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A Novel Neighbor Discovery Technique for AdHOC Networks with Directional Antennas

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Abstract: In research scenario, omni-directional antennas were used for neighbor discovery in AdHoc networks. Due the technological advancements, directional antennas influenced the neighbor discovery in AdHoc networks. But, both the models have their own advantages and disadvantages in utilizing the channel and power utilization. In omni-directional antennas, energy is transmitted in all directions and the receiver receives only a minimal portion of the transmitted energy (signal transmitted in the other regions are wasted). Directional antennas beams energy only in the destination node direction. This will help in decreasing energy consumed by transmitting nodes. This will also help in increasing the spatial reuse gain and network capacity. But, the major drawback in using directional antenna is the interference in the ongoing transmission. To solve these problems, we propose a novel Neighbor Discovery technique –TRACE, which is self adaptive in nature. Further, the simulation results shows that TRACE have an excellent improvement in throughput, fairness and regularizing the traffic load.

Key words: Directional Antennas · AdHoc Networks · Network Discovery

INTRODUCTION

With the rapid advancement in the modern era, wireless networks like AdHoc Networks and Mobile AdHoc Networks are gathering vast attention from the research community for its network structure. Network structure of these AdHoc Networks is not that complex as the wired networks with base station, system administrator and so on. Communication between nodes in AdHoc Networks is based on peer-peer communication and uses multi-hop routing [1]. For a very long time, AdHoc Networks operates with omni-directional antennas. By definition, omni-directional antenna covers all nodes in its region at an angle of 360° [2-4]. In the olden days [3], where omni-directional antennas are used for broadcasting data, energy is distributed in all directions and only a part of the energy is received by the designated node. Then the research community came with a solution to use directional antennas in AdHoc Networks. The usage of directional antennas in AdHoc Networks gathered vast attention from applications like environment monitoring, industries and even military [5, 6]. Using directional antennas reduces the energy used for data transmission and increases the network lifetime. These directional antennas are capable of beaming the data in a one single direction or even to a longer distance than the omni-directional antenna can transmit [6]. Compared to omni-directional network design, directional antenna based network design has higher challenge in designing the network. The transmitter and receiver should be directed in the same direction to receive the data without any loss. And even each of them should be in transmitting and receiving mode respectively [5, 7, 8, 9]. Before initiating a communication between nodes, transmission slot should be reserved as all nodes use the wireless channel [7]. To maintain the reliability and to avoid interference in the ongoing communication a medium access protocol (MAC) protocol like D-TDMA (Directional – Time Division Multiple Accessing) is used [10]. As the reservation of time slots is proven to most

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priority action, we propose a novel neighbor discovery algorithm – TRACE based on D-TDMA protocol. We make use of adaptive neighbor discovery for reserving the slots to avoid waiting period for each to node to transmit/receive. This rest of the paper is organized as follows. Related works done in directional antenna based MAC protocol is discussed in section 2. The antenna model, network model are drawn and operation of TRACE is briefed in section 3. Section 4 discusses the simulation results and section 5 concludes the work.

Related Work: Abdullah *et al*. proposed a Dual Sensing Directional MAC [5] protocol, with relies on dual-sensing strategy to identify deafness, resolve hidden-terminal problem and avoid unnecessary blocking. In their study they consider that the hidden terminals are located much nearer to the source node. The nodes are distributed randomly (2D-poison distribution) in a circular fashion at a radius of 300m. With a probability of choosing nodes in 1/S direction, the DSDMAC is capable of resolving the hidden terminal problem. But the throughput of the overall systems finds no drastic improvements. Pan Li *et al*. finds that omni-directional antennas (Figure 1) posses a higher capacity gain than O (log n) of directional antenna networks [6]. Further the trade-off between transmission range and throughput is tested and found that directional antenna based network can achieve higher throughput when larger transmission range is used.

