ISSN 1975-8359(Print) / ISSN 2287-4364(Online)
The Transactions of the Korean Institute of Electrical Engineers Vol. 65, No. 12, pp. 2262~2269, 2016
http://dx.doi.org/10.5370/KIEE.2016.65.12.2262

IEEE 802.11 무선 랜에서 공평성 향상을 위한 추가 전송 프로토콜

Additional Transmission Protocol for Fairness Enhancement in IEEE 802.11 Wireless LANs

강태욱* · 김선명†
(Tae-Uk Kang · Sunmyeng Kim)

Abstract - In IEEE 802.11 wireless LANs, when a source node with low data rate occupies the channel resource for a long time, network performance degrades. In order to improve performance, the cooperative communication has been proposed. In the previous cooperative communication protocols, relay nodes deliver data packets only for a source node. In this paper, we propose an additional transmission scheme in which relay nodes select an additional source node based on several information and deliver data packets for the original source node and the selected additional source node. The proposed scheme improves performance and provides fairness among source nodes. Performance of the proposed scheme is investigated by simulation. Our results show that the proposed scheme outperforms the previous protocol in terms of fairness index and throughput.

Key Words : Additional transmission, Cooperative communication, Fairness, MAC, WLAN

1. 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 [1, 2]. 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. This technique is introduced to avoid the hidden terminal problem.

IEEE 802.11 DCF is essentially carrier sense multiple access with collision avoidance (CSMA/CA). Packet collisions on the medium are resolved using a binary exponential backoff algorithm. A node with a packet to transmit shall ensure that the medium is idle before attempting to transmit. It selects a random backoff counter less than the current contention window based on the uniform distribution, and then decreases the backoff counter by one at each slot when the medium is idle. If the medium is busy, the node defers until the end of the current transmission. A node transmits a packet when its backoff counter reaches zero.

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. To utilize several rates, it is required to deploy rate adaptation schemes at the MAC layer [3].

Cooperative communication was introduced to improve the overall performance of wireless LANs with the support of relay nodes with higher data rates [4]. Cooperative communication is based on the fact that transmission is significantly faster when sending data packets to a destination node through a relay node with a higher data rate, rather than sending data directly to the destination node at a low data rate. To apply cooperative communication in wireless LANs, several MAC protocols have been proposed [4-10].

In the cooperative communications, a source node determines based on the channel conditions whether to transmit its own data packets via direct communications between source node and destination node or via cooperative communications between source node, relay node and destination node [4-10]. If the channel conditions between a

---

† Corresponding Author : Dept. of Computer Software Engineering, Kumoh National Institute of Technology, Korea.
E-mail: sunmyeng@kumoh.ac.kr
* Dept. of Computer Software Engineering, Kumoh National Institute of Technology, Korea.

Received : October 14, 2016; Accepted : November 16, 2016

relay node and the destination node is more favorable than that of the source node and the destination node, then the source node selects the cooperative communications, rather than direct communications. In the CoopMAC protocol, each node maintains a table containing information such as data transmission rate between nodes [4]. When a source node has data packets to transmit, it selects a node with the least packet transmission time as a relay node. After that, the source node sends CoopRTS packets to the relay node. The selected relay node checks if it can provide the cooperative service. If so, then it sends a HTS (Helper ready To Send) packet. The destination node sends a CTS packet to the source node. After receiving the CTS packet, the source node sends data packets to the relay node, and then the relay node delivers the data packets to the destination node.

The rDCF protocol has similar concept to the CoopMAC protocol [5]. The biggest difference between the two protocols is the method of updating tables. In the CoopMAC protocol, based on the signal strength of packets received from nodes, data transmission rate is estimated and recorded. However, in rDCF, the node manages the process by using data transmission rate included in CTS packets.

In existing cooperative communications MAC protocols, a source node selects a node with the best throughput as a relay node and then transfers data packets. In these protocols, a relay node only transfers data packets transmitted from the source node. To improve performance of the existing cooperative communications MAC protocols, MSN (Multi-Source Node) protocol was proposed [11]. A relay node selected in the MSN protocol transmits data packets transmitted by the source node to the destination node. In addition, it relays data packets additionally from a node with the best transmission rate among neighboring nodes. From now on, for the sake of clarification of terms, we call a node, which acquires the channel access right and transmits data packets, as an original source node, while a node, which is selected by a relay node for additional transmission, is called as an additional source node.

