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A Comparative Study of MAC Layer Protocols for Mobile Ad-Hoc Networks

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Abstract

In today's world of mobility, Mobile Ad-Hoc Network (MANET) is of utmost importance because it provides connectivity to users while on move. The main issue in Mobile Ad-Hoc Network (MANET) is of accessing the wireless channel, where too many users try to get access simultaneously. Traditionally, IEEE 802.11 Standards provide two protocols at MAC layer i.e. Distributed Coordination Function (DCF) and Point Coordination Function (PCF). In this paper a comparative study of PCF and DCF with Distributed Queuing Mobile Ad-Hoc Network (DQMAN) and Distributed Point Coordination Function (DPCF) protocols is presented. After a comprehensive computer based simulation, DPCF out performs the traditional protocols by a huge margin.

Keywords: Communications, Ad hoc and Sensor networking.

1. Introduction

The IEEE 802.11 Standard was first released in 1999 for defining the MAC and PHY layers for WLANs. Afterwards in 2007 the standard was reissued with some amendments [1]. MAC and PHY layers allow a single data protocol to be applied for several RF transmission techniques. The IEEE 802.11 standard defines two types of networks: Adhoc and Infrastructure. Adhoc networks are self configuring networks between mobile and portable wireless clients. Infrastructure networks use fixed, interconnected access points to provide connectivity to mobile and portable wireless clients. IEEE 802.11 defines two standard protocols for WLAN compatible devices: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). Out of these DCF is a mandatory access method to be followed by the compliant devices.

DCF is based on Carrier Sensing Multiple Access (CSMA) along with Binary Exponential Backoff (BEB) mechanism. Collision Avoidance mechanism is also mentioned in the standard for reducing the hidden terminal problem. This mechanism follows Request to Send (RTS) – Clear to Send (CTS) to establish connection between source and destination for the purpose of data transmission. DCF is protocol which can be implemented in any of the two networks i.e. Adhoc and infrastructure. PCF, the other protocol mentioned in the standard is defined as an option for infrastructure based networks. PCF is a polling based access method in which the access point (AP) polls every station to transmit data. This method provides better performance under heavy traffic.

Apart from DCF and PCF there are many more protocols designed at MAC layer to increase the performance of network under heavy load. But they are not the standards under IEEE 802.11. PCF being the protocol for infrastructure based networks has been very less experimented to extend to Adhoc networks. Though few works have been done to improve the overall performance of network, by designing polling mechanism to reduce the overhead related to the polling process [2]. Contrarily if DCF is considered, a lot of work has been done over past few years to make the protocol more efficient. Few works propose to improve the throughput by tuning the back-off algorithm at the run time [3-5]. These works are based on tuning of contention window i.e. the way how contention window size is increased or decreased on collision of packet or successful delivery of packet. Apart from this a power control mechanism has also been worked upon to improve the performance of the networks. In power control mechanism, the RTS/CTS signals are transmitted at high power whereas data and Acknowledge (ACK) signals at minimal power [6] [7]. So we can see that though Carrier Sense Multiple Access (CSMA) based protocol is a simple one but is a trial and error approach. Hence in future the combination of different access methods could improve the overall network performance.

Here in this paper four MAC layer protocols including the traditional ones are compared. Protocols discussed are Distributed Coordination Function (DCF), Point Coordination Function (PCF), Distributed Queuing MAC protocol for Adhoc Networks (DQMAN) and Distributed Point Coordination Function (DPCF). This paper is aimed at comparative study of these protocols for determining the performance of network and concludes with the best protocol.

The paper is organized as follows. In section 2, DCF; PCF; DQMAN and DPCF protocols are discussed. In next section 3 a comprehensive performance evaluation of all the protocols with the help of computer simulation is done. The simulation helps in performing the comparative study of these protocols. Finally section 4 concludes the comparison.

2. Media Access Control (MAC) Protocols

A brief description of MAC protocols i.e. DCF, PCF, DQMAN and DPCF is done in this section. A detailed description of the same can be found in [1].

2.1 Distributed Coordination Function (DCF)

DCF is a mandatory method by which clients work together and differ access to the medium so that the all users can use the same wireless channel. DCF uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and BEB to complete its performance. CSMA/CA is based on the multiple access technique used in wired Ethernet connections, Carrier Sense multiple Access with collision Detection (CSMA/CD). In both types of CSMA users first sense the transmission medium just before transmitting the packet of data. When two or more packets are transmitted simultaneously, a collision is said to have occurred. To handle the inability to detect a collision, IEEE 802.11 attempts to avoid collisions by designing waiting periods that allow multiple users to defer access to shared wireless channel to one another. DCF presents the protocols to be followed for designing this waiting period. DCF defines two modes of operations:

1. Basic Access Mode (BASIC): There is no prior handshake before transmitting the data. In this mode station which seizes the channel transmits its data without handshaking with destination.
2. Collision Avoidance Access Mode (COLAV): In this mode, handshaking between transmitter and receiver is done prior to transmission using RTS/CTS mechanism. This RTS/CTS mechanism is used to reduce the effect of collision and hidden terminal problem.