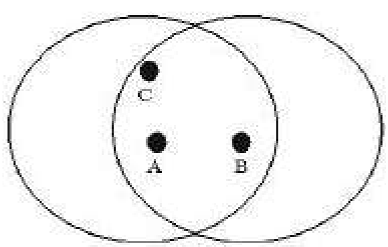

Fig. 1: Omni Directional Transmission

Yin Chen *et al*. has done a brief work on studying the achievable throughput in Mobile AdHoc Networks with directional antennas [7]. The numerical study of the network model for beamwidth θ for transmission, packet redundancy *f*, is adopted for packet routing. The network model is proved for the directional antenna beamwidth variation from 0 to Đ and the maximum achievable throughput $\mu(\theta, f)$ is noted for n=64, 120 and 240. Bipula *et al*. proposed a novel multi-channel MAC protocol for directional antennas (MCMDA) for 802.11 based adhoc networks [8]. In MCMDA, each peer node has multiple interfaces for multiple directional antennas to participate in concurrent transmission and receptions at the same time. The simulation results also conclude that MCMDA has better performance than Yin Chen *et al*. model in terms of reducing the hidden terminals and deafness. Though these works concentrate on decreasing hidden terminal and deafness problem, but fail achieve higher throughput demands. On the other hand Dong Hao et al. addressed the drawbacks of random access MAC protocols with directional antennas considering inevitable collisions in the networks [9]. As an upgrade from the conventional techniques, binary countdown mechanism is used instead of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) for offering priority based services. Though the technique is addressed and analyzed theoretically, extensive care should be taken for simulation process where additional problems may be faced. The most recent work by Koutsopoulos et al. takes the problem of fast neighbor positioning in wireless networks with directional antennas [10]. Another work by DNM Dang et al. addresses the unfairness caused due to omni-directional antennas for 802.11 standard networks [11]. To increase the spatial reuse in the channel, Dang et al. proposed Multi-channel MAC protocol with directional antennas. Even the simulated results are pleasing with a higher throughput, packet delivery ratio and energy efficiency.

Proposed Trace Protocol: As our TRACE protocol is self-adaptive in nature, our antenna model is selected in a way that it can operate in both omni-directional mode and directional mode. As discussed in the literature [5, 8, 9, 11] when the directional antennas are used for the wireless communication, hidden terminal problem arises in higher rate as shown in Figure 1.

The node ‘S’ and ‘R’ are in communication where both the nodes use directional antennas to beam the data. ‘T’ the neighbor node of ‘S’ is not aware of the ongoing communication between S-R. Because, to initiate the communication, ‘S’ send Directional Request To Send (DRTS) to node ‘R’. On the reception of DRTS, the receiver node ‘R’ responds with a Directional Clear To Send (DCTS). In both the case, no other nodes i.e neighbor nodes of ‘S’ & ‘T’ is aware of the ongoing S-T communication.

On the same scenario, there is an ongoing communication between ‘U-V’ and when it ends, the node ‘U’ tries to make a contact with node ‘T’ as it is unaware about the ongoing communication which causes inference between ‘S-T’. This hidden terminal problem is new to directional antennas as the transmission in omni directional antennas (RTS & CTS) are broadcasted in all the directions (say θ=360°). This hidden terminal problem will affect the spatial gain of the wireless network.

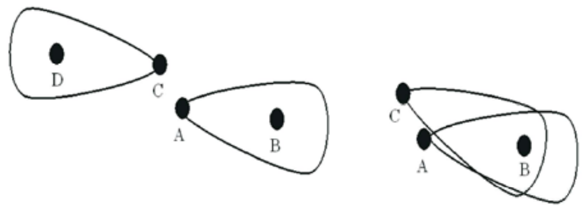

Fig. 2: Hidden Terminal Problem in Directional Antenna Transmission

To address this problem, instead of using the busy-tone signaling based MAC protocol, we propose a new MAC protocol – 'TRACE' which is self adaptive in nature. In busy-tone based [5 , 9] MAC protocols, the busy signals needs to be ON until the transmission is finished.

