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

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ABSTRACT

The directional MAC (DMAC) protocol improves the spatial reuse, but directional packets on the control channel cause the deafness problem. In this paper, we propose a tone dual-channel DMAC protocol for mobile ad-hoc networks. In the proposed MAC protocol, the use of omnidirectional transmissions using an omnidirectional out-of-band tone solves the deafness problem and decrease packet collisions on the control channel. The use of an omnidirectional out-of-band tone also mitigates the hidden terminal problem. We use the negative CTS (NCTS) mechanism to solve the exposed terminal problem. The throughput performance of the proposed MAC protocol is confirmed by simulations using the Qualnet simulator.

***Keywords**: Ad-hoc MAC Protocol, Directional Antenna, Dual-channel MAC, Out-of-band Tone.*

1. INTRODUCTION

Ad-hoc medium access control (MAC) protocols [1] using an omnidirectional antenna have been proposed to W-LANs and ad-hoc networks. The use of omnidirectional transmission has a low the spatial reuse and has a poor throughput performance. The directional MAC (DMAC) protocols [2]-[4] have been proposed to improve the spatial reuse, but have the deafness problem caused by directional transmissions. The DMAC protocol [2] uses the blocking algorithm for directional antennas to improve the spatial reuse. In the DMAC protocol, the directional antenna after overhearing RTS or CTS is blocked to prevent packet collisions. If all directional antennas of node are unblocked, node uses the omnidirectional RTS (ORTS) to mitigate deafness. However, the use of omnidirectional transmission reduces the spatial reuse. If one or more directional antennas of node are blocked, node sends DRTS to improve the spatial reuse. However, the use of directional transmission has the deafness problem. Retransmissions of RTS to node in deafness exponentially increase the back-off duration of the sender. Therefore, the DMAC protocol has a tradeoff between the spatial reuse and the deafness problem.

The ToneDMAC protocol [5] has been proposed to mitigate deafness. In the ToneDMAC protocol, an out-of-band tone is uniquely assigned to each node using a static hash function of a node's unique identifier. An out-of-band tone is transmitted to its neighbors after transmitting DDATA or DACK. Nodes after overhearing an out-of-band tone reset the increased back-off period caused by deafness and start retransmission after their back-off duration. Therefore, an out-of-band tone mitigates the deafness problem, but cannot reduce interference packets caused by retransmissions to node in deafness. Retransmissions to node in deafness increase the packet collision probability and degrade the throughput of ad-hoc networks.

In the dual-channel (DUCHA) MAC protocol [6], the use of the separated control and data channels has been proposed to improve the throughput performance. In the DUCHA MAC protocol, RTS and CTS are transmitted on the control channel and DATA is transmitted on the data channel. An out-of-band busy tone and the negative CTS (NCTS) mechanism solve the hidden and exposed terminal problems, respectively. However, the use of omnidirectional transmission in the DUCHA MAC protocol degrades the throughput of ad-hoc networks. The dual-channel DMAC (DUDMAC) protocol [8] has been proposed to improve the spatial reuse. In the DUDMAC protocol, RTS and CTS are transmitted omnidirectionally on the control channel to overcome deafness and DATA and ACK are transmitted directionally on the data channel to improve the spatial reuse. However, the use of omnidirectional transmission on the control channel reduces the spatial reuse and degrades the throughput of ad-hoc networks.

In this paper, we propose a tone dual-channel DMAC (ToneDUDMAC) protocol to improve the throughput capacity of ad-hoc networks. In Section 2, we describe the operation of the proposed MAC protocol. In Section 3, the throughput performance of the proposed MAC protocol is confirmed by simulations. Finally, we draw our conclusions in Section 4.

2. TONE DUAL-CHANNEL DMAC PROTOCOL

In this paper, we propose a dual-channel DMAC protocol with an omnidirectional out-of-band tone. An out-of-band tone is uniquely assigned to each node using a static hash function of a node's unique identifier as that in the ToneDMAC protocol

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[5]. In the proposed MAC protocol, RTS and CTS are transmitted on the control channel and DATA and ACK are transmitted on the data channel directionally. Before transmitting DRTS or DCTS, the transmitter sends an omnidirectional out-of-band tone to solve the deafness problem and mitigates the hidden terminal problem.

