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[2B-3] Rate-Adaptive MAC Protocol for Efficient Use of Channel Resource in Wireless Multi-hop Networks
Byungjoo Lee(Innowireless, Korea), Seung Hwan Lee, Seung Hyong Rhee (Kwangwoon University, Korea)

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[2C-2] Minimizing the Joining Delay for Cooperation in Mobile Robot Networks
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[2C-3] A Cooperative Communication System using Cross-Layer Coding Method base on Hybrid-ARQ
Tae Doo Park, MinHyuk KIM, Chul Seung Kim, Jiwon Jung (Korea Maritime University, Korea)

[2C-4] Seamless Mobility Provisioning by Dual Cross-linking Method in WLAN
Myeongyu Kim, Kyungseok Lee, Youchan Jeon, Jinwoo Park (Korea University, Korea)

[2C-5] Mobile Media Distribution using Segment Scheduling for Opportunistic Regional Clusters
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Session 3A: Wireless Ad-Hoc Networks

Chair: Sejun Song (Texas A&M University, USA)

[[3A-1] Performance of Modified AODV (Waiting AODV) Protocol in Mobile Ad-hoc Networks
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[3A-2] Joint Grouping and Scheduling in Complexity-Constrained Broadcasting Ad-Hoc Networks
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[3A-3] Quantifying traffic anonymity in MANETs: a case study
Marga Nacher, Carlos Calafate, Juan Carlos Cano Escriba, Pietro Manzoni (Universidad Politecnica de Valencia, Spain)

[3A-4] Development of 27MHz/40MHz Bands M aritime Wireless Ad-hoc Networks
Toru Yoshikawa, Masahiro Takase, Yasushi Hiraoka(Furuno Electric, Japan), Shinichiro Kawasaki(Hokuoh Information, Japan), Yumi Takaki, Chikara Ohta, Takeshi Inoue (Kobe University, Japan)

[3A-5] Performance Analysis of Circular Directional MAC Protocol
Woong Soo Na, Lai Hyuk Park, Gun Woo Lee, Sungrae Cho (ChungAng University, Korea), Seung-Eun Hong, Woo Yong Lee (ETRI, Korea)

Session 3B: QoS/QoE Provisioning

Chair: Ryoichi Shinkuma (Kyoto Univ., Japan)

[3B-1] Performance Analysis of a Prioritization Scheduling Scheme for Asynchronous Optical Packet Switching Networks
Kuan-Hung Chou, Woei Lin (National Chung-Hsing University, Taiwan)

[3B-2] Approximate Queuing Analysis For IEEE 802.15.4 Sensor Network
Nan Tuan Le, Sun Woong Choi, Yeong Min Jang (Kookmin University, Korea)

[3B-3] NGOSS Based OSS/BSS Architecture for Hosting Common Platform for Convergence Services
Young-Hyun Choi, Dong-Min Kang, Soo-Duek Kim, Seon-Ho Park (Sungkyunkwan University, Korea), ChangSup Keum (ETRI, Korea), Tai-Myoung Chung (Sungkyunkwan University, Korea)

[3B-4] Towards a Schedule Based MAC Protocol with QoS Provisioning for Sensor Networks
Kazi Ashrafuzzaman, Kyung Sup Kwak (Inha University, Korea)

[3B-5] Application Level QoS Control in Wireless LANs
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Session 3C: Cellular and Broadband Wireless

Chair: Eiji Okamoto (Nagoya Inst. of Tech., Japan)

[3C-1] Wireless Security and Monitoring System Based on Space-Time Signal Processing
Tomoaki Ohtsuki (Keio University, Japan)

[3C-2] Performance and Complexity Evaluation of Pilot-based Channel Estimation Algorithms for 3GPP LTE Downlink
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[3C-3] Full Duplex 60 GHz Millimeter Wave Transmission over Multi-Mode Fiber
S. R. Abdollahi, H.S. Al-Raweshidy (Brunel University, United Kingdom), S. Mehdi Fakhraie, R. Nilavalan and M. Kamarei(Tehran University, Iran)

