

Data Rate Based Grouping Scheme for Cooperative Communications in Wireless LANs

Sunmyeng Kim

Abstract—IEEE 802.11a/b/g standards provide multiple transmission rates, which can be changed dynamically according to the channel condition. Cooperative communications were introduced to improve the overall performance of wireless LANs with the help of relay nodes with higher transmission rates. The cooperative communications are based on the fact that the transmission is much faster when sending data packets to a destination node through a relay node with higher transmission rate, rather than sending data directly to the destination node at low transmission rate. To apply the cooperative communications in wireless LAN, several MAC protocols have been proposed. Some of them can result in collisions among relay nodes in a dense network. In order to solve this problem, we propose a new protocol. Relay nodes are grouped based on their transmission rates. And then, relay nodes only in the highest group try to get channel access. Performance evaluation is conducted using simulation, and shows that the proposed protocol significantly outperforms the previous protocol in terms of throughput and collision probability.

Keywords—Cooperative communications, MAC protocol, relay node, WLAN.

I. INTRODUCTION

THE most 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.

Cooperative communications were introduced to improve the overall performance of wireless LANs with the help of relay nodes with higher transmission rates [1], [2]. The cooperative communications are based on the fact that the transmission is much faster when sending data packets to a destination node through a relay node with higher transmission rate, rather than sending data directly to the destination node at low transmission rate. To apply the cooperative communications in wireless LAN, several MAC protocols have been proposed [1]-[6].

Previous cooperative MAC protocols are classified into two categories: proactive cooperation communication and distributed cooperative ARQ communication [3]

The distributed cooperative ARQ communication exploits the broadcast nature of the wireless channel. A source node transmits its own data packet to a destination node directly (i.e.,

direct transmission). When the destination node receives an erroneous data packet from a source node, it requests retransmissions from any of the relays which overheard the original data packet from the source node. The relays in the network are enabled to forward the original packet to the destination node [3]-[6].

In the proactive cooperation communication, a source node decides how to transmit its own data packet (source-destination direct communication or source-relay-destination cooperative communication) based on the channel condition. When the channel condition between the relay and the destination is better than the channel condition between the source and the destination, a cooperative communication is selected instead of the direct one.

The focus of this paper is on the design of an MAC protocol based on the distributed cooperative ARQ communication. Cooperative ARQ(C-ARQ) is one of the distributed cooperative ARQ communication protocols [3], [4]. In the C-ARQ protocol, a source node transmits a data packet to a destination node. If the destination node receives the data packet without any error, it sends an ACK to the source node. Otherwise, it sends a CFC (Call for Cooperation) packet to nodes in the network. Relay nodes which receive the data packet and the CFC packet measure signal-to-noise ratio (SNR) between themselves and the destination node. And then, they decide their backoff time based on the SNR in order to avoid collisions among them. When the backoff time of a relay node expires, it forwards the data packet to the destination node. Fig. 1 shows an example of the C-ARQ protocol.

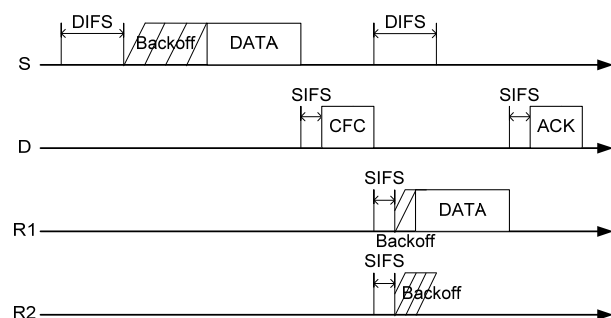


Fig. 1 Example of the C-ARQ protocol

The C-ARQ protocol still has a problem. There may be several relay nodes. The backoff time is less than DIFS. Therefore, the relay nodes can make collisions one another in a dense network. In order to solve this problem, we propose a new protocol, called DRGS (Data Rate based Grouping

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2010-0025495).

