Tone Dual-Channel MAC Protocol with Directional Antennas for Mobile Ad Hoc Networks

JeongWoo Jwa

The directional medium access control (MAC) protocol improves the throughput of mobile ad hoc networks but has a deafness problem and requires location information for neighboring nodes. In the dual-channel directional MAC protocol [12], the use of omnidirectional packets does not require the exact location of destination node. In this letter, we propose a tone dual-channel MAC protocol with directional antennas to improve the throughput of mobile ad hoc networks. In the proposed MAC protocol, we use a directional CTS and an out-of-band directional DATA tone with a new blocking algorithm to improve the spatial reuse. We confirm the throughput performance of the proposed MAC protocol by computer simulations using the Qualnet simulator.

Keywords: Ad hoc MAC protocol, directional antennas, tone, dual-channel, deafness.

I. Introduction

Ad hoc networks are wireless networks without fixed base stations or any wired backbone infrastructure such as access points [1]. IEEE 802.11 medium access control (MAC) protocols [2], [3] have been proposed for wireless LANs and multihop wireless networks. The use of an omnidirectional antenna in IEEE 802.11 leads to a poor throughput performance in multihop ad hoc networks. MAC protocols with directional antennas [4]-[9] have been proposed to improve the spatial reuse and the throughput of multihop ad hoc networks. In the directional MAC (DMAC) protocol [4], the directional antenna is blocked on the reception of a request-to-send (RTS) or clear-to-send (CTS) packet to prevent packet collisions on the data channel. Nodes having one or more blocked directional antennas use a directional RTS (DRTS) instead of an omnidirectional RTS (ORTS) as the blocked directional antennas cannot transmit any packets. Directional transmission using DRTS improves the spatial reuse but has a deafness problem and requires the exact location of a destination node [7], [8]. In [6], the directional virtual carrier sensing (DVCS) scheme has been proposed to improve the capacity of mobile ad hoc networks using directional antennas. The DVCS scheme uses angle of arrival caching and a directional network allocation vector (NAV). The ToneDMAC protocol [8] has been proposed to improve the spatial reuse and mitigate the deafness problem. In the ToneDMAC protocol, an omnidirectional out-of-band tone uniquely assigned to each node is used to mitigate the deafness problem caused by directional transmission.

The dual-channel (DUCHA) MAC protocol [10], [11] uses separate channels: the control channel for RTS/CTS/negative CTS (NCTS) and the data channel for DATA. An out-of-band busy tone is used to solve the hidden terminal problem. The NCTS mechanism on the control channel also solves the receiver blocking problem. The DUCHA MAC protocol with directional antennas (DUDMAC) [12] has been proposed to improve the spatial reuse. In the DUDMAC protocol, ORTS/omnidirectional CTS (OCTS)/NCTS/negative DATA (NDATA) is transmitted on the control channel and DDATA/DACK is transmitted on the data channel. The use of ORTS and OCTS on the control channel does not require the exact location of the neighboring nodes and overcomes the deafness problem. The NCTS and NDATA mechanisms with a blocking algorithm for directional antennas improve the spatial reuse on the control channel.

In the DUDMAC protocol, the use of ORTS and OCTS reduces the spatial reuse on the control channel. In this letter,

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JeongWoo Jwa (phone: +82 64 754 3638, lcr02@jejunu.ac.kr) is with the Department of Telecommunications, Jeju National University, Jeju, Rep. of Korea.
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we propose an improved version of DUDMAC that uses a directional CTS and an out-of-band directional DATA tone to improve the spatial reuse compared to that of DUDMAC.

II. Tone DUDMAC Protocol

The DUDMAC protocol [12] has been proposed to improve the throughput of mobile ad hoc networks without the aid of location information on the neighbor nodes. In the DUDMAC protocol, ORTS and OCTS are used on the control channel as the source node does not know the exact location of the destination node. The use of omnidirectional transmissions on the control channel solves the deafness problem caused by the directional transmission on the data channel. However, this omnidirectional transmission reduces the spatial reuse and degrades the throughput of mobile ad hoc networks. In this letter, we propose a tone DUDMAC (ToneDUDMAC) protocol to improve the spatial reuse. We use an out-of-band tone that is uniquely assigned to each node using a static hash function of a node's unique identifier as in the case of the ToneDMAC protocol [8]. In the proposed MAC protocol, we use ORTS and an omnidirectional out-of-band tone (OCTS_tone) instead of OCTS in the DUDMAC protocol to solve the deafness problem. The use of directional CTS (DCTS) and a directional out-of-band tone (DDATA_tone) with the blocking algorithm for directional antennas improves the spatial reuse compared to that of the DUDMAC protocol.

