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DYNAMIC RATE ADAPTATION FOR WIRELESS MULTICAST

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ABSTRACT

Most communication styles in tactical networks are one-to-many communications, which is multicast transmission. Recently, tactical networks has been evolving to Ad-Hoc-like distributed networks with OFDM-based Wideband Networking Waveform (WNW). In this paper, novel rate-adaptive multicast transmission method over OFDM-based wireless networks is proposed. Transmission rate for wireless multicast over Ad-Hoc Networks has always been the lowest data rate without dynamic link-adaptation. Even though it degrades the performances of networks, implementing dynamic rate adaptation over wireless multicast seems impossible because it causes overhead increasing as a function of the number of member stations. The MAC protocol proposed in this paper utilizes OFDMA mechanism, so that all members can report their rate preferences at one time without increasing overhead. A multicast source is able to find each member's rate preference from the multiple three-OFDM symbols arrived simultaneously. From the rate-preferences from all members, the source dynamically choose appropriate data rate for upcoming multicast data transmission. As a result, the proposed protocol increases network performances comparing with the multicast transmission using the lowest and constant data rate. It is proven through the extensive simulations.

I. INTRODUCTION

To obtain capability to reliably and quickly deal with broadband data over combat environment, Joint Tactical Radio System (JTRS) is planned and is being developed. JTRS adopts Software Defined Radio (SDR) over tactical Mobile Ad-Hoc Network (MANET). To realize Tactical MANET, enhanced encryption method and broadband network technologies are adopted. JTRS allows inter-operability over four different waveforms; WNW (Wideband Networking Waveform), SRW (Soldier Radio Waveform), JAN-TE (Joint Airborne Networking-Tactical Edge), and MUOS (Mobile UHF Objective System). Particularly, WNW adapts OFDM waveform. Most communication styles over tactical MANET will be one-to-multipoint communications, which is called Group communication or Multicast. Multicast is to transmit data to a group of nodes identified by a single destination address. Because it requires only one transmission to many receivers per a data frame, multicast has the potential of bandwidth-efficient technique for group communication. This makes it possible to provide many applications for wireless networks, which are group-oriented and mission-critical, requiring both accurate data delivery and timeliness [1]. Due to such a great advantage, multicast transmissions over wired networks have been extensively researched. For multicast transmission over wired networks, the key issue has been how to set up an optimal multicast routing path. Reliability and Rate adaptation has not been issued due to reliable channel condition. On the other hand, issues in multicast transmission over wireless networks are different from that in wired networks due to time-varying nature of wireless. Therefore, the reliability and channel utilization of wireless multicast over ad-hoc networks have been showed up as issues for multicast transmission over wireless networks. However, the issues are hard to solve 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 ACK packet transmission. However, this causes 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, the widely-used MAC and PHY layers for ad-hoc networks including IEEE 802.11 standard simply transmit the multicast data frames by using the lowest data rate. Recently, the provision of multicast reliability at the MAC layer has received increasing attention in [2]–[6]. Main focuses of proposed protocols in [2]-[6] are on reliable multicast transmission including solution for hidden node problems and error recovery process. However, although the protocols provide reliability over wireless multicast, they create much overhead, which increases as a function of multicast member stations. Therefore, their throughput

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performances have been poor due to such overhead. Recently, OFDMA-based ACK (OMACK) in [7] remarkably reduces overhead as well as achieves reliability. OMACK applies OFDMA characteristics into ACK frame format.

Regarding the data rate for multicast transmission, there are also a few researches as shown in [8]–[10]. 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 channel information, this information cannot be applicable at the moment of transmitting a data. In this paper, an efficient rate-adaptation method is proposed for WNW-based tactical MANET. By utilizing our previous works [7], 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. In the next section, the novel link-adaptive MAC protocol is proposed after the OMACK is reviewed. In Section III, the proposed method is evaluated through simulations and the performance improvements of the method are demonstrated. Finally, conclusions are given in the last section.

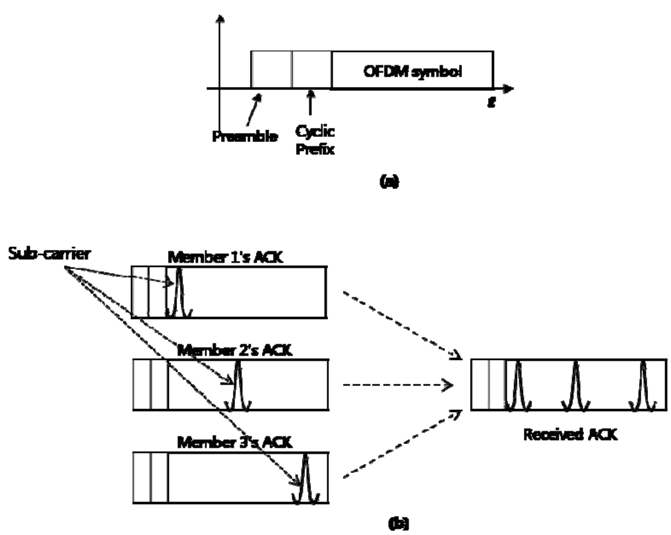

Figure 1. (a) Generic OMACK structure and (b) OMACK transmitted by each STA (left) and a received OMACK at the source (right)

