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On an Opportunistic Forwarding Protocol Using Smart Antennas for Ad Hoc Networks

Yasuhiro KATO†, Masaki BANDAI††, and Takashi WATANABE†††

† Graduate School of Informatics, Shizuoka University
3–5–1 Johoku, Hamamatsu Naka-ku, Shizuoka 432–8011, Japan
†† Faculty of Science and Technology, Sophia University
7–1 Kioicho, Chiyoda-ku, Tokyo 102–8554, Japan
††† Graduate School of Science and Technology, Shizuoka University
3–5–1 Johoku, Hamamatsu Naka-ku, Shizuoka 432–8011, Japan
E-mail: †kato@aurum.cs.inf.shizuoka.ac.jp, ††bandai@sophia.ac.jp, †††watanabe@inf.shizuoka.ac.jp

Abstract Smart antennas can electronically control beam direction. With smart antennas, several nodes may potentially communicate simultaneously in ad hoc networks. In addition, the higher gain of certain direction allows a node to communicate with other nodes far away. However, existing directional protocols has several problems and are not capable of fully exploiting the benefit. One of the major problems is deafness. Deafness problem may cause the increase of the delay and the packet discard. In this paper, we propose a deafness avoidance protocol. The proposed protocol applies the opportunistic forwarding, which can reduce the probability of the retransmission by making use of the neighbor node. Simulation results show that the proposed protocol can outperform than traditional directional protocols.

Key words smart antennas, deafness, MAC, opportunistic forwarding

1. INTRODUCTION

Recently, Medium access control (MAC) protocols using smart antennas for wireless ad hoc networks attract attention. Nodes that cannot communicate directly can communicate each other via data relay some surrounding nodes in ad hoc networks. In addition, network infrastructures such as base stations or access points are unnecessary. Ad hoc networks can be deployed in a place where maintenance is difficult a geographically or disaster area. MAC protocols for wireless ad hoc networks with smart antennas have been focused on. Smart antennas can control antenna directivity through software. Smart antenna can improve spatial reuse by suppressing interference and can extend communication distance compared with omni-directional antenna. However, there are some problems in MAC protocols with smart antennas. One of them is deafness problem. In general, a sender node controls its transmission antenna gain toward its receiver node. In this case, some neighbor nodes cannot hear the communication between the sender and receiver. Therefore, if a neighbor node begins to communicate with the sender, the sender cannot hear the transmission of the neighbor node. The neighbor node tries and tries transmissions and it reaches maximum number of transmission failures. The deafness problem incurs increase of delay and packet discard.

Several deafness avoidance protocols are devised, such as controlling the packet transmission and making use of surrounding nodes. These protocols can mitigate effects of the deafness problem. However, there are some problems, increase delay and traffic.

In this paper, we consider an opportunistic forwarding that can reduce the probability of retransmissions and propose a protocol to solve the deafness problem. The opportunistic forwarding is a technique based on the idea of making use of available nodes at that time. The proposed protocol suppresses the retransmissions due to the deafness problem by partially applying the opportunistic forwarding. We show that the proposed protocol improves throughput compared with a conventional method via computer simulations.

2. RELATED WORK

In wireless ad hoc networks, throughput decreases due to packet losses. In this section, we first explain the deafness problem and proxy node method as a solution controlling the deafness problem. Then, we explain the opportunistic forwarding as a solution to reduce packet losses in low data transmission reliability of wireless communications.

2.1 Deafness Problem

DMAC (Directional MAC) [1] is an IEEE 802.11-based MAC protocol with directional antennas for wireless ad hoc networks. RTS (Request to send, CTS (Clear to send), DATA, and ACK (Acknowledgement) frames are transmitted by directional antennas in DMAC. The RTS/CTS are frames to confirm whether the destination node can communicate before the communication begins. The ACK is a frame to confirm whether the destination node has received DATA correctly. DMAC avoids to a collision by transmitting DATA/ACK after RTS/CTS. However, directional MAC protocol such as DMAC cannot transmit data to multiple directions at the same time. Node outside range of the transmission beam from the sender cannot know neighbor' s state. Consequently, wireless resource is wasted by useless repeating the RTS sending when the sender and the destination are communicating each other [2].