Figures 1 and 2 show the operation of the proposed MAC protocol. Node A check its deafness table whether destination node B's identifier is in its table or not. If destination node B is in its table then wait for expiring node B’s waiting timer. If destination node B is not in its deafness table then node A sends the omnidirectional out-of-band tones Tone A with the unique identifier and DRTS. Destination node sends the omnidirectional out-of-band tones Tone A with the unique identifier and CRTS after receiving DRTS.

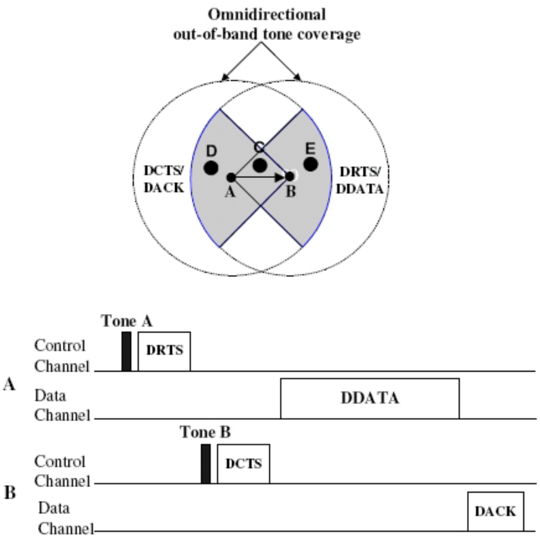

Fig. 1. The tone dual-channel DMAC protocol: an omnidirectional out-of-band tone before transmitting DRTS or DCTS solves the problem of deafness and mitigates the hidden terminal problem.

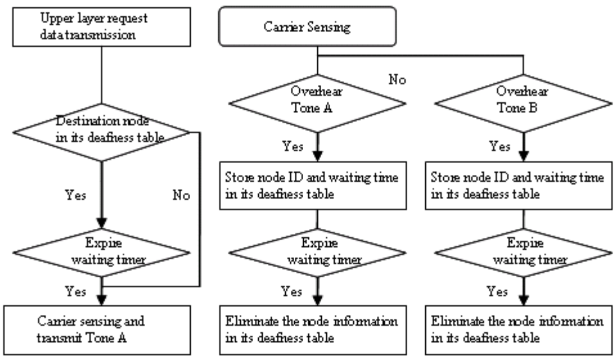

Fig. 2. The operation of the tone dual-channel DMAC protocol.

Nodes C, D, and E after overhearing Tone A and Tone B store the received node A and B's unique identifiers and the received time in their deafness tables. In this paper, nodes C, D, and E receive the out-of-band tones directionally to improve the tone detection probability as in the case of the ToneDMAC protocol. Then, nodes A and B exchange DDATA and DACK on the data channel. If node D has a packet to transmit node A node D checks its deafness table whether node A's identifier is in its table or not. If node A's identifier is in its deafness table node D waits for the end of transmission using the received time of Tone A saved in its deafness table. The waiting time is calculated as the received time plus transmission time interval from RTS to ACK. Therefore, an out-of-band tone solves the problem of deafness and improves the throughput of ad-hoc networks.

In the proposed MAC protocol, we use the NCTS mechanism on the control channel combined with a blocking algorithm for directional antennas as that in the DUDMAC protocol [8]. The directional antenna of node is blocked on the reception DRTS or DCTS. In a single channel MAC protocol such as the ToneDMAC protocol, node cannot transmit any packets with the blocked directional antenna. However, in the dual-channel MAC protocol, the receiver can send NCTS on the separated control channel in the blocked directional antenna direction. The sender after receiving NCTS waits until the blocked directional antenna of the destination node is unblocked using the duration field in NCTS. Therefore, the NCTS mechanism solves the exposed terminal problem and prevents retransmissions to the blocked directional antenna. Figure 3 shows the operation of the NCTS mechanism. The directional antennas of node C that overhear DRTS of node A and DCTS of node B are blocked and the received time of DRTS and DCTS is stored in its NCTS table. If node C receives RTS of node D or node E from the blocked directional antenna, node C sends NCTS with the received time of DRTS or DCTS in its NCTS table to avoid packet collisions on the data channel. Node D or E receiving NCTS waits for the end of communications between nodes A and B using the duration field in NCTS.

