Reliable MAC Broadcast Protocol in Directional and Omni-directional Transmissions for Vehicular Ad hoc Networks

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ABSTRACT

This paper presents the design, implementation and simulation results of a reliable Medium Access Control (MAC) broadcast protocol for Vehicular Ad hoc Networks for omni-directional and directional transmissions. The IEEE 802.11 MAC protocol uses control frames for handshaking to reliably communicate unicast data. In contrast, the broadcast data is transmitted without any control frames. This results in increased collisions due to hidden terminal problem, which in turn reduces the reliability of the broadcast service. This problem also exists in MAC protocols based on directional transmissions. To overcome this problem in Directional MAC (DMAC), we adapted Batch Mode Multicast MAC (BMMM) protocol, which uses control frames for broadcast transmissions. We implemented BMMM in NS-2 for omni-directional and Directional MAC protocols. Simulations are run for city traffic scenarios and the results are compared with IEEE 802.11 unreliable broadcast support. The simulations and comparison are done for two variants of BMMM protocol implementation integrated with DMAC.

Categories and Subject Descriptors

C.2.2 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Protocols – *Protocol architecture (OSI model), Protocol verification.*

General Terms

Algorithms, Performance, Design, Reliability.

Keywords

End-to-end delay, Hidden Terminal Problem, Successful Delivery Rate, Throughput, Broadcast, Directional MAC, Vehicular Ad hoc Networks.

1. INTRODUCTION

The Active Safety and De-centralized floating car data application for Vehicular Ad hoc Networks requires each car to broadcast periodically data such as position, driving direction and velocity to all neighbors. Since this data increases driver safety in certain situations such as emergency braking, a MAC protocol that provides efficient broadcasting of packets with high reliability is needed [1].

When a node transmits a packet, all nodes within the sender's transmission range can potentially receive the packet with a single transmission since radio transmission is inherently broadcasting in nature. However, it results in interference with other transmissions, creating Exposed Terminal Problem (ETP) and Hidden Terminal Problem (HTP). In ETP, a node might defer transmission because the medium is busy around it while the medium around the intended recipient could be free. ETP keeps the available resources idle resulting in lower throughputs. In HTP, a node might initiate a transmission because the medium is free around it while the medium around the intended recipient is busy. Because of this collision occurs at the intended recipient and consequently throughput becomes low. ETP and HTP exist in unicast and broadcast transmissions. Also, the high mobility of nodes in the vehicular network increases the probability of transmission errors and link failures.

Given the problems caused by transmission errors, collisions, and hidden/exposed nodes in wireless networks, Media Access Control (MAC) is of fundamental research interest. These problems become severe when support is provided for multicast/broadcast communication in wireless networks. Such support is necessary for delivering acceptable quality of service in many applications of Vehicle-to-Vehicle communications. A broadcast communication is termed 'reliable' if the transmitter receives acknowledgements (ACK) from all its intended receivers upon successful delivery of a packet.

IEEE 802.11 MAC provides broadcast support but it has the problem of ETP and HTP. In IEEE 802.11, the broadcast data packets are sent without any control packets. This results in collisions with ongoing transmissions thereby making the broadcast unreliable and less efficient. To improve reliability and efficiency some multicast MAC protocols based on IEEE 802.11 frame format and using additional control packets, are designed [3]-[5]. Broadcast Medium Window (BMW) protocol [5] uses RTS-CTS mechanism to solve HTP. In BMW protocol, all the receiving nodes send back ACK to the sender to make the transmission reliable. But, the contention time is directly proportional to the number of neighboring nodes. Due to large contention times, the protocol could lead to frequent message

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timeouts. The efficiency of this protocol for broadcast is very poor.

Batch Mode Multicast MAC (BMMM) protocol [6] overcomes the above limitations using only one contention phase as compared to multiple contention phases in BMW. BMMM has an additional control packet RAK in the RTS-CTS-RAK-ACK mechanism. RAK controls sequence of ACK's from the receiving nodes. BMMM frame format is similar to IEEE 802.11 frame format. BMMM showed improved reliability and efficiency over BMW protocol for omni-directional transmissions.

In vehicular ad hoc networks, the node movements are predictable. For example, the vehicles on the road move on a predetermined path in the same direction or opposite directions. As a result the communication links between vehicles is concentrated in a sector rather than in all directions. The network performance in Vehicular Ad hoc Networks becomes dependent on the traffic scenario. More communication links may be established in the network if directional transmissions are employed. Considerable work has been done in MAC protocols employing directional transmissions [7]-[11].

Reference [12] studied network performance of vehicular ad hoc networks using a Directional MAC (DMAC) protocol. The DMAC protocol was integrated with IEEE 802.11 to study network performance for multi-hop unicast transmissions. The results showed improved network performance of DMAC protocol as compared to Omni-directional (OMAC) protocol for city roads and highways.

In this study, we adapted and implemented BMMM protocol for DMAC with reliable broadcast (DMAC-RB) and OMAC with reliable broadcast (OMAC-RB). We used traffic scenarios of cities to study the network performance of DMAC-RB, OMAC-RB and compare the simulation results against IEEE 802.11 with unreliable broadcast (IEEE-URB). Two variants of BMMM are integrated with DMAC and compared.

The paper is organized as follows. Section 2 discusses the unreliable and reliable MAC broadcast protocols and the protocol selected for implementation. Section 3 discusses the protocol design. Two variants of the reliable BMMM protocol for integration with DMAC are discussed. Section 4 discusses the results of simulations of omni-directional reliable broadcast MAC protocol, directional reliable broadcast MAC protocol and IEEE 802.11 unreliable broadcast MAC protocol, for city vehicular traffic scenarios. Section 5 compares the simulation results of two variants of integrated BMMM-DMAC protocol. Section 6 gives conclusions.

This work is done as part of development of MAC layers with reliable broadcast, for vehicular networks, for project FleetNet. "FleetNet – Internet on the Road" was set up by a consortium of six companies including DaimlerChrysler and part funded by German Ministry of Education and Research. The PHY layer is a communication system based on 24 GHz Short Range Radar [2].

