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A DMAC Protocol to Improve Spatial Reuse in Wireless Ad Hoc Network

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Abstract:- Generally, a node have omnidirectional antenna in wireless network. While a node is communicating, the vicinity nodeshave tosilent even they have packet to send. Thus, we can't get better spatial reuse because of the Omni direction antenna. Because of collision in the network with more nodes reduces the performance. But, since last decade the researcher got more attention with directional antenna than omnidirectional antenna because of its spatial reuse and higher range of packet transmission. But, the hidden and deaf node problem is severe as well. We proposed a system that takes benefits of directional antennas like spatial reuse, higher transmission range. Moreover, our scheme combat against deaf and hidden node problem. Using our scheme we derived saturation network throughput and delay. In order to validate we use OPNET simulation tool. The analytical and simulation results illustrations that the performance of the network is enhanced.

Keywords :- *WSN, hidden and deaf node problem, Directional antenna, Directional MAC.*

I. INTRODUCTION

Generally the nodes are mounted with isotropic antennas,[1]that radiates signals around the node. Since the signal is omnidirectional it stops the vicinity nodes to transmit. Resulting we cannot used the large portion of the network. Therefore the MAC protocols such as IEEE 802.11 DCF[2] can't accomplish well spatial reuse as DMAC. Moreover, with directional antenna brings better transmission range, higher spatial reuse and inferior interference form the undesirable direction. However, it bring some serious problem such as deaf and hidden node problem. Determination of neighbour's location with directional antenna is a big issue as well.

In directional MAC protocol most researchers assumes that the nodes are able to switch its antenna as Omni directional or directional mode. The nodes sense the channel omnidirectional mode while they are idle, if they have packet they form their beam towards the receiver node to transmit a packet. The operating in both modes by the node could not achieve the full latent of directional antenna because of their asymmetry in antenna gain[3]–[5]. Our proposed scheme overwhelms the problem by using the directional antenna we call it Multi Beam Smart Antenna (MBSA). It can produce multiple beams and point them towards different directions. Moreover, it can transmit/ receive packet simultaneously through its all beams.

We suggested a new DMAC for wireless networks, in which the nodes are mounted with MBSA. We introduced a new control packet Neighbour Information Packet (NIP), to intimate the vicinity nodes of communicating nodes regarding the ongoing communication. It combat the problem of deaf and hidden node. We analysed our DMAC in to get saturation point of throughput and delay. We develop a markov chain to examine the performance of our DMAC protocol and confirm it with OPNET simulations tool.

The rest of this paper is prepared as follows. We discussed background and related work on DMAC protocols in Section 2. In Section 3 the proposed model is discussed. In Section 4 the mathematical preparation discussed. The simulation and results are presented in Section 5. Finally, in section 6 the paper is concluded.

II. BACKGROUND AND RELATED STUDY

Since last decade, the design of DMAC protocols is more popular in wireless ad hoc networks[2], [6]–[16].In these works, Choudhury *et al*[2]suggested a MAC protocol, in which to establish links with receiver node, the sender sends multi hop RTS, then sends CTS, DATA and ACK ona single hope directionally. Takai *et al.* [6] proposed directional virtual carrier sensing shared with a DNAV table to escalation of spatial reuse of the network. Ramanathan *et al.* [11] proposed the throughput of aggressive and conservative collision avoidance models with power control and neighbour detection. In these study researched focused to improve network performance through spatial reuse of the network. Whereas, the above study suffers from deaf and hidden node problem as well.

Nasipuri *et al.*[9]suggest a scheme, in which Omni directional transmission of the RTS and CTS packets, whereas directional transmission of DATA and ACK packets. Ko *et al.*[10]suggest a scheme, the node transmits DRTS when at least one of its antenna beams is blocked (DNAV set), otherwise it sends ORTS, whereas, the receiver replies with omni directional CTS. They consider that the all nodes has neighbor location information using technology such as GPS. In the above research, the neighbor nodes unnecessarily take back off while RTS/CTS handshake is failed.

Gossain *et al.*[12]propose a scheme that cuts the issue of previous MACs. In its scheme after successful directional RTS/CTS handshake by sender and receiver, the node transmits optimized circular RTS/CTS. Further, for neighbor determination the nodes in the network sends periodic hello packet to their neighbors. We follow the same scheme for neighbour determination in our system. The deaf and hidden node problems are reduced due to optimized circular RTS/CTS. However the idle nodes receive packet omnidirectional increases asymmetric in gain problem.. Bazan *et al.*[7]have surveyed several directional MAC protocols.

