Performance evaluation of Directional MAC protocol for Inter-vehicle communication

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Abstract— **In this paper, the performance of Directional MAC protocol, proposed in [1], and IEEE 802.11 MAC protocol are compared for an Inter-vehicle communication application. Actual vehicle movement in a city and highway road scenarios are used for simulating inter-vehicle communication among nodes in network simulator (ns-2). DMAC protocol was implemented in ns-2. The results obtained from simulations demonstrate the performance improvement of Directional MAC protocol as compared to IEEE 802.11 MAC for inter-vehicle communication.**

***Keywords-** Medium Access Control protocol, Directional antennas, Inter-vehicle communication*

I. INTRODUCTION

A wireless, mobile network is an autonomous system of mobile nodes, which are typically assumed to be equipped with omni-directional antennas. A wireless mobile network for inter-vehicle communication system operates with limited bandwidth and high mobility. For efficient sharing of the available channel among nodes, a robust MAC scheme is required. A number of MAC protocols based on the IEEE 802.11 standard adapted for wireless ad-hoc networks are available. Most of these MAC protocols are designed for omni-directional antennas. Recently, directional antennas have been applied in wireless ad-hoc networks. The use of directional antennas in ad-hoc networks requires MAC protocols to incorporate the directional transmission capabilities of the physical layer. The directional MAC protocols can largely improve the spatial re-use of the channel, thereby improving the network performance.

In the recent past, a number of directional MAC protocols [1][2][3][4], which showed significant performance improvement over IEEE 802.11, have been proposed. The performance results are usually shown for scenarios with random node movement. But this set of results may not be valid for inter-vehicle communication (IVC) scenarios in cities and highways. Unlike the random node movement scenario, the vehicle movement on road network is constrained and is more structured. This might limit the spatial reuse of the communication channel when directional MAC scheme is applied to IVC. The high mobility of vehicles introduces additional problems such as locating and tracking of neighboring nodes in directional MAC protocols during random channel access.

In order to study the performance of directional MAC schemes for IVC in city and highway traffic scenarios, we have simulated the traffic movements and implemented DMAC protocol [1] in ns-2. We evaluated the network performance of DMAC, in terms of throughput and delay, and compared against IEEE 802.11 MAC protocol. We refer to IEEE 802.11 MAC protocol as OMNI MAC in all the subsequent references to emphasize the point that it uses omnirdirectional transmission.

The performance studies are done for the physical layer developed by DaimlerChrysler [5]. The physical layer and MAC layer are developed as alternate systems for the FleetNet project. “FleetNet – Internet on the Road” was set up by a consortium of six companies including DaimlerChysler and part funded by German Ministry of Education and Research.

II. DIRECTIONAL MAC PROTCOL

The Directional MAC protocol proposed in [1] is selected for our study because we feel that this protocol is more suitable for IVC application due to its efficient neighbor location maintenance scheme. The Directional MAC protocol (DMAC) [1] considered for implementation has the following features:

- Employs only directional transmissions
- A mechanism to inform neighbors to defer their transmission if this is going to harm the pending transmission, thereby avoiding the hidden terminal and deafness problems.
- Neighbor’s location information is obtained in a simple and efficient way, and maintained for use in directional transmissions.

A. Working of the Protocol

When a node is ready to transmit data, RTS (Request To Send) is sent directionally in a circular way, in all the directional antennas, until the area around the source node is scanned. This circular RTS (CRTS) contains the duration of the intended four-way handshake, RTS-CTS-DATA-ACK, as in OMNI MAC. As this duration information is spread around by circular RTS, the neighbors are informed about the intended transmission. The neighbors inhibit their transmissions only towards the direction of the sender for the duration set in the overheard CRTS packet. A simple scheme for track and maintenance of other nodes’ location by the use of location

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table is employed. The nodes update the location table entries whenever they overhear transmissions from other nodes. Neighbors use the location table information to inhibit transmissions in the direction of the destination nodes so that hidden terminal problem is avoided.

In idle mode all nodes hear omnidirectionally. On reception of a signal, a node uses selection diversity, which means that it can identify and use the signal from the antenna that is receiving the maximum power of the desired signal. The destination node waits until completion of circular RTS transmission and then sends directional CTS (Clear To Send) in the direction of the source node. The destination node knows the direction of the source node by employing selection diversity mechanism. When the source node completes circular transmission of RTS, it hears the medium omnidirectionally to receive CTS from destination node. That means carrier sensing at the source node is performed in an omnidirectional mode. If the CTS is received during a predefined period then the source node continues with the transmission of the data packet, and reception of ACK. All packets are transmitted directionally, and the source and destination nodes do not need any information about each other’s absolute location.