2. MAC PROTOCOLS DESCRIPTION

2.1 IEEE 802.11 MAC protocol

The fundamental access method of the IEEE 802.11 MAC is a DCF known as Carrier Sense Multiple Access with collision avoidance (CSMA/CA) [13]. The CSMA/CA consists of the basic access mode as well as the optional RTS/CTS/ACK access mode. In basic access mode, a node senses the channel to determine whether another station is transmitting before initiating a transmission. If the medium is sensed to be free for a DIFS interval, the node transmits. If the medium is found busy, the node defers its transmission until the end of the current transmission. Then, it will wait for an additional DIFS interval and generate a random backoff delay to initialize the backoff timer before transmission. The backoff timer is decreased as long as the medium is sensed as idle and suspended when a transmission is detected on the channel, and resumed when the medium is sensed as idle again for more than a DIFS interval. Only when the backoff timer reaches zero, the node transmits its packet. The destination node waits for SIFS duration and transmits ACK.

In RTS/CTS access mode, after obtaining the channel access right, the sender sends an RTS frame prior to data transmission to announce the upcoming transmission. When the destination node receives the RTS frame, it will transmit a CTS frame after a SIFS interval. Both the RTS and CTS frames are short control frames. The source node is allowed to transmit its packets only if it receives the CTS frame correctly. Nodes receiving RTS, CTS, or data frame that is not intended for them will yield channel long enough for the source and destination nodes to complete the data exchange.

For broadcast packets, IEEE 802.11 nodes simply execute basic CSMA/CA and then transmit the data frame. Broadcast data transmission is not preceded by RTS/CTS exchange resulting in increased interference or collisions. The probability of lost frames increases thereby reducing the reliability of multicast/broadcast service. To avoid HTP, handshaking mechanism is necessary before broadcast packet is transmitted. Reliability and solution to HTP is built in Broadcast Medium Window (BMW) [5] and Batch Mode Multicast MAC protocols [6] using virtual carrier sensing.

2.2 Batch Mode Multicast MAC protocol

Batch Mode Multicast MAC (BMMM) Protocol [6] is an improvement over the BMW protocol. In BMW, the sender uses at least n rounds of DCF-like unicasts for a broadcast request intended for neighboring nodes. Each round requires one contention phase before an RTS frame can be sent. The contention time is directly proportional to the number of neighboring nodes. Due to the need for n contention times, the protocol could lead to frequent message timeouts. By consolidating the n contention phases into one, the required time to serve a broadcast is reduced.

Though BMMM is a multicast protocol, in the current context, the protocol caters to broadcast needs. Although intended receivers are selected based on Location Table entries at the sender, all the neighbors receive the broadcast DATA packet. Therefore, broadcasting is achieved through multicasting.

The protocol coordinates the transmissions of the control frames, including RTS, CTS and ACK, with no modification of the frame format in IEEE 802.11 specification. It ensures that there is no collision among control frame transmissions. In this protocol the sender instructs its intended receivers to transmit the control frame in order. The sender uses its RTS frames to sequentially instruct each intended receiver to transmit CTS. The sender transmits Request for ACK (RAK) frames periodically after sending the data. RAK frame allows coordination of ACK transmissions from receivers. The RAK frame, as shown in figure 1, has the same format as the ACK frame. It contains frame control duration, receiver address (RA) and frame check sequence (FCS). Even if one of the sender's neighbors has data to send, it does not pass its contention phase when the sender is exchanging control frames with its intended receivers. The medium will never be idle for more than $2 \bullet SIFS + (T_{CTS}$ or $T_{ACK})$, which is less than DIFS. Any neighbor wishing to transmit data must listen for at least DIFS to ensure the channel is free. The sender transmits RTS and RAK periodically to prevent any neighbor from passing its contention phase. Figure 2 illustrates the difference between BMW and BMMM.

Octets:	2	2	6	4
	Frame Control	**Duration**	**RA**	**FCS**

Figure 1. RAK frame

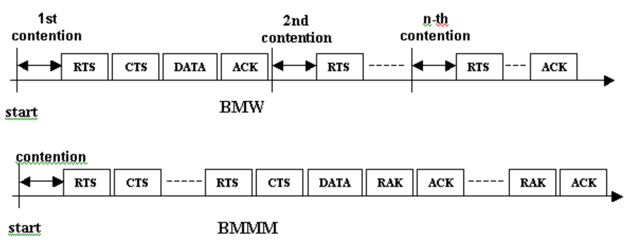

Figure 2. Timing Diagrams of BMW and BMMM

Reliability is achieved through coordination of ACK control frames using RACK. Time required to serve a broadcast request is reduced through consolidating the number of contention phases. BMMM protocol can co-exist with the other IEEE 802.11 protocols, including the unreliable IEEE 802.11 broadcast MAC protocol, as the control frame format is similar.

The MAC protocol can be designed such that the broadcast request generated at the upper layer can specify if it needs a reliable service or not. This feature will be useful for certain vehicle-to-vehicle communication applications to assign whether the broadcast message transmission needs reliability or not.

3. BMMM PROTOCOL DESIGN FOR DMAC

The BMMM protocol has been described for an omni-directional antenna. However, for automotive applications directional MAC protocol could be more useful for better spatial reuse and improved network performance. We have modified the BMMM protocol to make it suitable for reliable broadcast transmission with DMAC protocol.

In DMAC implementation, if the receiving antenna beam direction is known then, the RTS packet can be sent directionally. However, to overcome the hidden terminal problem due to asymmetry in gain, circular directional RTS is sent. In the current investigation, the circular transmission of a packet is implemented by sending the packet simultaneously on all beams.

3.1 DMAC protocol for Unicast

The hidden terminal problem solved using DMAC [7] is illustrated in figure 3. Suppose node A transmits directional RTS only on beam 4 to node B. During this time node B will be in an omni-directional receive mode.

After the reception of the RTS packet, node B sends directional CTS on beam 2. However, node C cannot receive the CTS transmission from B since node C is in omni-directional receiving mode. Subsequently when A sends a DATA packet to B, if C also transmits directionally on beam 4, then there will be a collision of DATA packet sent by A and the packet sent by C at beam 2 of node B. Therefore, B will not be able to receive the DATA packet.