Several techniques for controlling the deafness are presented. Moving the transmission timing of the packet in network layer is one of the solutions for avoiding deafness [3]. In MAC layer, polling to some potential deafness nodes [4], turning around the directional beam [5] and selecting a proxy node among neighbor nodes are the promising technologies for avoiding deafness.

2.2 Proxy Node Protocol

The technique for controlling the deafness problem by using idle neighbor node is proposed in [6]. An idle neighbor node is selected as a proxy node. The proxy node gets neighbor information and postpones unavailable communication. Useless RTS transmissions by the deafness problem can be reduced by this method. However, in this method, idle time of the proxy node increases because the proxy node and postponed node have to wait until the end of the communication of the sender and the receiver.

2.3 Opportunistic Forwarding Protocol

In traditional routing protocols of ad hoc networks, when a data is delivered to the destination, the route from the source to the destination is determined before actual data transmissions. On the other hand, opportunistic forwarding does not determine the route beforehand [7]. Some relay nodes opportunistically transmit a packet toward the direction of the destination node when the packet is received. Data is transmitted from the source to the destination by repeating the opportunistic relays by some relay nodes.

ExOR [8] does not construct a route beforehand. Instead, it repeats the relay by the node which can receive the packet by chance, and transmits the packet toward the destination. Statistics of packet error rate of each link and location information of nodes are acquired by flooding of packets. After the sender node elects a node located between the destination and itself as a relay candidate considering packet error rate, the sender broadcasts the packet with omni-directional antenna. When the relay candidate node receives the packet, it broadcasts the packet with omni-directional antenna. The packet is forwarded to the destination by repeating the relay. The packet delivery rate improves by opportunistic forwarding. However, ExOR incurs increase of traffic in the network by spreading packets.

OPDMAC is proposed in [9]. When a node fails to receive CTS, the node transmits RTS to another direction except present RTS transmitting direction. RTS is retransmitted when CTS cannot be received during the CTS reception waiting period by directional MAC protocol such as DMAC. In OPDMAC, the node checks the packet queue and transmits the other packet if there is a packet for another direction. The influence of the deafness problem can be reduced by controlling RTS retransmission and the utilization of a wireless resource improves. However, the increase of delay cannot be solved because previous packet cannot be transmitted until following packet delivery. Moreover, the original direction may be occupied by another node during another direction transmission.

Opportunistic forwarding tries to avoid the communication with the unavailable node, and also determines the delivery route of packets at that time [10]. The deafness problem is caused by persisting with the unavailable node, so opportunistic protocol is effective for the problem. There is a possibility that packet retransmission and delay decreases.

3. PROPOSED APPROACH

This section presents a technique for decreasing effect of the deafness problem. Proposed protocol relays the packet to available nodes in order to avoid the node suffered deafness.

3.1 Protocol Overview

The proposed protocol is based on the DMAC, and uses opportunistic forwarding in some situation. When packet loss by the deafness problem or the signal collision occurs, nodes overhearing the communication by chance forward the packet instead of the sender node. As a result, the deafness problem is mitigated; useless transmissions of RTS and packet loss decrease.