When a relay node selects an additional source node in MSN protocol, it uses transmission rate only. Since the relay node does not check whether there is any data packet in a neighboring node, if there is no data packet to transmit in the selected additional source node, the channel is wasted. In addition, as it selects a neighboring node with the highest transmission rate as an additional source node, any node with low transmission rate does not have opportunity to be selected, thus a fairness issue occurs among neighboring nodes.

In this paper, we propose a protocol of selecting additional source nodes by taking into account not only the transmission rate, but also the other information to solve issues inherent of the MSN protocol. The proposed protocol is called as FEAT (Fairness Enhancement based on Additional Transmission) protocol.

This paper is composed of as follows: Section 2 describes briefly the MSN protocol, which uses additional data transmission to improve performance of the cooperative communications MAC protocol. Section 3 explains the operational processes of the proposed protocol in detail. Section 4 describes the simulation results and Section 5 shows the conclusion.

2. MSN Protocol

In the MSN protocol, each node maintains a table for the selection of relay nodes and additional source nodes. This table includes MAC addresses and information on transmission rates of neighboring nodes.

To acquire channel access rights, each node acts like a DCF. Any node which acquires the channel access right becomes an original source node and determines whether to transmit data packets in direct communications or cooperative communications. If it selects the direct communications, then the original source node acts as a DCF and sends a data packet to the destination node.

If the original source node selects the cooperative communications, then it transmits a cRTS (Cooperative RTS) packet to the destination node and the selected relay node. The destination node, which receives the cRTS packet, sends a cCTS (Cooperative CTS) packet to the original source node and the relay node. The relay node, which receives the cRTS packet and the cCTS packet, selects an additional source node to transmit additional data packets. A node with the highest data transmission rate among neighboring nodes included in the table maintained by the relay node is selected as the additional source node. The relay node sends a FAS (Find Another Source) packet to the selected additional source node. The additional source node, which receives a FAS packet, sends a FAS-ACK packet. The FAS packet transmitted by the relay node is also received by the original source node. By receiving the FAS packet, the original source node recognizes the additional source node, and waits for a time period during which the transmission of a FAS-ACK packet is ensured, and then sends its data packets to the relay node. The relay node, which receives the data packets from the original source node, sends an ACK packet. After receiving the ACK packet, the additional

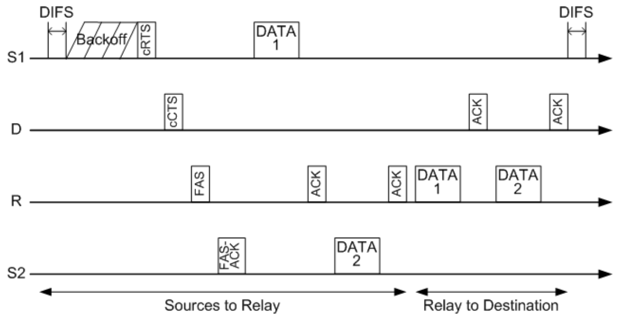

Fig. 1 Cooperative communication procedure in MSN protocol

source node sends its data packets to the relay node. The relay node is also sending an ACK packet to the additional source node. The relay node, which receives data packets from both the original source node and the additional source node, sends the data packets to the destination node by turns.

Fig. 1 shows an example of cooperative communications procedure of the MSN protocol. This figure shows two source nodes (S1 and S2), a destination node (D), and a relay node (R). Through the backoff process, S1 acquires the channel access right and becomes the original source node. S1 transmits a cRTS packet to D. D sends a cCTS packet. R, which receives both cRTS packet and cCTS packet, looks up its table to select an additional source node. Then, it selects a node with the highest transmission rate among neighboring nodes as the additional source node. In here, the selected additional source node is S2. After that, R transmits a FAS packet to S2. After receiving the FAS packet, S2 sends a FAS-ACK packet. And then S1 sends its own data packets to R. In addition, S2 sends its own data packets to R. After receiving the data packets from S1 and S2, R sends the packets to D in sequence.

3. Proposed FEAT Protocol

The proposed FEAT protocol determines whether to send data packets via direct communications or cooperative communications. To select an additional source node in the cooperative communications, each node maintains a table of neighboring nodes. Fig. 2 shows the format for a neighboring node table.