III. PROPOSED MODEL

In our proposed system, the nodes are fixed and the network is wireless ad hoc network. The nodes are link their direct neighbor. The communication by the nodes is directional.

A. Antenna Model

All the nodes are attached with directional antenna that can produce M number of beams that covers around the node. The directional antenna can transmit or receive packet simultaneously by using its beam. We are just utilizing the property of MBSA to transmit RTS and CTS in the vicinity node. The use of directional antenna prevents unnecessary interference from other direction, improves spatial reuse.

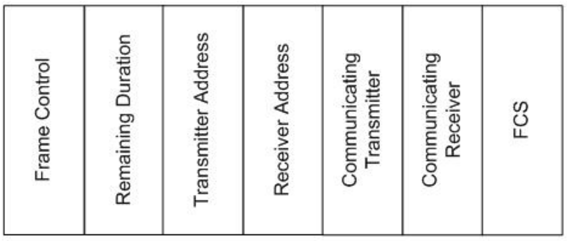

Figure1-Packet structure of NIP

B. NIP (Neighbour Information Packet)

Since the communication is directional in our proposed system, more than one communication can possible at a time in same omnidirectional range in the network. So, the nodes just completed their communication have no information regarding other uncompleted communication in the network. Our proposed control packet (NIP) informs the nodes that just completed its communication in [17]. The structure of control packet is depicted in figure1. After receiving the NIP packet, the nodes (communicating nodes that recently complete its communication) established their DNAV for remaining duration of the on-going communication in the network.

C. The Suggested MAC

Since in our suggested scheme, the beam of the directional antenna covers the 360^0 area of the network. With the help of beams of directional antenna, the idle nodes sense the channel around the nodes.

If a node has packet to send, it sends DRTS towards receiver. When node receive CTS, then the communicating nodes send RTS and CTS by using their beams which covers the 360^0 area. The vicinity of the communicating nodes sets their DNAV. During the communication other beans are block for communication.

In directional MAC the spatial reuse is one of big advantage. Sending of our suggested NIP control packet increases the spatial reuse in the network. When a node complete their communication the vicinity node sends NIP to inform it about the ongoing communication in the network.

IV. NUMERICAL ANALYSIS

We evaluate the saturation throughput and delay of our suggested MAC protocol. We are using the similar approach given in [20] for our model. We considered only saturation case, it means that our nodes have always packet to send. The N active nodes are arbitrarily spread in two-dimensional space. The source node arbitrarily chooses the receiver to send a packet. The discrete time Markov chain process is showed in figure 2. Each node have to be in one of the seven states. A node is consider in IDLE state, when it takes back off or the channel is detected idle. When a transmission successful, the node is in SUCCESS state and when it fails to transmit, it resides FAIL state. When a packet receive successfully, the node is in RECEIVE state. A node is in DEFER state when it is unable to transmit a packet due to its DNAV. When a node overhears a packet it is in OVERHEAR state. When a node transmits NIP packet it is in NIP state.

The all node in our network are probabilistically identical transition state. We calculate the basic steady state distributions for states and develop formulas for the transition probabilities. The results help to calculate the performance of our system.

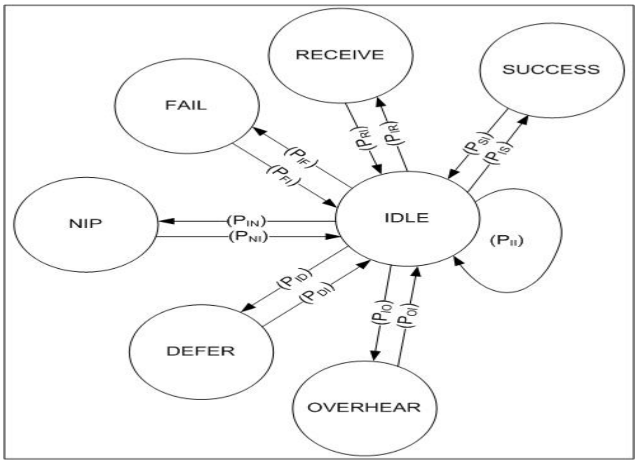

Fig. 2 : Transition state of proposed MAC

A. Throughput Analysis

We consider the same approach for random back off scheme defined in [18]. The back off mechanism procedure taken by a node is demonstrated as a Markov Chain.

