A Medium Access Control Protocol with Retransmission using NACK and Directional Antennas for Broadcasting in Wireless Ad-Hoc Networks

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Abstract: **To improve the throughput performance keeping high reliable broadcasting, we propose an efficient Medium Access Control protocol for broadcasting in wireless ad-hoc networks with IEEE 802.11. In the proposed protocol, to reduce the number of retransmissions, a broadcast packet is retransmitted according to NACK instead of ACK. Moreover, the broadcast packet is retransmitted only to the area including nodes that request retransmission by using directional antennas. By computer simulations, we show that the proposed protocol can improve throughput performance keeping high reliable broadcasting compared with the BACK protocol. Especially, the proposed protocol 2 achieves the high throughput of 6, keeping the high success rate of data packet reception of approximately 0.7.**

I. Introduction

Recently, wireless ad-hoc networks attract much attention. In wireless ad-hoc networks, since a central control and the fixed infrastructure are unnecessary, it can easily realize flexible and efficient networks [1]-[7]. Ad hoc networks are constantly changing the network topology and require a MAC (Medium Access Control) protocol providing high reliable broadcasting for efficient dynamic routing protocols [1],[2].

IEEE 802.11 is focused on as one of the standards for wireless ad-hoc networks [3]. The IEEE 802.11 MAC protocol adopts CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). IEEE 802.11 protocol guarantees a reliable unicasting by response of ACK (ACKnowledgement) and retransmission of the unicast packet. However, broadcasting over IEEE 802.11 is unreliable compared with unicasting because no response of ACK and no retransmission for any broadcast packets shall be used. Unfortunately, most of routing protocols need broadcasting to exchange important information between nodes. Therefore, IEEE 802.11 has a problem that routing protocol does not work smoothly because of uncertain broadcasting MAC protocol. To overcome this unreliable broadcasting problem, BACK (Broadcast ACKnowledgement) protocol has been proposed [4]. The BACK protocol realizes high reliable broadcasting by retransmission of a broadcast packet according to ACK. However, the BACK protocol has a problem that throughput degrades compared with the IEEE 802.11 protocol because of large number of the retransmission due to collision of ACKs.

On the other hand, to improve throughput performance in the wireless ad-hoc networks, MAC protocols using directional antennas have been proposed [5]-[7]. In these protocols, a source node transmits a data packet only to the area including a destination node by using directional antennas. The source node searches the direction that the destination node is located by using RTS(Request To Send)/CTS(Clear To Send) handshaking. In the case of broadcasting, most packets need to be transmitted to all directions because there are several destination nodes. However, in the protocols with ACK and retransmission such as BACK protocol, when the source node retransmits a data packet only to nodes that fail to receive the data packet, it would be improve the throughput performance by using directional antennas. In the case of broadcasting, it is difficult to

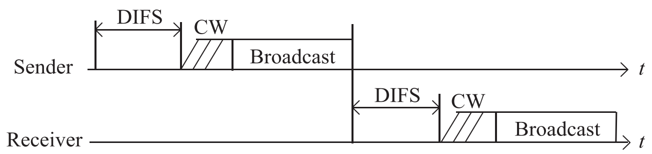

Fig. 1: Channel access of broadcasting using the IEEE 802.11.

search the direction, because no RTS/CTS shall be used in the IEEE 802.11 MAC protocol. Therefore, it needs a new MAC protocol for broadcasting that the source node is able to know the direction of several destination nodes without RTS/CTS.

In this paper, to improve throughput performance keeping high reliable broadcasting, we propose an efficient MAC protocol for broadcasting in wireless ad-hoc networks with IEEE 802.11. In the proposed protocol, to reduce the number of retransmissions, a broadcast packet is retransmitted according to NACK (Negative ACKnowledgement) instead of ACK. However, the protocol using NACK degrades the success rate of data packet reception compared with that using ACK, when the hidden nodes problem occurs. To be sure the response of NACK and keep high reliable broadcasting, in the proposed protocol, after succeeding in receiving a broadcast packet, the nodes transmits ARB (Announce Reception of Broadcast). The nodes, which fail to receive the broadcast packet, would detect the transmission of the broadcast packet by ARB, and are able to respond NACK. Moreover, the broadcast packet is retransmitted only to the area including nodes that request retransmission by using directional antennas. While the broadcast packet is retransmitted, the nodes that are located out of the range of the directional antennas can make other communications. We evaluate the throughput performance and the success rate of data packet reception by computer simulations. As a result, we show that the proposed protocol can improve the throughput performance keeping high reliable broadcasting compared with the BACK protocol.