The main advantages of DMAC over the previous directional MAC protocols [2][3][4] are 1) Sector-wise RTS-CTS mechanism, 2) No need of neighbor’s absolute location information and 3) increased antenna gain. Sector-wise RTS-CTS transmission mechanism allows more simultaneous communication links to be formed. This is very useful in exchange of safety critical data in IVC applications. Since the absolute location information is not available in IVC applications, the DMAC is more useful. The feature of increased antenna gain is not usable as physical layers available for IVC could be based on Ultra-Wide band (UWB) [5] that are limited in EIRP (effective isotropic radiated power) by regulatory bodies.

Since DMAC protocol has better spatial reuse compared to OMNI, DMAC is expected to perform better in inter-vehicle communication scenarios. However, the mobility of vehicles may degrade the performance to some extent. In random node scenarios discussed in [1], the throughput of DMAC is 35 % to 50 % better when compared with OMNI MAC, but the end-to-end delay parameter is not studied in [1]. End-to-end delay is very important in the case of IVC because information transfer such as safety related data requires quick delivery to the intended recipients. All simulations in [1] are done only for stationary nodes, which again is not applicable to IVC scenarios.

III. SIMULATIONS

The DMAC protocol is simulated using ns-2.27 (Network Simulator version 2.27). The physical layer implemented in *ns* is based on Communication Radar system [5] using 6 directional antennas per node. The beam-width of each antenna is 60°. The DMAC protocol is implemented and integrated with *ns* modules [7]. The FleetNet traffic scenario data sets are converted to ns specific format. The communication links across vehicles are formed using data traffic generator.

A. Data traffic generation procedure

Using traffic scenario data as input, the CBR (Constant bit rate data traffic) generator, a tool in *ns*, chooses pairs of nodes randomly to form communication links, and generates data at the source node to be sent to the destination node. In all our simulations the number of links used is equal to 50 % of the total number of nodes present in the scenario. This represents a high communication density scenario.

B. FleetNet Traffic Scenarios

The FleetNet traffic scenarios [6] has 3 types of data sets.- 1) Berlin city scenario- smaller network, 2) Berlin city scenario-Bigger network and 3) highway with 3-lanes.

The traffic scenario information has the following details:

- Vehicle ID/FleetNet ID
- Time stamp
- Vehicle location
- Vehicle velocity

Performance of DMAC is studied for all the three types of vehicle movement scenarios and compared against OMNI MAC.

1) Berlin city scenario – smaller network

The vehicle movement information is available for every second for 180 minutes duration. Information of all vehicles present at every instance of time in the road network is provided. The total road network area considered is 1.3 Km X 1.03 Km. The road network along with the average speeds for each lane at a particular time instance is shown in figure 1. Lanes are color coded to indicate different average speed ranges.

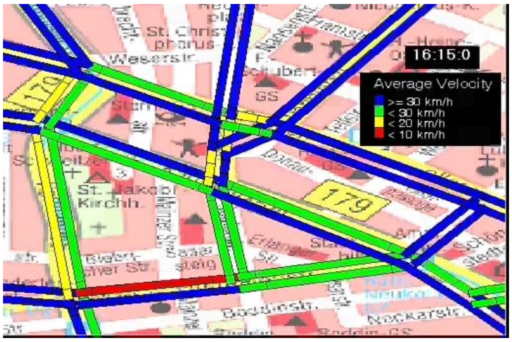

Figure 1. Berlin city scenario – Smaller network

2) Berlin city scenario – Bigger network

Like the smaller network, the bigger network data contains vehicle movement information for every second for 180 minutes duration. The total geographical area is 5.9 km x 6.1 km. The Berlin-bigger network is shown in figure 2. Total length of road network is 94.493 km, with 72 crossings, and 196 edges. This scenario consists of both a mixture of major roads, like the highways, and city roads.