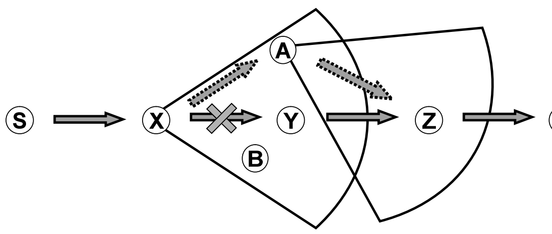


Figure 1 Proposed protocol Behavior

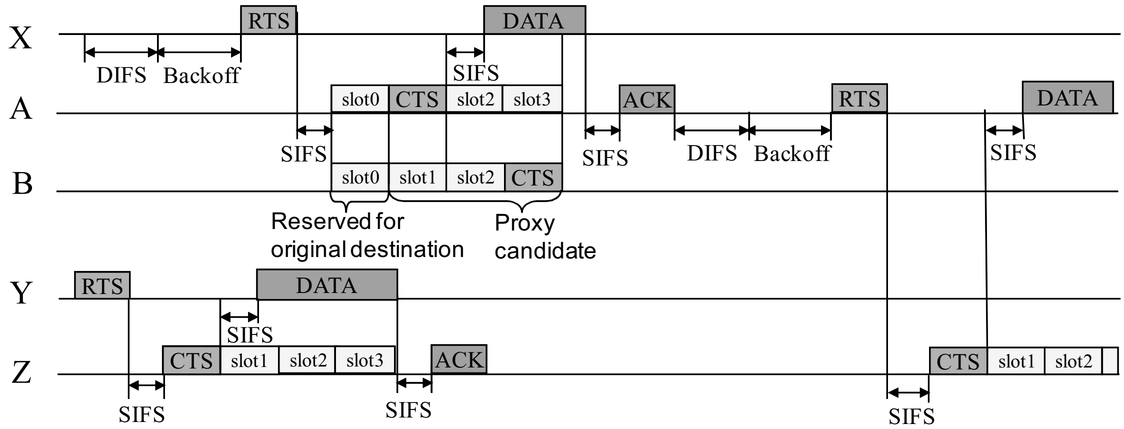


Figure 2 Sequence chart ($N = 4$)

Figure 1 shows a basic example of the operation of the proposed protocol. The route from source S to destination D through node X, Y, and Z is constructed in the topology. A packet loss occurs on the link between X and Y. Node A overhears the communication from X, and forwards the packet to Z instead of X. The link with high packet loss is temporarily detoured; the packet is relayed through the node located near original receiver. Afterwards, the packet is forwarded along the original route.

At this time, nodes overhearing RTS such as node A and B are called proxy candidates. Node A forwarding the packet is called a proxy node.

3.2 Communication Process

The proposed protocol uses RTS/CTS/DATA/ACK as well as DMAC does. In the traditional DMAC, only the receiver node returns CTS to the sender. However, in the proposed protocol, several nodes receiving RTS may return CTS.

3.2.1 Frame format

The proposed protocol uses four kinds of frames, RTS, CTS, DATA, and ACK. The proposed protocol uses the same frame with DMAC except RTS. RTS includes the location information of sender, receiver and next hop node. It is necessary to inform proxy candidates the location of next hop in case they cannot communicate with the next hop node.

3.2.2 Proxy node

Two or more proxy candidates may appear in a general communication. If all nodes return CTS simultaneously, CTS collisions occur. The proposed protocol selects a proxy node among the proxy candidates. We explain which node should be elected as a proxy node in the proposed protocol. The proposed protocol limits the proxy node candidate when a condition satisfies. The condition to be a proxy candidate is that the node can communicate with the next hop node. If some proxy candidates satisfy the condition, a proxy candidate is selected randomly as the proxy node among the proxy candidates.

3.2.3 Sequence chart

We first define some time slots for sending CTSs. RTS sender waits for CTS in N time slots. Nodes overhearing RTS select a time slot from among slot 1 to N-1 randomly. Only the destination can select the slot zero.

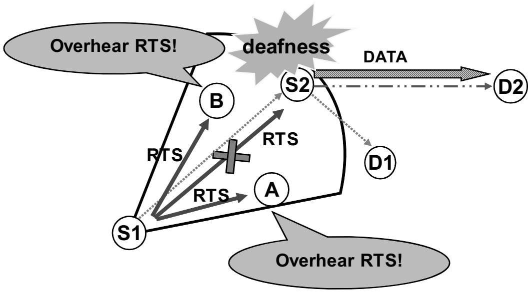
In the last one hop to the destination, the node uses RTS/CTS/DATA/ACK without any help of proxy nodes.

Then, we explain the communication sequence of the proposed protocol. Figure 2 shows the sequence chart when node X transmits RTS to node Y in Figure 1. Node X transmits RTS to Y after DIFS and Backoff, node A and B overhear RTS at this moment. However, CTS from node Y is not returned because node Y is communicating with node Z. Then, proxy candidate A and B send CTS in different timing. Node A is selected as a proxy node because node X previously received CTS from A and the transmission of DATA begins. Node A transmits ACK after receiving DATA correctly. After this communication ends, node A begins to communicate for node Z instead of node Y.