Performance Analysis of Circular Directional MAC Protocol

Woongsoo Na, Laihyuk Park,
Gunwoo Lee, Sungrae Cho
School of Computer Engineering and Science
221 Heukseok, Dongjak
Seoul, South Korea
wsna@uclab.re.kr

Seung Eun Hong, and Woo Yong Lee
Super-Speed Wireless Transmission Research Team
Electronics and Telecommunications Research Institute
Daejon, South Korea
iptvguru@etri.re.kr

***Abstract*—There have been great attentions on directional MAC (D-MAC) protocol recently in wireless ad hoc networks. Even if directional MAC has benefits such as spatial reuse and thus increased throughput, it has significant problems that have not been effectively rectified including hidden terminal and deafness problems. To tackle the hidden terminal and deafness problems, we propose a new D-MAC protocol that uses circular RTS (CRTS) and circular CTS (CCTS). We evaluate the performance of our protocol using ns-2 simulator. Performance evaluation shows that our proposed D-MAC protocol can reach up to 800% throughput gain with scenario 2 (24 nodes) against scenario 1 (3 nodes).**

Keywords*—*Circular Directional MAC, CRTS , CCTS , Ad Hoc Net works , Directional Antenna.

I. INTRODUCTION

MAC protocols for directional antenna in ad hoc networks have recently drawn attentions due to 60GHz spectrum (IEEE802.11ad and IEEE802.15.3c). It has an advantage of spatial reuse compared with omni-directional antenna due to transmission range and increased aggregate throughput.

Despite of this advantage, directional MAC (D-MAC) has two major problems. The first is hidden terminal problem. Hidden terminal problem occurs if another device interfere on-going communication by causing collision. Consequently, throughput of on-going communication is degraded. For instance, let us assume 4 nodes (A, B, C, D) placed in series. Nodes C and D are communicating each other by switching their receiving and transmitting antenna mode to directional one. Assume that node A is not aware of this situation. Now, node A has a data to send B. However, A's RTS accidentally reaches to node D's receiving range due to some channel conditions. This leads to collision and the on-going communication's throughput is decreased (see Figure1).

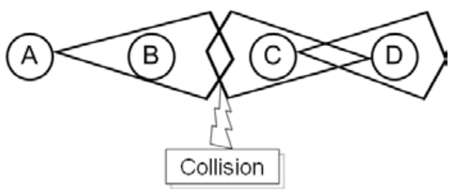

Figure 1. Example of hidden terminal problem

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The second one is called deafness problem. Deafness problem occurs if a device does not answer an RTS message addressed to it and consequently originator of the RTS will try more RTSs while increasing contention window, during which messages toward other devices are subject to be blocked. For example, assume that 3 nodes (A, B, C) which are equipped with 4 element-switched beam antenna. Assume that nodes B and C are communicating each other through the directional antenna. Since beams 2, 3, and 4 are not used, node B blocks corresponding antennas. Similarly, node C blocks beams 1, 2, and 3. At that time, assume that node A want to send data to node C. Then, node A send the RTS frame to node C. However, node A does not listen to the RTS frame unfortunately because the directional antenna toward to node A is blocked. Fig 2 depicts the deafness problem in the wireless ad hoc networks.

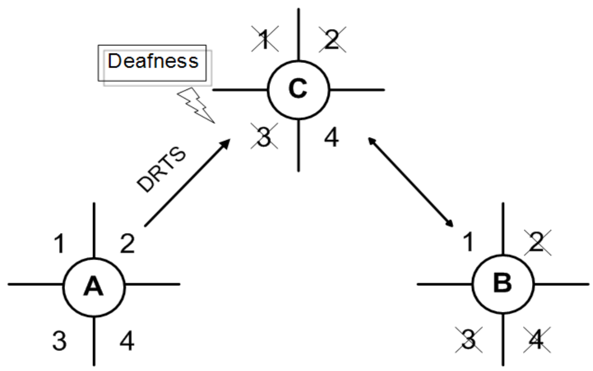

Figure 2. Example of deafness problem

To overcome these problems, many directional MAC protocol schemes have been proposed [1-12]. Although a lot of efforts have been developed to alleviate the problems, those are still existent.