When neighboring nodes transmit packets such as RTS, CTS, DATA, or ACK, each node overhears it and updates the neighboring node table. In the neighboring node table, there are information on six fields. Information in the first two fields contains MAC addresses of the source node and the destination node contained in packets transmitted. In the time field, the time of the last packet received from each neighboring node is recorded. If there is no new packet received for a certain period of time, then information on the relevant node is deleted. In the transmission rate field, transmission rate ($TR_{S,D}$) between the source node S and the destination node D is stored. The number of residual packets means the number of data packets in queues of a neighboring node. For this, the neighboring node always sends packets by inserting information on the number of residual packets. The number of non-selections contained in the last field shows how many times the node is not consecutively selected as the additional source node. More details on each field are explained later.

Like other existing protocols, the proposed protocol supports both direct communications and cooperative communications. The original source node, which acquires channel access right determines whether to send data packets in direct communications or cooperative communications by calculating the packet transmission time.

The packet transmission time ($TX_{S\rightarrow D}$) required when transmitting data packets in direct communications is as follows:

$$TX_{S\rightarrow D}=\frac{L}{TR_{S,D}} \tag{1}$$

The packet transmission time ($TX_{S\rightarrow i\rightarrow D}$) required when transmitting data packets in cooperative communications via neighboring node i is as follows:

$$TX_{S\rightarrow i\rightarrow D}=\frac{L}{TR_{S,i}}+\frac{L}{TR_{i,D}}+t_r \tag{2}$$

where, L is the size of a packet in bits. t_r is the overhead of a relayed data packet. $S\rightarrow i\rightarrow D$ means that the source

MAC Address of Source	MAC Address of Destination	Time	Transmission Rate	Number of Residual Packets	Number of Non-Selections
S_1	D_1	T_1	$TR_{S1,D1}$	RP_1	NS_1
…	…	…	…	…	…
S_n	D_n	T_n	$TR_{Sn,Dn}$	RP_n	NS_n

Fig. 2 Format of the Neighboring Node Table

node *S* sends data packets to a neighboring node *i*, and then the node *i* sends the packets to the destination node *D*.

After computing the transmission time required in direct communications or cooperative communications by the original source node, the results are compared each other. If the transmission time of the direct communications is smaller than that of the cooperative communications, then the original source node sends the data packets to the destination node via direct communications. If the transmission time of the cooperative communications is smaller than that of the direct communications, then the original source node selects a neighboring node *i* as a relay node and sends the data packets to the destination node via cooperative communications.

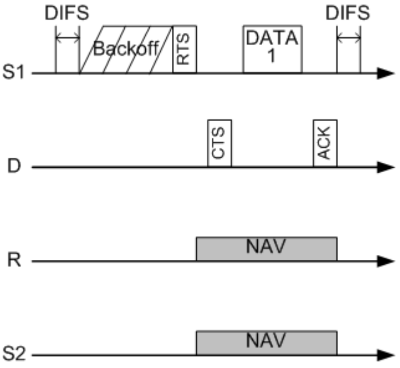

Fig. 3 Direct Communication Procedure

Fig. 3 shows an example of direct communications procedure of the FEAT protocol. Its transmission process of data packets is identical to that of the standard DCF. The figure shows two source node (S1, S2), a destination node (D), and a relay node (R). After S1 acquires the channel access right through backoff process, it sends a RTS packet to D. Then D sends a CTS packet. R or S2 receiving the RTS or CTS packet sets its own NAV (Network Allocation Vector) and does not participate in the data packet transmission process. After S1 receives the CTS packet, it sends a data packet, and D sends an ACK packet to complete the process of transmitting data packets.

If the original source node decides to send data packets via cooperative communications, then it acts as the CoopMAC protocol and sends a data packet via a relay node to the destination node. After the original source node completes the transmission of the data packet, the relay node selects an additional source node. If any additional source node is not selected, then the relay node does not perform anything anymore. Thus, the channel is in idle state during the DIFS (DCF Inter-Frame Spacing) period, every node starts the backoff algorithm for channel contention.