The τdenotes the transmission probability of a node, which exist in the idle state. From [18], the parameter τ given by:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1)+pW(1-(2p)^m)} \quad (1)$$

The conditional collision probability = p; the minimum contention window =W; and the maximum back off stage value= m.

Now, we determine the p. Let the steady states probabilities of the Markov Chain (IDLE, OVERHEAR, DEAFER, NIP, FAIL, RECEIVE and TRANSMIT) revealed in figure 2, denoted asI, O, D, N, F, R, S. The time period a node stays in the corresponding states are represented as $T_i, T_d, T_o, T_n, T_f, T_r, T_s$ respectively. We describe a continuous-time state transition process $X = \{X_t, t \geq 0\}$ by defining the node state variable at time t,X_t, which denotes the state into which the system transitioned at the last transition time occurring before time t. Letδ (idle) is the steady-state probability that the continuous time semi-Markov state process X resides at any time at the idle state. We calculate δ in terms of its embedded discrete time state process, to be given by [19].

$$\delta = \frac{IT_i}{IT_i + OT_o + DT_d + NT_n + FT_f + RT_r + ST_s} \quad (2)$$

Let a node X has packet to transmitto node Y. then the probability of collision of the X's packet at a random time t0 is-

$$p = 1 - Pr\{success \mid attemptedtransmission\}$$
$$= 1 - \alpha\beta\gamma$$

Where,

$$\alpha = \Pr\{att_0 timethereceivernodeisidle\} = \delta$$

$$\beta = \Pr\{receiveriswithinthesender'srange\}$$

$$\gamma = \Pr\left\{\begin{matrix} nostationinsender'scommunicating \\ transmissiontowards \\ receiverdirectionint_{rts} + 1 \end{matrix}\right\}$$

Since the channel are sensed by the idle nodes through its all beams. Therefore, during calculating α we didn't consider the probability of the receiver pointing in direction of sender. For simplicity, we consider that the receiver node is always within the sender's range, therefore the$\beta = 1$. γ is given as –

$$\gamma = \left(1 - \frac{1}{M} \times I\,\tau \times \frac{1}{M}\right)^{(N-2)(t_{rts}+1)} \quad (3)$$

Therefore,

$$p = 1 - I\left(1 - I\tau\left({}^{1}/_{M}\right)^{2}\right)^{(N-2)(t_{rts}+1)} \quad (4)$$

Where number of beams =M, number of nodes in the network =N, andRTS transmission time = t_{rts}.

We derivate equation (3) for conditional probability p in terms of number of beams, steady-state probability and packet transmission probability.

We assume that the probability of transition from any state (except idle state) to idle state is one.

So,

$$P_{si} = P_{ri} = P_{fi} = P_{ni} = P_{di} = P_{oi} = 1 \quad (5)$$

The rest of transition probability to other state from idle sate is-

$$P_{is} = P_{ir} = \tau(1-p) \quad (6)$$

$$P_{ii} = (1-\tau) \times \left(1 - I\tau\left(\frac{1}{M}\right) - IP_{ir}\left(\frac{1}{M}\right)\right)^{N-1} \quad (7)$$

$$P_{is} = \tau p \quad (8)$$

Since a successful transmission corresponds a successful reception as well, the$P_{is} = P_{ir}$.

To simplify the calculation of we use approximation procedure for P_{id}, $P_{io}$and P_{in}.since we consider the RTS is successfully received, so its probability is 1. The other packet (CTS, DATA, ACK) may collide, so their probability is$(1-p)$ .Therefore the ratio of number of packets per packet type RTS:CTS:DATA: ACK is approximately $1 : (1-p) : (1-p) : (1-p)$. A node, which is in OVERHEAR state and sets DNAVs for at least two beams. The transition goes to NIP state after expiration of any DNAV.

$$P_{id} = \left(\tau \times \left(1 - P_{ii} - P_{is} - P_{ir} - P_{if}\right) \times \left(\frac{2 + (1-p)}{2 + 3(1-p)}\right) \times \frac{1}{M}\right)$$

$$P_{io} = \left((1-\tau) \times \left(1 - P_{ii} - P_{is} - P_{ir} - P_{if}\right) \times \left(\frac{2 + (1-p)}{2 + 3(1-p)}\right)\right) \quad (9)$$

$$P_{in} = \left(1 - P_{ii} - P_{is} - P_{ir} - P_{if} - P_{id} - P_{io}\right)$$