DMAC protocol solves this problem by circular directional RTS. That is, node A transmits RTS directionally on all the beams. Node C receives the RTS packet containing the beam number of B (in this case beam number of B is 2) and sets the D-NAV for the beam 4. Hence node C defers transmission on beam 4.

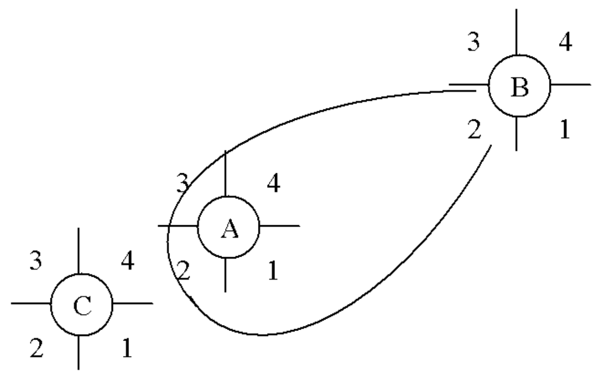

Figure 3. Hidden Terminal Problem

3.2 Integrated BMMM-DMAC protocol for broadcast

We integrated the BMMM protocol and the D-MAC protocol in network simulator NS2. NS2 simulator is a freeware available for simulating mobile ad hoc networks. The DMAC was implemented in NS2 as an event driven program. Event timers handle the control of execution. The starting and ending of events are tracked using these event timers. At the end of an event, (for example transmission of a packet on the channel), the control of execution will be transferred to the appropriate part of the program by the event timer.

By design DMAC covers limited geographical area when transmitting a packet. Unreliable broadcast support in DMAC transmits broadcast packets on beams that are free when backoff timer expires. So, the unreliable broadcast packet reaches lesser number of nodes. With regard to Reliable Broadcast, it is necessary to reach maximum number of nodes in one transmission. To achieve this we propose a scheme where the sender covers 360° by transmitting on all the beams. However, the sender has to wait for a longer duration for all the beams to become free. To achieve required performance, a tradeoff between spatial coverage and time delay has to be done. Two approaches are possible to implement the integrated BMMM-DMAC protocol- a) increased geographical coverage with longer wait time, b) reduced geographical coverage with lesser wait time. In the first variant, the throughput is maximized through increased spatial coverage and in the second variant, the throughput is maximized through sending more number of packets from the queue, as the wait time is less. The two variants of BMMM-DMAC integrated protocol are:

1. All-NAV free transmission (ALL-NFT)
2. Available-NAV free transmission (AV-NFT)

In ALL-NFT, the first RTS is transmitted only if the NAV settings of all the beams are free while in AV-NFT, the first RTS is transmitted if NAV settings of atleast one beam is free. Hence, the number of backoffs is more in ALL-NFT as compared to AV-NFT.

The BMMM protocol has a sender part and a receiver part. In other words, BMMM protocol defines the steps MAC layer has to take when it is the source of broadcast DATA packets or when it is expected to receive the DATA packet. So the implementation is logically divided into sender part and receiver part.

3.3 ALL-NAV Free Transmission (ALL-NFT)

3.3.1 Sender's protocol

In BMMM, a sequence of RTS-CTS is sent before DATA broadcast. In ALL-NFT mode, the sender transmits the first RTS packet only if the NAV settings of all its beams become free. When the backoff timer expires, the node checks the transmit-state and the receive-state of MAC. If either transmit-state or receive-state of MAC is busy, it will increment CW and backoff again. If both the states are idle, then the node checks the NAV state of all the beams. The node transmits the first RTS only if the NAV state of all the beams is idle. If atleast one NAV state is busy, then CW is incremented and the node backs off again. At the instance of transmitting the first RTS, the node makes a copy of the Location Table. This is because the Location Table may change during the broadcast cycle. RTS is sent to all the neighbors listed in the copy of the Location Table, irrespective of the sector in which they appear. To address HTP, RTS is transmitted in a circular manner directionally on all beams. For calculation purposes, the number of neighbors (NUM_OF_NBS value) is taken from this copy only. If the Location Table is empty, then the node increments CW and backs-off. CW is decremented only if the Virtual Carrier Sensing is idle.

After the first RTS is sent, the sender waits for CTS. If CTS arrives, MAC defers for SIFS and transmits the subsequent RTS without checking for the MAC state. That is, the node does not check transmit-state or receive-state or NAV-state while sending subsequent RTS. DATA is transmitted if atleast one CTS is received. DATA frame is transmitted in a circular manner directionally on all beams. The sender increments CW and backsoff if no CTS is received. Since separate RTS is sent for each node, the CTS received from the nodes do not collide.

After sending the DATA, RAK is transmitted in a circular manner directionally on all the beams to the neighbors listed in the copy of the Location Table. RAK is sent on all beams to minimize the problem of link failure due to mobility. While sending RAK, the node does not check transmit-state or receive-state or NAV-state. The number of ACK's received is recorded.

An additional bit field in RTS and DATA packets is incorporated to identify whether the packet is meant for reliable broadcast or not. This field will be useful to take appropriate action at the receiving node.

3.3.2 Receiver's protocol:

When a node receives RTS packet belonging to a reliable broadcast transmission, it sets the NAV of all the beams to busy state. This NAV setting will prevent the node from getting engaged in another transmission. Also, the node makes all beams -- except the beam on which it received RTS -- to passive state. This prevents interference from other ongoing transmissions. A timer (MAKE_PASSIVE timer) is started corresponding to beam passive settings. The duration for the expiry of this timer is calculated using the information in the RTS packet namely duration value, and the intended number of neighbors for the broadcast packet. The duration of the timer is equal to the duration until the reception of the broadcast DATA packet. After receiving RTS, the node sends CTS packet after a delay of SIFS.

The difference between NAV and MAKE_PASSIVE settings is as follows. Directional NAV prevents a node from transmitting a packet on a particular beam, but the node can still receive incoming packets on that beam. When Directional MAKE_PASSIVE is set, the beam is switched off for both transmission and reception. In this way, MAKE_PASSIVE timer achieves spatial re-use.

