A Tone Dual-Channel DMAC Protocol in Location Unaware Ad Hoc Networks

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Abstract *- Directional antennas are used to improve spatial reuse, but have the problem of deafness. The DUDMAC protocol [9] uses the ORTS, OCTS, DDATA, and DACK mechanisms and a blocking algorithm for directional transmissions. In this paper, we propose a tone dual-channel directional MAC (ToneDUDMAC) protocol to improve spatial reuse. The ToneDUDMAC protocol uses the ORTS, DCTS, DDATA, and DACK mechanisms including the DDATA_tone and OCTS_tone. We use ORTS as that in DUDMAC because of location unawareness of neighbor's nodes. The DDATA_tone and OCTS_tone reduce a blocking area and improve spatial reuse. We confirm the throughput performance of the proposed MAC protocol by computer simulations using Qualnet ver.3.8 simulator.*

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

1 Introduction

Ad hoc Networks is a wireless network without fixed base stations or any wired backbone infrastructure such as base station or AP [1]. The IEEE 802.11 medium access control (MAC) protocols using an omnidirectional antenna [2][3] have been proposed to wireless LANs and multi-hop networks. However, an omnidirectional antenna has a poor throughput performance in multi-hop ad hoc networks. The MAC protocols using directional antennas [4]-[7] have been proposed to improve spatial reuse and throughput of multi-hop ad hoc networks. But, directional antennas have the problem of deafness and require the location information of neighbor's nodes [6][7]. The ToneDMAC protocol [7] uses an out-of-band tone to inform the end of directional transmissions to nodes in the coverages of the transmitting and receiving node. An out-of-band tone mitigates deafness and improve throughput of multi-hop ad hoc networks.

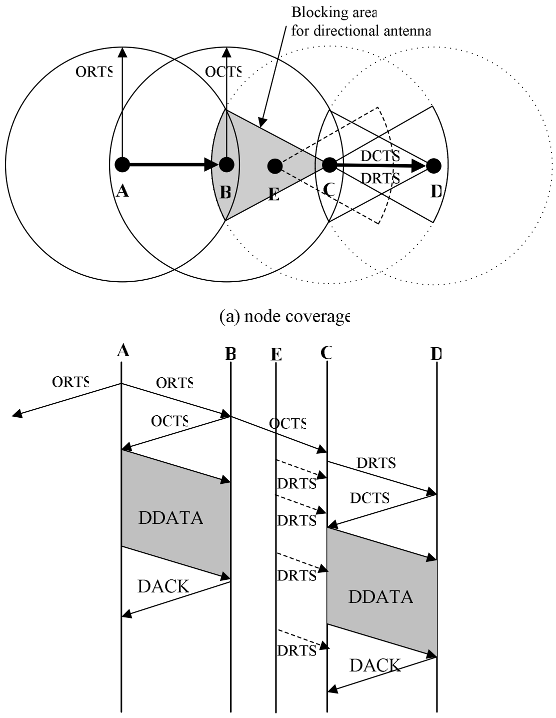
The dual-channel (DUCHA) MAC protocol [8] uses the separated channels: control channel for RTS and CTS and data channel for DATA. The dual-channel directional MAC (DUDMAC) protocol [9] uses omnidirectional RTS (ORTS) and omni directional CTS (OCTS) directional ACK (DACK) in data channel. In control channel, the blocking algorithm for directional transmissions is used to prevent collision of packets. The DDATA and DACK mechanism improve spatial reuse and the ORTS and OCTS mechanisms mitigate deafness. DUMAC does not require the location information of neighbor's node as that in omnidirectional transmission due to ORTS and OCTS. But, ORTS and OCTS reduce spatial reuse.

In this paper, we propose the ToneDUDMAC protocol to improve spatial reuse in multi-hop ad hoc networks. In section 2, we describe the previous studies on ad hoc DMAC protocols: the DMAC, ToneDMAC, DUCHA MAC, and DUDMAC protocols. In section 3, we describe the operation of the proposed MAC protocol. We confirm the throughput performance of the proposed MAC protocol by computer simulations in section 4. We finally conclude the paper in section 5.

