An Efficient MAC Protocol with Direction Finding Scheme in Wireless Ad Hoc Network using Directional Antenna

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Abstract - **In this paper, we propose an efficient directional MAC protocol with direction finding scheme for wireless ad hoc network. This efficient directional MAC protocol uses the receiver oriented direction finding scheme, where each node n periodically collects its neighborhood directional information and forms an Angle-Signal Table(AST). Directional DATA/ACK packets are transmitted, after the omni-directional RTS/CTS which not only inform the hidden nodes of on-going communication status and but also are especially effective for the string topology in ITS(Intelligent Transportation System). This omni-directional RTS/CTS can be issued without disturbing the neighbors' on-going communication, by the utilization of DNAV(Directional Network Allocation Vector) with the angle information from AST. Simulation results in highway traffic scenarios show the performance improvements by this proposed directional MAC scheme conjunct with the equalized Receiver Sensitivity and Receiver Threshold.**

Keywords: Wireless ad hoc network; Directional antenna; Space Division Multiple Access; Intelligent Transportation System; Medium Access Control.

1. INTRODUCTION

Wireless ad hoc network, where each wireless and moving terminal acts as a router, enables the temporal and rapidly deployable moving infrastructure-less network. Since a large portion of the network capacity is wasted by the reservation of the communication area through the exchange of omni-directional RTS-CTS, researchers study the directional transmission and reception that improve the SDMA(Space Division Multiple Access) efficiency drastically [1-4]. However, at first, in order to communicate with directional antenna, it is necessary for each node to know the direction of the target nodes. In addition, the accumulation of neighborhood information is a serious problem in wireless ad hoc networks, because it produces a lot of overhead. Secondly, in order to fully exploit the capability of directional antenna, each node should not only avoid transmission in directions where data communications are already in progress, but also inform other neighbors about its communication status. In other words, the exposed terminal problem and the hidden terminal problem should be solved at the same time. Specially, in the highway traffic scenario of ITS (Intelligent Transportation System) i.e., in string topology, some nodes, being unaware of the on-going communications, may try to communicate with a node, which is already busy in some communication. This may degrade the throughput of directional mode and may become worse than that of omni-directional mode. So, even if multiple parallel communications are possible by directional antenna, hidden terminal factor limits the gain offered by directional antenna. Consequently, it is imperative not only to have a location tracking mechanism of neighbors which sets its transmission direction towards the target node, but also to implement a broadcast mechanism which prevents the hidden nodes to transmit many wasteful packets which interfere the neighbors' on-going data communication.

In this paper, we propose an efficient directional MAC protocol with direction finding scheme for wireless ad hoc network. This efficient directional MAC protocol uses the receiver oriented direction finding scheme, where each node n periodically collects its neighborhood directional information and forms an Angle-Signal Table(AST). Based on AST, each node knows the directions of neighbors and controls the medium access during transmission-reception. Directional DATA/ACK packets are transmitted, after the omni-directional RTS/CTS. This omni-directional RTS/CTS can be issued without disturbing the neighbors' on-going communication, by the utilization of DNAV(Directional Network Allocation Vector) with the angle information from AST. Also, the effect of the equalized Receiver Sensitivity and Receiver Threshold is investigated.

2. RELATED WORK

In spite of the advantages of directional antennas, work on developing efficient MAC protocol using directional antennas in the context of ad hoc network is limited, because of the inherent difficulty to cope up with mobility and decentralized control in ad hoc networks. The mobile nodes in the schemes of [1], are assumed to know the physical locations of themselves and their neighbors using GPS, but the exact mechanism of information exchange and the consequent overhead have not been discussed. In [2], the location information can be identified by omni-directional RTS-CTS exchange in an on-demand basis. However, omnidirectional RTS/CTS packets provide no benefits in the spatial reuse of the wireless channel. In [3], although Ramanathan studied the performance of ad hoc networks using beamforming antennas, the authors assume prior knowledge of location information. Although the concept of DNAV in [4] can prevent some part of hidden nodes to interfere the neighbors' on-going data communication, it can't solve all hidden nodes, because this directional MAC protocol uses directional-RTS/CTS. Under the topology where all nodes locate in a line, which is the typical scenario of ITS, directional RTS/CTS can't inform source nodes' communication intention to the opposite direction of the destination node, and many packets are transmitted from the hidden nodes.