II. LINK-ADAPTIVE MAC PROTOCOL FOR WIRELESS MULTICAST

A. PRELIMINARY

OMACK proposed not only an acknowledgement method for multicast, but also a new format of ACK for multicast as shown in Fig. 1(a). 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 OMACKs at the same time after an SIFS idle period. At the multicast sender, the sub-carriers of 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 the orthogonality of subcarriers. Thus, this scheme requires no additional overhead. Fig. 1(b) illustrates transmitted OMACKs from multicast member stations and a received OMACK at a source station. 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 [11]-[13] which is longer than a delay spread profiles.

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

Figure 2. New CTS frame format.

B. 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 "RTS Reception", is composed of one OFDM symbol and is used to indicate RTS reception state at a member STA. The second field, named "CSI Indication", is used to indicate a preferred data rate at a member STA. The number of OFDM symbols in "CSI Indication" is three. Each one of the additional OFDM symbols is composed of N data subcarriers, and each member STA is assigned with one sub-carrier among them. When a member STA sends the CTS frame, it will set its own subcarrier to 1 or -1 of 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 [14]. An initial process of a STA acquires Subcarrier Identification (*SID*) as described in OMACK

[7]. *SID* is.

$$S\_ID \in \{1,2,\cdots N\} \quad (1)$$

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

$$S_{ID}(G_{ID}) = \arg \max_{n \in Unused} SNR_n \quad , \quad (2)$$

where *GID* is a multicast group ID, *n* is one of *SID*s, and *Unused* is a subcarrier set, which is not assigned to any member STA. SNR is Signal-to-Noise Ratio. Although one *SID* is assigned, a member STA will use three subcarriers because it will use the same *SID* subcarrier from three OFDM symbols in "CSI Indication" of a CTS frame. Therefore, a member STA uses three sub-carriers to inform an preferred data rate. Through the multicast group join process, it is assumed that a multicast sender knows current number of member STAs, and assignments of *GID* and *SID* are completed. When the multicast sender has a multicast data frame, the proposed protocol operates as follows.

- 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 [16]–[18]. That is, the selected data rate, *R*, is

$$R = R_i \ , \qquad \text{if } \Gamma_i \le SNR < \Gamma_{i+1} \quad (3)$$

  where *Ri* is the *i*th rate in a rate set and ¡*i* is an SNR threshold to use *Ri*. SNR threshold defined in IEEE 802.11a [15] is shown in Table I. For example, if the measured SNR is -78 dBm, the selected rate is 12 Mbps.

- 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 "CSI Indication". The Binary representations corresponding to data rates are shown in Table I. For instance, if the preferred data rate is 9 Mbps, then 0 is set to *SID* on the first OFDM symbol, 0 to *SID* on the second OFDM symbol, and 1 on the third OFDM symbol. To indicate the successful reception of RTS, 1 is set to *SID* subcarrier in OFDM symbols of "RTS Reception" subfield. Now, formatting 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 "RTS Reception" OFDM symbol in CTS frame. If 1s are allocated over expected subcarriers (assigned *SID* sub-carriers), then it checks "CSI Indication" 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 frame, 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.

III. PERFORMANCE EVALUATIONS

The performance of the proposed method is compared with legacy multicast method in IEEE 802.11. We consider an OFDM based physical as in IEEE 802.11a [15] operating in the 5 GHz frequency band. Wireless channel characteristics are modeled as three components: path loss, shadowing and multipath fading. The path loss is modeled as

$$PL(d) = PL(d_0) + 10\alpha \log(\frac{d}{d_0}) \quad , \quad (4)$$

where d_0 is a reference distance and ® is the path loss exponent. We consider $d_0 = 1$ m and $\alpha = 2.56$. To represent fading, we consider the ETSI indoor channel A delay profile, which models a typical office environment with no line-of-sight [19]. The power delay profile has an RMS delay spread of 50 ns and a maximum delay spread of 390 ns. This delay profile results in frequency selective fading in the IEEE 802.11a 20 MHz band. In the computation of SNR, the noise is modeled as additive white Gaussian noise (AWGN). We consider a hard-decision Viterbi decoder in the receiver, and assume perfect synchronization of the receiver to the transmitted signal. The PHY layer has eight PHY modes characterized by different modulation schemes and convolutional coding rates, as shown in Table I.

