Directional Mac with Deafness Solution for Ad Hoc Network

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Abstract - This paper addresses deafness problem that occur when MAC protocols are designed by using directional antennas. Briefly, Deafness is caused when two nodes are busy in ongoing transmission and another node (Deaf Node) wants to communicate with any of these busy nodes. But it gets no response because transmission of two nodes is in process. This paper proposes DMAC/DS (Directional MAC with Deafness Solution) to overcome the deafness problem. In DMAC/DS, WTP (Wait for Time Period) frames are transmitted by the transmitter and the receiver after the successful exchange of RTS (Request To Send) and CTS (Clear To Send) directionally to notify the ongoing communication to potential transmitter node that may experience deafness. We evaluate our protocol through extensive simulation study with different values of parameters such as the number of flows, data size and bandwidth. The experimental results show that DMAC/DS outperforms existing directional MAC protocols, such as DMAC/DA (MAC with Deafness Avoidance) and MDA (MAC protocol for Directional Antennas), in terms of throughput, RTS failure ratio, and control overhead.

Keywords - Ad Hoc Network, Medium Access Control, Directional antennas.

1. Introduction

A wireless ad hoc network is a network where nodes can communicate with each other without the support of fixed infrastructure or central administration [1]. Communication is directly between nodes or through intermediate nodes acting as routers. It can be set up easily and quickly with low cost. In previous works on wireless ad hoc networks [2], omnidirectional antennas that radiate or receive power equally well in all directions are usually used. Traditional MAC protocols using omnidirectional antennas such as IEEE 802.11 DCF (Distributed Coordination Function) [3] cannot achieve high throughput in wireless ad hoc networks because they waste a large portion of network capacity as discussed in [3]. Directional antenna has great potential to deal with this problem and to improve the network performance, such as range extension and high spatial reuse. Therefore, several MAC protocols using directional antennas for ad hoc networks have been proposed recently.

This paper proposes DMAC/DS (Directional MAC with Deafness Solution) to handle the issue of deafness problem in directional MAC protocols. Deafness occurs when the transmitter is not able to communicate to its intended receiver, because the receiver’s antenna is oriented in a different direction [15]. In DMAC/DS, WTP (Wait for Time Period) frames are transmitted by the transmitter and the receiver, when they receive RTS request from potential transmitter after the successful exchange of RTS and CTS directionally to notify the ongoing communication to potential transmitter node that may experience deafness. WTS frames are transmitted only in that direction where potential transmitter nodes are located to reduce the control overhead. We evaluate our protocol through extensive simulation study with different values of parameters such as the number of flows, data size and bandwidth. The experimental results show that DMAC/DS outperforms existing DMAC (directional MAC) protocols in terms of throughput, RTS failure ratio, and control overhead in the majority of scenarios investigated.

2. Related Work

Although omnidirectional RTS/CTS [4, 5] are one simple solution to avoid deafness by notifying the on-going communication to all neighbors, this reduces the benefits of spatial reuse and range extension. Recently, various MAC protocols using directional antennas, typically referred to as directional MAC protocols, have been developed for wireless ad hoc networks. In [6], Choudhury et al. propose DMAC in which all frames are transmitted and received directionally, and physical and virtual carrier sensing functions are also performed directionally. In this paper, we refer to this protocol as directional MAC with DPCS (Directional Physical Carrier Sensing). Directional virtual
carrier sensing is realized by a directional version of NAV which is called DNAV. The issues of directional MAC protocols including deafness are discussed in paper but no solution is provided.

To solve the deafness problem, several other directional MAC Protocols use additional control frames to notify neighbor nodes about ongoing communication. In Circular RTS MAC [7], multiple directional RTS frames are transmitted consecutively in a circular way to notify the ongoing communication to neighbor nodes. While it prevents deafness in the neighborhood of the sender, but deafness in the neighborhood of the receiver node may still appear. To handle deafness problem at the receiver side, Circular RTS and CTS MAC (CRCM) [8] uses the circular CTS frames transmitted towards unaware neighbor nodes. Although it can notify the ongoing communication to all neighbor nodes around the sender and the receiver, the circular transmission of RTS-CTS for each transmitted data packet may incur the delay and large control overhead as well as collisions between control frames. In MDA Protocol (MAC protocol for Directional Antennas) [9], multiple RTS and CTS frames are transmitted directionally in DOD procedure, called Diametrically Opposite Directions, through the antenna beams with neighbors after the successful exchange of RTS and CTS directionally to optimize the circular transmission of control frames. However, it is unnecessary to notify the imminent communication to neighbors, which is not intended to communicate with the transmitter or the receiver. Obviously, there is a fundamental tradeoff between deafness avoidance by using control frames and overhead reduction by using the optimized control frame transmission mechanism.