II. Conventional Protocol

A. IEEE 802.11 protocol

The IEEE 802.11 becomes widely used as wireless LAN (Local Area Network). In the IEEE 802.11, the DCF (Distributed Coordination Function) is a fundamental access method used to support asynchronous data transfer on a best effort basis. The DCF is based on CSMA/CA. In the unicasting, the hidden node problem is solved by RTS/CTS handshaking. In addition, reliable unicasting is guaranteed by response of ACK and retransmission of data packet. On the other hand, in the broadcasting, no response of ACK and no retransmission for any broadcast packets shall be used. Fig. 1 shows the channel access of broadcasting using the IEEE 802.11. If a node with a broadcast packet to transmit initially senses the channel, the node waits until the channel becomes idle for a DIFS (Distributed Inter Frame Space) period, and then computes a random backoff time. The backoff time minimizes collisions during contention between multiple nodes. The backoff time is chosen as

$$int(CW * RM) * ST \tag{1}$$

where CW (Contention Window) is an integer, RM (random) is a uniform random value between 0 and 1, and the value of ST (Slot Time) depends on the physical layer implementation. When the channel becomes idle after a DIFS period, each node decrements own backoff timer until the channel becomes busy again or the timer reaches zero. If the timer does not reach zero and the channel becomes busy, the node freezes its timer. After a busy period, each node restarts the decrementing of the own backoff timer only when the channel has been idle longer than DIFS. When the timer is finally decremented to zero, the node transmits a broadcast packet. The receiving nodes only forward the broadcast packet according to same procedure without response of ACK to the source node. Therefore, the source node has no idea about the status of the transmitted broadcast packet and no broadcast packet shall be retransmitted. At a result, broadcasting over IEEE 802.11 becomes unreliable.

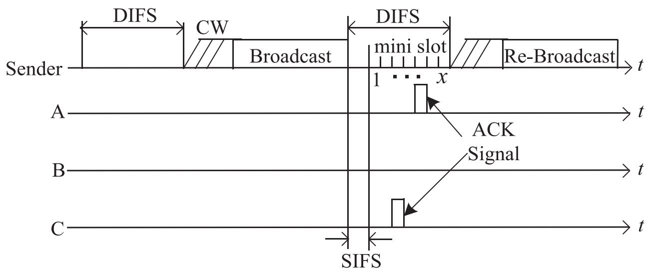

Fig. 2: Channel access of broadcasting using the BACK protocol.

B. BACK protocol

To overcome unreliable broadcasting problem, BACK protocol has been proposed [4]. Fig. 2 shows the channel access of broadcasting using the BACK protocol. As IEEE 802.11 protocol, a node with a broadcast packet to transmit initially senses the channel, the node waits until the channel becomes idle for a DIFS time period, and then computes a random backoff time. When the channel becomes idle after a backoff time, the source node transmits a broadcast packet. The DIFS time period after transmission of broadcast packet is divided into several mini slots of x. Node A and node C succeed in receiving the broadcast packet, and select one of mini slots randomly to transmit ACK. In the BACK protocol, ACK is not a data packet as the IEEE 802.11 protocol but simple pulse signal. The source node retransmits the broadcast packet until either the number of ACKs is sufficient or the number of retries reaches the maximal retry threshold.

The BACK protocol realizes high reliable broadcasting by retransmission according to ACK. However, when some receiving nodes choose a same mini slot to transmit ACK, collisions of ACKs occur. The source node misses counting the exact number of ACKs and retransmits the broadcast packet redundantly. Therefore, the BACK protocol has a problem that throughput degrades compared with the IEEE 802.11 protocol because of large number of retransmissions due to collision of ACKs.

III. Proposed Protocol

In this section, we explain the structure and the operation of the proposed protocol. To reduce the degradation of throughput in the BACK protocol due to large number of the retransmission, we propose an efficient MAC protocol with retransmission using NACK as proposed protocol 1. Moreover, to improve the throughput performance more in wireless ad hoc networks, we propose a novel MAC protocol for broadcasting by using directional antennas in addition to NACK as proposed protocol 2.

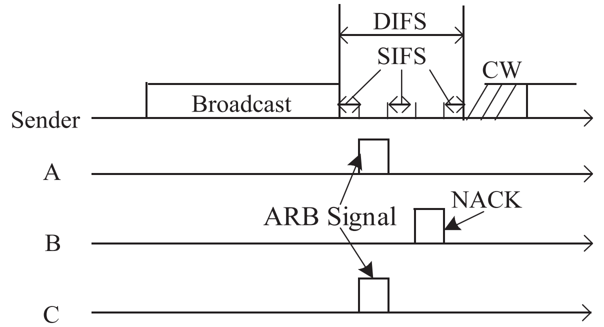

Fig. 3: Channel access of broadcasting using the proposed protocol 1.

