LETTER

Link-Adaptive MAC Protocol for Wireless Multicast

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SUMMARY Previous researches on ad-hoc networks did not consider the dynamic rate adaptation for wireless multicast. Instead, they statically use the lowest data rate for multicast transmission. The MAC protocol proposed in this paper utilizes the OFDMA mechanism, so that all members can report their rate preference at one time. As a result, the best rate for each member is dynamically selected.
key words: *multicast, MAC, rate-adaptation, OFDMA*

1. Introduction

Multicast is an efficient way to transmit data to a group of nodes identified by a single destination address. In multicast, only one data packet transmission is required to deliver the packet to multiple receivers. Thus, multicast has the potential of bandwidth-efficient technique for group communications. This makes it possible to provide many applications over wireless, that are group-oriented and mission-critical, requiring both accurate data delivery and timeliness [1]. However, the reliability and channel utilization of wireless multicast over ad-hoc networks are restricted because of no feedback channel from member stations (STAs) and using the lowest data rate. To achieve reliability, the wireless multicast requires a feedback channel such as acknowledgement (ACK) packet transmission. However, this cause lots of overheads increasing as a function of the number of members. In addition, dynamic link adaptive technique cannot be achieved without feedback information from member STAs due to asymmetric channel characteristic. Because of such a reason, even IEEE 802.11 standard, the widely-used MAC and PHY layers for ad-hoc networks, simply transmits the multicast data frames once by using the lowest data rate. Recently, the provision of multicast reliability at the MAC layer has received increasing attention in [2]–[4]. While most of these could not solve the overhead issues, OFDMA-based ACK (OMACK) in [5] remarkably reduces overhead. OMACK applies OFDMA characteristics into ACK frame format.

Regarding the data rate for multicast transmission, a few reports have been published as shown in [6]–[8]. All these protocols are assumed over a centralized network environment, so that the channel information is periodically updated using predetermined time slots. However, this is not applicable for ad-hoc networks since the periodic reports over contention-based transmission increase overheads. Furthermore, even though a central STA collects all the channel information, this information could not be applicable at the moment of transmitting a data. In this paper, an efficient method to realize rate-adaptation is proposed by utilizing our previous work, OMACK [5]. The proposed method requires only a few additional OFDM symbols. In spite of the overhead added by this additional OFDM symbol, the network throughput and delay performances are improved. The proposed method targets on OFDM physical layer-based networks without OFDMA-based feedback channel. However, it is also applicable for OFDMA-based system if the system does not have sub-channel-wise feedback channel.

2. Link-Adaptive MAC Protocol for Wireless Multicast

2.1 Preliminary

OMACK, which is one of our previous works, is not only a proposed acknowledgement method for multicast, but also a new format of ACK for multicast. OMACK is a simple packet consisting of a preamble and an OFDM symbol with a cyclic prefix. Each member STA has a pre-assigned unique sub-carrier number for each group ID. The detail for sub-carrier assignment is in [5]. When a member STA receives a multicast packet from the sender, it allocates one of the two BPSK symbols (1 or -1) on the pre-assigned sub-carrier as an acknowledgement for the packet. A successful reception of the multicast packet on the sub-carrier is indicated by a 1, and a -1 indicates a failed reception. It is assumed that all of the member STAs send their OMACK at the same time after an 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. Therefore, all ACKs from all members are simultaneously received at the sender without collision due to orthogonality of sub-carriers and this scheme requires no additional overhead. 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 [9] which is longer than a delay spread profiles.

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Preamble	PLCP Header (1 OFDM symbol)	MPDU	RTS Reception (1 OFDM symbol)	CSI Indication (3 OFDM symbols)

Fig. 1 New CTS frame format.

2.2 Proposed Protocol

For the rate adaptation over wireless multicast, RTS and CTS frame formats defined in IEEE 802.11 standard are manipulated. The new CTS frame has two more fields after legacy CTS frame format as shown in Fig. 1. The first field, named "*RTSReception*," is composed of one OFDM symbol and is used to indicate RTS reception state at a member STA. The second field, named "*CSIIndication*," is used to indicate a preferred data rate at member STAs. The number of OFDM symbols in "*CSIIndication*" is three. Each one of the additional OFDM symbols is composed of N data subcarriers, and each member STA is assigned with one subcarrier among them. When a member STA sends the CTS frame, it will set its own subcarriers to $1/{-1}$ BPSK symbol.

In order to inform the use of rate-adaptation for wireless multicast to all member STAs, "*Subtype*" subfield of frame control field in RTS frame is set to 0001. The values from 0000 to 0111 are defined as "*Reserved*" bits in the standard [10]. During the multicast group joining process as described in [5], a sender knows the number of member STAs for each multicast group, which is identified by a multicast group identification (G_{ID}). In addition, during the process, each member STA informs sub-carriers' state information to the sender so that the sender assigns unique subcarrier identification (S_{ID}) to the STA, which will be used to indicate its rate preference. S_{ID} is

$$S_{ID} \in \{1, 2, \cdots, N\}, \tag{1}$$

where N is the total number of subcarriers possible for data subcarriers, not including pilot subcarriers. Subcarriers in all OFDM symbols have a unique S_{ID} in accordance with the location over the OFDM symbol. A multicast sender assigns unique S_{ID} to each member STA, which satisfies the following rule;

$$S_{ID}(G_{ID}) = \arg \max_{n \in Unused} \mathrm{SNR}_n, \tag{2}$$

where n is one of S_{ID}s and $Unused$ is a subcarrier set, which is not assigned to any member STA. SNR is Signal-to-Noise Ratio. Although one S_{ID} is assigned, a member STA will use three subcarriers because it will use the same S_{ID} subcarrier from three OFDM symbols in "*CSIIndication*" in a CTS frame. Therefore, a member STA uses three subcarriers to inform an preferred data rate. Because multicast STAs may frequently join and leave the group, the multicast sender keeps track of how many members are in G_{ID}, each STA's S_{ID}, and whether or not a certain S_{ID} is being used. When the multicast sender has a multicast data frame, the proposed protocol operates as follows.

