OFDMA-Based Reliable Multicast MAC Protocol for Wireless Ad-Hoc Networks

Sung Won Kim and Byung-Seo Kim

ABSTRACT—Compared with unicast, multicast over wireless ad-hoc networks do not support reliability due to their inability to exchange request-to-send/clear-to-send (RTS/CTS) and ACK packets with multiple recipients. Although several media access control (MAC) layer protocols have been proposed to provide reliable multicast, these introduce additional overhead, which degrades system performance. A novel MAC protocol for reliable wireless multicast is proposed in this paper. By adapting orthogonal frequency division multiple access characteristics in CTS and ACK packets, the protocol achieves reliability over wireless multicast with minimized overhead.

Keywords—Wireless multicast, OFDMA, ad-hoc.

I. Introduction

Multicast is the transmission of data to a group of nodes identified by a single destination address. Unlike multicast in wired networks, mobile multicast takes advantage of the broadcast-channel nature of wireless networks to efficiently and simultaneously disseminate common information to multiple location-independent receivers such that wireless resource consumption is reduced. Thus, multicast constitutes a bandwidth-efficient technique for group communication. However, it introduces new challenges due to error-prone wireless channels. Unlike wired multicast, mobile multicast packets are corrupted and lost for many reasons. First, channel fading, environmental interference, and mobility can produce random-like data loss. Another cause of data loss is packet collision. Some protocols have been proposed to overcome the disadvantages of wireless multicast. For channel error, automatic repeat requests (ARQs) are applied for wireless multicast [1]-[4]. However, these schemes introduce excessive overhead because all member nodes have to reply to the multicast data. Therefore, it causes congestion and possibly forces the system to undergo total collapse. Request-to-send/clear-to-send (RTS/CTS) handshake in IEEE 802.11 media access control (MAC) protects against hidden nodes in unicast. However, RTS/CTS handshake is unavailable in the IEEE 802.11 multicast specification. Thus, collisions among hidden nodes are quite frequent in multicast.

In [5], we proposed a new multicast MAC protocol, called orthogonal frequency-division multiple access (OFDMA)-based multicast ACK (OMACK). By adopting the concept of OFDMA into acknowledgement, the protocol achieves an error recovery process without increasing the overhead. However, the protocol concerns only error recovery and does not address the issue of hidden nodes over ad-hoc networks. In this paper, we enhance our previous work to resolve the hidden node problem over wireless multicast.

II. OFDMA-Based Multicast MAC Protocol

1. Motivations

Although some prior arts have been proposed to implement ARQ and to solve the hidden node problem for reliable multicast over wireless ad-hoc networks, they still incur serious overhead which degrades the system throughput [1]-[4]. Recently, we proposed an ARQ method for wireless multicast in [5]. Although it solves the overhead issues of wireless multicast, it still has a hidden-node problem because RTS/CTS packet exchange is not considered in [5]. Therefore, we utilize the OFDMA concept in [5] for both ACK and CTS packets.

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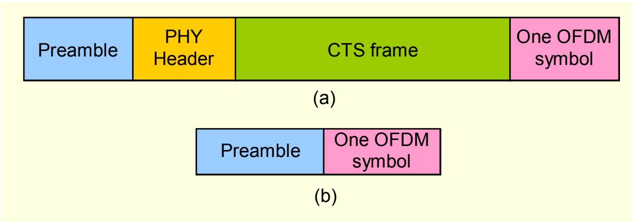

Fig. 1. (a) CTS and (b) ACK packet format.

