This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the ICC 2008 proceedings.

Reliable Wireless Multicasting with Minimum Overheads in OFDM-based WLANs

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Abstract— **Even though multicast data transmissions in wireless communication standards doesn't require ARQ, to achieve reliable multicast over wireless channel, using ARQ is inevitable. However, unlike unicast, a sender needs to receive multiple acknowledgements (ACKs) from group members, and transmitting ACK from each group member degrades the network performance due to the overhead including multiple ACK packet transmissions and channel access process for ACKs and so on. An acknowledgement method with a minimum overhead is proposed in this paper, called OFDMA-based Multicast ACK (OMACK). The scheme uses one OFDM symbol for acknowledgements from all member stations (STAs), and each member STA indicates their packet reception status by allocating a symbol on previously allocated its own sub-carrier within the OFDM symbol. The proposed scheme is extensively evaluated by using simulation, and the results show that the scheme significantly reduces the aforementioned overhead comparing to legacy solutions and as a consequence improves the performance of the wireless networks.**

Keywords- Wireless Multicast, OFDMA, ARQ, WLAN

I. Introduction

Many applications for wired networks have been adopted by the wireless networks as wireless communication is getting popular. One of such applications is a multicast communication. The multicast communication enables to reach to all intended receivers by only one transmission, so that it achieves the better channel efficiency comparing to a unicast method. Besides of the bandwidth efficiency, the multicast over the wireless has not importantly been considered so far. The multicast even in the wireless standards such as IEEE802.11 is not well specified. While the reliable unicast methods over the Radio Access Networks (RAN) have extensively been studied, the multicast traffic is unreliably delivered. In other words, the multicast traffic delivery over the RAN is not guaranteed since most of wireless networks require neither an acknowledgement nor a retransmission for the multicast traffic transmissions. In order to compensate this unreliability, a fixed lowest data rate or an additional error correction coding is adopted for the multicast transmission. However, with considering the nature of wireless channel such as location dependence and time-varying, the lowest data rate or the additional error correction coding may not provide a reliable transmission at all since these methods reduce the packet error probability in the multicast, not eliminate the packet error. To support more reliable multicast, adopting an Automatic Repeat reQuest (ARQ) to multicast seems inevitable.

In order to achieve the reliable multicast over the both ad-hoc-based and centralized WLANs, many enhancements over the wireless MAC protocol are proposed [1]-[5]. The proposed methods have mainly focused on solutions for hidden node problems, which disrupt a contention free multicast transmission, and an error recovery process which is how the sender knows whether or not a multicast packet is successfully received at all of the member stations (STAs). The fact, that the error recovery process requires feedbacks from receivers such as acknowledgement (ACK) packet, disables to make the wireless multicast be bandwidth efficient since the feedback is an overhead in nature. Moreover, the overhead caused by the feedbacks increases as the number of intended receivers increases.

An acknowledgement method with a minimum overhead is proposed in this paper, called OFDMA-based Multicast ACK (OMACK). The scheme uses one OFDM symbol for acknowledgements from all of the member STAs, and each member STA indicates its packet reception status by allocating a symbol on previously allocated its own sub-carrier within the OFDM symbol. Therefore, the time consumed for error recovery process is reduced as less as that for the IEEE802.11-based unicast packet transmission. This paper, at first, reviewed the wireless multicast protocols proposed in literatures as well as in IEEE 802.11 standard. In Section 3, the detailed description of the proposed scheme is followed after the motivation is presented. In Section 4, the proposed scheme is thoroughly evaluated through simulations as well as theoretical methods, and the superiority of it is proved. Finally, the conclusion is made in the last section.

II. Related Works

For IEEE 802.11b standards [6] and IEEE 802.11e draft standard in [7], multicast packet is transmitted without RTS/CTS/ACK handshaking and fragmentation, which naturally provides unreliable transmission. To compensate unreliability of multicast, the lowest data rate is applied for a physical layer data rate. Furthermore, all of the multicast packets are transmitted right after a beacon packet transmission. The rational of this is to prevent a STA in power

This research was supported by the MIC (Ministry of Information and Communication), Korea, under the ITRC (Information Technology Research Center) support program supervised by the IITA (Institute of Information Technology Advancement) (IITA-2008-(C1090-0801-0003))

save mode from not receiving a multicast packet since all of the STAs have to be awake to receive the beacon packet.