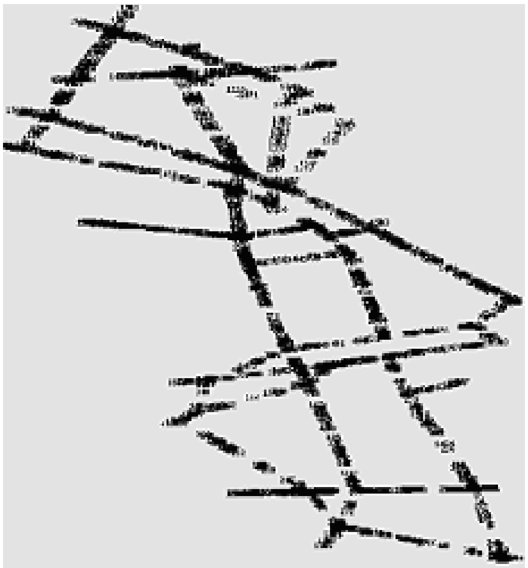

Figure 2. Berlin city scenario – Bigger network

3) Highway with 3 lanes

In addition to the above-mentioned scenarios, a highway scenario with 3 lanes was used to study the network performance. Length of the road is 40 kms with approximately 600 vehicles simulated on this road. Figure 3 shows snapshots of vehicle locations at six time instances. A total of 18-minute data was available for this scenario.

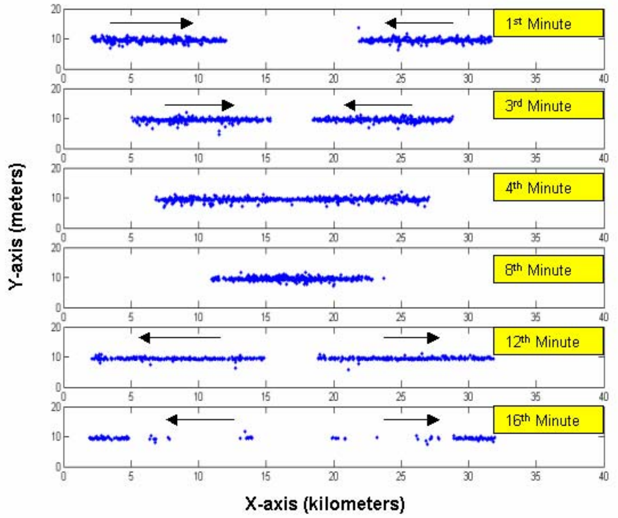

Figure 3. Node position in autobahn scenario

Using these node movement scenarios, the communication links were formed between pairs of nodes that were picked randomly in the network and the mobile wireless network performance results were obtained. Since the number of vehicles at any given instance of time is large, ns2 was unable to handle the complete 180-minute data at once. So, we split the 180-minute traffic scenario data into one-minute durations; obtained the network performance results for selected one-minute traffic scenario data.

C. Simulation parameters

In all the simulations, the following values are used for the parameters mentioned

- Communication range of nodes -- 250 meters
- No. of directional antennas – 6 in DMAC; 1 in OMNI
- Packet size: 500 bytes
- Data Rate: 1 Mbps
- Routing protocol: AODV
- Location table update rate: Updated upon reception of any packet from the neighbors
- Location table purging rate: 2 seconds
- Number of nodes generating packets: 50 % of the nodes

The communication range for both directional antenna simulations (DMAC) and OMNI MAC simulations used is same. Location table entries are updated as and when a new packet arrives. The table entries are purged every 2 seconds so that only latest entries are used. The purging rate can be set based on the type of application, scenario, and mobility of nodes.

IV. NETWORK PERFORMANCE

A. Performance Measures

The network is evaluated using the following performance measures:

1) Throughput is the fraction of the available channel capacity used for data transmission. A MAC protocol's objective is to maximize the throughput rate.

In our simulations, the throughput is calculated by counting the total number of packets received at the application layer of all the destination nodes in the network for the full simulation duration. Then using this total number of received packets, the amount of data delivered in kbps was computed. Since the same node movement scenario and the data traffic scenario is used in both DMAC and OMNI MAC, the total number of packets delivered gives a relative measure of throughput for both the protocols.

2) End-to-end delay is defined as the average time spent by a data packet in the MAC queue, i.e., from the instant the packet is generated till its transmission is complete. The time taken by a packet sent from the source node (application layer of source) to reach the destination node (application layer of destination) is the time delay of that packet. The total time delay of all delivered packets divided by the total number of packets delivered gives the average end-to-end delay of the network. The average end-to-end delay per packet is computed as

$$\tau_{av} = (\sum_{i=1}^{n} \Delta t_i)/n$$

Where Δt_i: Time delay in delivering the i^{th} packet (application layer of source node to application layer of destination node)

n : Total number of packets delivered

The network performance is obtained by computing the throughput and end-to-end delay of the entire network under consideration. The performance of DMAC with OMNI MAC is compared in the next sub-section.

B. Results

Inter-vehicle communication on a realistic road network and vehicle movement scenario is simulated in ns. The three scenarios mentioned in the previous section, which covers most of the possible cases in IVC are used in the simulations.