2 Related Work

2.1 The Directional MAC Protocol

The DMAC protocol [4] with an omnidirectional antenna and directional antennas is proposed to improve spatial reuse. In the DMAC protocol, the blocking algorithm for directional antennas is used to prevent collision of packets. The directional antenna overheard RTS or CTS is blocked and does not use for data transmission. Node having unblocked directional antennas uses ORTS to solve the problem of deafness. The node having one or more blocked directional antennas uses DRTS to improve spatial reuse. Figure 1 shows the operation of the DMAC protocol. Node A transmits ORTS to node B as directional antennas of node A are unblocked. Node B sends OCTS to node A. Then, the DDATA and DACK packets are transmitted. Node C in the coverage of node A overhears ORTS of node A and the directional antenna is blocked. To improve spatial reuse, node C transmits DRTS to node D as node C has blocked directional antenna. Node E sends DRTS to node C in communication because Node E does not overhear DRTS of node C. Node E retransmits DRTS to node C in deafness after a backoff period. The backoff period of node E can be



(a) node coverage

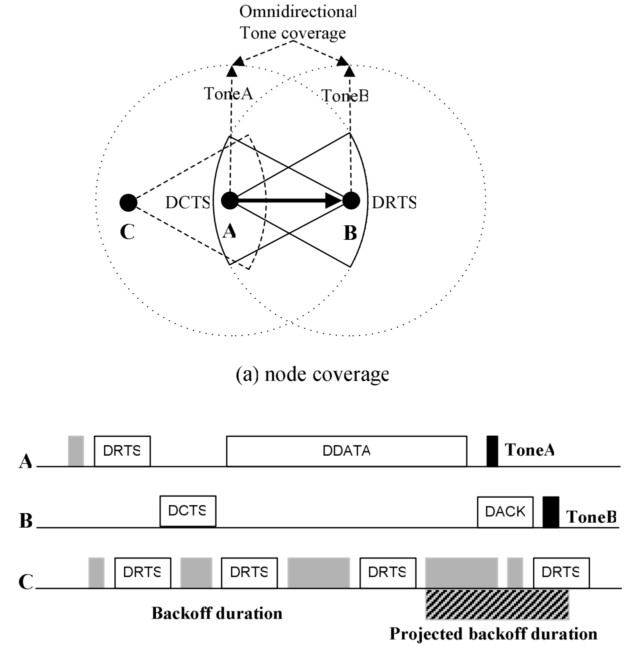
(b) signal flow chart

Fig. 1. The operation of the DMAC protocol: The circle centered at each node shows its transmission range. An arrow represents the transmission direction.

exponentially increased at every retransmission. Therefore, the throughput performance of ad hoc networks is severely degraded. Directional transmission has trade-off between spatial reuse and deafness.

2.2 The Tone DMAC Protocol

The ToneDMAC protocol [7] is proposed to improve spatial reuse and mitigate deafness. ToneDMAC protocol uses the DRTS, DCTS, DDATA, and DACK mechanisms to improve spatial reuse. An-out-of-band tone uniquely assigned to each node is used to mitigate deafness caused by directional transmission. Figure 2 shows the operation of the ToneDMAC protocol. Node A transmits DRTS to node B and node B sends DCTS to node A. Then, DDATA and DACK are transmitted between node A and node B. An out-of-band tone is used to inform the end of directional transmissions nodes in the coverage. Node B transmits omnidirectional ToneB after transmitting DDATA and node A transmits omnidirectional ToneA after transmitting DACK. ToneA and Tone B are uniquely assigned to node A and node B, respectively. But, node C in the coverage of node A does not overhear DRTS of node A caused by directional transmission. Therefore, node C transmits DRTS to node A and does not receive DCTS from node A in deafness. Node C retransmits DRTS to node A until ToneA is received. Therefore, the back-off period of node C is exponentially increased at every retransmission as that in DMAC caused by deafness. When node C receives ToneA, node C resets the increased back-off-period and transmits DRTS to node A. An out-of-band tone mitigates deafness and improves throughput of ad hoc networks.