This Paper addresses this tradeoff. In [10] Masanori Takata et al. proposed a DMAC/DA. In DMAC/DA (Directional MAC with Deafness Avoidance), WTS (Wait To Send) frames are transmitted by the transmitters and the receiver after the successful exchange of RTS (Request To Send) and CTS (Clear To Send) directionally to notify the ongoing communication to potential transmitter node that may experience deafness. Wang et al. [11] proposed SYN-DMAC, which alleviates deafness problem using the timing structure with clock synchronization. The time that deafness lasts is compressed to a short duration. However, this scheme requires that nodes are synchronized to identify the timing structure. Choudhury and Vaidya [12] proposed a ToneDMAC, a tone based directional MAC mechanism to handle deafness problem reactively. They first proposed the omnidirectional physical carrier sensing during backoff periods. In this paper, we refer to this variation of directional MAC (DMAC) as DMAC with OPCS (Omnidirectional Physical Carrier Sensing). DMAC with OPCS is simple but it prevents deafness problem only during backoff periods. They then propose the ToneDMAC, to distinguish deafness from collision. However, ToneDMAC needs a dedicated control channel to transmit tones as well as data channel.

3. Antenna Model

We have implemented a complete and flexible directional antenna Module (switch beam antenna) at the Network Simulation (NS – version 2.34) [13] and assume that each node in the network is equipped with a switched beam antenna which is comprised of M fixed beam pattern (Fig. 1). Non-overlapping directional beams are numbered from 1 to M, and starting at the three o’clock position and running clockwise. The antenna system operates in two separate modes: Omni and Directional. In Omni mode, a node receives signals from all directions with gain Go. An idle node waits for signals in Omni mode. After a signal is sensed in Omni mode, the antenna detects the direction on which the signal power is highest and goes into the Directional mode.

In Directional mode, a node can point its beam towards a specific direction with gain Gd > Go.

4. Deafness Problem

Directional antennas can provide us with a much higher spatial reuse because we can allow several transmissions carried out at the same time, which is not possible when we use omnidirectional antennas. In the scenario 1 shown in Fig. 2, by using directional antennas we can allow the transmission between A and B, and the transmission between C and D at the same time. However, when we use directional antennas, deafness is a severe problem [1] [14]. This happens when a node sends a RTS to the intended receiver but gets no response because receiver is busy in other communication. Then the senders will double its contention window and then backoff. If the intended receiver is transmitting or receiving a long data, the sender will fail to get CTS for many times. So after the receiver finishes its
transmission and becomes idle, the sender will have a large contention window and may probably have chosen a very long backoff period. Then the channel will be idle for a long time. Worse is that, the receiver may want to initialize a new transmission with other nodes. It will choose a backoff interval according to a much smaller contention window than that of the sender. As a result, the receiver will be able to start another transmission before the sender sends out its RTS. Thus, the sender will keep deaf for a very long time. It may even drop the packet after it exceeds the maximum number of unsuccessful attempts. Scenario 2 in Fig. 2 shows the deafness problem. In this case, there is a transmission between node A and node B. During this transmission, A will not be able to receive the RTS from C because it is beam forming in a different direction. So C will not get any response from A. Similar to that, D will not get any response from B if it sends a RTS to B. Thus, both C and D suffer from the deafness problem.

5. DMAC/DS

In this section, we propose DMAC/DS (Directional MAC with Deafness Solution) protocol to solve the deafness problem. In DMAC/DS each node maintains a neighbor table, and WTP (Wait for Time Period) frames are transmitted by the sender or receiver after the successful exchange of RTS and CTS directionally to notify the ongoing communication to potential transmitter node. WTP frames are transmitted only when sender or receiver receives RTS frame from their potential transmitter. The details of DMAC/DS Protocol are presented next.

5.1 Procedure of Communicating Nodes

To explain the procedure of DMAC/DS, We use Fig. 3. When node A has a packet to be sent in the direction of node B, firstly, it will perform physical carrier sensing in Omni mode during backoff period as similar to DMAC with OPCS [12]. If the channel remains idle during backoff period than node A switches to the Directional mode and sends RTS towards B and waits for the CTS (Fig.3). If node B is also idle then it switches to the directional mode and sends CTS in the direction of A. after the RTS-CTS handshake is successfully completed. Than both node will calculate the time duration for which they will be busy, once this time period has been calculated, node A sends the DATA frame to receiver and wait for ACK frame from node B. if DATA has been lost and node A does not receive ACK in predefined time than node A resend the DATA frame. After node B receives the DATA frame successfully than it sends the ACK frame to node A. Both A and B switch back to the Omni mode after the Data-ACK frame exchange.

