Cooperative Communication Protocol Based on EDCA in IEEE 802.11e WLANs

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Abstract. The IEEE 802.11 standard provides multiple transmission rates. When using multiple transmission rates, the capacity of wireless LAN improves, but the performance anomaly problem may occur. Cooperative communications were introduced to alleviate the performance anomaly problem with the help of relay nodes with higher transmission rates. Previous cooperative communications protocols are based on the IEEE 802.11 DCF MAC protocol. In this paper, we apply the IEEE 802.11e EDCA features such as TXOP and block ACK for cooperative communications. Simulation results show that the proposed protocol works well and improves network performance.

Keywords: Cooperative communications, EDCA, WLANs.

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. 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 IEEE 802.11 MAC protocol cannot support quality of service (QoS) requirements. In order to support QoS in the IEEE 802.11 MAC protocol, the IEEE 802.11e has been standardized. It introduces a contention-based new channel access mechanism called enhanced distributed channel access (EDCA). The EDCA supports the QoS by introducing four access categories (ACs). To differentiate the ACs, the EDCA uses a set of AC specific parameters. The EDCA also introduces a TXOP (Transmission Opportunity) parameter to provide service differentiation and QoS of

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the traffic. A node can continuously transmit multiple packets for the duration of a TXOP. In the IEEE 802.11 MAC protocol, each data packet is immediately acknowledged after a successful transmission. The IEEE 802.11e MAC defines the block ACK scheme to reduce the ACK transmission overhead by integrating multiple ACKs.

These standards provide multiple transmission rates, which can be changed dynamically according to the channel condition. When using multiple transmission rates, the capacity of wireless LAN improves, but the performance anomaly problem may occur [1]. In a wireless LAN, when a node gets an opportunity to access a channel, a node with lower transmission rate tends to occupy more channel time than a node with higher transmission rate. Therefore, when there are more nodes with lower transmission 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 transmission rates.

Cooperative communications were introduced to alleviate the performance anomaly problem with the help of relay nodes with higher transmission rates [2]-[6]. 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 the best of our knowledge, none of the existing work has focused on cooperative communications in the IEEE 802.11e EDCA. Therefore, we propose a novel cooperative MAC protocol for QoS enhancement in WLANs based on the IEEE 802.11e EDCA MAC protocol. It is called ECC-MAC (EDCA based Cooperative Communication MAC). In the proposed protocol, the TXOP and block ACK features of the EDCA are applied for cooperative communications to improve network performance and to overcome overheads by reducing the number of control packets for multiple data transmissions.

The paper is organized as follows. In Section 2, the proposed ECC-MAC protocol is presented in detail. In Section 3, performance studies are carried out through simulation results. Finally, we draw a conclusion in Section 4.

2 ECC-MAC Protocol

We describe how to select a helper node and flow of packet exchange in subsection 2.1, and then how to decide block ACK size in subsection 2.2.

2.1 Helper Node Selection and Flow of Packet Exchange

As shown in Fig. 1, each node maintains a table, referred to as the *ECTable* (EDCA Cooperative Table). A node overhears transmissions of packets such as RTS, CTS, DATA, and ACK by other nodes, and then updates its ECTable. The ECTable contains 5 fields. Data in the first field is MAC address of a helper node. In the time field, time of the last packet received from the helper node is recorded. In the transmission rate fields, transmission rates ($R_{S,H}$, $R_{H,D}$) between source node S and helper node H, and between helper node H and destination node D are stored, respectively. In the last field, channel credit (C_H) of the helper node is stored. The channel credit tracks the channel status of the particular helper node. This value is used to calculate the block ACK size, which is the number of data packets to be transmitted and to be acknowledged by a single block ACK. How to calculate the size is described in detail in subsection 2.2.