Figure 1 shows the operation of the proposed Tone DUDMAC protocol. Source node A transmits ORTS to the destination node B because node A does not know the exact location of node B. After overhearing ORTS, neighbor nodes C, D, and E store node A's identifier and the waiting time in their deafness tables to solve the deafness problem. Nodes C, D, and E cannot transmit RTS to node A until their waiting timers expire. Neighbor nodes set their NAVs for the duration of OCTS_tone-DCTS-DDATA_tone using the duration field in ORTS. Destination node B transmits OCTS_tone to its neighbor nodes to overcome the deafness problem. After overhearing OCTS_tone, neighbor nodes D, E, and F store node B's identifier in their deafness tables. Neighbor nodes set their waiting time for the duration of DCTS-DDATA_tone-DDATA-SIFS-DACK because an out-of-band tone does not have any information on the waiting time. In this letter, we use constant-bit-rate (CBR) traffic. In the case of variable-bit-rate traffic, we should change the duration of OCTS_tone to the duration of DCTS-DDATA_tone-DDATA-SIFS-DACK. The use of omnidirectional transmissions using ORTS and OCTS_tone solves the deafness problem as in the case of the DUDMAC protocol. Destination node B sends DCTS to node A using the directional antenna with the maximum received

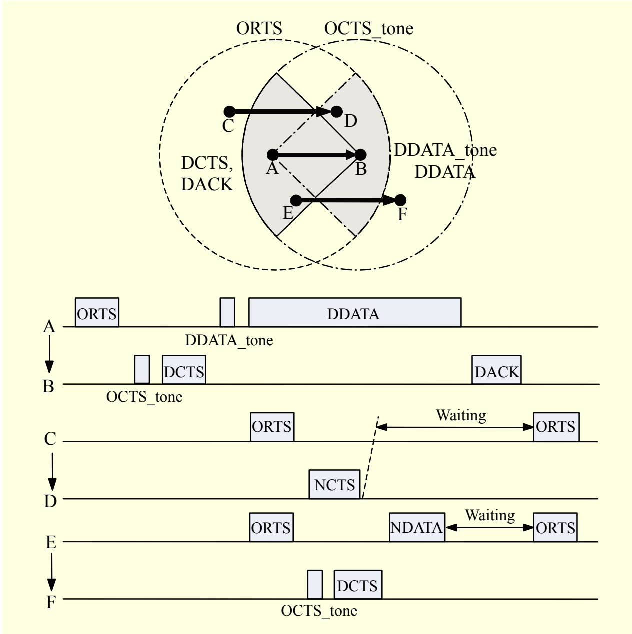

Fig. 1. ToneDUDMAC protocol: ORTS, DCTS, NCTS, and NDATA on control channel, DDATA and DACK on data channel, and out-of-band OCTS_tone and DDATA_tone.

power of ORTS. Neighbor nodes set their NAVs for the duration of DDATA_tone-DDATA-SIFS-DACK using the duration field in DCTS. After receiving DCTS, node A transmits DDATA_tone to its neighboring nodes to improve the spatial reuse. Then, source node A sends DDATA using the directional antenna with the maximum received power of DCTS. Neighbor nodes set their NAVs for the duration of DDATA-SIFS-DACK using the field in DDATA. Destination node B sends DACK on the data channel after receiving DATA without any bit errors.

In this letter, we use the NCTS and NDATA mechanisms to reduce the number of packet collisions as in the case of the DUDMAC protocol. In Fig. 1, node D sends a directional NCTS to node C on the control channel when the blocked directional antenna receives ORTS of node C. After receiving a directional NCTS, node C waits for the end of communication between nodes A and B using the waiting time in its deafness table. Therefore, the NCTS mechanism solves the receiver blocking problem. We use NDATA when the destination node is in the coverage area of the blocked directional antenna of the source node. In Fig. 1, node E sends ORTS to node F and then receives DCTS of node F from the blocked directional antenna. Then, node E sends a directional NDATA instead of DDATA to node F to prevent packet collisions on the data channel.