(a) node coverage

(b) signal flow

Fig. 2. The operation of the Tone DMAC protocol: Out-of-band tones are used to inform the end of directional transmissions to the neighbor's nodes.

2.3 The dual-channel MAC Protocol

The dual-channel (DUCHA) MAC protocol [8] uses the separated control channel and data channel and an out-of-band busy tone as shown in figure 3. The RTS, CTS, and negative CTS (NCTS) packets are transmitted over control channel and the DATA packet is transmitted over data channel. The NCTS mechanism instead of CTS is used to prevent collision of the DATA packets in data channel. In the DUCHA MAC protocol, an out-of-band busy tone is used to mitigate the problems of the hidden/exposed terminal. If DATA is correctly received the receiving node stops sending the busy tone and terminates the communication. If the reception of DATA is failed the negative ACK (NACK) signal of the continued busy tone is transmitted to the transmitter for an appropriate period.

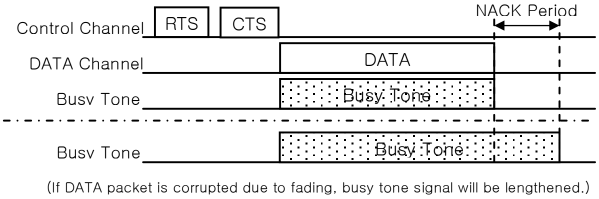


Fig. 3. The DUCHA MAC Protocol with the separated control channel, data channel, and an out-of-band channel.

When NACK is sensed during the NACK period, the node starts the retransmission procedure. Therefore, an out-of-band busy tone solves the hidden terminal problem.

2.4 The Dual-Channel DMAC Protocol

The dual-channel directional MAC (DUDMAC) protocol [9] without location information of neighbor's mode is proposed to improve spatial reuse. In the DUDMAC protocol, ORTS, and OCTS, NCTS and NDATA are transmitted over control channel and DDATA and DACK are transmitted over data channel. The ORTS and OCTS mechanisms overcome the problem of deafness caused by directional transmission in data channel. The NCTS and NDATA mechanisms and a blocking algorithm for directional antennas to prevent collisions of packets on data channel. Figure 4 shows the operation of the DUDMAC protocol. Node A transmits ORTS to node B over control channel and node B sends OCTS to node A. Then DDATA and DACK is transmitted over data channel. Nodes D and E overhear ORTS and OCTS and the directional antennas are blocked. Node C transmits ORTS to node D transmits NCTS as the directional antennas is blocked. Node E transmits ORTS to node F and node F sends OCTS to node E. Node E transmits NDATA to node F as node F is in the blocking area of node E. The NCTS and NDATA mechanisms and the blocking algorithm for directional antennas improve spatial reuse without deafness.

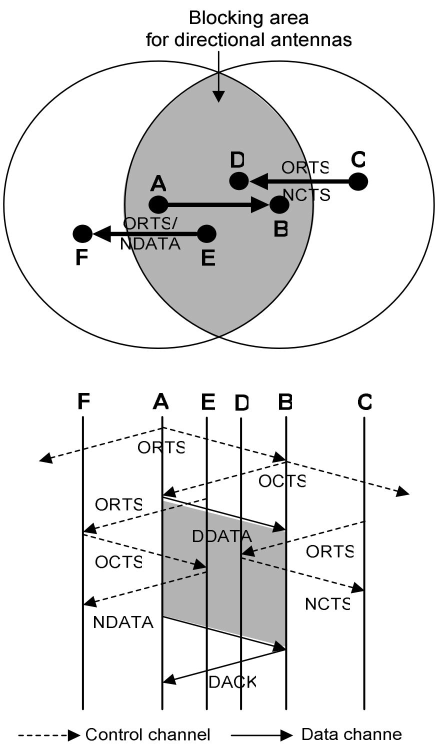


Fig. 4. The operation of the DUDMAC protocol: the NCTS and NDATA mechanisms and the blocking algorithm for directional antennas.