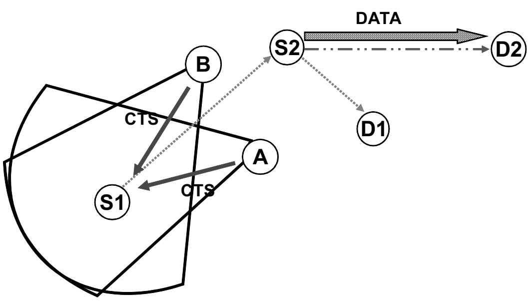
3.2.4 Operation example

This section explains how DOMAC avoids the deafness problem. An example of the operation of the proposed protocol is shown in Figure 3. Two routes S1 → S2 → D1 and S2 → D2 are constructed, and S2 and D2 are communicating. A packet generates at S1, and is transmitted to S2 which is the original relay node in Figure 3(a). However, the deafness problem occurs because S2 is communicating with D2. At the same time, neighbor nodes A and B overhear RTS from S1. Next, proxy candidates A and B transmit CTS to S1 as shown in Figure 3(b). A and B have avoided the collision of CTS by selecting the CTS transmission slot at random respectively as described in 3.2.2. In this example, since A previously transmitted CTS to S1, it is selected as a proxy node. Node A elected as a proxy node receives DATA from sender, and after the reception succeeds, ACK is transmitted. And then proxy node begins the communication with the following node.

Node S1 keeps sending RTS again and again to S2 in the situation of Figure 3(a) in traditional protocol and the deafness problem occurs. Sending useless RTS repeatedly is avoided in using the neighbor node as a proxy node and the deafness problem is avoided.



(a) RTS Sending



(b) CTS Sending

Figure 3 Operation example

4. EVALUATION

In this section, we evaluated the throughput performance of the proposed protocol. We assume the situation where deafness problems occur and compare the performance of the proposal with typical directional MAC DMAC. We also compare with two derivatives of the proposed protocol, to investigate the effect in case unsuitable proxy node is selected. Proposal (RAND) is to select the proxy node from among nodes overhearing RTS at random. Proposal (COND) is to select the proxy node from among part of nodes with conditions described in 3. 2. 2.

4. 1 Simulation Environment

Table 1 shows simulation parameters; the nodes are located as shown in Figure 4. The packets are generated according to Poisson distribution. Two routes S1 → S2 → D1 and S2 → D2 are constructed. Each plot in the figure is the average of 10 attempts; the throughput is defined as equation 1.

$$throughput = \frac{DateSize * EndtoEndSuccessCount}{SimulationTime} \quad (1)$$

Table 1 Simulation parameters

number of Nodes	8
Area size	1000m × 500m
Directional-range	500 m
Directional-degree	60 °
Data size	1024 bytes
CBR flow	S1 → D1, S2 → D2
Physical speed	11 Mbps
Mobility	No
Simulation time	300 sec

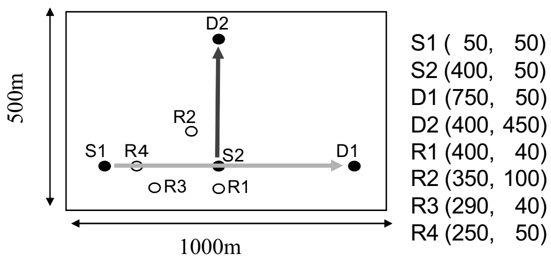


Figure 4 Simulation topology

4. 1. 1 Aggregated throughput

Figure 5 shows the total throughput of two flows at different sending rates. The horizontal axis is sending rate, and the vertical axis is the aggregated throughput of two flows. The number of slots N is 5.

As the sending rate increase, the proposed protocol achieves better performance than the DMAC. The transmission rate increases the probability of deafness problem. However, the proposed protocol avoids the deafness problem by utilizing proxy nodes.

We consider why DMAC and the proposed protocol are similar performance at 1Mbps. In DMAC, deafness problem occurs when S1 starts to communicate with S2 while S2 and D2 are communicating. Deafness problem makes S1 repeat retransmissions. However, the communication between S2 and D2 finishes before reaching maximum number of retransmissions. As the sending rate increase, the number of reaching the limit is faster. Therefore, DMAC gradually reduce the throughput according to the sending rate.

When the sending rate is high, the aggregated throughput of all protocol becomes flat. This is because of packet saturation. Since almost all nodes are communicating, following transmission is not able to start.