A. Proposed protocol 1

In the proposed protocol 1, a broadcast packet is retransmitted according to NACK instead of ACK. We apply new signals named ARB and NACK over the IEEE 802.11 protocol. Both ARB and NACK are simple pulse signals. Fig. 3 shows the channel access of broadcasting using the proposed protocol 1. A node with a broadcast packet to transmit initially senses the channel, the node waits until the channel becomes idle for a DIFS time period, and then computes a random backoff time. When the channel becomes idle after a backoff time, the source node transmits broadcast packet. Node A and node C succeed in receiving a broadcast packet, and transmit ARB after SIFS (Short Inter Frame Space) time has passed from the end of the transmission of the broadcast packet. Node B fails to receive a broadcast packet, and transmits NACK after SIFS time has passed since the transmission of ARB by node A and node C finished. When source node detects any signal power at scheduled time of NACK, source node determines to retransmission of the broadcast packet. The source node retransmits the broadcast

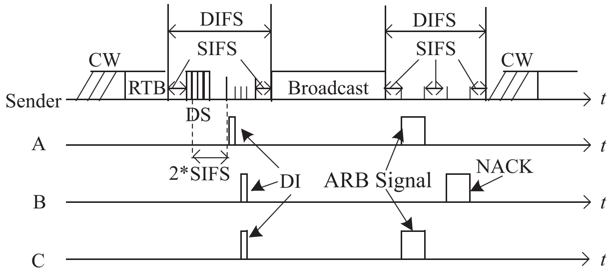

Fig. 4: Channel access of broadcasting using the proposed protocol 2.

packet until either no NACK is detected or the number of retries reaches the maximal retry threshold.

The proposed protocol 1 reduces the number of the retransmission by retransmitting a broadcast packet according to NACK instead of ACK. Since a broadcast packet is retransmitted by whether source node detects any signal power or not at scheduled time of NACK, collision of NACKs is no problem. Moreover, to be sure the response of NACK and keep high reliable broadcasting, in the proposed protocol 1, after succeeding in receiving a broadcast packet, the nodes transmits ARB. The other nodes, which fail to receive the broadcast packet, would detect the transmission of the broadcast packet by ARB. Therefore, the proposed protocol 1 improves the throughput performance keeping high reliable broadcasting in wireless ad-hoc networks with IEEE 802.11.

B. Proposed protocol 2

The proposed protocol 2 adopts retransmission using directional antennas in addition to the proposed protocol 1. We define new RTB (Request To Broadcast) packet, DS (Direction Search) and DI (Direction Information) signals over the IEEE 802.11 protocol. Fig. 4 shows the channel access of broadcasting using the proposed protocol 2, when the number of directional antennas $m = 4$. In Fig. 4, each node has $m = 4$ directional antennas. A node with a broadcast packet to transmit initially senses the channel, the node waits until the channel becomes idle for a DIFS time period, and then computes a random backoff time. When the channel becomes idle after a backoff time, the source node transmits RTB packet. RTB packet includes address information source node, time duration of transmission and ID (IDentification) of broadcast packet that will be transmitted. After receiving RTB packet, node A, B and C send no packet until the end of the broadcasting. After SIFS time passed from the end of the transmission of RTB packet, source node transmits DS signal to each area of m directional antennas in turn. If the ID in RTB packet is new for each node and the broadcast packet has not been received yet, node A, B and C respond DI signal to request transmission of the broadcast packet from the source node using a same directional antenna as receiving DS signal. In Fig.4, since node B and C are located in the same area from source node, node B and C respond DI signal at the same time. The nodes that the broadcast packet has received correctly, respond no DI signal. Source node transmits a broadcast packet only to the area including nodes that respond DI with directional antennas. After transmission of broadcast packet, procedure is same as the proposed protocol 1. Node A and node C succeed in receiving a broadcast packet, and transmit ARB after SIFS time passed from the end of the transmission of the broadcast packet. Node B fails to receive a broadcast packet, and transmits NACK after SIFS time has passed since the transmission of ARB by node A and node C was done. When source node detects any signal power at scheduled time of NACK, source node determines to retransmit the broadcast packet. The source node retransmits the broadcast packet until either no NACK is detected or the number of retries reaches the maximal retry threshold.