Reliable multicast has been studied relatively little compared to reliable unicast. In addition, most of studies for this topic have focused on IEEE 802.11-based Wireless Local Area Networks (WLAN) and Mobile Ad hoc Network (MANET). The paper in [1] proposes Broadcast Medium Window (BMW). BMW exchanges RTS/CTS/DATA/ACK with one of member STAs, and then RTS/ACK are exchanged with the entire member STAs. RTS/ACK are transmitted through contention based channel access. In [2], the authors propose Leader-Based Protocol (LBP) for multicast to reduce the overhead caused by multiple CTSs and ACKs. A sender in LBP selects one STA among the multicast group member STAs, called a leader. Then, only the leader responses with CTS and ACK corresponding to RTS and data packets. If a member STA fails to receive a data packet, it sends NACK packet at the end of data packet and this NACK causes a collision with ACK from the leader. If there is a collision after data transmission, the sender recognizes that at least one data packet is lost. In that case, it sends the data again. As an enhanced version of BMW, Batch Mode Multicast MAC (BMMM) protocol is proposed in [3]. The transaction of BMMM between the sender and member STAs is a sequence of multiple RTS/CTS exchanges between a sender and member STAs, data packet transmission, and multiple Request ACK (RAK)/ACK exchanges between a sender and member STAs. During this sequence, there is no contention-based channel access. Therefore, comparing to BMW, BMMM reduces the overhead due to multiple contention periods to access channel for transmitting RTS/ACK. Multicast aware MAC Protocol (MMP) is proposed in [4]. Unlike aforementioned protocols, MMP does not use RTS/CTS handshaking, but uses data/ACK. After a data packet is transmitted, all of the member STAs transmit their ACK packets to the sender following the pre-assigned sequential order. The scheme proposed in [5] focuses only on the hidden node problem. Therefore, the error recovery process in [5] adopts one of the aforementioned schemes.

III. OFDMA-Based Reliable Multicast MAC Protocols

A. Motivation

Based on preliminary studies, the proposed error recovery processes for multicasting can be categorized by two types: Multiple ACKs and Leader-based ACK. For the Multiple-ACKs-based scheme, the sender can collect the information of multicast packet reception from all of the multicast group members STAs. However, ACK transmissions degrade the channel efficiency and reduce the overall network performance. The degradation is exaggerated as the number of member STAs increases. On the other hand, Leader-based ACK scheme reduces the overhead caused by multiple ACK packet transmissions by allowing only a leader to send ACK. In fact, the overhead of Leader-based ACK scheme is just the same as that of the unicast. However, when one of the member STAs fails to receive a data packet, it cannot send NACK packet since it cannot recognize that the received packet is multicast

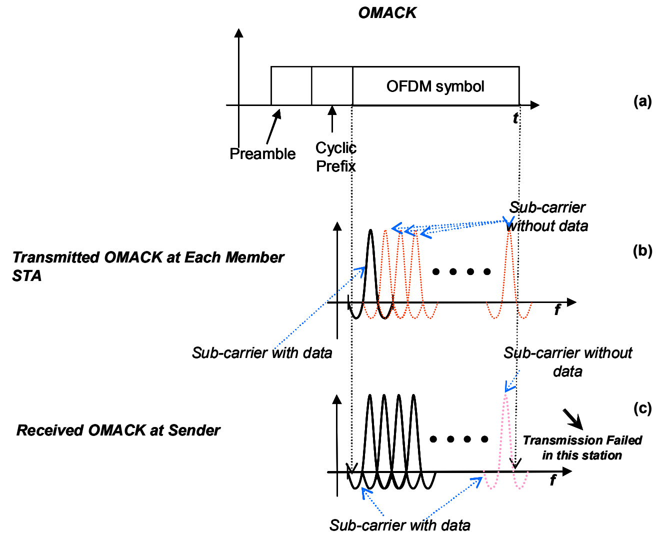

Figure 1. (a) Generic OMACK structure, (b) OMACK transmitted by each STA, and (c) a received OMACK at the sender.

and it is the destination of the packet. Since the STA does not send NACK, no collision is experienced at the sender. Therefore, Leader-based ACK scheme may not be reliable in terms of the detection of the failed transmission.

B. OFDMA-based Reliable Multicast for Centralized WLAN

In this paper, new reliable multicast transmission method is proposed over IEEE 802.11-based WLAN. Even though IEEE 802.11 standard specifies distributed mode with contention-based channel access as well as centralized mode with polling-based channel access, the WLAN deployed in a real world uses a centralized architecture with a contention-based channel access. Therefore, the proposed scheme is targeting on a centralized WLAN with contention-based channel access. As with the IEEE 802.11 standard, all of the multicast packets are transmitted right after a beacon packet to deal with STAs in Power Save (PS) mode.

