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Relay Node Selection Algorithm for Cooperative Communications in Wireless Networks

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***Abstract*—**IEEE 802.11a/b/g standards support multiple transmission rates. Even though the use of multiple transmission rates increase the WLAN capacity, this feature leads to the performance anomaly problem. Cooperative communication was introduced to relieve the performance anomaly problem. Data packets are delivered to the destination much faster through a relay node with high rate than through direct transmission to the destination at low rate. In the legacy cooperative protocols, a source node chooses a relay node only based on the transmission rate. Therefore, they are not so feasible in multi-flow environments since they do not consider the effect of other flows. To alleviate the effect, we propose a new relay node selection algorithm based on the transmission rate and channel contention level. Performance evaluation is conducted using simulation, and shows that the proposed protocol significantly outperforms the previous protocol in terms of throughput and delay.

***Keywords*—**Cooperative communications, MAC protocol, Relay node, WLAN.

I. Introduction

THE IEEE 802.11 wireless LAN is widely used for wireless access due to its easy deployment and low cost. The IEEE 802.11 standard defines a medium access control (MAC) protocol for sharing the channel among nodes. The distributed coordination function (DCF) was designed for a contention-based channel access. The DCF has two data transmission methods: the default basic access and optional RTS/CTS (request-to-send/clear-to-send) access. The basic access method uses the two-way handshaking (DATA-ACK) mechanism. The RTS/CTS access method uses the four-way handshaking (RTS-CTS-DATA-ACK) mechanism to reserve the channel before transmitting long data packets.

The fundamental method available to enhance the capacity of wireless LAN is providing higher transmission rate at the physical layer. IEEE 802.11a/b/g were standardized to expand the physical layer capable of offering higher transmission rates. These standards provide multiple transmission rates, which can be changed dynamically according to the channel condition. To utilize several rates, it is required to deploy rate adaptation schemes at the MAC layer.

When using multiple transmission rates, the capacity of wireless LAN improves, but the performance anomaly problem may occur owing to such characteristics [1]. In a wireless LAN using CSMA/CA, the probability of channel access is same regardless of the transmission rate of a node. When a node gets an opportunity to access a channel, a node with lower rate tends to occupy more channel time than a node with higher rate. Therefore, when there are more nodes with lower rate, then overall network performance decreases. That is, in a wireless LAN supporting multiple transmission rates, the network performance is affected by nodes with lower rates.

Cooperative communication was introduced to alleviate the performance anomaly problem with the help of relay nodes with higher transmission rates [2], [3]. The cooperative communication is based on the fact that the transmission is much faster when sending data packets to a destination node through a relay node with higher rate, rather than sending data directly to the destination node at low transmission rate. To apply the cooperative communication in wireless LAN, several MAC protocols have been proposed [2]-[9].

When there are more than one relay node between the source node and the destination node, legacy MAC protocols tend to select a relay node by considering transmission rate. That is, the source node selects a relay node with the least packet transmission time required to send packets to the destination node. The packet transmission time can be calculated by using packet size and transmission rate. However, these protocols are not working well in multi-flow environments. Nodes are cooperative each other to send packets between them through the networks. The efficiency of a node may be affected by its own transmission rate as well as transmissions of neighboring nodes owing to contention of shared channels. That is, each multi-hop flow has channel contentions with other flows passing through neighboring nodes (i.e., the inter-flow interference). If a source node selects a relay node just by considering transmission rate, not the transmissions by neighboring nodes, it may select a node, which may adversely affect the transmissions of other flows. In this case, serious collisions or congestion may occur, and the performance of multi-hop networks may be degraded. Therefore, a source node shall select a relay node by considering the transmissions of neighboring nodes as well.

The proposed protocol selects a relay node by considering data transmission rate, as well as the transmissions occurred in neighboring nodes around the relay node to be selected. The proposed protocol is called TRCCL (Transmission Rate and Channel Contention Level) protocol. We use the channel contention level to consider the transmissions of neighboring nodes.

The paper is organized as follows. In Section II, we describe the proposed TRCCL protocol in detail. In Section III, performance studies are carried out through simulation results.

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Finally, we draw a conclusion in Section IV.

II. Proposed TRCCL Protocol

In this Section, we present a basic idea of our proposed TRCCL protocol. Although the proposed TRCCL protocol has the same procedure of exchanging packets as that of the CoopMAC protocol, it uses a different method in selecting relay nodes.

The CoopMAC protocol estimates packet transmission time by using transmission rate, and selects a node with the least packet transmission time as a relay node. Unlike the CoopMAC protocol, the proposed TRCCL protocol selects a relay node by considering not only transmission rate, but also channel contention level.