We have developed a wireless ad hoc network testbed using small, low-cost smart antenna, known as ESPAR (Electronically Steerable Passive Array Radiator) antenna[5]. In our earlier work, we have developed a MAC protocol[6], where each node keeps certain neighborhood information dynamically through the maintenance of an Angle-SINR Table. In this method, in order to form AST, each node periodically sends a directional beacon in the form of a directional broadcast, sequentially in all direction at 30 degree interval, covering the entire 360 degree space. The nodes, which receive these signals at different angles, determine the best received signal quality and transmit the information back to the source node as data packet with RTS/CTS handshake. However, the overhead due to control packets is very high in this method [6].

3. Proposed Directional MAC Protocol with Directional Finding Scheme

In this work, our directional MAC protocol is basically a *Receiver-oriented, Rotational Sector Based Directional MAC protocol* which also serves as a direction finding scheme. In order to track the direction of its neighbor, each node n periodically *collects* its neighborhood information and forms an AST. *$SIGNAL^{\theta}_{n,m}(t)$ is the maximum strength of received signal at node n from node m at an angle θ with respect to n and as perceived by n at any point of time t.* Based on AST, a node n knows the direction of node m and controls the medium access during transmission-reception. Here, each node waits in omni-directional-sensing-mode while idle. Whenever it senses some signal above a threshold, it enters into *rotational-sector-receive-mode*, and rotates its directional antenna sequentially in all direction at 30-degree interval, covering the entire 360-degree space in the form of the sequential directional receiving in each direction and senses the received signal at each direction. After one full rotation, it decides the best possible direction of receiving the signal with maximum received signal strength. Then it sets its beam to that direction and receives the signal. However, in order to enable the receiver decoding the received signal, each control packet is transmitted with a preceding tone with a duration such that the time to rotate a receiver's rotational receive beam through 360 degree is little less than the duration of the tone (200 microseconds in our case). The purpose of this transmitted tone before any control packet is to enable the receiver to track the best possible direction of receiving the signal. Once it sets its beam to that direction, the purpose of tone signal is over and subsequently the control packet is transmitted. Each node periodically transmits an omni-directional beacon and its neighbors on receiving the beacon decodes it and makes its entry in the AST. Here, since RTS and CTS are sent with a preceding tone and contains source address, they also serve as beacons, which minimize the overhead of transmission of beacon at high traffic.

Whenever node n wants to start data communication with, say j, it checks the medium and if it is free, n issues an omni-directional RTS. The target node j on receiving RTS, issues omni-directional CTS. The objective of RTS/CTS here is *not to inhibit the neighbors of n and j from transmitting or receiving (as is the case with omni-directional antenna), but to inform the neighbors of j and n that j is receiving data from n*. It also specifies the approximate duration of communication. All the neighboring nodes of n and j keep track of the communication between n and j by setting their DNAV towards n and j. Thus, nodes in the neighborhood of n and j can initiate communication in other directions *without disturbing the existing communication between n and j*. Then the source and destination nodes transmit Data and Acknowledgement directionally and wait for Acknowledgement and Data in directional receive mode respectively.

4. Performance Evaluation

We have evaluated our proposed MAC protocol, termed as "E-MAC" in comparison with omni-directional IEEE 802.11, termed as "IEEE802.11(Omni)"and a conventional directional MAC protocol termed as "D-MAC" in String Topology, using QualNet 3.1[7]. In D-MAC, RTS, CTS, DATA and ACK packets are sent directionally. Static nodes are separated with the distance of 300m. 1024bytes CBR packets is transmitted at an interval of 5.4msec, over 2Mbps data rate. The duration of preceding tone in RTS/CTS/Beacon is

200microseconds. Initially, the evaluation has been performed in ideal case, where the directional gain equals omni-directional gain. The results in Fig. 1(a) and 1(b) shows that E-MAC performs much better than D-MAC and its performance is comparable to that of IEEE802.11(Omni). Due to the hidden terminal and deafness issues, as pointed out in [8], D-MAC performs poorly in String Topology. But E-MAC performs even better than IEEE802.11(Omni) with increasing number of hops. But, in reality, directional gain of antenna is greater than omni-directional gain. So, we have evaluated E-MAC with directional gain greater than omni-directional gain and is equal to 5.4dBi. As in IEEE 802.11, Receiver Sensitivity(RS) is kept lower than Receiver Threshold(RT). The graph “E-MAC (RS<RT)” shows that the performance of E-MAC does not deteriorate even with unequal gains of antenna.