When broadcast DATA packet arrives, the node stops the MAKE_PASSIVE timer and restarts the timer with a new duration specified in the DATA packet. The duration is till the end of the broadcast cycle. A flag (DATA_PKT_FLAG) corresponding to DATA packet reception is set. This flag will be a useful check whether or not to send ACK in response to received RAK. If the flag is set and a RAK meant for the current node arrives, then ACK is sent; else ACK is not sent. A new timer is started corresponding to DATA packet reception. This timer resets the DATA_PKT_FLAG flag at the end of the broadcast cycle.

3.4 Available-NAV Free Transmission (AV-NFT)

3.4.1 Sender's protocol

When a node wants to transmit a broadcast packet, it starts a backoff timer. On the expiry of this timer, the node checks the transmit-state and receive-state of the MAC. If either transmit-state or receive-state of MAC is busy, then the node increments CW and backs-off again. If both the transmit-state and receive-state are idle, then the node checks the NAV state of all the beams. The node transmits the RTS on beams that are free at this point of time. At the instance of transmitting the first RTS, the neighbors (listed in the Location Table) that can be reached using the available free beams are listed in a new table. RTS is sent to only the neighbors listed in the new table. For calculation purposes, the number of neighbors (NUM_OF_NBS) value is taken from the new table only. If the new table is empty, then the node increments CW and backs-off.

After the first RTS is sent, the sender waits for CTS. If CTS arrives, MAC defers for SIFS duration and transmits the subsequent RTS without checking for the MAC state. That is, it will not check transmit-state or receive-state or NAV-state while sending subsequent RTS. If the CTS do not arrive, the sender proceeds with the transmission of subsequent RTS. DATA is transmitted if atleast one CTS is received. DATA frame is transmitted in a circular manner directionally on free beams. If the sender does not receive any CTS, it will increment the CW and backs-off.

After sending the DATA, RAK is transmitted in a circular manner directionally on free beams to the neighbors listed in the copy of the Location Table. RAK is sent on all free beams to minimize the problem due to mobility. While sending RAK, the node does not check transmit-state or receive-state or NAV-state.

In both ALL-NFT and AV-NFT modes, the number of acknowledgements received is recorded. If this value exceeds some pre-assigned threshold, then the broadcast transmission is said to be successful. For example, if a threshold of 80 % is set, then a DATA packet is considered successful if sender receives ACK from more than 80% of NUM_OF_NBS.

3.4.2 Receiver's protocol:

The receiver's protocol is identical to that of ALL-NFT.

4. RESULTS & ANALYSIS

BMMM is implemented in NS2 for omni-directional and directional transmissions. The BMMM protocol implementation in omni-directional broadcast is referred as omni-directional MAC Reliable Broadcast (OMAC-RB). The BMMM protocol implementation for directional broadcast is referred as Directional MAC Reliable Broadcast (DMAC-RB). IEEE 802.11 broadcast implementation currently available in NS2 is unreliable broadcast and is referred as IEEE-URB.

Simulations are run for vehicle movement scenarios. The following simulations are compared:

1. OMAC-RB with unreliable broadcast in IEEE802.11
2. DMAC-RB with OMAC-RB.

OMAC-RB comparison with IEEE-URB would give effect of handshake on network performance. Due to reduced collisions in OMAC-RB, the network performance is expected to improve and due to overheads in OMAC-RB, the network performance is expected to degrade.

The unicast transmission of DMAC showed better results as compared to OMAC for city traffic scenarios [12]. In our simulations, we studied the network performance of DMAC and OMAC for reliable broadcast through simulations. An additional performance measure, Successful Delivery Rate (SDR) is introduced to study the reliability of the network. SDR is a quantitative measure of reliability of the broadcast transmission.

4.1 Traffic Scenarios

4.1.1 Berlin City Vehicular Traffic scenario

Figure 4 is a map of Berlin city on which the average velocity of the vehicles is indicated through color-coding. It shows the velocity distribution of vehicles in the streets. The minimum velocity is 0 km/h, average velocity is 25 km/h and the maximum is 50 km/h. There are a maximum of 5 streets in the network. The area of the network is 1.03x1.3 sq. km.

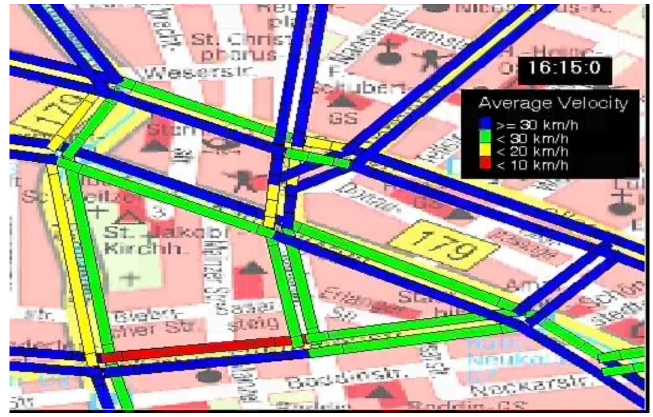

Figure 4: Velocity Distribution

4.1.2 Vehicle Spatial Distribution and Vehicle movement scenarios

Figure 5 shows the spatial distribution of 100 cars that form the MANET in the simulation. The markers indicate the (x,y) coordinates of the cars superimposed on the road network extracted from the Berlin city road map of figure 4.

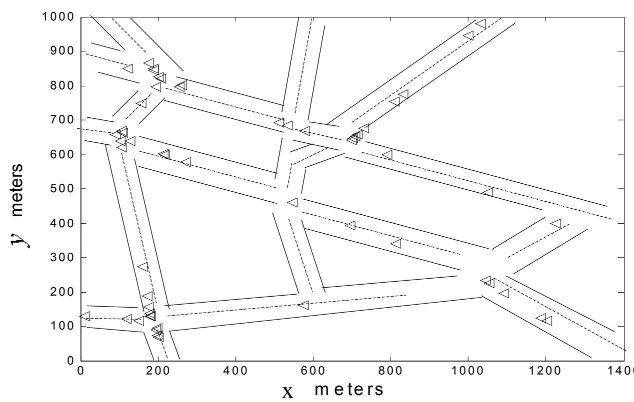

Figure 5: Vehicle Spatial Distribution

Ad hoc network of vehicles in city traffic scenario is simulated in ns2. Approximately, one tenth of the nodes generate Broadcast packets and one half of the nodes generate unicast CBR packets in all the scenarios. Simulations are run for Broadcast packet rate 0.1kbps to 500 kbps, while that for unicast CBR packet rates are 200kbps, 400kbps, 600kbps and 800kbps. Identical node movement scenario and the data traffic scenario are used for both DMAC and OMAC simulations.