We obtained the following specific expressions- By solving the balance equations for the steady-state probabilities

$$\begin{gathered} I = \frac{1}{(2-I)} \\ S = R = P_{is} I \\ F = P_{if} I \\ D = P_{id} I \\ O = P_{io} I \\ N = P_{in} I \end{gathered} \quad (10)$$

The time ofa node stays in individual states are given as-

$$\begin{gathered} T_i = \sigma \\ T_s = T_r = T_d = \begin{pmatrix} 2(RTS + SIFS + CTS + H) \\ +DATA + SIFS + ACK + DIFS \end{pmatrix} \\ T_f = RTS + DIFS \end{gathered} \quad (11)$$

Where σ represents empty slot time duration and H denotes the size of the header of physical and MAC layer. The $T_s =, T_r = T_d$ because of a successful transmission is equal to successful reception and some nodes defer their transmission due to the communication. The total time of overheard packet transmission is the duration of overheard time. We evaluate the expected length of T_o is given as –

$$T_o \approx \left(\frac{2}{2+3(1-p)} (RTS) + DIFS + \frac{(1-p)}{2+3(1-p)} \begin{pmatrix} CTS + DATA \\ +H + ACK \end{pmatrix} \right) \quad (12)$$

$$T_n = NIP + DIFS \quad (13)$$

It is noted that the length of $T_{f,} T_o and T_n$ from upper formulas providespredictable calculations. We measured the value of $\tau, pand I$ by using the iterative method. Then by using the aboveequations, we calculate the throughput in bit per second, is expressed as-

$$\begin{gathered} S_{bps} = \sum_{i=0}^{N} (throuughputofnodei) \\ = \frac{N \pi_s E[P]}{IT_i + OT_o + DT_d + NT_n + FT_f + RT_r + ST_s} \end{gathered} \quad (14)$$

The$E[P]$is the average payload size of a data packet stated in bits. We calculate the performance of our system model in terms of saturation throughput by using the upper derived expressions.

B. Delay Analysis

We calculate the packet delay for our proposed MAC. The delay is defined as the average time that elapses between the beginning of packet transmission and the time a packet reaches its destination. Let two nodes are trying to connect with each other in the network. The average time to receive the data packet successfully by the receiver depends upon three factors: 1) theRTS transmission time, 2) the DATA packet transmission time and 3) average back off (BO) time taken before the transmission. Therefore the verage access delay can be characterized as–

$$E[AccessDelay] = 2 \times RTSTxtime + DATApktTxtime + E[BO] \quad (15)$$

In our model, two RTS sends by the source before DATA transmission (first RTS towards receiver and second RTS towards other neighbors). The RTS transmission time is given as

$$RTSTxtime = \frac{RTSpacketsize}{DataRate} \quad (16)$$

The DATA packet time is given as –

$$DATATxtime = \frac{DATApacketsize}{DataRate} \quad (17)$$

The E [BO] is the average number of the slot time for a successful packet transmission. Our model is using the same backoff mechanism as IEEE 802.11. E [BO] can be calculate by multiplying the number of slot timesd_i in each backoff stage and the probabilityq_i to reach the backoff stage [23]

Thus,

$$E[BO] = d_i \times q_i \qquad (18)$$

$$d_i = \frac{W_i + 1}{2}, \qquad i \in [0, m] \qquad (19)$$

$$q_i = \begin{cases} p^i, & i \in [0, m-1] \\ \dfrac{p^m}{1-p}, & i = m \end{cases} \qquad (20)$$

Thus after some algebraic calculation, we can rewrite the equation (26) as –

$$E\,[BO] = \frac{(1-2p)(W+1) + pW(1-(2p)^m)}{2(1-2p)(1-p)} \qquad (21)$$

By putting the value of equation (16), (17) and (21) into equation (15), we can calculate the average access delay for the node.

V. PERFORMANCE ASSESSMENT

A. Setup of Simulation

We examine our simulation results to authenticate the numerical analysis. We executed our proposed MAC in OPNET 14.5 [20]. The table 1 has the value of the parameters used in the simulations. In the simulation scenario, the 300 nodes are arbitrarily dispersed in a 1200×1200 m2 area. We consider the half of nodes are source and the rest of the nodes are destination. The sender and receiver nodes are arbitrarily chosen by OPNET.