Fig. 4 shows the omni-directional and directional communication. According to IEEE 802.11, nodes in the carrier-sensing zone have to sit idle while AB communication is going on. This is required using omni-directional antenna, because, if any node, say C, in the carrier-sensing zone, starts communicating, while AB communication is in progress, interference will occur at B, since node B is receiving omni-directionally. But, using directional antenna, node B can rotate its beam-pattern towards A, forming null towards all other directions and thus minimizing the chance of interference from other directions. Now, if node C starts communicating, C’s signal cannot create interference at B. So, using directional antenna, we can improve SDMA efficiency by equaling the Receiver Sensitivity and Receiver Threshold. Thus, a node is kept silent by that signal only, which has the potential to be received and decoded by the node. So, in Fig. 2(a) and 2(b), the graph “E-MAC (RS=RT)” shows the improvement in gain of E-MAC in String Topology, which is nearly twice that of “IEEE802.11(Omni)”. E-MAC also outperforms “IEEE802.11(Omni)” in Parallel Topology, where the maximum gain obtained is nearly four times than that of “IEEE802.11(Omni)”, as evident from Fig.3(a) and 3(b).

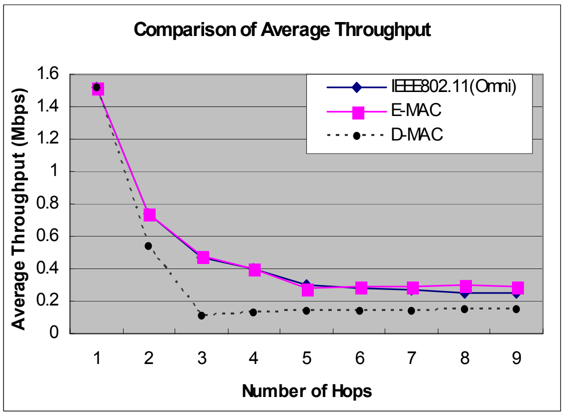

Fig. 1(a). Comparison of Average Throughput with increasing number of hops in String Topology where directional gain equals omni-directional gain

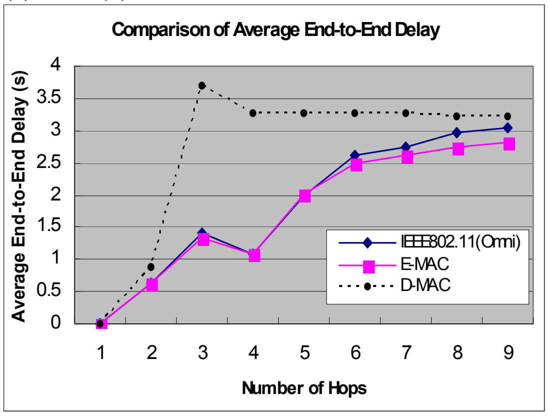

Fig. 1(b). Comparison of Average End-to-End Delay with increasing number of hops in String Topology where directional gain equals omni-directional gain

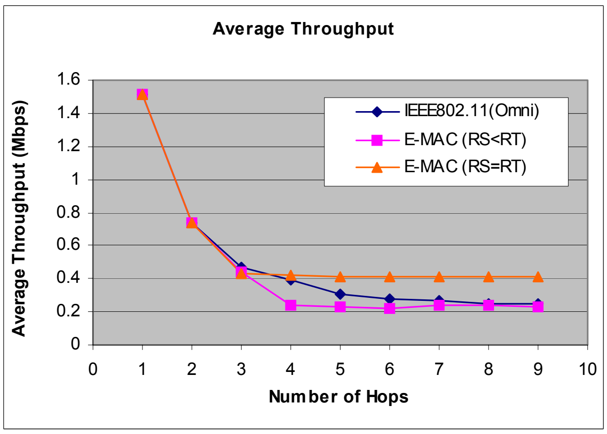

Fig. 2(a). Comparison of Average Throughput with increasing number of hops in String Topology where directional gain is greater than omni-directional gain