3 A Tone Dual-Channel DMAC Protocol

In this paper, we propose a tone dual-channel DMAC (ToneDUDMAC) protocol without the location information of neighbor's nodes. In the DUDMAC protocol, the ORTS and OCTS mechanisms reduce spatial reuse of directional transmission and increase the probability of collisions of packets in control channel. The proposed MAC protocol uses the ORTS and DCTS packets in control channel and the DDATA and DACK packets in data channel. The ORTS mechanism is used as that in the DUDMAC protocol because the location information of neighbors is unknown. The DCTS mechanism is used to reduce the probability of collisions of packets in control channel. We use an omnidirectional CTS_tone to solve the problem of deafness. The directional DATA_tone is used to reduce the blocking area for directional antennas.

Figure 5 shows the operation of the ToneDUDMAC protocol. Node A transmits ORTS to node B and node B sends DCTS to node A. Then node B transmits omnidirectional CTS_tone to nodes in the coverage to solve the problem of deafness. Node E overhears DCTS and the received directional antenna is blocking. Nodes C, D, and E overhear omnidirectional CTS_tone and these nodes register node B in their deafness table. Therefore, CTS_tone omnidirectional overcomes deafness. Node A received DCTS transmits directional DATA_tone to mitigate the blocking area for directional antennas and

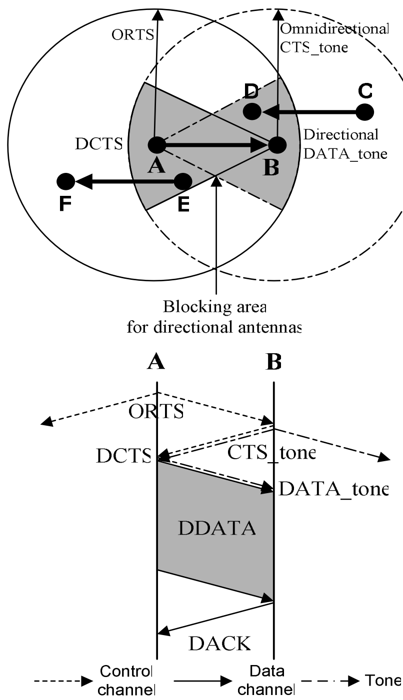


Fig. 5. The operation of the ToneDUDMAC protocol: ORTS and DCTS in control channel and DDATA and DACK in data channel, and omnidirectional CTS_tone and directional DATA_tone.

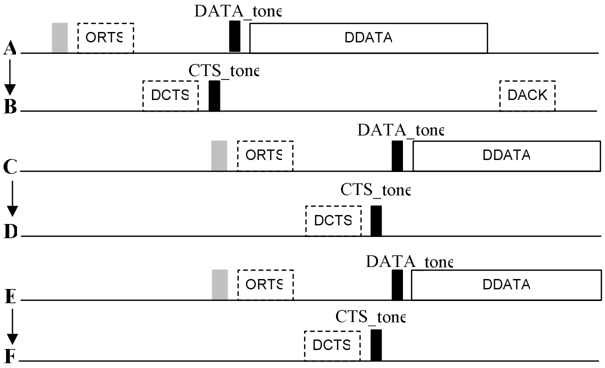


Fig. 6. The operation of the ToneDUDMAC protocol: nodes C and E are transmitted data to nodes D and F, respectively, due to DCTS and directional DATA_tone.

improve spatial reuse. Node D overhears DATA_tone and the received directional antenna is blocked. In DUDMAC, Nodes D and E overhear ORTS and OCTS and the received directional antennas are blocked as shown in figure 4. Therefore, DCTS and directional DATA_tone reduce the number of the blocked directional antennas and improve spatial reuse. The NCTS and NDATA mechanisms as those in DUDMAC are used in ToneDMAC protocol.