Each node maintains a table, referred to as the *RelayTable*. A node overhears transmissions of packets such as RTS, CTS, DATA, and ACK by other nodes, and then updates its RelayTable. The RelayTable contains 5 fields. Data in the first two fields are MAC addresses of the source node and the destination node included in the ongoing packets. In the time field, time of the last packet received from the source node is recorded. In the transmission rate field, transmission rate ($R_{S,D}$) between source node S and destination node D is stored. In the last field, channel contention level measured by the source node is stored.

As an indicator of channel contention level, we use the collision probability. Each node records the collision probability. And then it sends packets including the collision probability to neighboring nodes. As the number of nodes with channel contention increases, the collision probability gets higher. If the collision probability is high, it means that there are many nodes in the neighborhood, and each of them contends for the channel to send data. Therefore, if a node with high collision probability is selected as a relay node, then the possibility of occurring inter-flow interference gets larger, and that of setting NAV owing to the transmissions of other nodes is also high. Therefore, it is necessary to avoid selecting a node with high collision probability as a relay node.

The proposed TRCCL protocol selects an optimal relay node by considering both packet transmission time and channel contention level. These two values can be obtained easily by using data in the RelayTable. The packet transmission time is the transmission time of a packet between a source node and a destination node, which includes the total relay time by all the intermediate relay nodes.

When a source node has a data packet to send, it calculates packet transmission time (TX) to its neighboring nodes based on information in the RelayTable:

$$TX_{S\to i\to D} = \frac{L}{R_{S,i}} + \frac{L}{R_{i,D}} + t_r \tag{1}$$

where, S is source node ID, D is the destination node ID, and *i* is a node ID located around the source node. L is packet size in bits. t_r denotes the overhead of a relayed data packet. $S \to i \to D$ means that the node S sends packets to node *i*, which resends the packets to node D. As the packets are sent directly from node S to node D (S → D) without passing through node *i*, the packet transmission time is obtained as follows:

$$TX_{S\to D} = \frac{L}{R_{S,D}} \tag{2}$$

After calculating the packet transmission time, the source node makes an intermediate node satisfying the following condition as a relay node candidate:

$$TX_{S\to i\to D} < TX_{S\to D} \tag{3}$$

After that, the source node computes DRT (Direct-to-Relay Transmission Time Ratio) of the relay node candidate. This is the ratio of the packet transmission time between source and destination directly to the packet transmission time via relay operation. DRT_i for relay node candidate *i* is as follows:

$$DRT_i = \frac{TX_{S\to D}}{TX_{S\to i\to D}} \tag{4}$$

The larger the DRT of a relay node is, or the smaller the channel contention level, the better the performance of the system. The efficiency (Ef_i) when the source node sends packets to the destination node through a relay node candidate *i* is obtained also follows:

$$Ef_i = DRT_i \times (1 - C_i) \tag{5}$$

where, C_i is channel contention level (i.e., the collision probability) of relay node candidate *i*. The performance of a node is the best when there is no collision at all, and it degrades progressively, as the collision probability gets higher. Therefore, low collision probability is preferred.

We want to maximize the benefit for the nodes by selecting the best relay node. Therefore, we select a relay node candidate with the highest efficiency as the relay node:

$$max_{i\in V_r}\{Ef_i\} \tag{6}$$

where, V_r indicates the set of relay node candidates. Here, a node with the highest efficiency is selected as the relay node.

III. Simulation Results

Let us discuss the simulation results of the proposed TRTCCL protocol. To validate the proposed protocol, we compare them to the results of the CoopMAC protocol. In the simulation, we consider the topology shown in Fig. 1. The network supports four different rates (1, 2, 5.5 and 11 Mbps) determined by the distance of a source node to a destination node, while the control packets are transmitted at basic rate (1 Mbps). In the simulation topology, there are two transmission range groups (upper and lower). In the lower group, there are one source node (S0), one destination node (D0), and two relay nodes (H0 and H1). In the upper group, there are one destination node (D1) and one relay node (H1). And, the number of source nodes varies from 0 to 20 (i.e., S1, S2, …, S21).

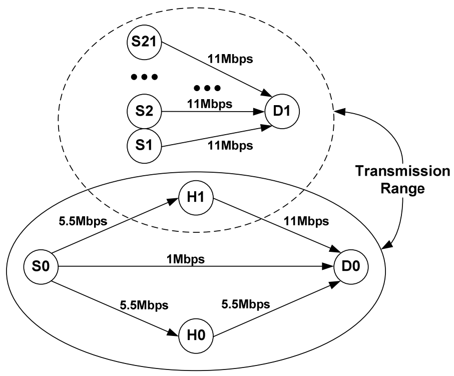

Fig. 1 Simulation topology

Main performance metrics of interest are throughput and delay. Delay is the time elapsed from the moment a packet arrives at the MAC layer queue until the packet is successfully transmitted to the destination node including the receipt of acknowledgement.