Table1- Simulation parameter

Parameters	**Values**	**Parameter**	**Values**
Number of nodes	50	Slot_Time	50 μs
Area	1200 m^2	PHY_header	128 bits
CW_{min}	32	MAC_header	272 bits
Tx_Power	15 dbm	SIFS	28 μs
Rx_Threshold	-81 dbm	RTS	160 bits + PHY header
Sensing_Threshold	-91 dbm	CTS	112 bits + PHY header
ACK	112 bits + PHY header	DIFS	128 μs
Packet_payload	8184 bits	NIP	160 bits + PHY header

B. Performance Comparison

We compare the analytical and simulation results of our MAC protocol with IEEE 802.11 MAC protocol.We give M = 1 for original IEEE 802.11 DCF and M > 1 is for our system.

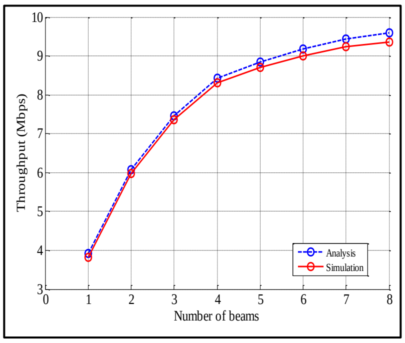

Fig.3: Throughput vs. Sectors

We detected in figure 3 that when the no. of beams rises in the network reaches its maximum performance. We also perceived that in directional MAC, (number of beams>1) network achieves better performance than omnidirectional MAC (number of beams = 1). Among the directional antenna, when number of beams increasing, the throughput is increasing accordingly. Although, the network achieve the highest throughput with eight beams, but the slop of the curve is increasing slowly after 4th beam.

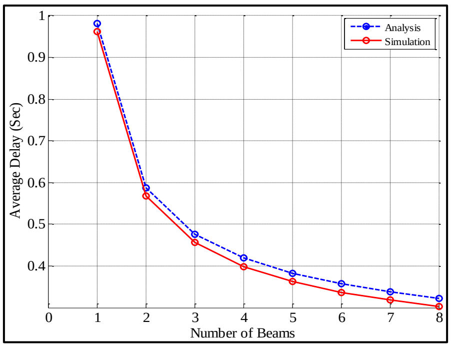

Fig. 4 : Delay vs. Number of sectors

In figure 4, the average delay is maximum in case of Omni directional antenna (number of beam = 1). Among the directional antenna (number of beams >1), as the number of beams is increasing the average delay decreased. However, as figure 3, after 4th beam the slop is falling slowly. As figure 3 and figure 4, we observed that the network not get more benefits with higher beams. The reason behind that, with increasing

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number of beams increases the chance of a node to become hidden or deaf.

Figure 5 shows the arc of total throughput of the network vs. number of nodes. We observe that the network get better performance with the directional antenna (M>1) as compare to Omni directional nodes (M= 1) because of spatial reuse in the network. Moreover, we can see that, the throughput is increasing when the no. of nodes rise in the network, but after the certain point (saturation point) the slop of graph going down. The saturation point for M = 1, M=2, M = 4 and M = 8 is 50, 100, 175 and 200 nodes respectively.