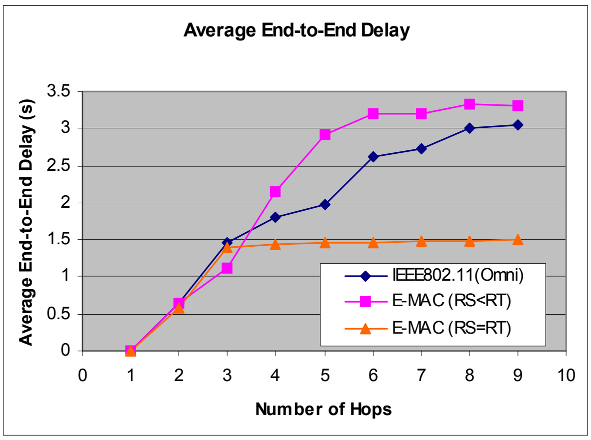

Fig. 2(b). Comparison of Average End-to-End Delay with increasing number of hops in String Topology where directional gain is greater than omni-directional gain

It is shown in [9] that in Random Topology, E-MAC performs much better than IEEE 802.11 with Receiver Sensitivity less than Receiver Threshold as in IEEE 802.11, and the gain is nearly 1.7 times than that of omni-directional IEEE 802.11.

5. Summary

This paper presents an effective directional MAC protocol where direction information can be maintained through the receiver oriented direction finding scheme and omni-directional RTS/CTS with DNAV is effective for hidden and exposed terminal problems. When combined with the equal Receiver Sensitivity and Receiver Threshold, throughput can be improved twice in string topology and four times in parallel topology, compared to those of conventional omni-directional IEEE802.11. For the implementation to ITS, we will investigate mobility and random distance between nodes.

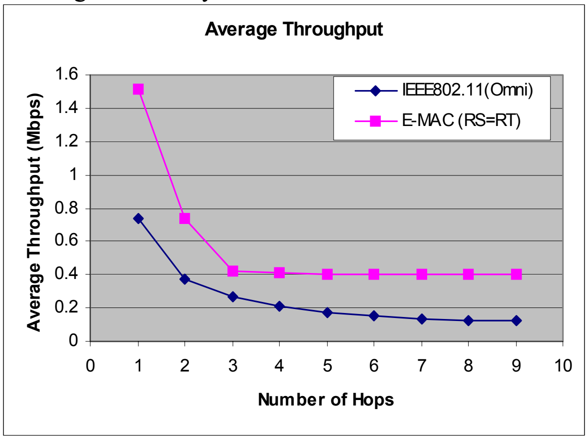

Figure 3(a): Comparison of Average Throughput with increasing number of hops in Parallel Topology where directional gain is greater than omni-directional gain

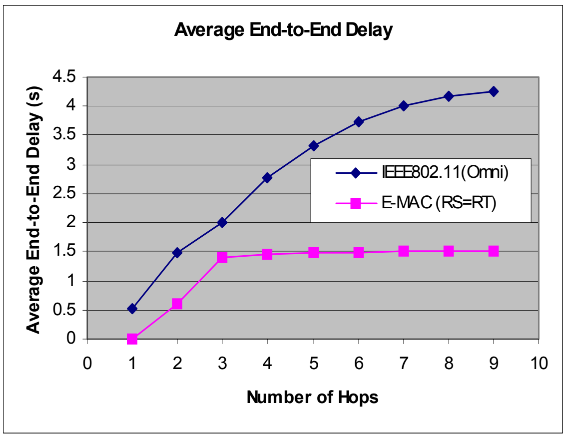

Figure 3(b): Comparison of Average End-to-End Delay with increasing number of hops in Parallel Topology where directional gain is greater than omni-directional gain

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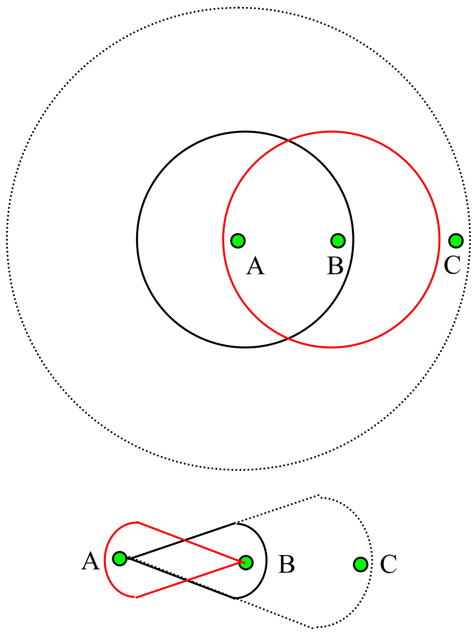

Fig.4. Omni-directional and Directional Communication, where black line shows the transmission zone, red line shows the reception zone and dotted black line shows the carrier-sensing zone, where nodes can sense the signal, but cannot receive it correctly to be decoded.