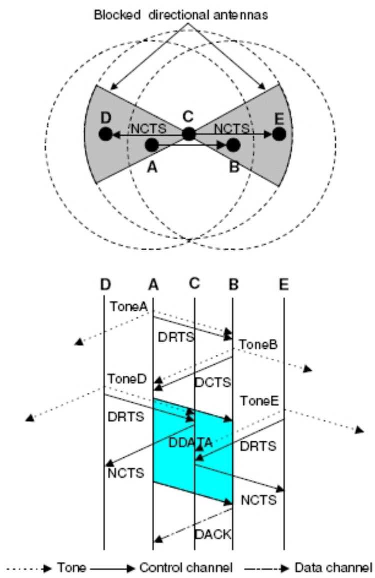

Fig. 3. The NCTS mechanism on the control channel: node C with the blocked directional antennas sends NCTS on the separated control channel to solve the exposed terminal problem.

3. SIMULATION RESULTS AND DISCUSSIONS

We confirm the throughput of the proposed MAC protocol by simulations using the Qualnet simulator [10]. The throughput of the proposed MAC protocol is compared with those of dual-channel DMAC, ToneDMAC, DMAC, DUCHA MAC, and IEEE 802.11 MAC. For the simulations, we use IEEE 802.11b physical layer and a data rate of 2Mbps and a two-ray Rayleigh fading channel model. Other default values of the important simulation parameters are as follows: transmission range of each node 250m, a DATA packet size of 1000byte, 8 switched beam (beamwidth=45^{o}) antennas, static routing, and constant bit rate (CBR) traffic. The important parameter values in the simulations are shown in table 1.

Table 1. Key parameter values in the simulations.

Topology	Single-hop	Multi-hop
CBR traffic	0.2∼1.0Mbps	0.1∼0.5Mbps
Distance between nodes	0∼250m(random)	200∼250m
Data rate : 2Mbps	Control channel	Data channel
	0.5Mbps	1.5Mbps
Channel model	two-ray model	
DATA packet size	1000bytes	
Simulation time	120sec	

Figure 4 shows a single-hop random topology of 180 nodes. In this scenario, 180 nodes are randomly arranged into the square area of 1000x1000m2. Figure 5 shows a 5-hop random topology of 60 nodes. This scenario arranges 60 nodes into the square area of 1000x1000m^2. We use the random waypoint mobility model in which the mobility scenarios are created by BonnMotion [9]. In the mobility model, each node has the maximum speed of 2.2m/sec and the pause time of 0.

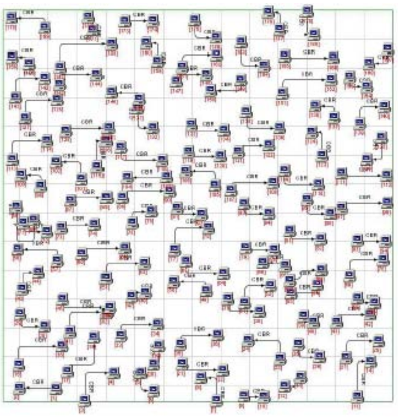

Fig. 4. The single-hop random topology of 180 nodes in the square area of 1000x1000m^2.

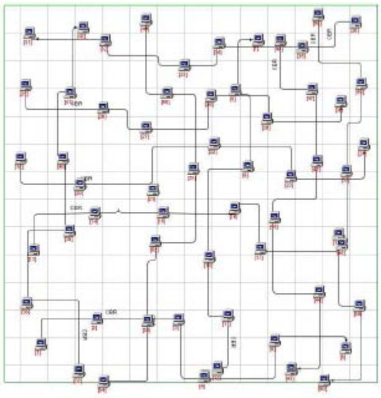

Fig. 5. The 5-hop random topology of 60 nodes in the square area of 1000x1000m^2.

In the dual-channel (DUCHA) MAC protocol [6][7], the channel bandwidth allocation for the separated control and the data channels is an important design parameter. In DUCHA MAC, channel bandwidths for the control and data channels are determined to minimize the total time for a successful transmission of a packet as follows

$$T_p = \frac{L_{RTS} + L_{CTS}}{R_{CTS}} + \frac{L_{DATA}}{R_{DATA}} \quad (1)$$

where L_{RTS}, L_{CTS}, and L_{DATA} are the lengths of RTS, CTS, and DATA, respectively. R_{CTS} and R_{DATA} are data rates of control and data channels. In this paper, we modify (1) to consider the transmission time of the PLCP preamble as follows

$$T'_p = T_p + PLCP_{RTS} + PLCP_{CTS} + PLCP_{DATA} \quad (2)$$

where $PLCP_{RTS}$, $PLCP_{CTS}$, and $PLCP_{DATA}$ are the PLCP preamble transmission time in RTS, CTS, and DATA, respectively. We also calculate the total time for a successful transmission of a packet in the proposed MAC protocol as follows