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Scheme) protocol. In the proposed protocol, relay nodes are grouped based on their transmission rates. And then, relay nodes only in the highest group try to get channel access. Therefore, the proposed protocol can reduce the collision probability among the relay nodes, and improve the performance of the network.

The paper is organized as follows. In Section II, the proposed GC-MAC protocol is presented in detail. In Section III, performance studies are carried out through simulation results. Finally, we draw a conclusion in Section IV.

II. PROPOSED DRGS PROTOCOL

The proposed DRGS protocol is similar to the C-ARQ protocol. However, in the proposed protocol, relay nodes are grouped based on their transmission rates. And then, relay nodes only in the highest group try to get channel access. Therefore, the proposed protocol can reduce the collision probability and increase the network performance.

The proposed protocol is consisted of 3 phases: awareness phase, group selection phase, data forwarding phase. In the awareness phase, every node in the network is aware of the start of cooperative communication and the existence of relay nodes. In the group selection phase, relay nodes in the highest group are selected. In the data forwarding phase, the collisions are resolved among the selected relay nodes by using the backoff mechanism and the original data packet is forwarded to the destination node.

In the proposed protocol, we use a new control packet (i.e., CFC) which is similar to ACK packet. However, it has an additional SN field which is a sequence number of CFC packet. The initial value of SN filed is 0 and increased by 1 whenever the CFC packet is transmitted. When the cooperative communication is complete, its value is reset to 0. When the value is 0, relay nodes sequentially execute awareness, group selection, and data forwarding phases. However, when it is greater than or equal to 1, they execute only data forwarding phase.

When a source node has data packet, it transmits the data packet to a destination node if its own backoff timer expires. And the destination nodes transmit an ACK packet to the source node when it receives the data packet without any error. If the destination node receives the data packet with error, the cooperative communication begins. The destination node sets the SN field value to 0 and transmits CFC packet to nodes in the network. Relay nodes which receive the original data packet and the CFC packet without any error transmits a busy tone after SIFS time. When the destination node receives the busy tone, it transmits another busy tone at the next slot time. From the two busy tones, every node in the network knows that the start of cooperative communication and the existence of relay nodes. When non-relay nodes receive the busy tones, they set the NAV (Network Allocation Vector) and do not contend for the channel access in order to avoid collisions. The value of NAV to be set is different according to the value of SN field in CFC packet. The NAV is set as followings;

$$NAV = \begin{cases} (GRmax + CW_{co}) * aSlotTime, & \text{if } SN = 0 \\ SIFS + CW_{co} * aSlotTime, & \text{else} \end{cases} \quad (1)$$

where, $GRmax$ is the maximum number of groups used in the proposed DRGS protocol. CW_{co} is the contention window size used during cooperative communications. In this paper, we use CW_{co} of $(CW_{min} / 4 - 1)$, which CW_{min} is minimum contention window size. $aSlotTime$ is the duration of a slot time.

After the awareness phase, the group selection phase begins. In the C-ARQ protocol, all relay nodes contend for the channel access to forward the original data packet. Therefore, they can make high collision probability in a dense network. In the proposed protocol, the relay nodes are grouped based on their transmission rates. And then, only relay nodes in the highest group are selected and execute the data forwarding phase in order to reduce the collision probability.

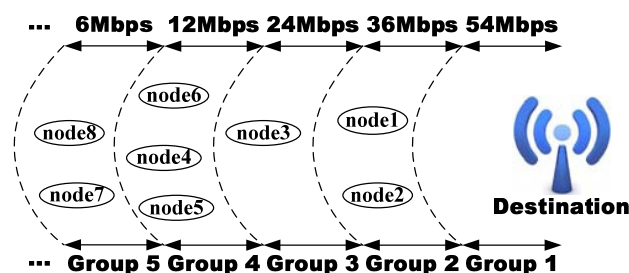


Fig. 2 Groups of relay nodes

Each relay node decides its group based on the data rate between itself and the destination node in a distributed fashion. Fig. 2 shows the groups of relay nodes. For example, the data rate for nodes 1 and 3 are 36Mbps and 24Mbps, respectively. Therefore, they belong to Group 2 and 3.