The vehicular traffic data was available for 180 min. It is split into 180 files each of one-minute duration. The resulting one-minute data are simulated in ns2. The simulated network has about 100 vehicles. The number of vehicles generating broadcast packets is 10 and the number of vehicles generating CBR packets is 50.

4.1.3 Vehicular Network Parameters

The following values are used as parameters for the network being simulated:

Table 1: Simulation parameters

Communication range	250 m
Number of beams	6 (only DMAC)
Packet size	500 bytes
Channel Bandwidth	2 Mbps
Simulation time	60 seconds
Hello interval	0.1 seconds
Network Layer protocol	AODV
Location table purge rate	0.1 sec.

The vehicular networks need a minimum of 250m of physical range. A large broadcast packet size is considered by taking size as 500 bytes.

4.1.4 Network Simulator

Network simulator NS2 is a discrete event simulator targeted at networking research. NS2 provides support for simulation of routing, MAC, and multicast protocols over wired and wireless networks [14][15]. We ran simulations on 512 MB RAM Pentium-4 Processor on Linux9.0. The control packets of AODV are sent using unreliable broadcast support in MAC layer. In real vehicular ad hoc network, broadcast transmissions and unicast transmissions exist. MAC layer segregates the broadcast packets coming from higher layers into unreliable broadcast and reliable broadcast streams. Control packets of higher layers are sent using unreliable broadcast support and DATA using reliable broadcast support.

4.2 Performance measures

4.2.1 Throughput

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

In our simulations, the throughput is calculated by counting the packets received per second at the LL of the receiving node. Depending on the packet size the number of bits received by all the receiving nodes is calculated and the value is normalized with the channel Bandwidth (= 2Mbps). It is given by

$$\text{Throughput} = \left[\frac{\text{rate of data bits received at LL}}{\text{Channel Bandwidth}}\right]$$

4.2.2 End-to-End Delay

The difference between time of sending a packet at the source node (LL of source) and the time of receipt of the packets at all the destination node (LL of destination nodes) is the delay (t_i) of that packet. The total delay of all delivered packets divided by the total number of packets (n) delivered gives the average end-to-end delay t_{avg} of the network given by

$$t_{avg} = \sum_{1}^{n} t_i \Big/ n$$

It is dependent on protocol and traffic characteristics. Therefore, when comparing different protocols, it is necessary to compare them based on the same data traffic parameters and node movement scenarios.

4.2.3 Successful Delivery Rate

Successful Delivery rate (SDR) is defined as the number of successful message transmissions divided by the total number of broadcast requests. A MAC protocol is reliable if it has a high SDR of broadcast packets. A broadcast message transmission is considered successful if the message reaches a certain percentage of the intended receivers. We call such a percentage the reliability threshold. The reliability thresholds considered are 50% and 80% for our case. These values represent medium and high successful transmissions. The values depend on the nature of the data packet (safety/multimedia).

SDR = Number of successful packets / Number of sent packets at the MAC layer

4.3 Network Performance with ALL-NFT BMMM-DMAC protocol

4.3.1 Throughput

Figure 6 shows throughput of the network with ALL- NFT variant. The results are generated for CBR = 200 kbps, 400 kbps, 600 kbps and 800 kbps. The throughput is compared for DMAC-RB, OMAC-RB and IEEE-URB. The throughput for OMAC-RB is found to be better for broadcast rates less than 10 kbps. When the rate exceeds 10kbps, the throughput for IEEE-URB is higher than DMAC-RB/OMAC-RB. In the DMAC-RB/OMAC-RB the sender node waits till CTS from all the nodes in the Location Table are received. This increases handshaking overheads considerably for DMAC-RB/OMAC-RB. As a result throughput is much lower for DMAC-RB/OMAC-RB. Throughput of DMAC-RB is marginally less than OMAC-RB. The reasons for lower throughput for DMAC-RB as compared to OMAC-RB are due to Deafness [16], Longer Wait Time and Mobility.

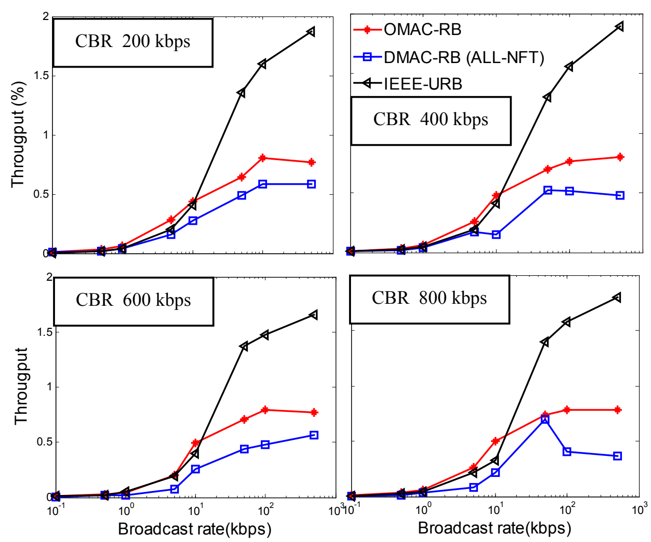

Figure 6. Throughput for different CBR rates

Deafness: A is trying to send broadcast packet to B and C (figure 7). D has established a unicast link with C. Here, C receives RTS from D before A transmits its first RTS. C makes its beams 2, 3 & 4 passive immediately after receiving RTS from D. When A sends RTS (meant for reliable broadcast) to C, then C will not be able to receive RTS from A. Later on, A also sends broadcast DATA to all the neighbors. But, C is still in the process of communicating with D. So, C will not receive broadcast DATA sent by A. Therefore, C would receive neither the RTS packet nor the broadcast DATA packet from A. Hence the throughput for DMAC-RB reduces as compared to OMAC-RB.