In the proposed protocol 2, source node gets information of the direction that destination nodes are located by exchanging DS/DI signals between source node and destination nodes. The broadcast packet is retransmitted only to the area including nodes that request retransmission by using directional antennas. While the broadcast packet is retransmitted, the nodes that are located out of the range of the directional antennas can make other communications. Moreover, the proposed protocol 2 reduces the num-

Table 1: Computer simulation parameters.

Common Parameters	
Channel Rate	2 Mbps
Channel	Error free
Transmission Range	100 m
SIFS Time	10 μsec
DIFS Time	50 μsec
Contention Window Slot Time	20 μsec
Minimum Contention Window Size	31
Maximum Contention Window Size	1023
Average Data Packet Length	1,200 bytes
Maximum Data Packet Length	2,347 bytes
Packet Arrival Process	Poisson
BACK Model	
Number of Mini Slots	20
Time Duration of ACK	2 μsec
Proposed 1 and Proposed 2 Models	
Time Duration of ARB	10 μsec
Time Duration of NACK	10 μsec
Maximal retry threshold	4
Proposed 2 Model	
Number of Directional Antennas	4
Time Duration of DS	2 μsec
Time Duration of DI	2 μsec
RTB Packet Length	20 bytes

ber of the retransmission by retransmitting a broadcast packet according to NACK instead of ACK as the proposed protocol 1. Therefore, the proposed protocol 2 achieves the high throughput performance keeping high reliable broadcasting in wireless ad-hoc networks with IEEE 802.11.

IV. Simulation Results

We evaluate the performance in terms of the throughput and the success rate of data packet reception. Table 1 shows the parameters of the simulation. Since both proposed protocol 1 and 2 are applied over IEEE 802.11, the parameters follow the specifications of IEEE 802.11 [3]. In the simulations, the network load is generated only by broadcast packets.

Fig. 5 shows the throughput performance versus offered load when the number of nodes $N = 30$. We define throughput as follows.

$$Throughput = \frac{Length\ of\ transmitted\ data\ packets}{Channel\ rate * Total\ time} \quad (2)$$

When all nodes in the transmission range of source node succeed in receiving a broadcast packet, the broadcast packet is added to throughput. It is

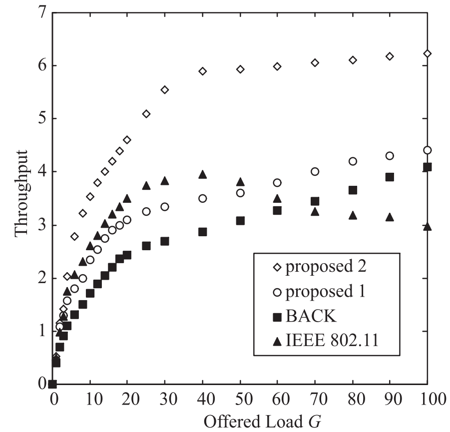

Fig. 5: The throughput performance versus offered load ($N = 30$).

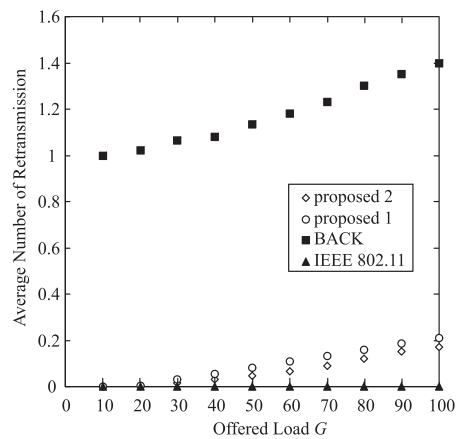

Fig. 6: The average number of retransmission versus offered load ($N = 30$).

known that large throughput shows high reliable broadcasting without redundant retransmission. In Fig. 5, it is found that both proposed protocol 1 and 2 improve the throughput performance compared with the BACK protocol. This is because that the proposed 1 and 2 reduce the number of redundant retransmission by using NACK instead of ACK. It is also found that the proposed protocol 2 achieves the highest throughput in all of protocols. The reason is that the proposed protocol 2 transmits a broadcast packet only to the area including nodes that request retransmission with directional antennas. Moreover, it is found that the throughput of the IEEE 802.11 protocol increases when $G < 40$ and decreases when $G \geq 40$. This is because that collision of packets increases and broadcasting fails more easily with increasing offered load G. On the other hand, the throughput of the BACK, proposed 1 and proposed 2 protocols increase with increasing offered load G. Therefore, the IEEE 802.11 protocol without retransmission gets different tendency in the throughput performance from the BACK, proposed 1 and proposed 2 protocols with retransmission.