In this paper, we propose a new directional MAC protocol with the aim to resolve the above problems. The main idea of our protocol is to transmit RTS and CTS frames circularly, i.e., circular RTS (CRTS) and circular CTS (CCTS). When a node has a data to transmit, these control frames can advertise neighboring nodes that the node wants to transmit data. Using these control frames, hidden terminal and deafness problems can be effectively resolved.

The rest of this paper is organized as follows. In section 2, related work on directional MAC protocols are described by discussing benefits and drawbacks. Section 3 presents our circular directional MAC protocol. In section 4, the throughput performance evaluation of our proposed D-MAC protocol is given. Finally, we draw conclusions and suggest future directions in section 5.

II. RELATED WORK

D-MAC protocols can be classified by non-circular and circular protocols with means of transmitting control frames (RTS or CTS). Unlike RTS/CTS, DATA and ACK frames are transmitted directionally. Circular D-MAC is the one whose antenna beam rotates using beam-forming technique or ratchets using switched beam antenna only when transmitting control frames (RTS/CTS). Other than ones that fall in category of circular D-MAC is called non-circular protocol.

According to the above taxonomy, MAC protocols in the [1], [2], [9], [3], [4], [5], [6], and [11] are non-circular D-MAC protocols. The above D-MACs are distinguished by transmitting method of RTS/CTS frames. The work in [1], [9], and scheme 2 in [2] uses the omni-directional RTS and omni-directional CTS (ORTS/OCTS) similar to IEEE802.11 MAC. Their aggregate throughput is very low since they do not fully exploit spatial reuse due to omni-directional coverage. In [2], Y. B. Ko proposed DMAC scheme 1 where RTS frame is transmitted directionally (DRTS), and uses physical and virtual carrier sense. Although this protocol utilizes benefit of spatial reuse, hidden terminal and deafness problems still exist. In [11], Tone DMAC is proposed. This D-MAC protocol uses DRTS, directional CTS (DCTS), and an additional control frames to handle deafness problem. In [4], R. R Choudhury proposed MMAC (Multi-hop RTS MAC) protocol where physical and virtual carrier sense functions are also performed directionally. Specifically directional virtual carrier sensing is implemented by DNAV (Directional NAV) which is directional version of NAV.

Researches in [7], [8], and [12] are circular D-MAC protocols. Except [7], the rest of the studies use CRTS and DCTS frames, which does not effectively resolve the hidden terminal and deafness problems. In [7], RTS frame keeps being sent directionally to cover all directions of the antenna beams. Then, the receiving node sends CTS directionally to all directions except the area that has been already covered by the previous RTS frame. This is to remove redundant coverage. However, we found that this approach increases hidden terminal and deafness problems. We will demonstrate this in the performance evaluation.

In this paper, we propose a new D-MAC protocol which fully utilizes CRTS/CCTS. Unlike [7], CTS frame covers all directions to remove any potential hidden nodes or deafness.

III. PROTOCOL DESCRIPTION

Our directional MAC scheme uses the CRTS/CCTS frames. These are helpful to alleviate existing D-MAC problems. Transmissions of CRTS frame follow the following procedure:

Step 1) The source node finds destination node's location

Step 2) The source node determines which beams can over the destination. Let B_D denote the beam.

Step 3) The source node starts to send CRTS frames using adjacent beams of B_D clockwise except B_D.

Step 4) The source node sends a CRTS frame using beam B_D lastly.