TABLE I. 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

The system under consideration is an IEEE 802.11a-based wireless ad-hoc network. We assume there are one multicast source station and multiple multicast-member stations. The member stations are located within radio range of the source station and receive multicast data from the source station. All the member stations except the source station are randomly distributed in a 100 m X 100 m square area, which is a radio range of the source station, and move randomly at a speed of 0.1 m/sec within the area. Communication between the source station and each member stations experiences a particular fading realization which maybe different from that experienced by another communicating pair (the source and other member station) in the BSS. We evaluate the proposed protocol with time-constrained traffic. The packet inter-arrival time is exponential random variable with parameter λ. The packets that wait more than 20 msec are dropped from queue. Each plot in the simulation results is obtained by running the model for 50 hours. The number of multicast member stations is 25 and ¸ λ is 500.

Fig. 3 shows the throughput of the proposed method by changing the packet size. Throughput is here defined as dividing total number of bits successfully transmitted during simulation by simulation time. Since the arrival rate is fixed, the increase of the packet size incurs the increase of the traffic load. As the traffic load increases (packet size increases), throughput of IEEE 802.11 is less than 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. For the small packet sizes, both proposed protocol and the legacy protocol achieve similar performances. The reason of this is that the simulation is conducted over unsaturated scenario that is the channel is

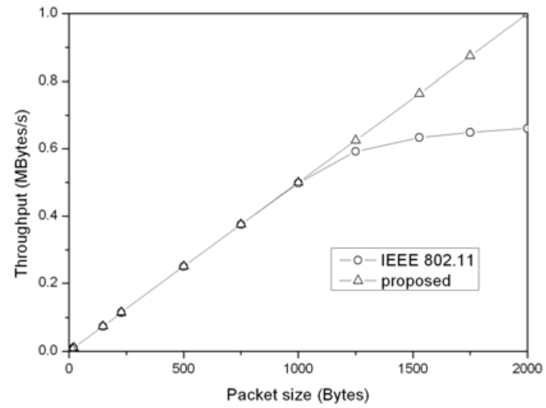

Figure 3. Throughput of the proposed method and IEEE 802.11.

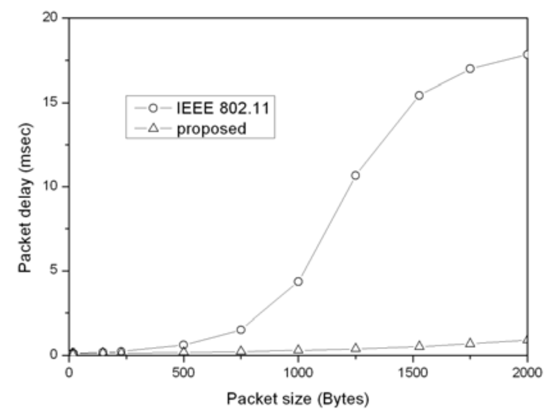

Figure 4. Packet delay of the proposed method and IEEE 802.11.

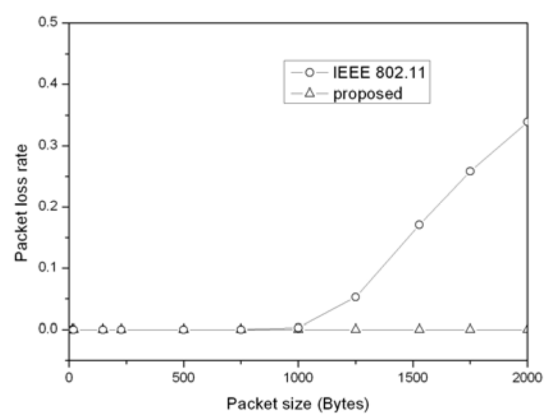

Figure 5. Packet loss rate of the proposed method and IEEE 802.11.

not fully utilized. Therefore, when packet size is small, even though the transmission time of a packet in legacy system is longer than that in the proposed system, it does not make enough delay in the transmission of the upcoming multicast packet.

This low throughput of IEEE 802.11 incurs longer delay and more packet loss as shown in Fig. 4 and 5. Because of low transmission rate of IEEE 802.11, packet delay increases as the packet size increases. The maximum delay that a packet can wait in queue is set to 20 msec. Thus, as the packet delay increases, more packets are dropped from the queue. This also causes the throughput degradation in IEEE 802.11. As shown in Fig. 5, the packet loss starts being differentiated from packet size 1000, where the throughput performances of both protocols start being differentiated.

IV. CONCLUSION

In this paper, a link adaptive protocol for wireless multicast over WNW-based Tactical MANET is proposed. By using this, unlike conventional multicast transmission using 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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