$$T''_p = T'_p + \frac{L_{ACK}}{R_{DATA}} + PLCP_{ACK} \quad (3)$$

where L_{ACK} is the length of ACK and $PLCP_{ACK}$ is the PLCP preamble transmission time in ACK. Figure 6 shows the total transmission time relative to a data rate of the control channel calculated from (1), (2), and (3). The total time for a successful transmission of a packet has a minimum value at the control speed of 0.5Mbps from (2) and (3). Therefore, we choose the control channel speed of 0.5Mbps and the data channel speed of 1.5Mbps to maximize throughputs of the proposed MAC protocol and DUCHA MAC. The length of the PLCP preamble is 192bits. Therefore, the transmission time of the PLCP preamble is 192μsec at IEEE 802.11 MAC and 768μsec at the proposed MAC protocol and DUCHA MAC. The transmission time of RTS and CTS is 384μsec.

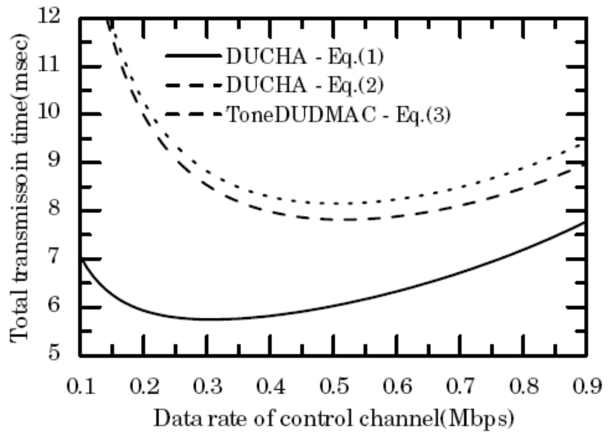

Fig. 6. The total time for a successful transmission of a packet relative to the control channel speed.

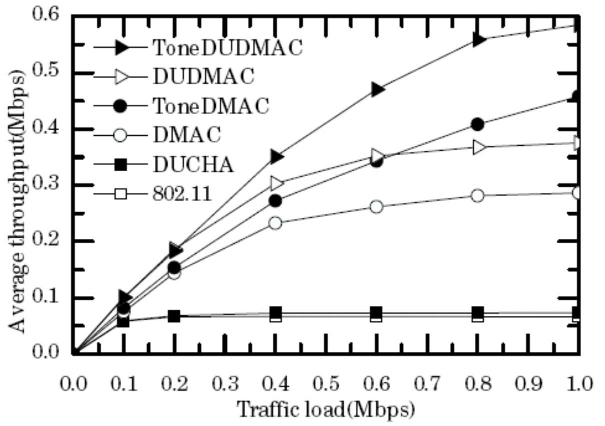

Fig. 7. The throughput performance of the tone dual-channel DMAC protocol in the single-hop random topology.

The throughputs of the proposed MAC protocol in the single-hop and 5-hop random topologies are shown in figures 7 and 8, respectively. Figure 7 shows that the throughput of the proposed MAC protocol in the single-hop random topology. In the single-hop environment, the use of omnidirectional transmissions using the out-of-band tone solves the deafness problem as that using ORTS and OCTS in the DUDMAC protocol. The directional packets on the control channel improve the spatial reuse compared to the DUDMAC protocol. The simulation results show that the propose MAC protocol improve the throughput performance relative to those of the DUDMAC and DUCHA MAC protocols improves at high traffic load. Figure 7 show that throughputs are 584.8kbps, 458.1 375.2kbps, 286.6kbps, 73.4kbps, and 66.9kbps for the proposed MAC protocol, ToneDMAC, DUDMAC, DMAC, DUCHA MAC, IEEE 802.11 MAC protocols at the traffic load of 1Mbps, respectively. We simulate the proposed MAC protocol in the single-hop random topology under the random waypoint mobility model. Simulation results show that the average throughputs are 232.2kbps, 147.3kbps, 80.2kbps, 75.0kbps, 38.9kbps, and 35.4kbps for the proposed MAC protocol, DUDMAC, ToneDMAC with ORTS, DMAC with ORTS, DUCHA MAC and IEEE 802.11 MAC protocols at the traffic load of 1Mbps.