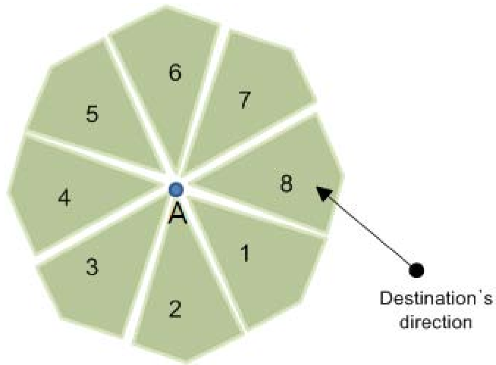

Figure 3. The circular-directionally transmission

If the CRTS frame is arrived to destination node successfully, the destination node prepares CCTS frames to all directions as a respond to CRTS frame. The CCTS frame is transmitted sequentially similar to CRTS frame. The CCTS frames are transmitted as the following step.

Step 1) The destination node checks the CRTS frame and identifies the source node location.

Step 2) The destination determines beam number where the source node belongs to. Let B_S denote the beam.

Step 3) The destination node start to send CCTS frame frames using adjacent beams of B_S clockwise except B_S.

Step 4 The destination node sends a CCTS frame using beam B_S lastly.

This mechanism is similar to [7]. But our scheme is different from the way of CCTS transmission. In [7], the destination node transmits CCTS frame to partial direction which does not overlap the area where CRTS is sent earlier. Therefore, there should be some areas which are not fully covered by CRTS and CCTS. This would create a potential hidden terminal or deafness problems due to unexpected channel conditions. However, our protocol sends CCTSs thoroughly all directions. Figure 4 illustrates CRTS and CCTS coverage in our scheme.

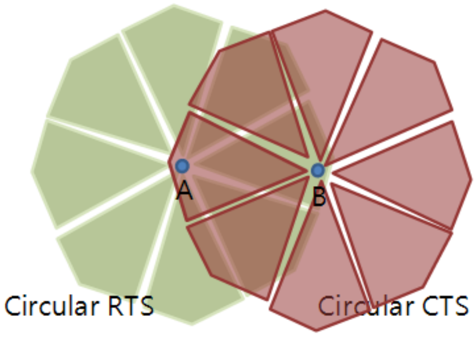

Figure 4. The range of Circular MAC Protocol

Now, we show how our protocol can mitigate problem through examples. In Figure 1, the hidden terminal problem occurred because node A does not aware of communicating nodes C and D. But this problem can be resolved if applying our scheme. Before node C transmits to node D, the CRTS frames are sent to all directions circularly. Then, the nodes A and B are aware that node C's state (transmitting). So, nodes A and B may block antennas towards C's direction. Then nodes A and B update D-NAV table. The D-NAV is a network allocation vector for directional version (see Figure 5). In Figure 5, each antenna has a special direction, and Remain_Time represents the residual transmission time of any communication in that beam. Information for updating D-NAV table is included in the control frames (CRTS and CCTS). After CRTS is transmitted, node D starts sending CCTS frames to all directions as well. When node A wants to transmit to node C, node A check its D-NAV table. If the D-NAV value is still positive, node A delays its transmission. Deafness problem can be also solved in this scheme in the similar way. Because a node that wants to communicate aware of on-going transmission information, the node does not transmit until neighbor nodes stop transmission.

Antenna_Number	Direction	Remain_Time
1	0-90	0.02
2	90-180	X
3	180-270	X
4	270-360	0.03

Figure 5. The example of D-NAV Table

IV. Simulation Result

We simulate our protocol with ns-2 simulator. NS-2 is one of the most popular network simulators with the merit of open source and versatile support for many MAC protocols. Despite of these merits, NS-2 does not support directional antenna feature. So we develop directional antenna feature additionally with modification of MAC protocol code in the ns-2.

Our simulation environment is as follows. The packet size is 1024 bytes and basic data rate is 2Mbps. We use the CBR traffic generator. All of the simulation result is run for 200 seconds. The distance is 200 meters between two nodes. The transmission power is changed by a beam width. We measure a aggregate network throughput. In our simulations, we use nodes that are equipped with antenna arrays of 4 elements. Also, we change the packet inter-arrival time.