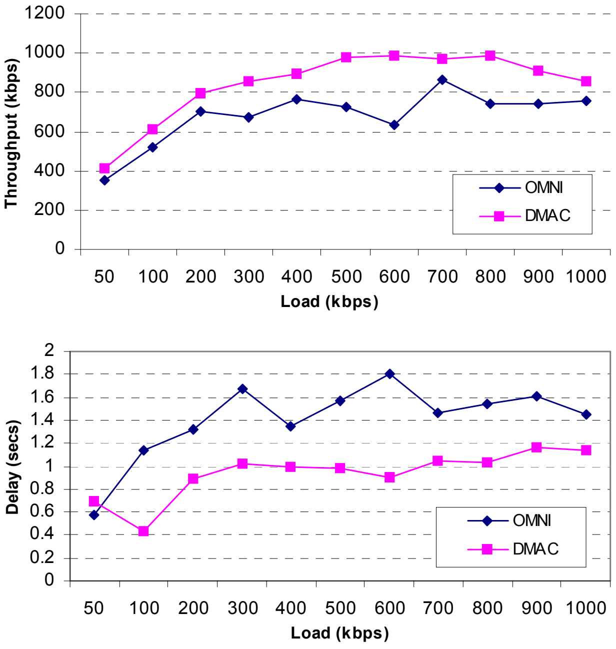

Figure 4. Network performance in Berlin city scenario– smaller network

1) Berlin City scenario – smaller network:

There are 370 vehicles in this scenario. The throughput and end-to-end delay is as shown in figure 4. Throughput and end-to-end delay of DMAC is better than OMNI MAC. At higher loads, the average throughput of DMAC is 25 % more than OMNI MAC. Average end-to-end delay of DMAC is less by 35 % compared to OMNI.

2) Berlin city scenario – Bigger network

The simulations for bigger city network are done for two 1-minute traffic movement data. There are around 450 nodes in this scenario. The results are shown in figures 5 and 6. The improvement in DMAC over OMNI in throughput and end-to-end delay is marginal.

This is due to the reduced node density as compared to the smaller network case.

At lower node density, the spatial re-use is not fully utilized and less communication links are formed. This reduced the expected throughputs and also did not improve the end-to-end delay significantly. For DMAC to perform better in inter-vehicle communication applications, the node density should exceed a minimum value.

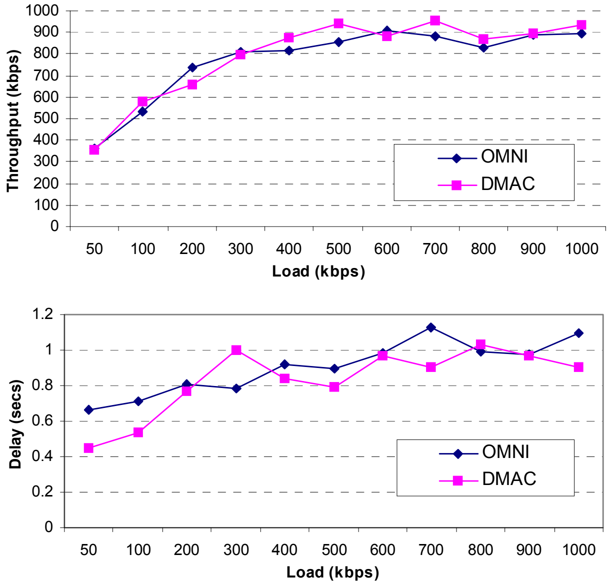

Figure 5. Network performance for Berlin city scenario–bigger network

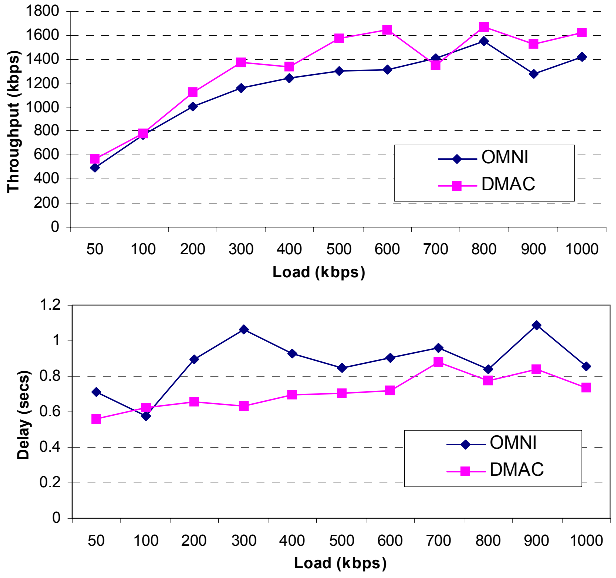

Figure 6. Network performance for city scenario- Bigger network

3) Highway with 3 lanes

The results are generated for 1st, and 4th minute data of traffic scenarios of figure 3 and are shown in figures 7 and 8 respectively. The road length is about 40 km and the nodes are clustered into two groups approaching each other in opposite lanes. The node density is higher. Total number of nodes is 600.