After deciding the group number, a relay node in Group n transmits a busy tone at the n th time slot to be aware of which group is the highest in a network. If a node senses a busy tone from other nodes before its own busy tone transmission time slot, it does not transmit the busy tone and sets its NAV by using (1). For example, in Fig. 2, relay nodes 1 and 2 transmits a busy tone at the 2nd time slot and the other nodes do not transmit their busy tone.

Only relay nodes in the highest group are execute the data forwarding phase. There may be several relay nodes in the highest group and they can make collision one another. To solve the collisions, we use backoff mechanism. A selected relay node uniformly chooses its backoff time within CW_{co} . If the medium is sensed to be idle for a duration of Backoff, the node forwards the original data packet to the destination node. If the destination node receives the data packet without any error, it sends an ACK packet. Otherwise, it increases the value of SN filed by 1 and sends a CFC packet. The selected relay nodes re-execute the data forwarding phase. The other nodes set their NAV by using (1) and stop their operation.

Fig. 3 shows the example of the proposed DRGS protocol. In the figure, there are 5 nodes: 1 source node (S), 1 destination node (D), and 3 relay nodes (R1, R2, and R3). S transmits a data

packet to node D when its backoff timer expires. D receives the data packet with error. It sends a CFC packet including SN field of 0. R1 and R2 receive the data packet and CFC packet without error. However, R3 receives the CFC packet with error. Therefore, R1 and R2 send their busy tone in the awareness phase, and R3 sets its NAV. Every node in the network are aware of the existence of relay nodes for S. The data rates for R1 and R2 are 36Mbps and 24Mbps, respectively. Their groups are 2 and 3. In order to select the highest group, R1 sends a busy tone at the 2nd time slot, and R2 senses the busy tone from R1 and does not send its busy tone. R1 forwards the original data packet to D after backoff, and D sends an ACK packet since it correctly receives the data packet. The cooperative communication for S is complete.

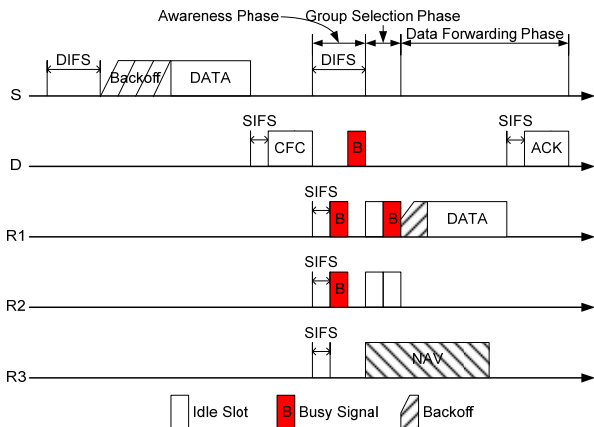


Fig. 3 Example of the proposed DRGS protocol

TABLE I
DATA RATES AND GROUPS ACCORDING TO THE DISTANCE

Distance (m)	Group	Data Rate (Mbps)
< 31	1	54
31 ~ 60	2	36
61 ~ 74	3	24
75 ~ 95	4	12
96 ~ 121	5	6
122 ~ 150	6	2
> 150	7	1

III. SIMULATION RESULTS

In this section, we discuss the simulation results of the proposed DRGS protocol. To study the performance of the DRGS protocol, we have implemented it. We compare them to the results of the 802.11 DCF. We simulated an IEEE 802.11a network with maximum transmission rate of 54Mbps. The nodes are uniformly distributed in a square area of 150 m × 150 m. The destination node is placed at the center of the square. A fixed number of nodes are randomly distributed over the network. The data rates and groups of nodes in the simulation network depend on the distance between nodes and the destination node (see Table I).

A constant data packet size of 1500 bytes is used. We assume that data packet error rate is 0.2. Simulations run for 100s, and all simulation results are averaged over 10 simulations.