Table 1: Pseudo Code for sending RTS at transmitter

```
if (! Ongoing transmission in
Neighborhood)
    Sel (Omni-Directional Tx)
    Tx: send RTS
else
    Sel (Directional Tx)
% Directed in the regions where no
transmission is happening
    Tx: send RTS
end
wait (SIFS)
```

This will solve the hidden terminal problem, but increase the power dissipation of the system which will no way increase the throughput of the network. By considering both the drawbacks, we propose an adaptive algorithm which follows the standardization of IEEE 802.11. The process of neighbor discovery to find the direction of new node is explained in Table 1-3.

Table 2: Pseudo Code for sending CTS at receiver

```
if (ORTS)
    Sel (Directional Tx)
    Rx : send CTS
elseif (RTS)
    if (! Ongoing transmission in
Neighborhood)
        Sel (Omni-Directional Tx)
        Rx: send CTS
    else
        Sel (Directional Tx)
        % Directed towards the transmitter
        Rx : send CTS
    end
end
```

Table 3: Pseudo Code for sending Data

```
if (CTS)
    Sel ( Directional Transmission)
%Directed towards the receiver
    Tx : Send Data
elseif (!CTS && Tw>Thw && !Full_Rot)
    Rotate Antenna @ beamwidth angle
    Goto (A)
elseif(!CTS && Tw>Thw && Full_Rot)
    Restart the session
end
```

As the TRACE can operate in two modes, i.e: omi-directional mode and directional mode, the earlier mode covers a region where θ=360° and the signal is beamed only towards the receiver based on the distance and power required for the transmission. Among the primary types of Directional antennas (Switched beam antenna system, Steered beam antenna system and Adaptive antenna system), in this work we choose adaptive antenna system.

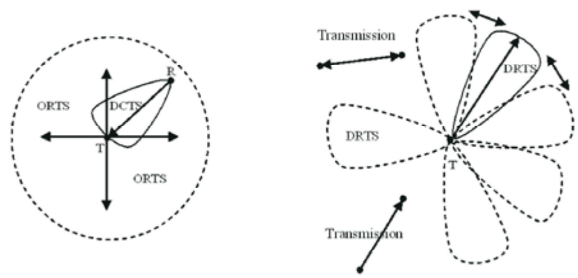

Fig. 3: (a) Omni Directional RTS and Directional CTS. (b) Multiple ongoing Directional RTS & Transmission

While initiating the discovery process for finding the node's direction, transmitter checks for any ongoing transmission in the neighbor table (NT) and when there is no ongoing transmission the transmitter is set to send Request To Send (ORTS) omni-directionally. On the other case if there is a ongoing transmission, the transmitter is set to send Request To Send (DRTS) directionally. Now the transmitter is set to wait state for receiving Clear To Send (CTS) packet from the receiver for a period of Short Inter Frame Spacing (SIFS) according to IEEE 802.11 standard. At the receiver when RTS is received through omni-directional transmission, the receiver sends CTS in directional mode (CTS) as the transmitter direction is known. Additionally during the omni-directional RTS, the neighbor nodes update the neighbor table with the direction of the transmitter. At the same time the neighbor nodes avoid beaming in the ongoing communication region. If the received RTS is directional transmission, first the receiver tries to send CTS omni-directionally.

If there is any ongoing transmission then the receiver chooses directional transmission directed towards the transmitter. If the transmitter fails to receive the CTS from the receiver even after the wait period, the directional antenna is rotated to the next available region and repeats the process as in Table 1. In rare cases, any on the node in communication may move out of the communication region. But this movement won't be much far from the last known direction. The transmitter will find the direction of the receiver in two iterations. The ongoing transmissions are updated in the neighbor table (NT) whenever a RTS or CTS signal is received. This NT will have information like ongoing transmission; neighbor nodes last know location and direction[12].

Simulation Results: For a fair evaluation, we compare our proposed MAC protocol with 802.11, CRTS [13], PMAC [14] for stationary and mobile random topologies as shown in Figure 4. The nodes are deployed randomly in 300m x 300m square area. The network throughput of the system is calculated as a product of packet size and *Expectation of* average number of packets sent successfully in one time slot [9].