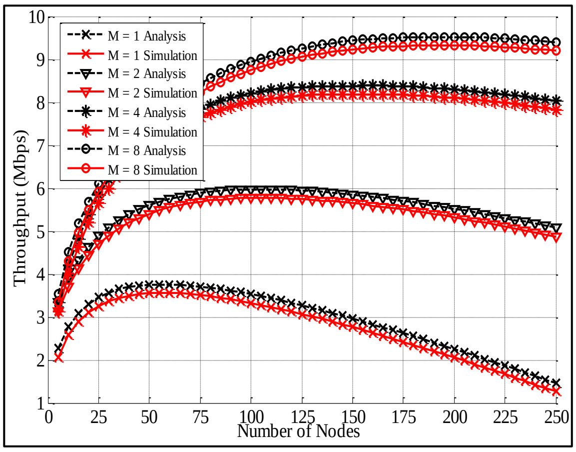

Fig. 3 : Throughput vs. No. Of Nodes

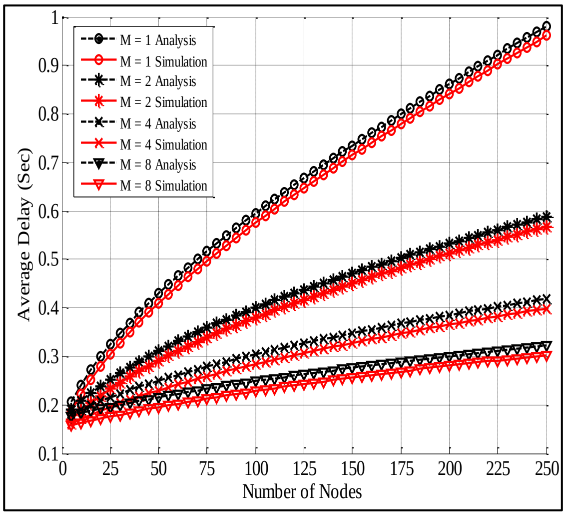

Fig. 4: Delay vs. No. of nodes

Figure 6, shows the graph of average delay vs. number of nodes. In figure we observed that, in the case of omni directional nodes the delay is higher than the directional nodes. Moreover, the average delay gap between omni directional network and directional network increases with increasing density of the network. The reason of higher average delay with omni directional antenna in dense network is more contending nodes in the network increases the BO time and higher probability of collision. Whereas, in directional MAC the whole network is divided into sectors equal to No. of beams decreases the competing nodes in a sector.

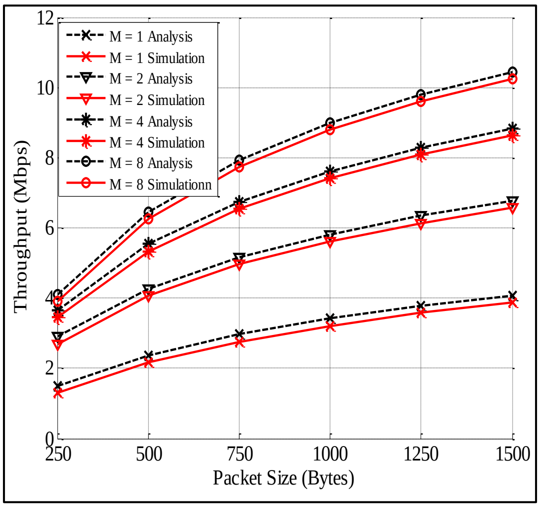

Fig. 5 : Throughput vs. Packet Size

The curve of the saturation throughput vs. packet size is presented in Figure 7. We observe that when packet size increase the network performance is growing and the directional antenna's performance is better than Omni directional.

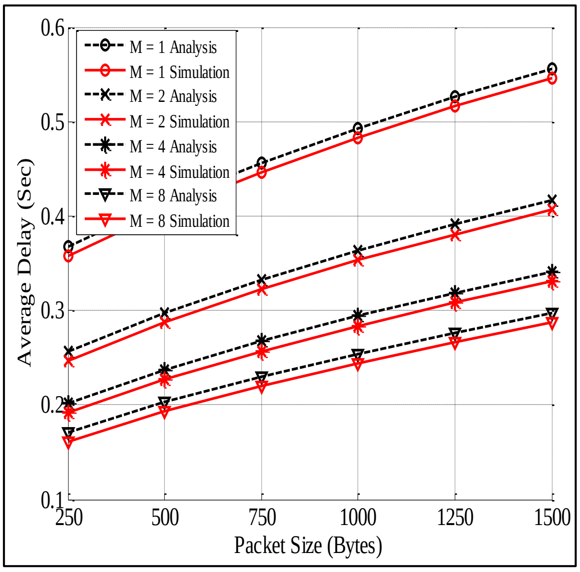

Fig. 6 : Delay vs. Packet Size

In Figure 8 demonstrations the average delay vs. packet size in the network. We observe an expected trend: as the packet size increases, the performance increases because of as the payload size increases and the time needed to transmit the control message remains the same. As the figure we can realize that the best performance is achieved in the M = 8. However, with 8 beam we can get as much benefit as with beam 2 and 4 due to higher number of beams increases the chance of hidden and deaf node problem.

VI. CONCLUSION

In our scheme we analyzed the saturation throughput of the network and improve the spatial reuse in the network. We proposed a control packet NIP. The transmission of NIP catchphrase the deaf and hidden node. The use of directional antenna with beams, gives the freedom from circular transmission of RTS/CTS that decreases the delay. We studied analytical model of our proposed MAC and verified by the simulation. Our proposed MAC significantly rise the network throughput.

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