The main performance metrics of interest are normalized throughput and collision probability.

Fig. 4 shows the collision probability according to the number of nodes. From this figure, we know that the collision probability linearly increases as the number of nodes increases. However, the graph is fluctuated since nodes are randomly distributed in the simulation network. The collision probability is generally high. We assumed in the simulation that the data packet error rate is 0.2. Each node does not distinguish between errors and collisions. Therefore, errors are also considered as collisions. The proposed DRGS protocol is always lower than the DCF because in the proposed protocol, nodes are grouped and some of them are selected in the highest group. The selected nodes contend for the channel to forward the original data packet to the destination node. Therefore, it results in lower collision probability. In the DCF, all the nodes try to send its own data packets and make collisions one another.

Fig. 5 depicts the throughput according to the number of nodes. The proposed DRGS protocol has better throughput regardless of the number of nodes in the network.

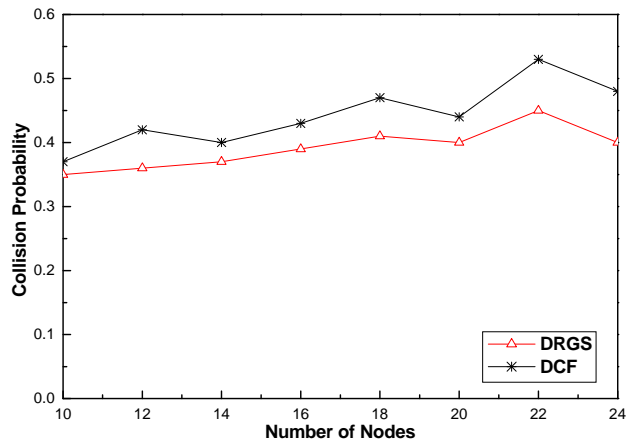


Fig. 4 Collision probability according to the number of nodes

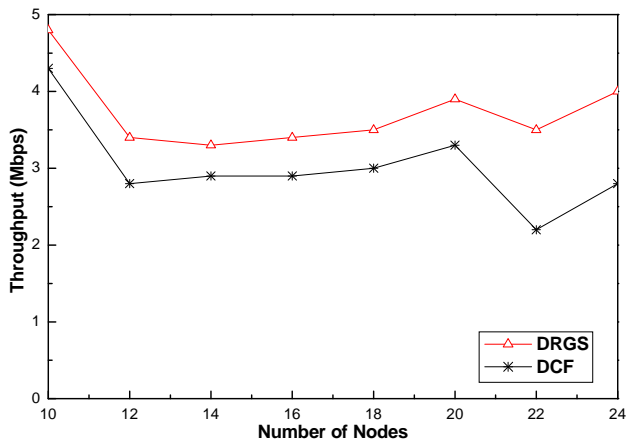


Fig. 5 Throughput according to the number of nodes

IV. CONCLUSION

IEEE 802.1 standards provide multiple transmission rates.

Cooperative communications were introduced to improve the overall performance of wireless LANs with the help of relay nodes with higher transmission rates. In the C-ARQ protocol, relay nodes try to forward the original data packet to the destination node. Therefore, they can make collisions one another. In order to reduce the collision probability, we propose a new protocol. Relay nodes are grouped based on their transmission rates. And then, relay nodes only in the highest group try to forward the data packet. So, they make low collisions. Simulation results show that the proposed protocol significantly outperforms the DCF in terms of throughput and collision probability.

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Sunnyeng Kim received the B.S., M.S., and Ph.D. degrees in information and communication from Ajou University, Suwon, Korea, in 2000, 2002, and 2006, respectively. From May 2006 to February 2008, he was a postdoctoral researcher in electrical and computer engineering with the University of Florida, Gainesville. In March 2008, he then joined the Department of Computer Software Engineering, Kumoh National Institute of Technology, Gumi, Korea, as an assistant professor. His research interests include resource management, wireless LANs and PANs, wireless mesh networks, UWSNs and quality of service enhancement.