During this data transmission between node A and node B any other neighbor node (potential sender) sends RTS to these node than an message WTP (Wait for Time Period) is generated by A and B. this message contain the time period for which intended receiver (A and B) is busy. This message means that potential node has to wait for a particular time period (which is given in WTP message). After that time period intended receiver will be free (idle), and it will send RTR (Ready to receive) frame to its potential sender. Potential node can sends DATA frame after receiving RTR frame from its intended receiver; they do not need to resend the RTS. First Potential node, which sends RTS to its intended receiver, will get first priority to connect with it. Node, who sends second RTS to same receiver, will get second priority and so on. Waiting time for next potential node (as in Neighbor Table) get double as compare to previous potential node. As in fig.3 node D and E are to potential sender of A. node D will get first priority because it sends the RTS to its intended receiver A first, and node E will get second priority. Node D and E will get WTP from node A. and node G is a potential sender of node B so it will get WTP from B.
5.2 Procedure of Neighboring Nodes

When the neighbor nodes receive the WTP, these nodes set the sender of the WTP as a deaf node in its own neighbor table and defer their own transmissions addressed to it for time period to avoid deafness until the entire data transmission completes. This can prevent packet drops due to unproductive retransmissions which are caused by the deafness problem. When neighbor node receives the WTP, than it simply wait for that time period. And as that time period completes, intended receiver become free than it sends the RTR to its potential sender. If potential sender does not receive RTR after time period completion than it may resend RTS or cancel its transmission by sending TC (Transmission Message) message to its intended receiver. Potential also cancel its transmission if its waiting time period is too long.

6. Simulation Results

To evaluate the performance of DMAC/DS, we have used an NS2 simulator and we make the following assumptions. 150 nodes are arranged at random in a square area using mesh topology with dimensions of 2000 m. Random source to destination pairs of CBR traffic is chosen at random and the routes are assigned using the shortest path algorithm. The transmission range of the omnidirectional antenna is 250 meter and that of the directional antenna is 500 meter. The data rate is 15 Mbps. We did not consider mobility in our simulations. We change the parameters such as number of flows, sending rate of each flow, data size and number of beams. The simulation results are the average of 15 runs, and many application packets are generated for each simulation.

In most cases, the 96 percent confidence interval for the measured data is less than 4 percent of the sample mean. We first evaluate the performance of different MAC protocols when the sending rate of each flow has been changed from 100 kbps to 8 Mbps. The number of flows is five, data size is 1024 bytes, and the number of beam $M$ is six. Fig. 5 shows the throughput of three MAC protocols. Throughput of MDA is good. This is because MDA solves deafness proactively using the DOD procedure and it has the larger control overhead. DMAC/DA performs well as compare to existing MAC protocols because in DMAC/DS, there is no need to resend the RTS frame to intended receiver. And its deafness ratio is almost the same as DMAC/DA. The throughput of DMAC/DA is much higher than that of other protocols because DMAC/DA reduces the control overhead.

Fig. 6 and 7 show the RTS failure ratio and deafness ratio, respectively. RTS failure ratio of DMAC/DS is lower than other directional MAC protocols because in DMAC/DS, there is no need to resend the RTS frame to intended receiver. And its deafness ratio is almost the same as DMAC/DA. The overhead performance. The overhead is defined as “the average number of bits transmitted to deliver 1 bit of payload to the receiver” at the MAC layer. Overhead becomes large when a large number of control bits are transmitted and/or frames are retransmitted. In DMAC/DS, WTP frames are transmitted only in those sectors where potential transmitter nodes are located, and potential node does not need to resend RTS but in other protocol as DMAC/DA, retransmission of RTS is necessary, so DMAC/DS reduce the control overhead, or It can be concluded that DMAC/DS solves deafness effectively and increases throughput performance by reducing the control overhead.

$$RFR = 1 - \frac{NCTS}{NRTS}$$

Where NRTS is the number of transmitted RTS frames towards the intended receiver and NCTS is the number of successful CTS frames. Deafness ratio is a ratio of the communication failure due to deafness over the whole communication failure factors. Fig. 6 and 7 show the RTS failure ratio and deafness ratio, respectively. RTS failure ratio of DMAC/DS is lower than other directional MAC protocols because in DMAC/DS, there is no need to resend the RTS frame to intended receiver. And its deafness ratio is almost the same as DMAC/DA. The throughput of DMAC/DA is much higher than that of other protocols because DMAC/DA reduces the control overhead.

To confirm the ability to handle deafness of each DMAC (directional MAC) protocol, we define RTS failure ratio and deafness ratio. RTS failure ratio ($RFR$) is calculated as follows:
7. Conclusion

This paper has focused on deafness problem that may affect the performance of MAC protocols for ad hoc network using directional antennas, and proposed DMAC/DS to handle the deafness problem proactively. In DMAC/DS, the WTP frames are transmitted by the transmitter or the receiver (only when they receive RTS frame from any potential transmitter), after the successful exchange of directional RTS and CTS to notify the ongoing communication to potential transmitters that may experience deafness. The experimental result shows that New DMAC/DS protocol improves overall network performance and provides effective handling of the network traffic. It should be noted that Ad hoc network is a dynamically changing scenario therefore the final performance depends on network topologies, and flow patterns in the network.

References

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