Figure 6 shows the operation of nodes C, D, E, and F as shown in figure 4. Node C transmits ORTS to node D in the blocking area caused by directional DATA_tone of node A. Node D transmits DCTS to node C as node D is not in the blocked directional antennas. Then node D transmits CTS_tone and node C transmits DATA_tone after receiving DCTS. Then DDATA and DACK are transmitted over data channel. If node C is in coverage of the blocked directional antenna node C transmits NCTS to node D as that in DUDMAC. Node E in the blocking area of DCTS of node B transmits ORTS to node F and node F sends DCTS to node E. Node E transmits DATA_tone as node F is not in the blocked directional antennas. Therefore, ToneDUDMAC improves spatial reuse by DCTS and directional DATA_tone. The DCTS mechanism also reduces the probability of collisions of packets in control channel. If node F is in coverage of the blocked directional antennas of node E node E transmits NDATA to node F as that in DUDMAC.

4 Simulation Results and Discussions

4.1 Simulations Environments

We use the physical layer of the IEEE 802.11b standard and data rate of 2Mbps. In the proposed MAC protocol and the DUCHA protocol, data rate of control channel and data channel are the same of 1Mbps and transmission range is approximately 250m. We use a static routing, constant bit rate (CBR) traffic, the size of the DATA packet of 1000byte, and 8 switched beam antennas. Important simulation parameter values are shown in table I.

TABLE I
DEFAULT VALUES USED IN THE COMPUTER SIMULATIONS

	Random topology	**Multi-hop topology**
CBR traffic	0.2 ~ 1.0**Mbps**	0.1 ~ 0.5**Mbps**
Distance between nodes	0~250m(random)	200~250m
Data Rate : 2Mbps	**Control channel**	**Data channel**
	1Mbps	1Mbps
Transmission range	250m	
DATA packet size	1000byte	
Simulation time	120sec	

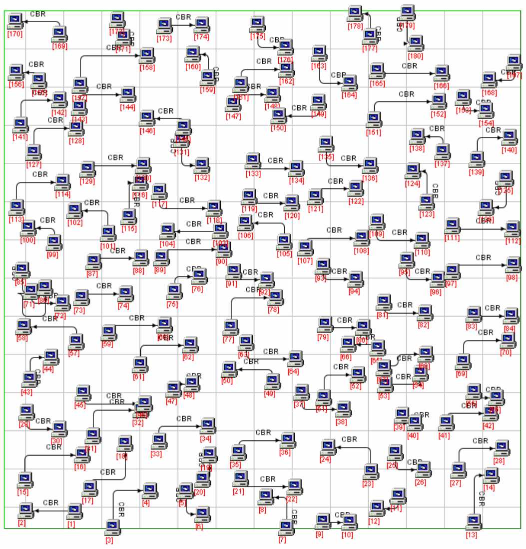


Fig. 7. Single-hop random topology of 180 nodes.

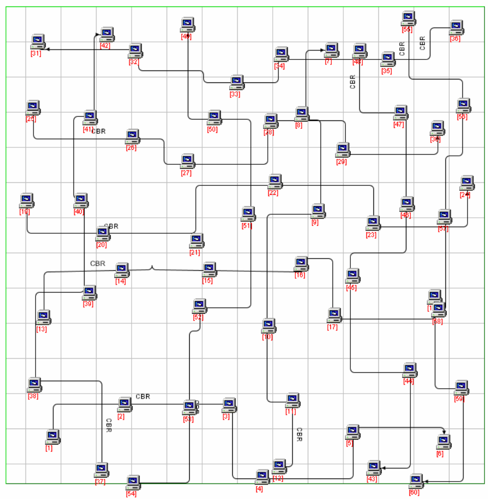


Fig. 8. Multi-hop random topology of 60 nodes.

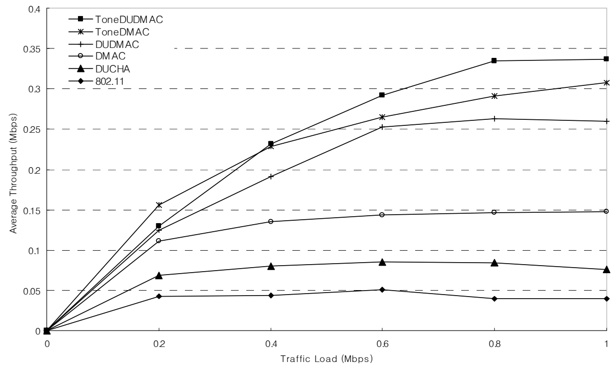


Fig. 9. The average throughput performance of the ToneDUDMAC protocol in the single-hop random topology.