In the proposed ToneDUDMAC protocol, we use a blocking algorithm for directional antennas to prevent packet collisions. Figure 2 shows the blocking regions for the directional antennas of neighbor nodes in the ToneDUDMAC and

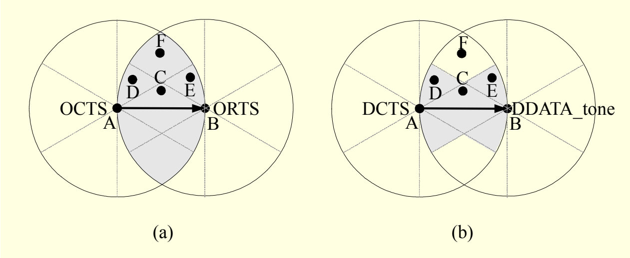

Fig. 2. Blocking regions for directional antennas in (a) DUDMAC and (b) ToneDUDMAC protocols.

DUDMAC protocols. In the DUDMAC protocol, the blocking region is determined by the intersection of ORTS and OCTS. In the blocking region, the directional antenna is blocked on the reception of ORTS or OCTS. The blocked directional antenna allows NCTS or NDATA to be sent but cannot transmit any packets on the data channel to prevent packet collisions. Therefore, in Fig. 2(a), neighbor nodes C, D, E, and F have two blocked directional antennas that can overhear ORTS or OCTS in the blocking region. In the ToneDUDMAC protocol, we make use of a directional transmission using DDATA_tone and DCTS to reduce the blocking region and to improve the spatial reuse. The directional antennas of the neighbor nodes are blocked on the reception of DCTS or DDATA_tone. In Fig. 2(b), neighbor node C has two blocked directional antennas and nodes D and E have one blocked directional antenna each. However, the directional antenna of node F is not blocked. Therefore, directional transmissions using DDATA_tone and DCTS improve the spatial reuse.

III. Simulation Results and Discussions

We confirm the operation of the proposed MAC protocol by computer simulations using the Qualnet simulator [13]. The simulation results of the proposed MAC protocol are compared with those of the DUDMAC, ToneDMAC with ORTS, DMAC with ORTS, DUCHA MAC, and IEEE 802.11 MAC protocols for mobile ad hoc networks. In this letter, we use the IEEE 802.11b physical layer, a data rate of 2 Mbps, and a two-ray multipath fading-channel model. In the DUCHA MAC protocol, the channel allocation is an important parameter for improving the throughput of mobile ad hoc networks. We choose a control channel speed of 0.5 Mbps and a data channel speed of 1.5 Mbps as in the case of the DUDMAC protocol. In the DUCHA MAC protocol [11], the total bandwidth of 2 Mbps is divided into the control channel speed of 0.3 Mbps and the data channel speed of 1.7 Mbps. We use static routing, CBR traffic, a DATA packet size of 1,000 bytes, and 8 switched beam antennas. The important parameter values used in the simulations are shown in Table 1.

Table 1. Key parameter values in simulations.

Topology	Single-hop	
CBR traffic	0.2 Mbps to 1.0 Mbps	
Distance between nodes	0 to 250 m (random)	
Data rate: 2 Mbps	Control channel	Data channel
	0.5 Mbps	1.5 Mbps
Channel model	Two-ray model	
DATA packet size	1,000 bytes (CBR)	
Simulation time	120 s	

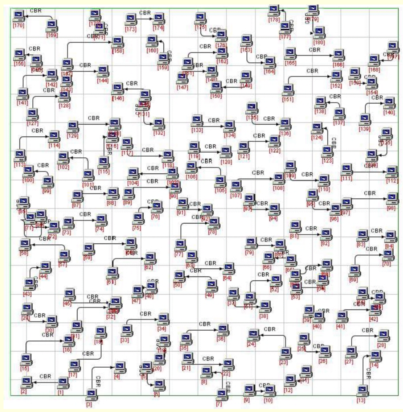

Fig. 3. Single-hop random topology of 180 nodes in square area of 1000 m ×1000 m.

For the simulations, we use a single-hop random topology of 180 nodes that are randomly arranged into a rectangular area of 1000 m ×1000 m. The destination nodes are randomly selected within a transmission range of 250 m as shown in Fig. 3. We also use the random waypoint mobility model in which the mobility scenarios are created by BonnMotion [14]. In the mobility model, each node has a maximum speed of 2.2 m/s and pause time of 0.