Table 1 Binary representations corresponding to data rates.

Last three bits in subtype	Data rate (Mbps)	SNR threshold (dBm)
000	6	−82
001	9	−81
010	12	−79
011	18	−77
100	24	−74
101	36	−70
110	48	−66
111	54	−65

Step 1 A multicast source sends a RTS frame. The first bit in "*Subtype*" subfield is set to 0001.

Step 2 After receiving the RTS frame, member STAs estimate the channel condition, which can be represented by SNR. Each member chooses the best data rate suitable for the estimated current channel conditions. We assume that the data rate is selected based on a predetermined threshold [1]–[3]. That is, the selected data rate, R, is

$$R = R_i, \qquad \text{if } \Gamma_i \leq \mathrm{SNR} < \Gamma_{i+1}, \tag{3}$$

where R_i is the ith rate in a rate set and Γ_i is an SNR threshold to use R_i. SNR threshold defined in IEEE 802.11a [11] is shown in Table 1.

Step 3 Once finding a preferred data rate, R, each member STAs sets binary values corresponding to the R on the assigned subcarriers over three OFDM symbols to build "*CSIIndication*." The binary representations corresponding to data rates are shown in Table 1. For instance, if the preferred data rate is 9 Mbps, then 0 is set to S_{ID} on the first OFDM symbol, 0 to S_{ID} on the second OFDM symbol, and 1 on the third OFDM symbol. To indicate the successful reception of RTS, 1 is set to S_{ID} subcarrier in OFDM symbols of "*RTSReception*" subfield. Now, formatting the CTS frame is completed.

Step 4 Members send their CTS frames to the multicast sender after SIFS.

Step 5 Receiving CTS frames, the multicast sender checks "*RTSReception*" OFDM symbol in CTS frame. If 1s are allocated over expected subcarriers (assigned S_{ID} sub-carriers), then, it checks "*CSIIndication*" to find the best data rate for the multicast data transmission. After the multicast sender checks members' preferences on a data rate for the pending multicast data packet, it chooses the lowest one among the preferred data rates.

Step 6 A multicast data frame is generated according to the chosen data rate, and sent to member STAs.

Step 7 Member STAs demodulate the received data frame by using the data rate found in "*Rate*" subfield in PLCP header of the data frame.

3. Performance Evaluations

The performance of the proposed method is compared with

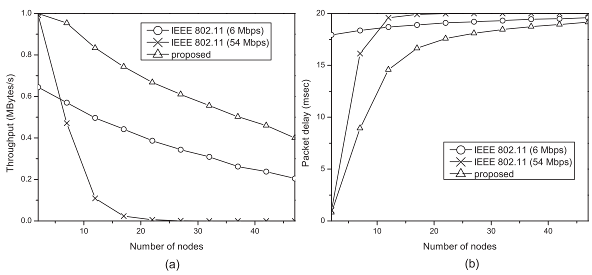

Fig. 2 (a) Throughput and (b) packet delay of the proposed method and IEEE 802.11.

legacy multicast method in IEEE 802.11 [7]. We consider an OFDM based physical layer as in IEEE 802.11a [11] standard which has eight PHY modes as shown in Table 1. Wireless channel characteristics are modeled as three components: path loss, shadowing and multipath fading. Path loss exponent is set to 2.56 for the path loss and shadowing model. To represent fading, we consider the "ETSI indoor channel A delay profile," which models a typical office environment with no line-of-sight [12]. The power delay profile has an RMS delay spread of 50 ns and a maximum delay spread of 390 ns. All of the nodes are randomly distributed in an 100 m × 100 m square area and move randomly at a speed of 0.1 m/sec. One node becomes multicast source node and the other nodes become receiver nodes. The packet inter-arrival time is exponential random variable with parameter λ setting to 500. The packets that wait more than 20 msec are dropped from the queue. Each plot in the simulation results is obtained by running the model for 50 hours. The packet size is 2000 bytes.

Figure 2(a) shows the throughput of the proposed method by changing the number of nodes. Since the minimum rate of the possible rates of receivers becomes the transmission rate of source node, the transmission rate decreases as the number of nodes increases. Because of the decreased transmission rate, the throughput also decreases as the number of nodes increases. The throughput of IEEE 802.11 is less than that of the proposed method. This is because the transmission rate of IEEE 802.11 is fixed at 6 Mbps while that of the proposed method is higher than 6 Mbps because of the dynamic rate adaptation. We also include the simulation result of fixed 54 Mbps even though IEEE 802.11 stipulates to use the fixed 6 Mbps. The throughput of 54 Mbps is worse than that of 6 Mbps for large number of nodes because the packet error probability increases as the rate increases. In other words, the channel condition is poor for the higher data rate. The lower throughput of IEEE 802.11 incurs longer delay as shown in Fig. 2(b). The increase of the number of nodes incurs the decrease of the transmission rate. Thus, the packet delay increases as the number of nodes increases. The maximum delay that a packet can wait in the queue is set to 20 msec. Thus, the packet delay converges on 20 msec.

4. Conclusions

In this paper, a link adaptive protocol for wireless multicast is proposed. By using this, unlike conventional multicast transmission, which uses the lowest data rate, transmission rate of multicast data is able to be dynamically changed according to channel condition. It is shown that the proposed method enhances the performances of wireless multicast over ad-hoc networks.

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