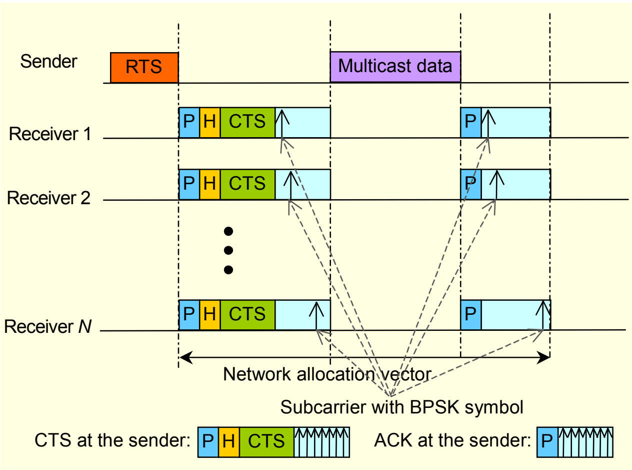

Fig. 2. Example of a data packet transmission cycle.

2. Protocol Operation

In the OFDMA-based multicast MAC protocol (OMMP), subchannel data carriers are orthogonal with each other, and they are used to transmit OFDM symbols. Each member node has a unique pre-assigned subcarrier location. When a member node receives an RTS packet within one-hop distance from the sender, it allocates one of the two binary phase-shift keying (BPSK) symbols, 1 or -1, on the pre-assigned subcarrier in an OFDM symbol, which is attached at the end of the CTS packet as shown in Fig. 1(a). Successful reception of the RTS packet is indicated by a BPSK symbol 1 on the subcarrier. On the contrary, a BPSK symbol -1 indicates that reception of the RTS packet failed. If a member node cannot demodulate the RTS packet, it does not generate a BPSK symbol. A BPSK symbol generated by each member node for the acknowledgement has only one subcarrier with a data symbol, and the other subcarriers are empty. The collection of these BPSK symbols constitutes the payload of the CTS packet. The CTS packet with an additional OFDM symbol is sent back to the sender. It is assumed that all of the member nodes send their BPSK symbols at the same time after the short interframe time idle period. At the multicast sender, the subcarriers in the received CTS packet are loaded by BPSK symbols to indicate each member's reception status.

An example scenario of the proposed method is shown in Fig. 2. A sender multicasts an RTS packet to all the member nodes from receiver 1 to receiver *N*. All of the receivers respond with an OFDM symbol to the pre-assigned subcarrier, and these symbols are merged at the sender as a CTS packet. Note that the OFDM symbol in the CTS packet is indicated by frequency domain, and the overall transmission sequence is indicated by the time scale in the figure. If receiver *N* does not receive the RTS packet, it does not send an OFDM symbol to the sender. After receiving the CTS packet, the sender checks the subcarriers assigned to member nodes. If any one of the member node subcarriers is not allocated any symbol or is allocated the BPSK symbol -1, the sender prepares to retransmit the RTS packet. When a CTS packet is received correctly, the sender transmits a multicast data packet to the member nodes. When the member nodes receive the multicast data packet from the sender, they allocate a symbol on the pre-assigned subcarrier as an acknowledgement for the packet. The generation of an ACK packet is the same as that of a CTS packet. An example scenario of ACK packet generation is shown in Fig. 2. An OFDM symbol plays the same role in the proposed method as CTS packets or ACK packets in previous works [1]-[4]. Thus, the proposed method shrinks the size of the overhead of multiple CTS packets and ACK packets. We solve the time offset problem due to imperfect time synchronization and different propagation delays from all of the member nodes by using a longer cyclic prefix given in [6] which is longer than a delay spread profile.

3. Subchannel Assignment

The subchannel assignment is managed by a multicast leader (ML). Each multicast group has an ML. When a node wants to join a multicast group, it broadcasts a multicast join request (MJREQ) packet. When the ML receives the MJREQ, it assigns an empty subchannel to the requesting node. Then, the ML responds with a multicast join ACK (MJACK) packet that has the information of the allocated subchannel. The assigned subcarrier has to be unique for each node within the same multicast group address. If there is no ML, no MJACK is multicast. In that case, if there is no response within some time threshold, the requesting node becomes the new ML for that multicast group address.