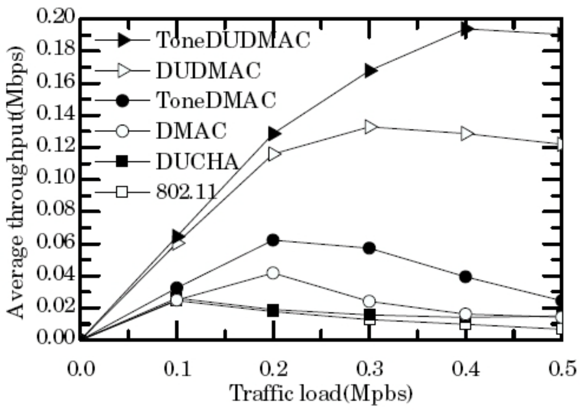

Fig. 8. The throughput performance of the tone dual-channel DMAC protocol in the 5-hop random topology.

Figure 8 shows the throughput performance of the proposed MAC protocol in the 5-hop random topology. In the multi-hop environment, the use of an omnidirectional out-of-band tone before DRTS or DCTS solves the deafness problem. The NCTS mechanism solves the exposed terminal problem. The DRTS and DCTS on the control channel improve the spatial reuse and throughput. Therefore, the throughput of the proposed MAC protocol is superior to those of the DUDMAC and ToneDMAC protocols at high traffic load. In figure 8, throughputs are 190.4kbps, 122.0kbps, 24.5kbps, 14.2kbps, 15.0kbps, and 6.7kbps for the proposed MAC protocol, DUDMAC, ToneDMAC, DMAC, DUCHA MAC, and IEEE 802.11 MAC protocols at the traffic load of 0.5Mbps, respectively.

3. CONCLUSIONS

In this paper, we propose a tone dual-channel DMAC protocol. In the proposed MAC protocol, the use of an omnidirectional out-of-band tone before sending DRTS or DCTS solves the problem of deafness and mitigates the hidden terminal problem. The use of directional antennas on the control channel improves the spatial reuse and the NCTS mechanism solves the exposed terminal problem. We confirm the throughput of the proposed MAC protocol by the simulations in the single-hop and 5-hop random topologies. The simulation results show that the throughput of the proposed MAC protocol is better than those of the DUDMAC, ToneDMAC, DMAC, DUCHA MAC, and IEEE 802.11 MAC protocols in the single-hop and multi-hop ad-hoc networks.

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REFERENCES

[1] C.S.R. Murthy and B.S. Manoj, *Ad Hoc Wireless Networks - Architectures and Protocols*, Prentice Hall, 2004.

[2] Y.B. Ko, V. Shankarkumar, and N.H. Vaidya, "Medium Access Control Protocols Using Directional Antennas in Ad Hoc Networks", *IEEE INFOCOM 2000*, March 2000, pp.13-21.

[3] R.R. Choudhury, X. Yang, N.H. Vaidya and R. Ramanathan, "Using directional antennas for medium access control in ad hoc networks", *MOBICOM*, 2002, pp.57-90.

[4] P. Li, H. Zhai, and Y. Fang, "SDMAC: Selectively Directional MAC protocol for wireless mobile ad hoc networks", *Wireless Networks*, 2009, vol. 15, no. 6, pp.805-820.

[5] R.R. Choudhury and N.H. Vaidya, "Deafness : A MAC problem in Ad hoc networks when using Directional Antennas", *ICNP*, 2004, pp.283-292.

[6] H. Zhai, J. Wang, and Y. Fang, "A Dual-Channel MAC Protocol for Mobile Ad Hoc Networks", *IEEE Globecom*, 2004, pp.27-32.

[7] H. Zhai, J. Wang, and Y. Fang, "DUCHA: A New Dual-Channel MAC Protocol for Multihop Ad Hoc Networks," *IEEE Trans. Wireless Commun.*, Nov. 2006, pp.3224–3233.

[8] D.H. Han, J.W. Jwa, H.I. Kim, "A Dual-Channel MAC Protocol using Directional Antennas in Location Aware Ad Hoc Networks," *ICCSA 2006, LNCS3983*, May 2006, pp.594-602.

[9] BonnMotion A mobility scenario generation and analysis tool,http://web.informatik.unibonn.de/IV/Mitarbeiter/dewaal/ BonnMotion/.

[10] Scalable Network Technologies, Qualnet simulator, www.scalable-networks.com.

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