In the scenario 1, we deploy three nodes in series (see Figure 6). We set nodes A and B communicate each other. Then, the node C starts sending packets to node B giving rise to collision. Figure 7 shows the result of scenario 1.

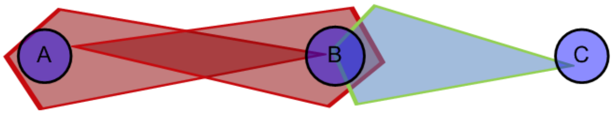

Figure 6. The scenario 1 topology

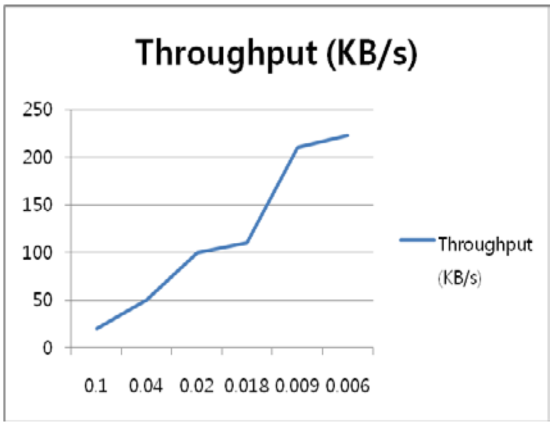

Figure 7. The result of scenario 1

Figure 7 depicts the aggregate throughput with varying inter-arrival times of packet generated from CBR source. The aggregated throughput ranges from 25 to 230KB/s.

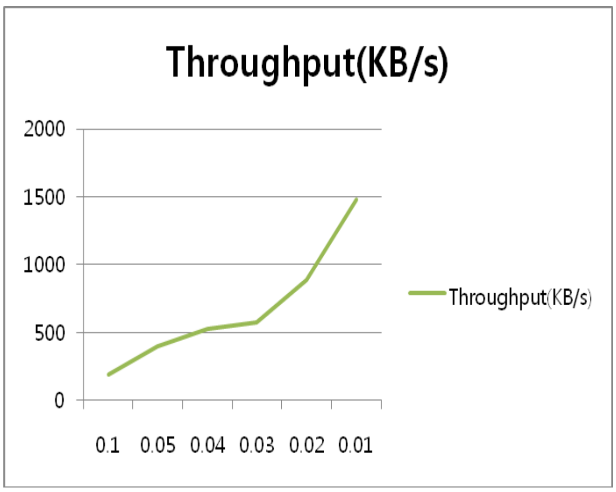

Figure 8. The result of scenario 2

In the scenario 2, we use 24 nodes that are transmitting pair wise. This topology uses a grid topology. The aggregate throughput is depicted in Figure 8. In Figure 8, we observe the similar behavior as we had in Figure 7. However, unlike Figure 7, the throughput ranges from 200 to 1,500 KB/s in the same size of space. Therefore, we obtain up to 800% of throughput gain. This is because we fully utilize spatial reuse with antenna arrays of 4 elements. In scenario 2, several parallel on-going transmissions are possible because of spatial reuse.

VI. CONCLUSION

MAC protocols for directional antenna in ad hoc networks have recently drawn attentions due to 60GHz spectrum (IEEE802.11ad and IEEE802.15.3c). It has an advantage of spatial reuse compared with omni-directional antenna due to transmission range and increased aggregate throughput.

In this paper, we propose a new D-MAC protocol with CRTS and CCTS. The proposed D-MAC protocol aims to resolve the hidden terminal and deafness problems which are inherited from unique features of directional antenna.

The simulation results show our protocol is efficient enough with respect to spatial reuse. Performance evaluation shows that our proposed D-MAC protocol can reach up to 800% throughput gain with scenario 2 (24 nodes) against scenario 1 (3 nodes).

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