1) Reliable Multicast with OFDMA-based Multicast ACK (OMACK)

New type of acknowledgement is proposed, called OFDMA-based Multicast ACK (OMACK). This is the main innovation of the proposed scheme in this paper. Fig. 1 shows the structure of OMACK. OMACK is a simple packet consisting of a preamble and an OFDM symbol with a cyclic prefix as shown in Fig. 1(a). Each member STA has a pre-assigned unique sub-carrier number for each group ID. The process of assigning a sub-carrier number is described in the following subsection. When a member STA receives a multicast packet from the sender, it allocates a symbol on the pre-assigned sub-carrier as an acknowledgement for the packet. The symbol is one of the two BPSK symbols, 1 or -1. 1 on the sub-carrier indicates a successful reception of the multicast packet and -1 does failed reception. If a member STA can not demodulate even the MAC header of the multicast data packet, it will not generate OMACK. OFDM symbol generated by each member STA for the acknowledgement has only one sub-

Group Address	Member MAC address	Sub-carrier ID
239.225.0.x	01-00-5e-7F-00-XX	10
	01-00-5e-7F-00-YY	15
	01-00-5e-7F-00-ZZ	22
239.225.0.x	01-00-8e-9F-00-XX	15
	01-00-8e-9F-00-YY	5

Figure 2. Example of layer-2 multicast table.

carrier with a data symbol and the other sub-carriers are empty as illustrated in Fig. 1(b). After attached with preamble, the OFDM symbol is sent to the multicast sender. It is assumed that all of the member STAs send their OMACK at the same time after SIFS idle period. At the multicast sender, the sub-carriers in the received OMACK are loaded by BPSK symbols to indicate each member's reception status as shown in Fig. 1(c).

For the time offset problem due to imperfect time-synchronization and different propagation delays from all of the member STAs, it is solved by using a longer cyclic prefix shown in [8]-[10] which is longer than a delay spread profile

2) Sub-Channel Assignment process

IEEE 802.11 standard does not specify the group join process. Since WLAN is mainly designed for wireless Internet extension, joining a group is completed by a Layer-3 protocol such as Internet Group Management Protocol (IGMP). When a STA wants to join a multicast group, it unicasts to the access point (AP) an IGMP Membership Query message as a payload of a MAC data packet. When the AP receives the packet, it goes to layer 3. If the packet is an IGMP Query message, the AP creates a Layer-2 multicast table with the group address and the address of the STA. An example of layer-2 multicast table is shown in Fig. 2. Then, the AP evaluates each sub-carrier's condition and selects a sub-carrier which has the best quality among available all sub-carriers. The selected sub-carrier identification (ID) is sent back to the member STAs by piggybacking with an ACK packet. The assigned sub-carrier ID has to be unique for each STA within the same multicast group address.

IV. PERFORMANCE EVALUATION

In Section 3, it is mentioned that the proposed schemes in the literature fall into two categories: Multiple-ACKs and Leader-based ACK. It is also mentioned that Leader-based ACK may fail to detect the failed transmission. As a consequence, OMACK and the latest Multiple-ACKs-based scheme, which is MMP, are evaluated and compared through the simulations in this section. The performances of OMACK and MMP are evaluated in terms of packet transmission delay and throughput. The packet transmission delay is defined as the time period from the start of a packet becoming a head-of-line (HOL) in the queue to the end of the packet removal from the queue [13]. The normalized system throughput is defined as the fraction of time that the channel is used to successfully transmit packets.

TABLE I. PARAMETER VALUES

Parameter	Value
CWmin	15
CWmax	1023
SIFS time	16 us
DIFS time	34us
Slot time	9 us
MAC header	272 bits
PHY header	46 bits
Preamble	16 us
ACK packet time	44 us
Packet payload	8192 bits (1436us)
Channel bit rate	6 Mbps

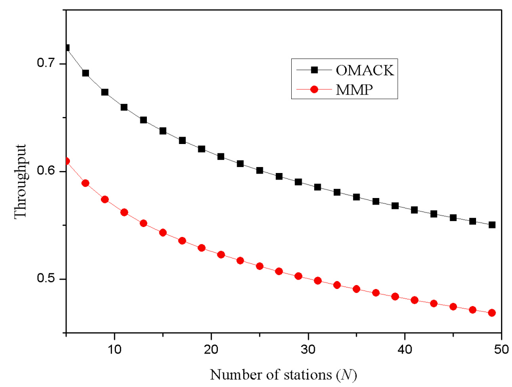

Figure 3. Number of STAs and throughput for a constant number of receivers (R=5).

