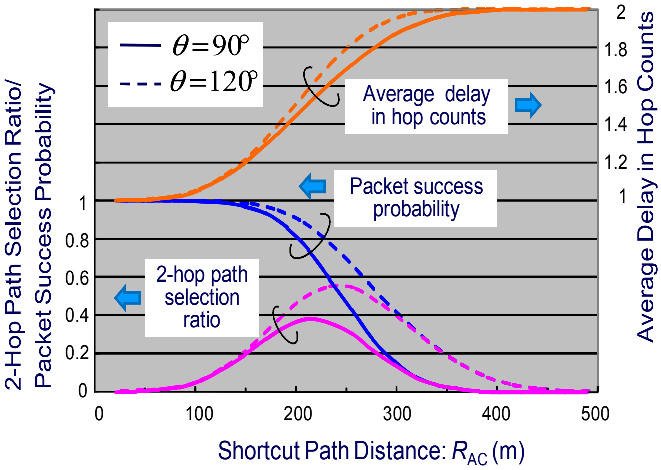

Fig. 9 Two-hop path selection ratio and average delay in hop counts.

because the unit link distance for the normal two-hop path is longer than that for the $\theta$ of 120 degrees.

Fig. 9 shows two-hop path selection ratio and average delay in hop counts for the proposed method. Since the proposed method selects shortcut path with priority, the probability of selecting two-hop paths is kept low until the packet success ratio decreases to around 0.8. When the shortcut distance exceeds 200 m, the packet success ratio of the shortcut path rapidly decreases as shown in Fig. 7 and 8. Then the two-hop path covers this range in cooperation with the shortcut path, and the two-hop path selection ratio gradually increases as in Fig. 9. The ratio of two-hop path to shortcut path reaches to even at a shortcut distance of around 220 m.

Consequently, the packet success probability is improved and the average delay in hop counts is reduced in the wide range of shortcut distance.

## V. CONCLUSIONS

A dynamic multi-hop transmission method and its protocol have been proposed to improve transmission quality and reduce radio resource consumption in wireless ad hoc networks. Packet success probability has been analyzed in a Rayleigh fading wireless link and the results show that the proposed method can improve the packet success probability and reduce average delay in hop counts.

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