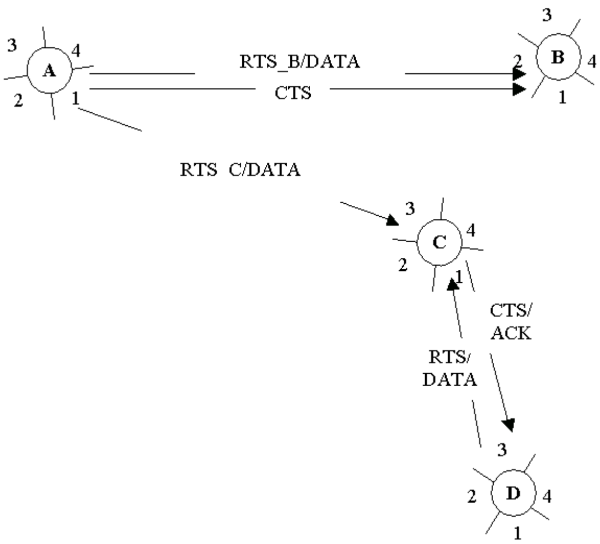

Figure 7. Node Scenario illustrating Deafness

Longer wait time: In the case of DMAC-RB, whenever the first RTS corresponding to a reliable broadcast DATA packet is to be sent, NAV settings for all the beams are checked. The first RTS is transmitted only if all NAVs are free. If atleast one NAV is busy, the node backs off by incrementing the contention window. Subsequent RTS is sent without checking for the NAV settings. The node waits for all NAV settings to be free since it allows more geographical area coverage with a single broadcast DATA transmission. Due to longer waiting time, the number of broadcast packets sent from the MAC layer of DMAC-RB is less as compared to OMAC-RB (figure 8). Hence, the number of packets received is less thereby resulting in reduced throughput.

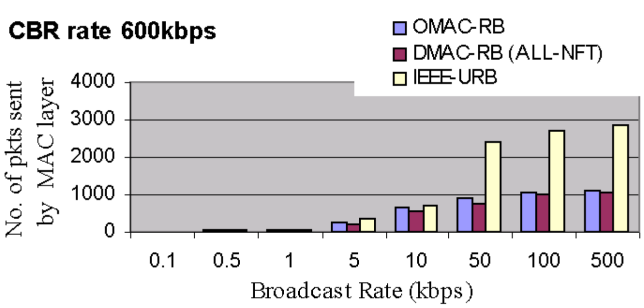

Figure 8. Number of Packets Sent

Mobility: In figure 9A, S is the sender of broadcast DATA packet and R is the intended receiver. S sends an RTS packet to R and R makes beams 2, 3 & 4 passive. R sends CTS on beam 1 to S. After receiving the final CTS from the last neighboring node, S sends broadcast DATA packet. In figure 9B, the nodes S and R moved

relative to each other before S sends the broadcast packets.

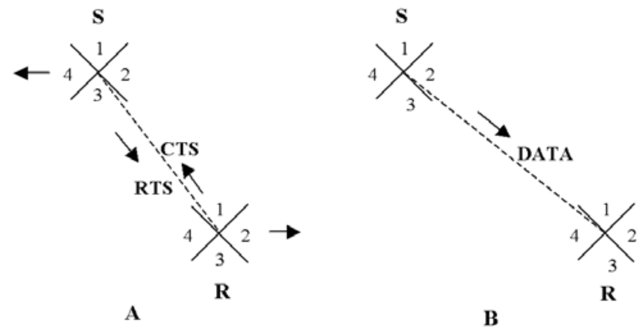

Figure 9. Mobility affects receiving of packets

R will not be able to receive the DATA packet as it arrives on beam 4, which is passive. This results in link failure. As the number of beams in DMAC-RB increase, the numbers of instances of link failure become more. In high mobility networks, the occurrences of link failures are even more. The throughput reduces due to such mobility induced link failures.

4.3.2 End-to-end Delay

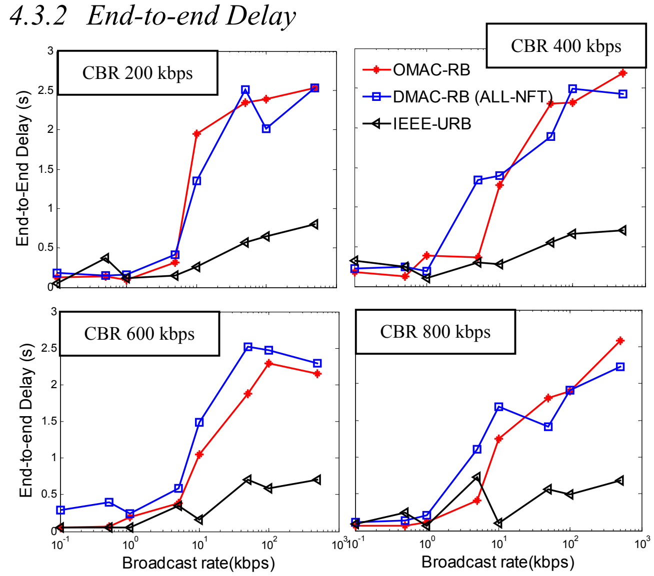

Figure 10. End- to-end delay for CBR rates 200kbps, 400kbps, 600kbps & 800kbps

End-to-end delay of DMAC-RB is marginally higher than OMAC-RB (figure 10). Delay is lower with IEEE-URB for all CBR rates. Longer wait time and reduced overhearing are the reasons behind higher end-to-end delay with DMAC-RB.

Longer Wait time is required for all NAV in DMAC protocol to become free in DMAC-RB. The broadcast packets are transmitted only after all the 6 beams become free. The number of times backoff happens before the packet is transmitted will be more. This results in increased end-to-end delay.