Figure 7 shows a single-hop random topology of 180 nodes. In this scenario, 180 nodes are randomly arranged into the rectangle area of 1000x1000 m^2. The destination nodes are randomly selected in the transmission range of 250m. Figure 8 shows a multi-hop random topology of 60 nodes. This topology arranges 60 nodes into the square area of 1500x1500 m^2 and the distance of each node is 200~250m. We use static routing to minimize effect of routing protocol.

4.2 Simulation Results

We confirm the proposed MAC protocol by computer simulations using Qualnet ver.3.0 simulator [10]. Simulation results of the proposed MAC protocol compare with DUDMAC without location awareness, DMAC with location awareness, DUCHA, and IEEE 802.11 MAC protocol. Figure 9 shows the average throughput of the proposed ToneDUDMAC protocol in the single-hop random topology. Simulation results show that the average throughputs of ToneDUDMAC and DUDMAC without location awareness are superior to those of DMAC, DUCHA, and IEEE 802.11 MAC protocol. The average throughputs are 336kbps, 307kbps, 259kbps, 147kbps, 75kbps and 39kbps for the proposed ToneDUDMAC, ToneDMAC, DUDMAC, DMAC, IEEE 802.11MAC protocol at the traffic load of 1Mbps, respectively.

Figure 10 shows the average throughput performance of the proposed MAC protocol in the multi-hop topology. Simulation result shows that the average throughput of the proposed Tone DUDMAC protocol is better than that of the DUDMAC protocol. The average throughputs are 110kbps, 94kbps, 55kbps, 27kbps, 21kbps and 10kbps for the proposed ToneDUDMAC protocol, DUDMAC, ToneDMAC, DMAC, DUCHA and IEEE 802.11 MAC protocol at the traffic load of 0.5Mbps, respectively. In the multi-hop topology, the throughput performance of the MAC protocols at the traffic load of 0.5Mbps is worse that at the traffic load of 0.2Mbps as collisions of the ORTS packets are increased in heavy traffic. Simulation results show that the throughput

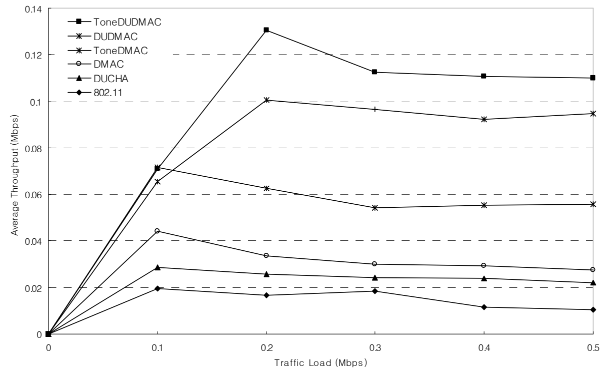


Fig. 10. The average throughput performance of the ToneDUDMAC protocol in the multi-hop topology.

performance of the proposed Tone DUDMAC protocol is better than that of the DUDMAC protocol although the proposed MAC protocol does not require the location information of neighbors.

5 Conclusion

We propose a ToneDUDMAC protocol to improve spatial reuse. In the proposed MAC protocol, ORTS and DCTS are transmitted over control channel and DDATA and DACK are transmitted over data channel. The NCTS and NDATA mechanisms are used to prevent collisions of packets in data channel as those in DUDMAC. DCTS and directional DATA_tone reduce the blocking area for directional antennas and therefore, improve spatial reuse. DCTS also reduces collisions of packets in control channel. We confirm the average throughput of the proposed MAC protocol in multi-hop and random topologies by using Qualnet ver3.8 simulator. Simulation results show that average throughput of the proposed MAC protocol is better than that of the DUDMAC, ToneDMAC, DMAC, DUCHA, and IEEE 802.11 MAC protocols in the multi-hop environments.

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