Figure 4(a) shows the throughput of the proposed ToneDUDMAC protocol in a single-hop random topology. In the proposed MAC protocol, the use of directional transmissions using DCTS and a directional out-of-band tone reduces the blocking area and therefore improves the spatial reuse compared to that of the DUDMAC protocol. The simulation results show that the throughput of the proposed MAC protocol is superior to that of the DUDMAC protocol. The average throughputs are 288 kbps, 232 kbps, 205 kbps, 179 kbps, 74 kbps, and 68 kbps for the proposed ToneDUDMAC, DUDMAC, ToneDMAC with ORTS, DMAC with ORTS, DUCHA MAC, and IEEE 802.11MAC protocols at a traffic load of 1 Mbps, respectively.

Figure 4(b) shows the throughput of the proposed MAC

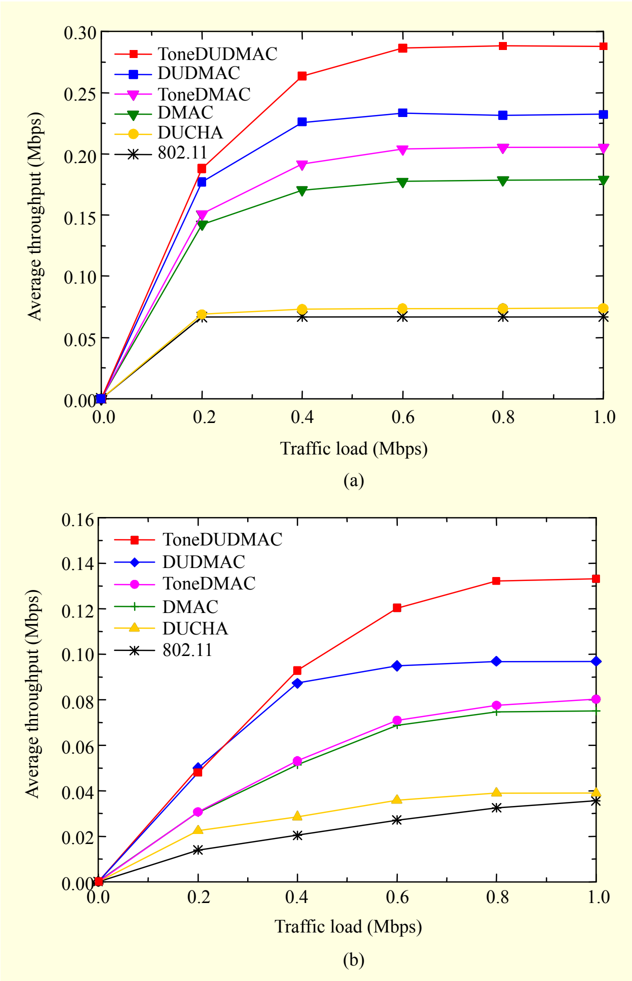

Fig. 4. (a) Average throughput of proposed MAC protocol in single-hop random topology and (b) that under random waypoint mobility model.

protocol in a single-hop random topology under the random waypoint mobility model. In the proposed MAC protocol, the use of DCTS and a directional out-of-band tone (DDATA_tone) leads to a good throughput performance also in a network with random mobility. The average throughputs are 133.1 kbps, 96.9 kbps, 80.2 kbps, 75.0 kbps, 38.9 kbps, and 35.4 kbps for the proposed ToneDUDMAC, DUDMAC, ToneDMAC with ORTS, DMAC with ORTS, DUCHA MAC, and IEEE 802.11 MAC protocols at a traffic load of 1 Mbps, respectively.

IV. Conclusion

In this letter, we proposed the tone dual-channel MAC protocol with directional antennas to improve the spatial reuse on the control channel. In the proposed MAC protocol, ORTS and DCTS are transmitted on the control channel and DDATA and DACK are transmitted on the data channel. The directional NCTS and NDATA mechanisms are used to prevent packet collisions on the data channel as in the case of the DUDMAC protocol. Using DCTS and a directional out-of-band tone (DDATA_tone), the blocking area for directional antennas is reduced, and therefore the spatial reuse is improved. DCTS also reduces the number of packet collisions on the control channel. The simulation results show that the throughput of the proposed MAC protocol is better than those of the DUDMAC, ToneDMAC with ORTS, DMAC with ORTS, DUCHA MAC, and IEEE 802.11 MAC protocols for mobile ad hoc networks.

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