For the 1st minute data, the improvement in throughput of DMAC is 60% and delay is better by 35% as compared against OMNI MAC. For the 4th minute data the absolute values of throughput have increased for both DMAC and OMNI. Hence we infer that throughput of DMAC increases with increased node density.

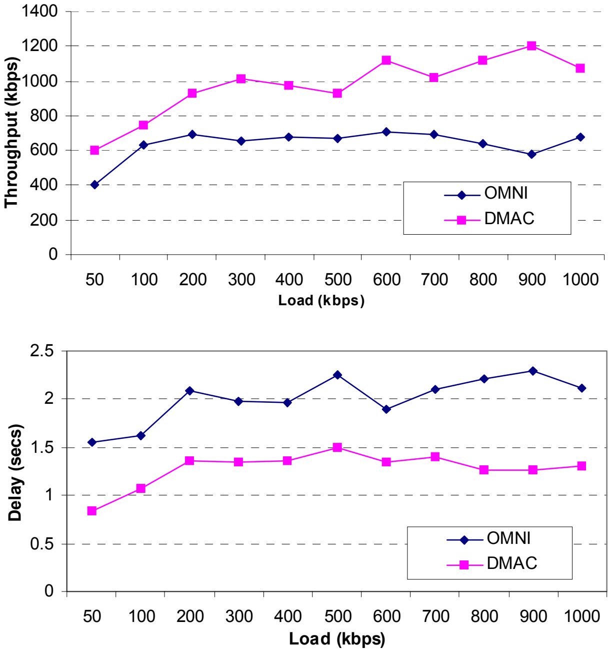

Figure 7. Network performance for highway scenario – 1st min. data

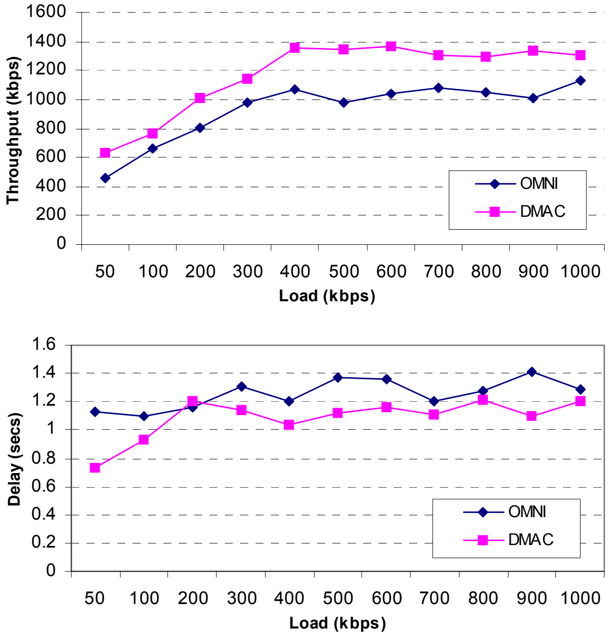

Figure 8. Network performance for highway scenario – 4th min. data

The relative improvement in DMAC for 4th minute data throughput is only 25%. The improvement in delay in 4th minute data is 12%. The improvement of DMAC is less for 4th minute data as compared to 1st minute data. In the 4th minute (figure 3) data, the two groups of nodes moving in opposite directions cross each other. The relative node mobility disturbs the location tables in DMAC protocol. Since two communicating nodes choose the directional beams for communication in the RTS-CTS phase and during data transmission, the same set of beam pairs are used assuming that the relative directions of each other do not change much. This assumption is not valid when the nodes cross each other with high relative velocity. The RTS-CTS handshake needs to be reestablished. This leads to increase in channel access times. As a result, the relative increase in throughput of DMAC is less for the 4th minute data.

V. CONCLUSIONS

Simulation results show improved performance of DMAC over IEEE 802.11 MAC in city smaller and bigger network scenarios and highways. Both the throughput and end-to-end delay showed significant improvement with DMAC protocol for inter-vehicle communication traffic scenarios. Node density and mobility affects the performance of the network.

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