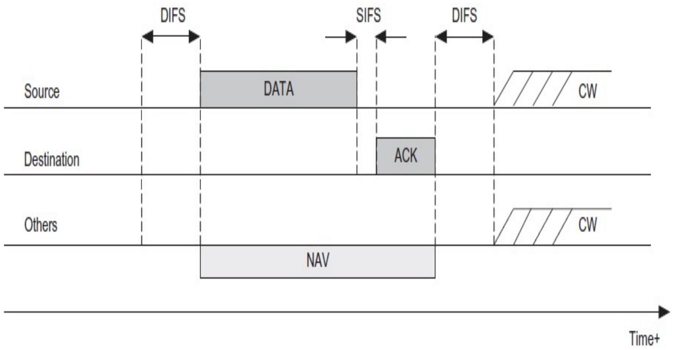

Fig. 1: DCF Operation in BASIC Mode.

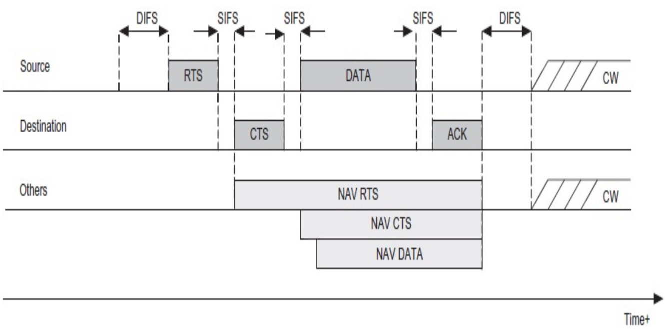

Fig. 2: DCF Operation in COLAV Mode.

Figures 1 and 2 represent the operations of DCF in BASIC and COLAV mode. Any station with data to transmit executes a Clear Channel Assessment (CCA) by which it listens to the channel for DCF Inter Frame Space (DIFS). If the channel is sensed idle for this DIFS period, the station seizes the channel and initiates the data transmission (or the RTS). Otherwise, if the channel is sensed busy, the station executes BEB algorithm. Any station suffering collision or failed transmission attempt, upon detection of the failure, sets a back-off counter at a randomized value within the interval [0, CW]. CW is referred to as contention window. As long as the channel is sensed idle, the back-off counter is decreased by one unit. Upon the expiration of the timer, the station attempts to transmit again. In the case of failure, the CW is doubled, where the maximum limit is given by $CW_m= 2^m.CW_{min}= CW_{max}$ and the back-off counter is reset to a random value within the range [0, CW]. Here, m is the maximum back-off stage.

Upon the correct reception of a data packet, the destination station sends back an ACK packet after a Short Inter Frame Space (SIFS). This SIFS is necessary to compensate for propagation delays and radio transceivers turnaround times to switch from receiving to transmitting mode. SIFS is shorter than DIFS, acknowledgements are given priority over regular data traffic.

Another important feature of DCF is the Virtual Carrier Sensing (VCS) mechanism. Stations not involved in an ongoing transmission defer from attempting to transmit during the time channel is expected to be used for an effective transmission between any pair of source and destination stations regardless of the physical carrier sensing. To do so, stations update the Network Allocation Vector (NAV) which counts for the time channel is expected to be occupied. This information retrieved from the duration field attached to the overhead RTS, CTS and data packets. This mechanism is mainly aimed to combat the hidden terminal problem.

2.2 Point Coordination Function (PCF)

PCF is an optional coordination function of IEEE 802.11 Standard. It can only run on infrastructure based networks wherein an AP sequentially polls stations to transmit data and thus collisions are totally avoided. In PCF, time is divided into Contention Free Periods (CFP), wherein the AP sends poll messages to give transmission opportunities to the stations and Contention Periods (CP), where the DCF is executed. A CFP is initiated and maintained by the AP, which periodically transmits a beacon (B). The first beacon after a CP (DCF access) is transmitted after a PCF Inter Frame Space (PIFS). The duration of a PIFS is shorter than a DIFS but longer than a SIFS, thus providing the initialization of a CFP with less priority than the transmission of control packets, but with higher priority than the transmission of data packets. The periodically transmitted beacons contain information regarding the duration of both CFP and CP and allow a new arrived station to associate to AP during a CFP. The CFP is finished whenever the AP transmits a CF End (CE) control packet. The operation of PCF is shown in figure 3.