Fig. 6 shows the average number of retransmission versus offered load, when the number of nodes $N = 30$. Note that the average number of retransmission of IEEE 802.11 protocol is constantly 0, since no ACK and no retransmission shall be used in IEEE 802.11 protocol. When G is large and collisions occur frequently, the IEEE 802.11 protocol has low throughput as shown in Fig. 5. On the other hand, the average number of retransmission of the BACK protocol is larger than any other protocols in any case. This is because that redundant retransmission occurs because of collision of ACKs in the BACK protocol. When G is small, the BACK protocol has low throughput as shown in Fig. 5. In Fig.6, the average number of retransmission of the proposed protocol 1 and 2 increase with increasing G. It means that a broadcast packet is retransmitted only when collision occurs in the proposed protocol 1 and 2. Therefore, even when G is large, the proposed protocol 1 and 2 keep high throughput.

Fig. 7 shows the success rate of data packet reception versus offered load. The success rate of data packet reception $R_{success}$ is given as

$$R_{success} = \frac{N_{receive}}{N_{all}} \quad (3)$$

where N_{all} is the number of nodes located in transmission range of source node. $N_{receive}$ is the number of nodes that succeed in receiving a broadcast packet. High success rate of data packet reception means high reliable broadcasting. It is found that the BACK, proposed 1 and 2 protocols keep high success rate of data packet reception in any case compared with the IEEE 802.11 protocol. This is because that in the BACK, proposed 1 and 2 protocols, a failed packet is recovered by retransmission.

Fig. 8 shows the throughput performance versus the number of nodes, when offered load $G = 50$. It is found that the throughput of the proposed protocol 1 becomes closer to that of the BACK protocol with

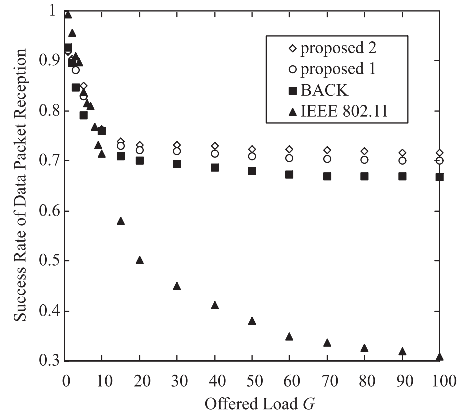

Fig. 7: The success rate of data packet reception versus offered load ($N = 30$).

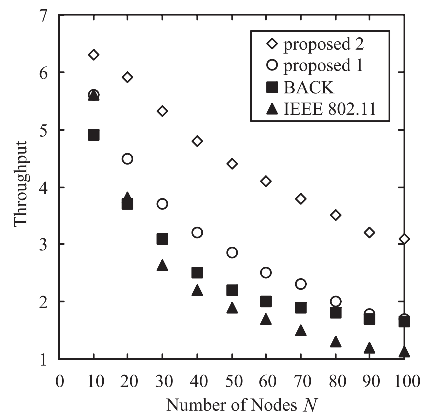

Fig. 8: The throughput performance versus the number of nodes ($G = 50$).

increasing number of nodes N. This is because that both proposed protocol 1 and BACK protocol need retransmission when collision frequently occurs due to large traffic load. It is also found that the proposed protocol 2 is effective, especially when N is large. The reason is that the proposed protocol 2 has more possibility to succeed several broadcasting at same time by using directional antennas in large ad hoc networks with many nodes.

V. Conclusions

To improve throughput performance keeping high reliable broadcasting, we have proposed efficient MAC protocols for broadcasting in wireless ad-hoc networks with IEEE 802.11. In the proposed protocol 1 and 2, to reduce the number of the retransmission, a broadcast packet is retransmitted according to NACK instead of ACK. Moreover, in the proposed protocol 2, the broadcast packet is retransmitted only to the area including nodes that request retransmission by using directional antennas. We evaluate the performance in terms of the throughput and the success rate of data packet reception by computer simulations. We show that both proposed protocol 1 and 2 can improve throughput performance keeping high reliable broadcasting compared with the BACK protocol. Especially, the proposed protocol 2 achieves the high throughput of 6, keeping the high success rate of data packet reception of approximately 0.7. Therefore, the proposed protocol 2 is effective in the wireless ad hoc networks with large traffic load and large number of nodes.

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