MAC Address of Helper	Time	Transmission Rate (*S-H*)	Transmission Rate (*H-D*)	Channel Credit
H_1	T_1	$R_{S,H1}$	$R_{H1,D}$	C_{H1}
…	…	…	…	…
H_n	T_n	$R_{S,Hn}$	$R_{Hn,D}$	C_{Hn}

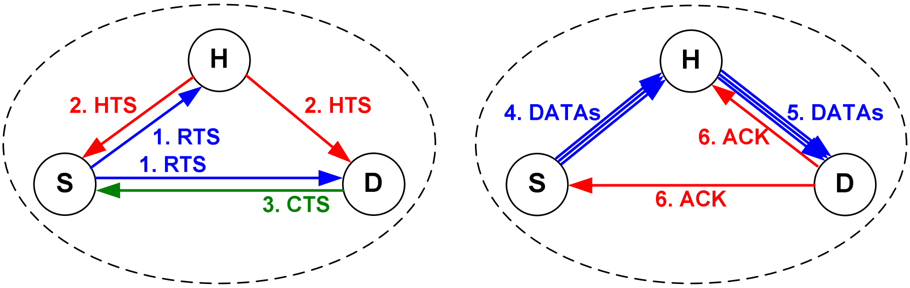
Fig. 1. Format of the ECTable

When there are data packets to send in a queue, a source node looks for helper node candidates in the ECTable. If there are one or more helper node candidates, then a node with the least packet transmission time is selected as a helper node. Packet transmission time is $L/R_{S,H} + L/R_{H,D}$. In here, overhead is omitted and L is the size of data packet in bits.

Although the proposed ECC-MAC protocol has the similar procedure of exchanging packets to that of the CoopMAC protocol, it uses a different method in transmitting data packets.

After selecting a helper node, a source node sends an RTS packet to the selected helper node. The helper node checks whether it can provide the service wanted by the source node after receiving the RTS packet. If so, the helper node sends an HTS (Helper ready To Send) packet. Finally, the destination node sends a CTS packet to the source node.

After receiving the CTS packet, the source node sends several data packets to the helper node, which forwards the packets to the destination node. The destination node sends a block ACK packet to the source node and helper node. Fig. 2 shows the packet exchange procedure in the ECC-MAC protocol.



(a) Control packet exchange (b) Data packet exchange

Fig. 2. Flow of Packet Exchange in the ECC-MAC Protocol

2.2 Block ACK Size Decision

The block ACK scheme allows multiple data transmissions without an immediate acknowledgement separated by SIFS time period. The single acknowledgement packet, block ACK, is sent by a receiver for a block of data packets transmitted by a source. A block ACK size is the number of data packets to be transmitted without an ACK packet.

A source node decides the block ACK size based on channel credit in the ECTable. Channel credit is the channel status of the selected helper node. The start value of channel credit is 50, which may be changed from 1 to 100 according to the status of the channel. This value can be changed by using the success ratio of packet delivery. The success ratio of packet delivery at helper node *i* is as follows:

$$Succ_i = \frac{N_{ack}}{N_{tx}} \tag{1}$$

where, N_{tx} is the total number of data packets sent from a source node and a helper node; N_{ack} is the number of ACK packets. The value of $Succ_i$ is located between 0 and 0.5. For cooperative communications, a source node sends data packets to a helper node, which in turn sends them to a destination node. When receiving all data packets without error, the destination node sends ACK packet for each data packet. If there is no error as above, to deliver a data packet, it is necessary to send the data twice, while delivering ACK packet for one time. Therefore, in this case, *Succ* is 0.5. If there is an error, then it is necessary to consider the retransmission of the data packet, this value decreases.

For the obtained $Succ_i$, the range of values is readjusted by using the following equation:

$$rSucc_i = \langle Succ_i \cdot 20 \rangle - 5 \tag{2}$$

where, $\langle x \rangle$ is rounded off value of *x* and $rSucc_i$ has a value between -5 and 5. A source node changes the channel credit (C_i) by using $rSucc_i$ as follows:

$$C_i = C_i + rSucc_i \tag{3}$$

By using the channel credit of helper node *i*, a source node decides block ACK size (*BS*) as follows:

$$BS = \left\lceil \frac{C_i}{100} \cdot MBS \right\rceil \tag{4}$$

where, $\lceil x \rceil$ is raised value of *x*, and *MBS* is the maximum block size. In the denominator, 100 is the maximum value of the channel credit.