In the simulation, a constant data packet size of 1500 bytes is used. Each source node generates data packets at a rate of 2 Mbps. In the figures, D0 and D1 mean the simulation results measured at the destination nodes D0 and D1, respectively.

Fig. 2 demonstrates the throughput performance. We see that there are no performance differences between the CoopMAC and TTCCL protocols when there is no source node in the upper transmission range group. As the number of source nodes increases, the proposed TRCCL protocol outperforms the CoopMAC protocol. In the CoopMAC protocol, when the source node S0 selects a relay node, it considers packet transmission time only. Thus, it always selects H1 with the fastest transmission rate as a relay node regardless of the number of source nodes in the upper transmission range group. Therefore, as the number of source nodes in the upper transmission range group increases, the throughput at D0 deteriorates rapidly. In addition, the performance at D1 also degrades according to the influence of the relay node H1. However, in the proposed TRCCL protocol, the source node S0 considers both packet transmission time and channel contention level when selecting a relay node. Thus, it is possible to select another relay node according to the number of source nodes in the upper transmission range group.

Fig. 3 demonstrates the delay performance. The proposed scheme outperforms the CoopMAC protocol regardless of the number of source nodes in the upper transmission range group. Result at D1 shows that in both the proposed TRCCL and the CoopMAC protocols, delay increases as the number of source nodes rises. However, the delay of the proposed TRCCL is always smaller than that of the CoopMAC. In the proposed protocol, the delay at D0 grows slowly following the increase of source nodes, though that at D0 in the CoopMAC shows rapid increase. Even the result at D0 in the CoopMAC is worse than that at D1.

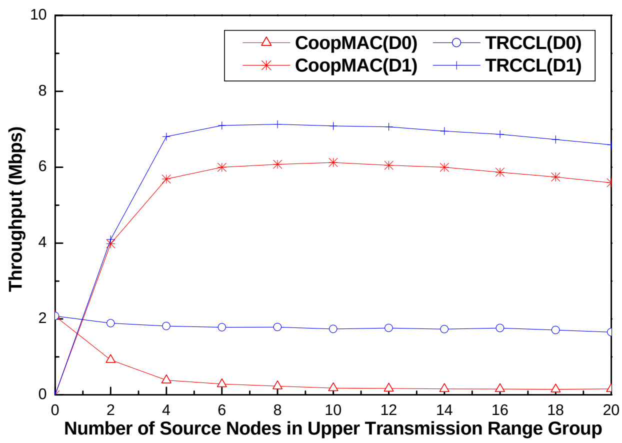

Fig. 2 Throughput according to the number of source nodes in the upper transmission group

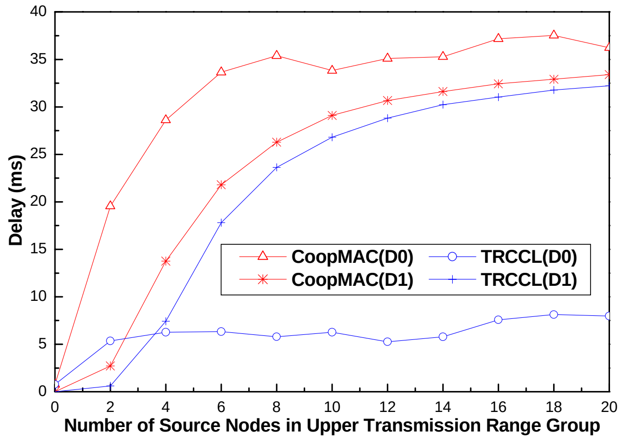

Fig. 3 Delay according to the number of source nodes in the upper transmission group

IV. Conclusion

In previous MAC protocols the cooperative communications in WLANs, a source node chooses a relay node only based on the transmission rate. They are not so feasible in multi-flow environments since they do not consider the effect of other flows. Wireless resources are wasted in information exchange for unsuccessful transmission due to unresponsive relays. Also, network performance is affected by the interference between multiple flows sharing the channel. To alleviate the problems, we propose a new relay node selection algorithm based on the transmission rate and channel contention level. Performance evaluation is conducted using simulation, and shows that the proposed protocol significantly outperforms the previous protocol in terms of throughput and delay.

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