Table 4: Probability Distribution table for average number of successfully sent packets (k)

K	1	2	3
P	P_1	P_2	P_3

where,

$$P_1 = \left(1 - \frac{N-3}{N-1} P_{reuse}\right)^{(N-2)} \quad (1)$$

$$P_2 = (1 - P_1)\left(1 - \frac{N-5}{N-1} P_{reuse}{}^{2}\right)^{(N-4)} \quad (2)$$

$$P_3 = (1 - P_1)\left(1 - (1 - \frac{N-5}{N-1} Preuse^2\right)^{(N-4)} \quad (3)$$

Expectation value of average number of packets sent successfully is derived in Eqn (4) & (5).

$$E(K) = 1 \text{ x } P_1 + 2 \text{ x } P_2 + 3 \text{ x } P_3 \quad (4)$$

$$Throughput = \frac{E(K) x Packetsize}{T_{Slot}} \quad (5)$$

For the simulation, we randomly consider the transmitter and receiver nodes. And also the transmission range of all nodes falls on a same range.

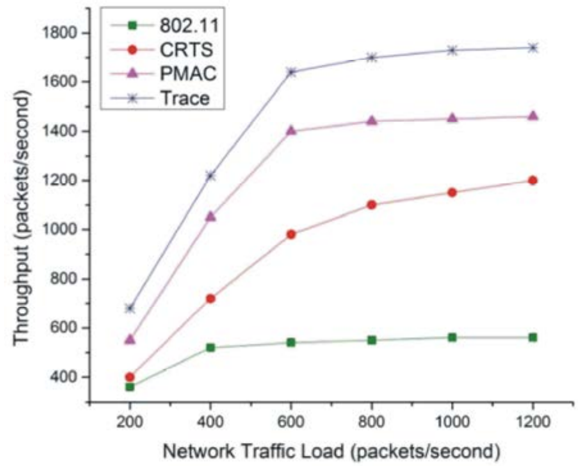

Fig. 4: Throughput vs Network Traffic Load in mobile random topology

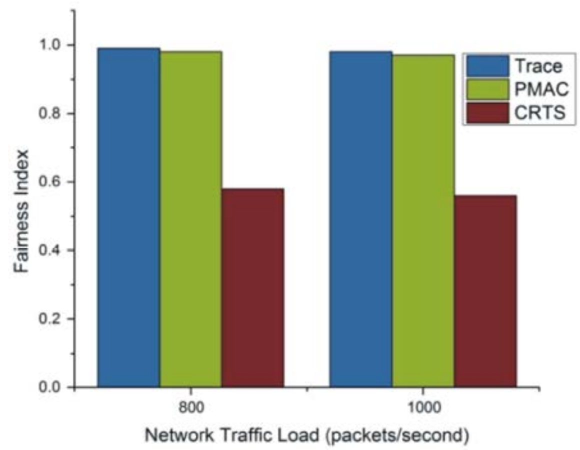

Fig. 5: Fairness Index of TRACE compared with PMAC & CRTS

The fairness index [15] for MAC protocols which uses directional antennas are evaluated under heavily loaded conditions as discussed in [14]. Even the simulation results shows that the proposed TRACE MAC protocol has acceptable improvement compared to PMAC and CRTS (Figure 5).

CONCLUSION

In this paper we proposed a novel MAC protocol – TRACE for adhoc networks which is capable of delivering higher throughput irrespective of the network traffic load in a randomly distributed network. Instead of using busy tone signaling to avoid hidden terminal problem, TRACE incorporates adaptive antenna transmission modes. Along with the benefits of omni directional MAC protocol in IEEE 802.11, TRACE uses Directional MAC protocol to achieve a higher throughput compared to PMAC and CRTS MAC protocols. The periodically updated neighbor table (NT) keeps the hidden terminal parameter lower than the conventional methods. As a future work, TRACE can be extended to other adhoc networks communications.

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