3 Simulation Results

Let us discuss the simulation results of the proposed ECC-MAC protocol. To validate the proposed protocol, we compare them to the results of the CoopMAC protocol. In the simulation, nodes are randomly deployed within the transmission range of an AP. Data rate of each node is determined according to the distance to the AP. We use the TXOP limit of 8000us. Every node sends data packets to the AP. A constant data packet size of 1500 bytes is used.

Fig. 3 shows the throughput based on the number of nodes. In the figure, PKT(*n*) means that each node generates *n* data packets at each packet arrival time. That is, the larger *n* value is, the more data packets are generated, and the larger the volume of transmission becomes. The proposed ECC-MAC protocol always shows better performance than existing CoopMAC protocol. In the ECC-MAC protocol, as PKT(*n*) is increasing, the throughput is also improving. This is because that as the larger PKT(*n*) becomes, the larger the number of packets generated by each node, and therefore the volume of transmitted data is increasing. However, as the number of nodes is increasing, the increase of the throughput becomes slower. As the number of nodes is growing, difference in the throughput of the two protocols becomes larger. In the proposed protocol, TXOP and Block ACK features of EDCA are applied to cooperative communications. Accordingly, it is possible to send multiple data packets with a backoff process and exchanging of control packets. In this way, the overhead is reduced, while the performance is improved. However, the CoopMAC protocol does not apply these features, it has larger overhead, and as a result, has poor performance.

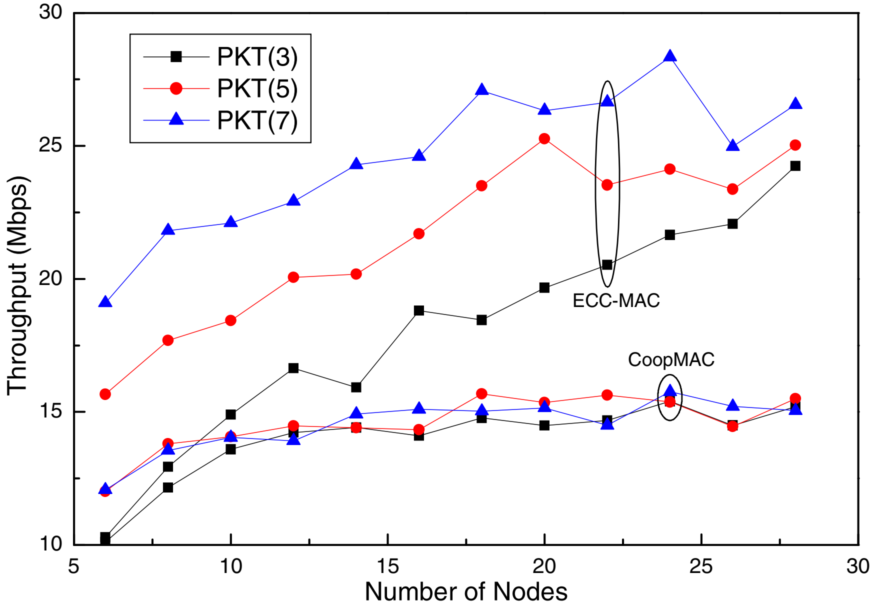


Fig. 3. Throughput according to the number of nodes

4 Conclusion

The IEEE 802.11 & 11e standards provide multiple transmission rates. When using multiple transmission rates, the performance anomaly problem may occur. Cooperative communications were introduced to alleviate the performance anomaly problem. None of previous cooperative communications protocols has focused on cooperative communications in the IEEE 802.11e EDCA. We proposed a novel MAC protocol, which applies the TXOP and block ACK features of the EDCA for cooperative communications. Simulation results show that the proposed protocol works well and improves network performance.

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