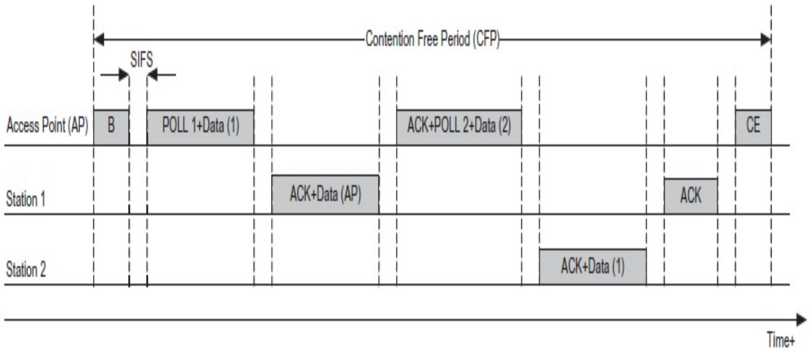

Fig. 3: Operation of PCF with CFP & CP.

2.3 Distributed Queuing MAC Protocol for Adhoc Networks(DQMAN)

The functionalities of both the network and the MAC layer are combined to achieve high performance in wireless Adhoc networks and this combination leads to formation of DQMAN. DQMAN combines a distributed dynamic clustering algorithm based on CSMA with near optimum infrastructure based MAC protocol for WLANs; the Distributed Queuing Collision Avoidance (DQCA) protocol [8]. In DQMAN, whenever a station seizes the channel to transmit its data packets by executing an access mechanism similar to DCF, it establishes a temporary one-hop cluster structure. The station which seizes the channel becomes the temporary cluster-head and it coordinates the data transmission of the stations in its range for a given period of time. The way the clustering algorithm is designed, constitutes an innovative concept design within the context of MAC protocols for wireless Adhoc networks. The main concept used in DQMAN is clustering algorithm. Clustering algorithms are designed on the base that the more stable the cluster set, the better the network performs [9 – 11]. In DQMAN, the clustering algorithm is designed on following basis:

1. Avoiding explicit clustering overhead.
2. Enabling future integration with legacy IEEE 802.11 networks.
3. Sharing in a fair manner the responsibility of becoming cluster head among all the stations in the network.

The clustering algorithm of DQMAN is based on a one-hop hierarchical master-slave architecture wherein any station can operate in any one of the following modes: master, slave or idle. Any station should be able to switch from one mode of operation to another according to the dynamics of the network. In DQMAN protocol, clustering beacon (CB) gets a control packet known as Feedback Packet (FBP). FBP is broadcasted periodically by the master, defining the time frame structure. This time frame structure is of utmost importance as the stations in the cluster are synchronized with it. Each frame is divided into 3 parts:

a) Contention Window (CW)
b) Data part
c) Control part

The frame structure of DQMAN is shown in fig 4.