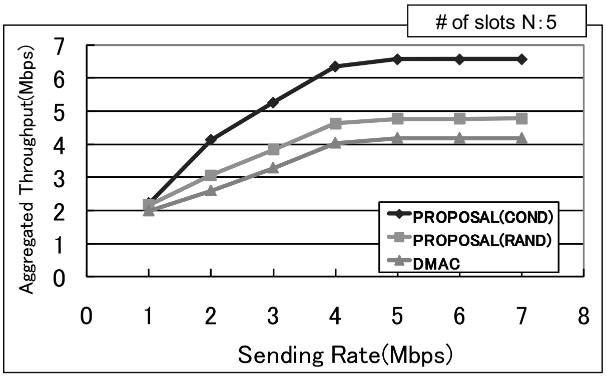


Figure 5 Aggregated throughput

4.1.2 The number of packet discard

The deafness problem causes a lot of retransmissions. As a result, the packet reaching the limit number of retransmission is discarded. Figure 6 illustrates whether the proposed protocol mitigates the effect of the deafness problem.

The proposed protocol has better performance than DMAC. It is because that RTS retransmissions are avoided. This result proves that the proposed protocol reduces the probability of the packet discards caused by retransmissions.

Proposal (COND) never selects the unsuitable proxy node such as R3 or R4, so packet drops are less than proposal (RAND).

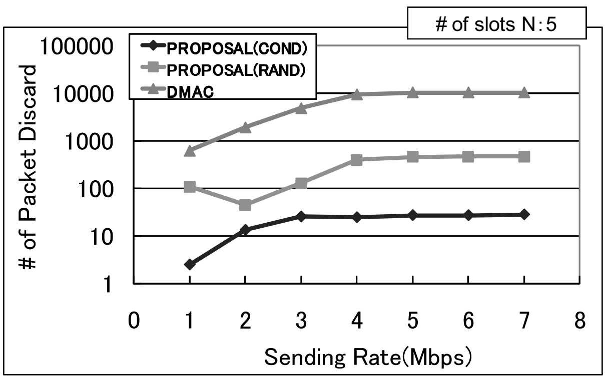


Figure 6 Number of packet discards

4.1.3 Aggregated throughput as the packet error rates change

Opportunistic forwarding has advantages in high error rate condition, because forwarding node is selected among a lot of nodes. We check whether the proposed protocol endure the high error rate condition.

Aggregated throughput changes due to packet error rates in Figure 7. Nodes retransmit the packet repeatedly each link in DMAC. On the other hand, if only one of neighbor nodes receive packets successfully, the node forwards the packet in proposed protocol. As a result, packet arrival rate of destination is improved.

In the hard condition, if there are some proxy nodes proposed protocol is expected to be able to maintain the performance.

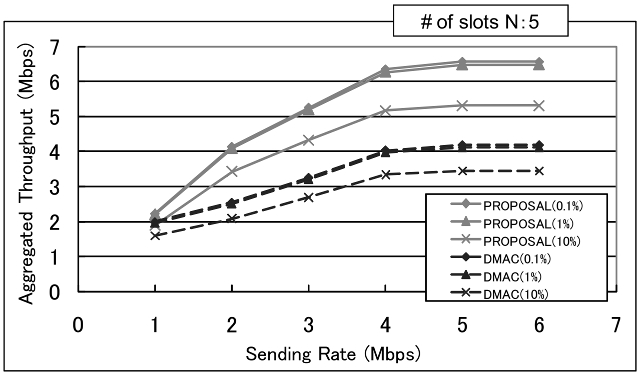


Figure 7 Efficiency in environment packet drops

5. CONCLUSIONS AND FUTURE WORK

Opportunistic forwarding is possible to use effectively by partially applying to the directional MAC protocol. Therefore, we proposed the protocol for the throughput performance improvement by decreasing the deafness problem in the ad hoc network. When there is the node that cannot be communicated, the node overhearing the communication by chance does the representation transmission. The node that cannot be communicated by deafness problem can be avoided, and sending RTS repeatedly is decreased. The proposal is showed that throughput is improved compared with traditional protocol by the evaluation in the situation in which the deafness problem occurred.

In the future, we will research effect of changing the beam width. Proposed protocol makes use of neighbor nodes. According to the number of neighbor nodes, the transmission beam width changes. For example, the beam width is narrowed in order to control the traffic if there are many neighbor nodes.

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