The 802.11 DCF-based simulator used for this performance evaluation is an event-driven custom simulation program previously used in [12]. The simulator, written in the C++ programming language, follows all the 802.11 protocol details for each independently transmitting STA. The values of parameters used to obtain numerical results for the simulation runs are summarized in Table I. The values of these parameters are based on the IEEE 802.11a standard [11]. All simulation results in the plots are obtained with a 95% confidence interval. Packet Error Rate (PER) is set to 0.08 as mentioned in the standard [11].

Fig. 3 shows the throughput of OMACK and MMP by changing the number of STAs. N. The number of a multicast group member, R, is fixed and set to 5. The throughputs of both OMACK and MMP decrease as the number of STAs increases. This comes from the increase of packet collision. The throughput of OMACK is higher than that of MMP. This is because MMP requires more overheads of multiple ACKs than OMACK does. The throughput difference between OMACK and MMP maintains constant because of the constant R.

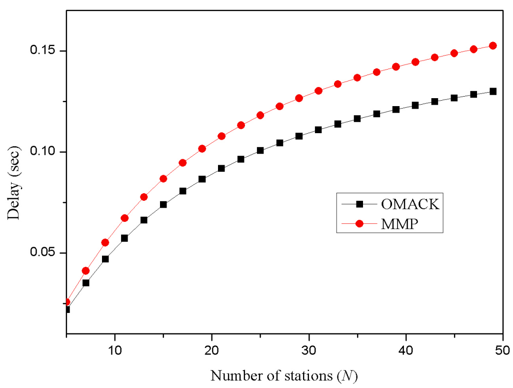

Figure 4. Number of STAs and delay for a constant number of receivers (R=5).

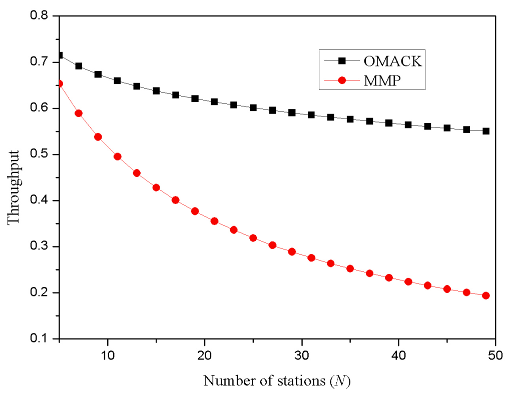

Figure 5. Number of STAs and throughput for a variable number of receivers (R=N-2).

Fig. 4 shows the delay as a function of the number of STAs where R is kept constant. It is noted that the delay of OMACK is less than that of MMP because OMACK requires less overhead of ACK. The delay difference between the two methods becomes larger as the number of STAs increase. As the number of STAs increases, the channel utilization of MMP is deteriorated due to the overheads comparing to OMACK.

Fig. 5 and Fig. 6 show the throughput and the delay of OMACK and MMP by changing the value of R to be N - 2, i.e. 2 less than the number of STAs. The performance of OMACK is independent of the number of receivers. However, the performance of MMP is largely dependent on the number of receivers. This is because the overhead of MMP increases as the number of receivers increase. Thus, the performance difference between the two methods becomes larger as the number of receivers increases.

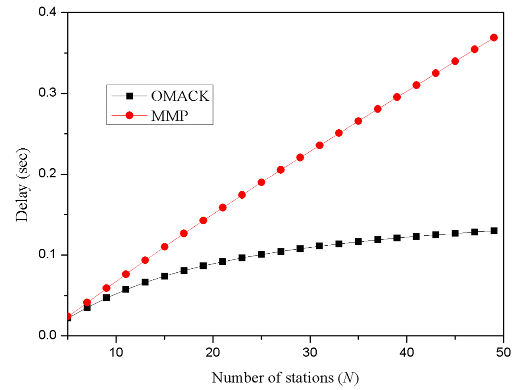

Figure 6. Number of STAs and delay for a variable number of receivers (R= N -2).

V. Conclusion

In this paper, we propose a reliable multicast protocol with a minimum ACK overhead over IEEE 802.11-based WLAN. The key contribution on the proposed protocol is the use of an OFDMA mechanism for acknowledging whether or not a multicast packet is successfully received at each group member STAs. When STAs successfully receive the multicast packet, they send an OFDM symbol, called OMACK, allocating one bit on their own sub-carrier, which is pre-assigned and unique to each member STA. By checking if there is a sub-carrier without a bit, a multicast sender considers the multicast packet transmission as a failure. Both OMACK and a legacy solution have been compared and evaluated through the simulations. The performances of OMACK outperform those of the legacy solution in terms of throughput and delay. Overall, OMACK provides a reliable error recovery mechanism for multicast transmissions with minimum overhead.

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