When an ML wants to leave a multicast group, it unicasts a multicast leader request (MLREQ) packet to one of the multicast group members. If the node responds with a multicast leader ACK (MLACK), the responding node becomes a new ML. If there is no MLACK within some time threshold, the ML selects another node and transmits the MLREQ packet until a new ML is selected.

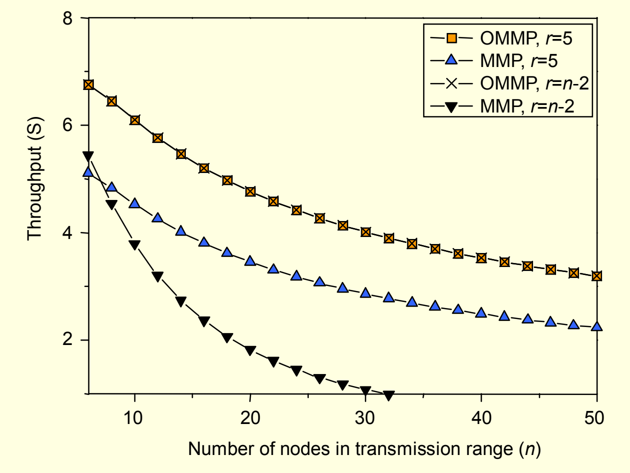

Fig. 3. Throughput improvement of the proposed method.

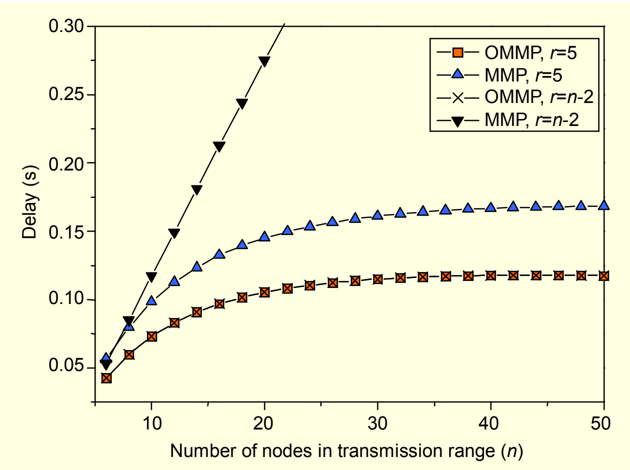

Fig. 4. Delay improvement of the proposed method.

III. Performance Evaluations

The 802.11 DCF-based simulator used for this performance evaluation is an event-driven custom simulation program previously used in [7]. The values of parameters used in this simulation are based on IEEE 802.11a standards [8]. OMMP is compared with the Multicast aware MAC Protocol (MMP) [3]. In MMP, after sending a single multicast RTS packet, the transmitter waits for the multiple CTS packets from each of its destinations. After receiving multiple CTS packets, the transmitter sends a data packet and waits for the multiple ACK packets from each of its destinations. Figure 3 shows the system throughput of OMMP and MMP defined in [3]. The number of multicast members in carrier sense range, r, is set to constant 5 or variable n–2, where n is the number of all wireless nodes. As the number of nodes in the carrier sense range increases, the throughput decreases. For MMP, the throughput with constant r is larger than that with variable r. This is because the number of control packets increases according to the number of receivers. However, the throughput of OMMP in both cases is the same. This is because OMMP requires only a single CTS packet and a single ACK packet irrespective of r. Thus, the proposed method can show better performance than MMP as the number of multicast receivers increases. Figure 4 shows the packet transmission delays of OMMP and MMP. The delay for MMP increases as the value of r increases because of the increased overhead. For the two cases of r, OMMP shows better delay performance than MMP because of the constant overhead.

IV. Conclusion

We have proposed a cross-layer design for reliable multicast in wireless networks. For the cross-layer design, the MAC layer uses an OFDMA mechanism for control packets. Thus, the overhead required for the reliable multicast is reduced, and this reduction of overhead enhances the system throughput. Compared with previous studies aiming to improve the reliability of multicast, the proposed method shows better performance and the performance gain increases as the number of multicast receivers increases.

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