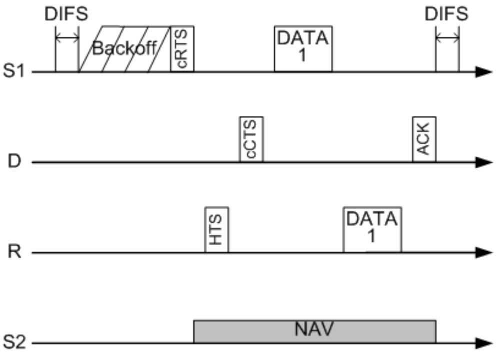

Fig. 4 Cooperative Communication Procedure When There is No Additional Source Node

Fig. 4 shows the cooperative communications procedure when any additional source node is not selected. S1 transmits a cRTS packet to R. After receiving the cRTS packet, R sends a HTS packet to S1 and D, respectively. D sends a cCTS packet to S1. After receiving the cCTS packet, S1 sends a data packet to R. Then, R sends the packet again to D, which sends an ACK packet. In this way, the cooperative communications process for the data from the original source node is finished. After that, R selects an additional source node. However, in here, as any additional source node is not selected, the relay node is not performing any action any more. Thus, every node starts its own backoff process after the DFIS period. After receiving the cRTS packet, S2 sets its own NAV, and does not participate in the cooperative communications process.

When an additional source node is selected, another cooperative communication is conducted to deliver data in the additional source node. The relay node transmits a polling packet to the additional source node. The additional source node sends a data packet to the relay node, which in turn sends the packet to the destination node. In this way, the cooperative communications process for additional transmission is finished.

Fig. 5 shows the cooperative communications procedure when an additional source node is selected. After completing the transmission of the data packet of the original source node S1, the transmission process of the data packet of the selected additional source node S2 is started. R sends a polling packet to S2. Then, S2 sends its own data packets to R, which in turn sends the data to D. After that, D sends an ACK packet and terminates the cooperative communications process. After receiving the poll S2 packet, S1 sets its own NAV, and does not participate in the

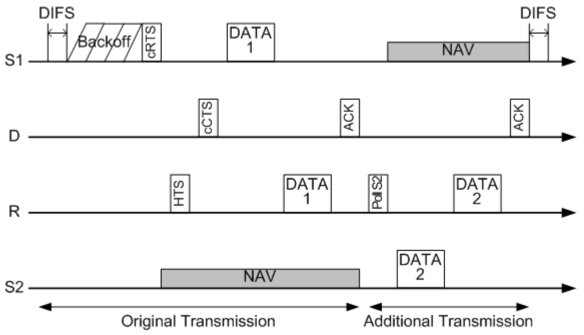

Fig. 5 Cooperative Communication Procedure When There is An Additional Source Node

cooperative communications process any more.

From now on, we discuss the method of selecting an additional source node by a relay node in the proposed FEAT protocol.

If there is no information in the neighboring node table or the number of residual packets in every node in the neighboring node table is 0, then it means that there is no neighboring node which needs the additional transmission. Therefore, the relay node does not select any additional source node. If there is any neighboring node, of which the number of residual packets is one or more, then the relay node selects an additional source node among them.

To select an additional source node, the relay node uses NSW(Node Selection Weight) value. NSWof a neighboring node i listed in the neighboring node table is as follows:

$$NSW_i = \frac{TR_{i,R}}{TR_{max}} \times RP_i \times (NS_i + 1) \tag{3}$$

where, $TR_{i,R}$ is the data transmission rate between the relay node R and a neighboring node i, and TR_{max} shows the highest data transmission rate among neighboring nodes, of which the number of residual packets is one or more as shown in the following equation:

$$TR_{max} = \max_{i \in V_R} \{TR_{i,R}\} \tag{4}$$

where, V_R is a set of neighboring nodes of the relay node R, of which the number of residual packets is one or more.

RP_i and NS_i are the number of residual packets and that of non-selections of a neighboring node i listed in the neighboring node table. Default value of NS_i is 0. If a neighboring node i is selected by the relay node as an additional source node, then NS_i is initialized to 0, and if not selected, then it increases by one.

The NSW value is made of three parts. The first part is granted with a higher weight as the data transmission rate becomes higher among neighboring nodes of the relay node. The second part has a higher weight as the number of residual packets is larger. The purpose of this is to provide QoS (Quality of Service) by preventing overflow with more data transmission opportunities when the number of data packets in a queue is larger. The third part is endowed with a larger weight, when it is not selected as an additional source node consecutively.