4.3.3 Successful Delivery Rate

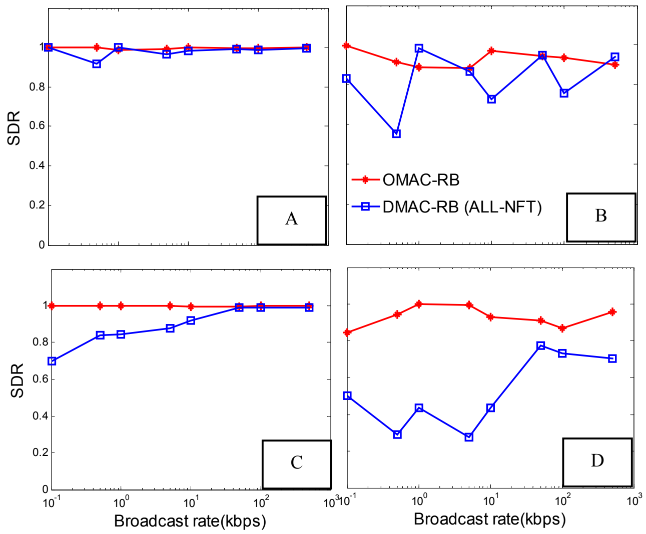

Figure 11. A & B show SDR at 50% and 80% reliability threshold respectively for CBR 200kbps; C & D show SDR at 50% and 80% reliability threshold respectively for CBR 800kbps

SDR is estimated by counting the number of ACK's received by the sender. SDR is measured for various broadcast rates for 50% and 80% reliability thresholds, for DMAC-RB and OMAC-RB (figure 11). The CBR rates are 200 kbps and 800 kbps. Since IEEE-URB protocol does not use ACK, SDR is not available for it.

SDR for DMAC-RB is observed to be less than that of OMAC-RB. This is due to Deafness and Reduced Overhearing explained below.

Deafness: Due to Deafness, the intended neighboring nodes do not receive the DATA packet. Consequently, the sender does not receive ACK from all the neighbors in the Location table. This results in less value of SDR for DMAC-RB.

Reduced overhearing: Figure 12 illustrates scenario of reduced overhearing. A sends unreliable broadcast DATA packet only on free beams 3 and 4 while beams 1 & 2 are busy. B and C receive the packet while D & E do not receive the packet. This reduces overhearing by D and E.

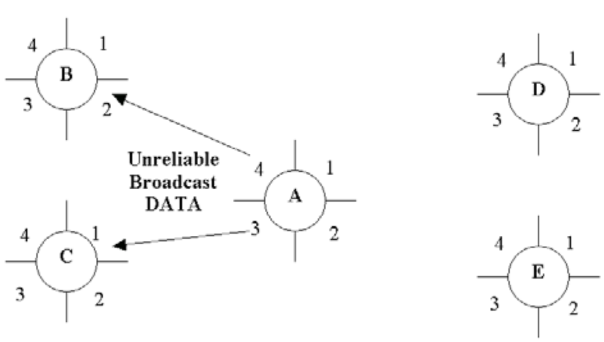

Figure 12. Scenario illustrating Reduced Overhearing

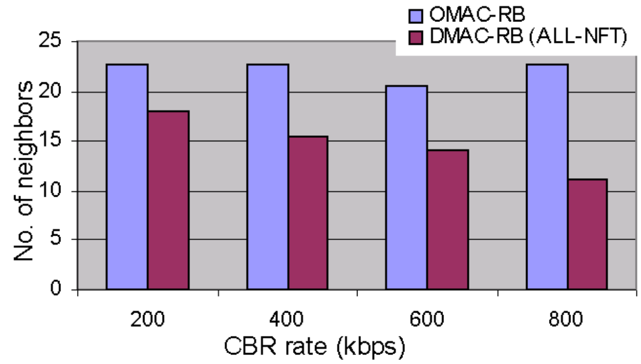

Figure 13. Average number of neighbors Vs CBR

DMAC-RB & OMAC-RB broadcast depends on Location Table updates. Location table gets updated when packets are overheard from ongoing transmissions. In DMAC-RB, unreliable broadcast DATA packets (from higher layers) are transmitted only on free beams resulting in reach to fewer nodes only. This results in reduced overhearing. As a consequence, the location table does not get updated properly. Figure 13 shows the average (over number of transmitted broadcast packets) number of neighbors in 60 seconds duration. We can see that the number of neighbors for DMAC-RB is less compared to OMAC-RB. Reduced number of neighbors in the location table reduces the number of packets exceeding the reliability threshold. This results in low SDR for DMAC-RB.

5. COMPARISON OF ALL-NFT AND AV-NFT

The simulations are repeated for AV-NFT variant of BMMM-DMAC protocol for identical vehicular traffic and data traffic parameters. Figure 14 compares throughput of ALL-NFT with AV-NFT for various broadcast rates.

5.1.1 Throughput

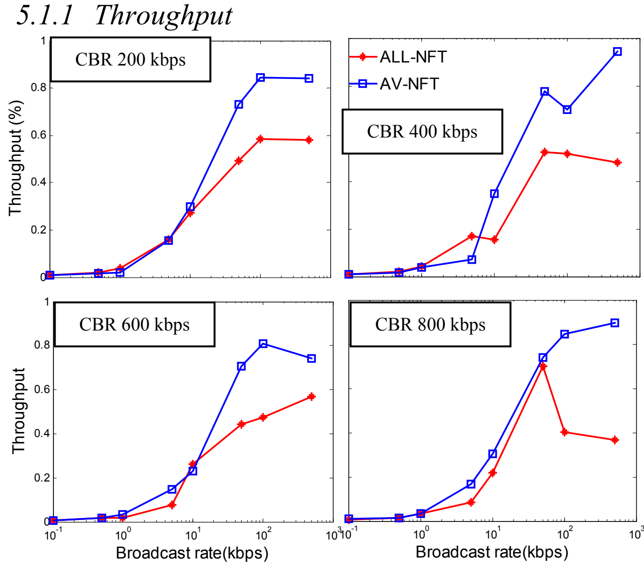

Figure 14. Throughput for ALL-NFT and AV-NFT

The throughput for AV-NFT is better for higher data rates. In AV-NFT the wait time for packets is less and hence the number of broadcast data packets sent from the MAC layer are more (figure 15). In addition, for higher broadcast rates, the number of packets sent at the MAC layer is significantly higher.