The relay node selects a neighboring node with the largest *NSW* value as the additional source node.

4. Simulation Results

In this section, we discuss the simulation results of the proposed FEAT protocol. To study the performance of the FEAT protocol, we actually implemented the protocol. We compared the results to the results of the MSN protocol. We simulated an IEEE 802.11g network with a data rate of 54 Mbps and control rate of 6 Mbps. A constant data packet size of 1,000 bytes was used.

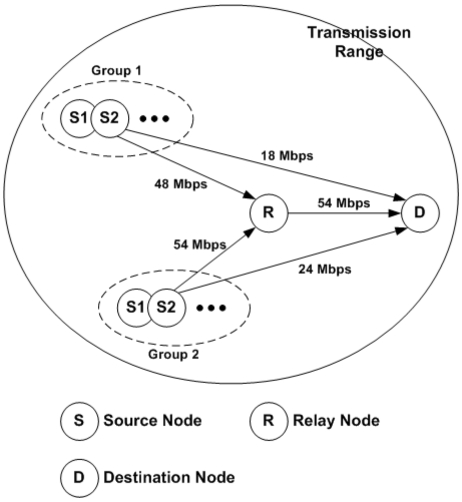

Fig. 6 Simulation Topology

Topology used in the simulation is as shown in Fig. 6. We considered a single hop topology. The topology is made of a destination node (D), a relay node (R), and the variable number of source nodes. The source nodes are divided into two groups (Group 1 and Group 2). The transmission rate between source nodes belonged to Group 1 and a relay node is 48 Mbps, while that between source nodes belonged to Group 2 and a relay node is 54 Mbps. In addition, the transmission rate between each group and the destination node is 18 Mbps and 24 Mbps, respectively. The transmission rate between the relay node and the destination node is 54 Mbps.

To generate data packets, we use a saturated traffic model. The saturated traffic model is a model full of data packets in each queue of every node all the time.

Major performance factors include throughput and fairness index. The fairness index is a criterion showing how fair the nodes are. In the paper, the following Jain's fairness index is used [12]:

$$FI = \frac{(\sum_{i=1}^{N} x_i)^2}{N \cdot \sum_{i=1}^{N} x_i^2} \tag{5}$$

where, x_i is the throughput of node i and N is the number of nodes in the network. The perfect fairness index value is 1, and as the fairness is degraded, the value is moving towards zero.

Figs. 7 and 8 show the results of a simulation topology in which the number of nodes belonged in each source group is identical. For example, if the number of nodes on the X-axis in the figures is 18, then the number of nodes of each group is 9.

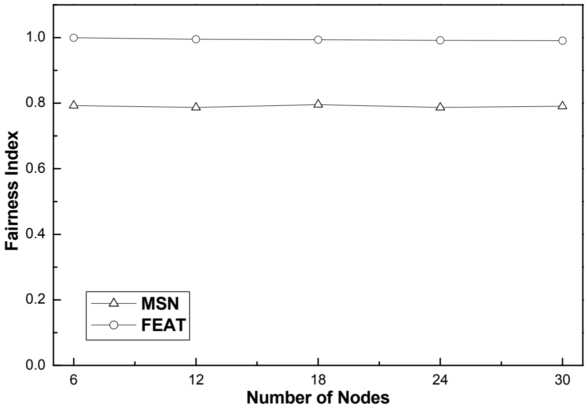

Fig. 7 Fairness Index According to the Number of Nodes When Two Groups have the Same Number of Nodes

Fig. 7 shows the fairness index following the increasing number of nodes. The proposed FEAT protocol has a fairness index of nearly one regardless of the number of nodes. However, the MSN protocol has a fairness index of around 0.8. In the proposed protocol, the relay node uses *NSW* value of Equation (3) to select an additional source node. Regardless of a node group, each node can be selected as an additional source node equitably. Thus, the fairness index of the proposed protocol approaches one. In the MSN protocol, additional source nodes are selected by data transmission rate of the source node, so only source nodes belonged to Group 2 can be selected. Therefore, its fairness index is low. However, regardless of the number of nodes, each node has a constant fairness index, because the ratio of the number of nodes belonged to the two groups is same.

Fig. 8 shows the change of average throughput per node following the increasing number of nodes. As the number of nodes is increasing, throughputs from both the FEAT protocol and the MSN protocol become smaller and smaller. As the maximum capacity of network is fixed, several nodes have to share channel, so the average throughput per node becomes smaller and smaller. As shown in the figure, there is almost no difference between throughputs of the proposed protocol and the MSN protocol.

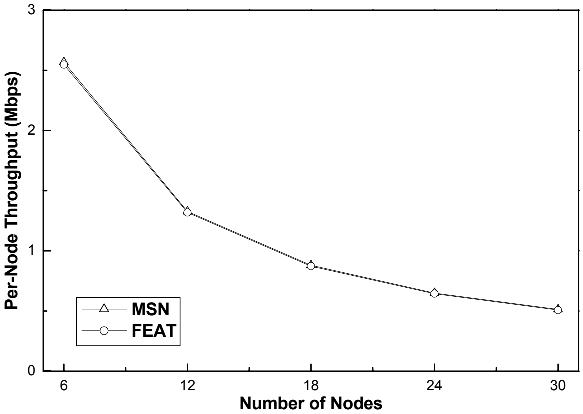

Fig. 8 Per-Node Throughput According to the Number of Nodes When Two Groups have the Same Number of Nodes

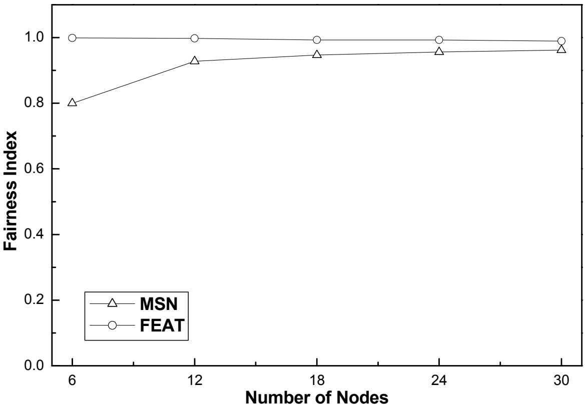

Fig. 9 Fairness Index According to the Number of Nodes When There are 3 Nodes in Group 1

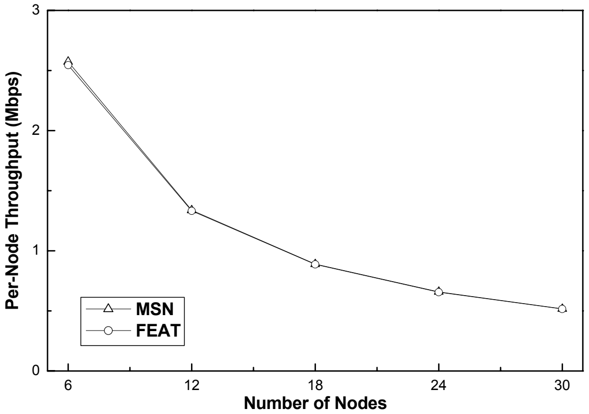

Fig. 10 Per-Node Throughput According to the Number of Nodes When There are 3 Nodes in Group 1

Figs. 9 and 10 show the results of a simulation topology, of which the number of nodes belonged to Group 1 is set at three, while that of nodes belonged to Group 2 is configured variably. For example, in the figures, if the number of nodes on the X-axis is 18, then the number of nodes in Group 1 is three and that of nodes in Group 2 is 15.

Fig. 9 shows the change of fairness indices following the increasing number of nodes in Group 2. Since the proposed FEAT protocol selects additional source nodes equitably all the time as explained in Fig. 7, the fairness index is nearly one regardless of the number of nodes. However, in the MSN protocol, the fairness index becomes better following the increasing number of nodes unlike the results shown in Fig. 7. In the simulation, the increasing number of nodes means the increasing number of nodes belonged to Group 2. Thus, the impact of nodes belonged to Group 1 on the fairness index becomes reducing, while that of nodes belonged to Group 2 tends to increase. As a result, if the number of nodes is large, then most nodes in the network belong to Group 2 and have channel contentions between the nodes. Since the nodes belonged to Group 2 have the same data transmission rate, their fairness tend to improve.