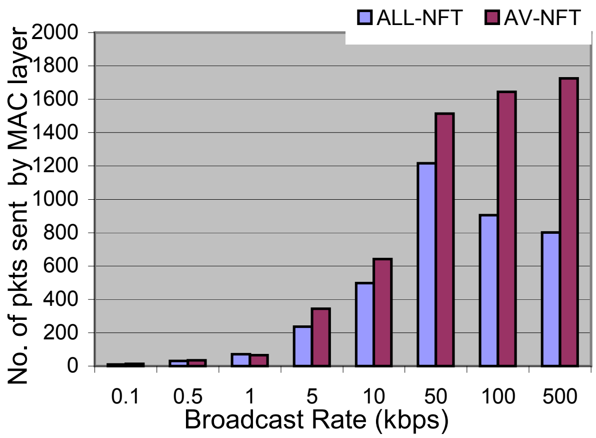

Figure 15. Number of packet sent at MAC layer

5.1.2 End-to-End Delay

End-to-end delay for AV-NFT is observed to be better than for ALL-NFT (figure 16). In the case of AV-NFT, the number of backoffs is less before the first RTS is sent. In the case of ALL-NFT, the number of backoffs is high since we wait for all NAV to become free before we transmit the first RTS.

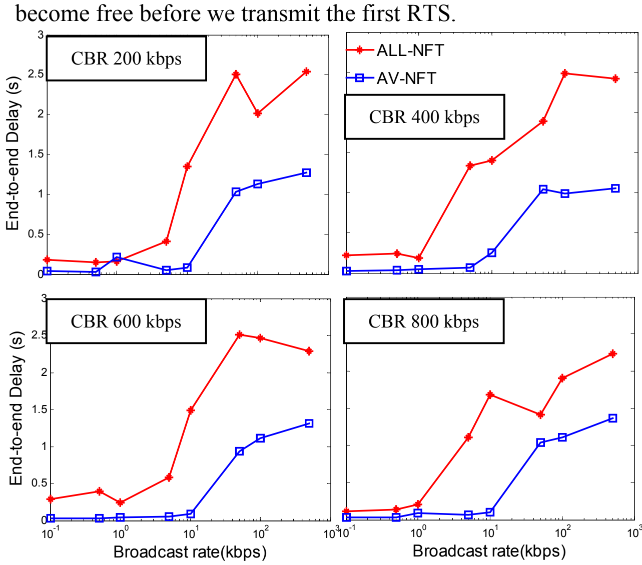

Figure 16. End-to-End delay of ALL-NFT and AV-NFT

5.1.3 Successful Delivery Ratio

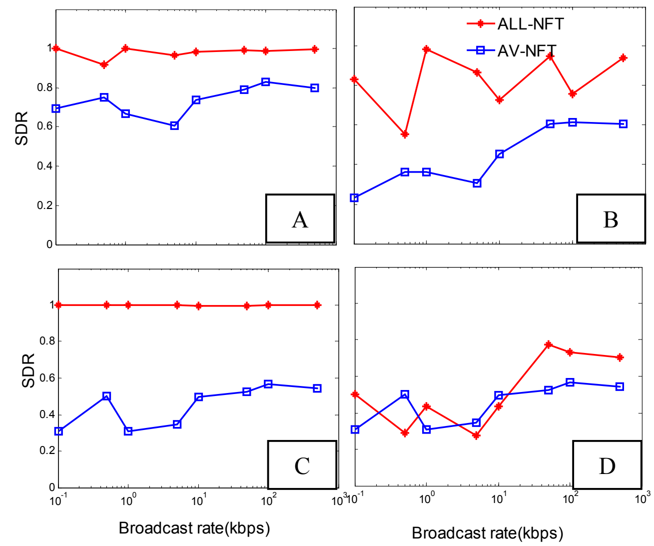

Figure 17: A & B show SDR at 50% and 80% reliability threshold respectively for CBR 200kbps; C & D show SDR at 50% and 80% reliability threshold respectively for CBR 800kbps

The SDR for AV-NFT is found to be poor (figure 17). As discussed earlier, SDR value for DMAC-RB (ALL-NFT) is less compared to OMAC-RB. This was due to Deafness and Reduced Overhearing problem described earlier. Deafness reduces the number of ACK's from the neighbors. Reduced overhearing reduces the number of neighbors in the location table. In the case of AV-NFT, the number of neighbors to whom broadcast DATA is transmitted decreases further because transmission is done only on available free beams. The broadcast DATA transmitted to only to those neighbors that lie in region of free beams.

6. CONCLUSIONS

We adapted the BMMM protocol and integrated it with DMAC protocol. The implementation is done in NS-2 with ALL-NAV and AV-NAV free variants. The simulations are run for city vehicular traffic scenarios. The network performance for DMAC-RB, OMAC-RB is compared against IEEE-URB with ALL-NAV free. The network performance is measured in terms of network Throughput End-to-End Delay and Successful Delivery Rate.

Simulation results indicate that for low broadcast rates (< 10 kpbs) the throughput of OMAC-RB, DMAC-RB and IEEE-URB are similar. As the reliable broadcast packets generation rate increases, the throughput of OMAC-RB and DMAC-RB levels off while that of IEEE-URB levels off at a higher broadcast rate. The results demonstrate that the introduction of reliability into DMAC-RB protocol for broadcast has reduced the network throughput. It is also true for broadcast using OMAC-RB protocol. The reasons for reduced throughput for DMAC-RB are analyzed to be Deafness, Longer Wait Time and Mobility. Application layer may decide which packets need reliable broadcast at the cost of reduced throughput.

End-to-End delay of DMAC-RB and OMAC-RB increases with reliability. The difference in delay between them is marginal. The reasons for increased delay as compared to IEEE-URB are analyzed to be Longer Wait time and Reduced Overhearing.

Successful delivery ratio of the packets is measured for DMAC-RB and OMAC-RB only. SDR is not relevant to IEEE-URB as no reliability is built into it using ACK. SDR is less in DMAC-RB compared to OMAC-RB. The reasons for this are analyzed to be Deafness and Reduced Overhearing. The decrease in SDR for DMAC-RB is significant at higher CBR rates.

We also compared implementation of ALL-NAV and AV-NAV for identical vehicular and data traffic scenarios. The throughput and end-to-end delay showed improvement in the AV-NFT implementation as compared to ALL-NFT for higher broadcast rates. However, SDR in AV-NFT is poor.

7. ACKNOWLEDGMENTS

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