Fig. 10 shows the average throughputs per node following the increasing number of nodes. As explained in Fig. 8, as the number of nodes increases, their throughputs tend to reduce in both the FEAT protocol and the MSN protocol. In Fig. 8 and Fig. 10, the throughput graphs look similar. When comparing numerically, the result in Fig. 10 is slightly better. The reason is that the number of nodes belonged to Group 2 in Fig. 10 is larger than that of nodes belonged to Group 2 in Fig. 8. In other words, Fig. 10 has more nodes with higher data transmission rate. However, as the difference in transmission rate between the two groups is small (48 Mbps and 54 Mbps, respectively), the difference of throughputs is also not large enough.

5. Conclusion

Since only data packets of the source node are transmitted in existing cooperative communications protocols, the performance improvement is not big enough. In the cooperative communications, the proposed FEAT protocol selects an additional source node to transmit data additionally and, as a result, it improve the performance. In addition, since the proposed protocol takes into account diverse factors when selecting an additional source node, it improve the fairness between nodes. Results of the simulation show that the proposed protocol is very efficient and has good performance.

감사의 글

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2015R1D1A1A01059644).

References

[1] IEEE 802.11 Working Group, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, IEEE Std. 802.11, 2012.

[2] S. Kim, and Y.-J. Cho, “Dynamic FEC Scheme for Multicasting Real-Time Multimedia Traffic in WLANs,” INFORMATION, vol. 16, pp. 5029-5042, 2013.

[3] G. Holland, N. Vaidya, and P. Bahl, “A Rate-Adaptive MAC Protocol for Multi-hop Wireless Networks,” ACM Mobicom, 2001.

[4] P. Liu, Z. Tao, S. Narayanan, T. Korakis, and S. S. Panwar, “CoopMAC: A Cooperative MAC for Wireless LANs,” IEEE Journal on Selected Areas in Communications, vol. 25, no. 2, pp. 340-354, 2007.

[5] H. Zhu and G. Cao, “rDCF: A Relay-enabled Medium Access Control Protocol for Wireless Ad Hoc Networks,” IEEE Transactions on Mobile Computing, vol. 5, pp. 1201-1214, 2006.

[6] B. Zhang and X. Jia, "Multi-hop Collaborative Relay Networks with Consideration of Contention Overhead of Relay Nodes in IEEE 802.11 DCF," IEEE Transactions on Communications, vol. 61, no. 2, pp. 532-540, 2013.
[7] D. An, H. Woo, H. Yoon, and I. Yeom, "Enhanced Cooperative Communication MAC for Mobile Wireless Networks," Computer Networks, vol. 57, no. 1, pp. 99-116, 2013.
[8] D. Yang, X. Fang, and G. Xue, "HERA: An Optimal Relay Assignment Scheme for Cooperative Networks," IEEE Journal on Selected Areas in Communications, vol. 30, no. 2, pp. 245-253, 2012.
[9] P. Ju, W. Song, and D. Zhou, "An Enhanced Cooperative MAC Protocol based on Perceptron Training," in Proc. of IEEE WCNC, pp. 404-409, 2013.
[10] J.-K. Lee, H.-J. Noh, and J. Lim, "TDMA-based Cooperative MAC Protocol for Multi-hop Relaying Networks," IEEE Communications Letters, vol. 18, no. 3, pp. 435-438, 2014.
[11] H.-J. Jung, U.-S. Lee, M. Lee, and T.-J. Lee, "Cooperative Communication using Multi-Source Node in IEEE 802.11 Wireless LANs," in Proc. of IEEK, pp. 466-468, 2011.
[12] R. K. Jain, D.-M. W. Chiu, and W. R. Hawe, "A Quantitative Measure of Fairness and Discrimination for Resource Allocation and Shared Computer System," Technical Report DEC-TR-301, Digital Equipment Corporation, 1984.

저자소개

강 태 욱 (Tae-Uk Kang)

He was a B.S. student in Computer Software Engineering, Kumoh National Institute of Technology. His research interests include wireless networks.

E-mail: kantau@naver.com

김 선 (Sunmyeng Kim)

He received the Ph.D. degree from Ajou University in 2006. He is now an associate professor in Department of Computer Software Engineering, Kumoh National Institute of Technology. His research interests include wireless networks and QoS.

E-mail: sunmyeng@kumoh.ac.kr