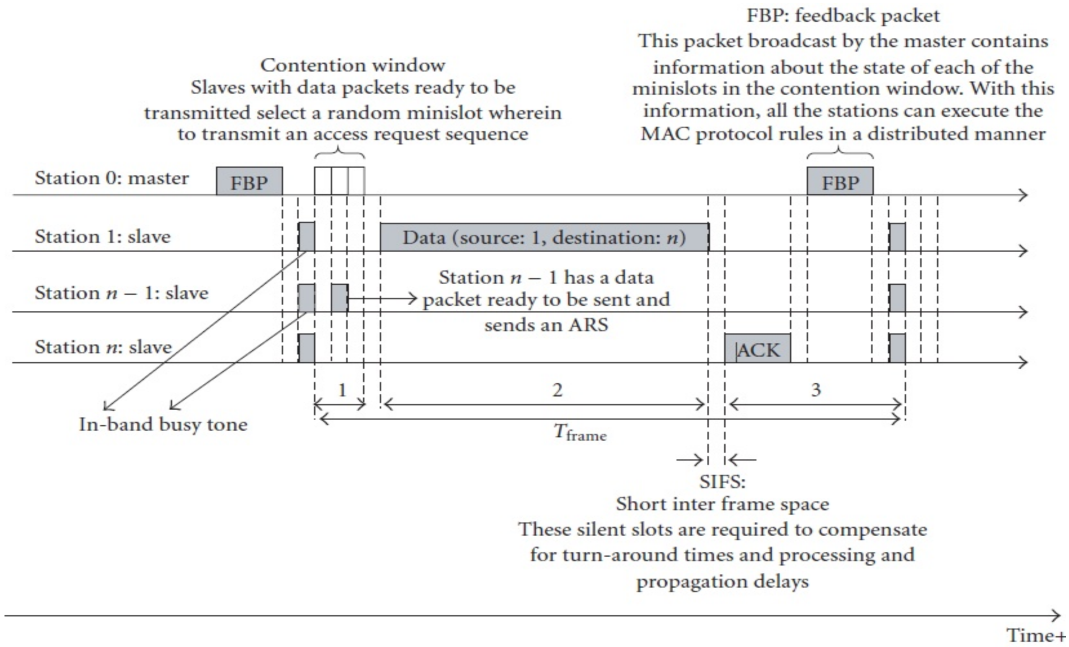

Fig. 4: DQMAN Frame Structure.

2.4 Distributed Point Coordination Function (DPCF)

Distributed Point Coordination Function (DPCF) is an adaptation of PCF to operate on wireless ad hoc networks. In this protocol the terminals must be able to operate in 3 modes: *idle, master and slave*. Initially all the terminals are in idle mode. Now the terminal which has data to transmit gets access to the channel using DCF protocol. Whenever a terminal gets access to the channel, it transmits an RTS for the intended destination terminal. This packet initiates a clustering process. After receiving the RTS, the destination terminal becomes master and responds to the RTS with a beacon followed by a poll for the terminal which transmitted RTS. A cluster is established and a Contention Free Period (CFP) is initiated inside this cluster. All the idle stations which receive the beacon become slaves and get synchronized to the master.

The duration of a cluster is variable and depends on the aggregate traffic load of the network. An inactivity mechanism is taken into consideration here to avoid the transmission of unnecessary polls when there are no more data packets to be transmitted. According to this mechanism, any master maintains a counter that is incremented by one unit upon each NULL packet received from a polled terminal with no data to transmit. This counter is reset to zero whenever a station responds to a poll with the transmission of a data packet. If the counter gets to a given tunable value, a CE packet is sent and the cluster is broken.

Any idle station with data to transmit gets access to the channel using the DCF. Whenever it gets access to the channel, it always transmits an RTS packet targeted to the intended destination of the data packet. This packet initiates a clustering process. The receiver initiated clustering mechanism of DPCF is illustrated in figure 5.

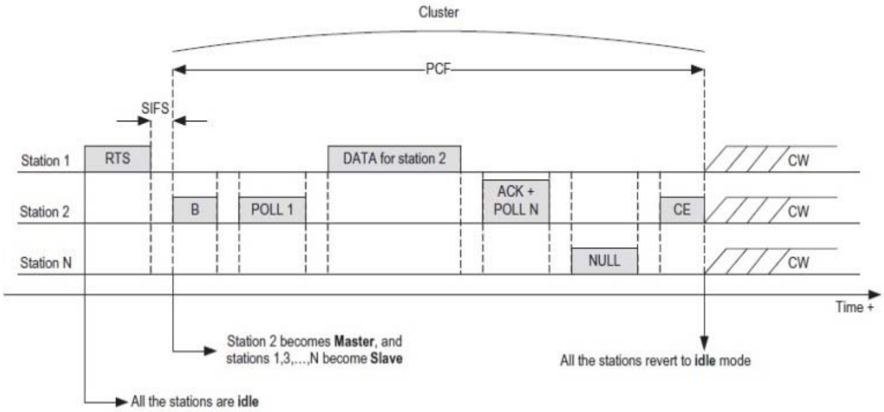

Fig. 5: DPCF Operation.

3. Performance Analysis and Comparison

System parameters for analysis of the different protocols discussed above is tabulated below in respective sections. An important point to be mentioned over here is that the comparative analysis of DQMAN and DPCF protocols is done in comparison with IEEE 802.11 standard protocols.

3.1 DQMAN Performance Analysis

Table 1: System Parameters.

Parameter	Value
Data packet length (MPDU)	1500 bytes
Data transmission rate	54Mbps
ACK & FBP packets	14 bytes
MAC header	34 bytes
MTO	100 frames
Access Mini slots (m)	3
Average message length	15000 bytes
Control transmission rate	6Mbps
Slot time	10μs
PHY preamble	96μs
(α, β)	(64, 10)
ARS and SIFS	10μs

Three different networks are evaluated:

a) A network where all the stations execute DQMAN protocol.
b) A network where all the stations execute DCF basic access mode.
c) A network where all the stations execute DCF COLAV mode with RTS/CTS mechanism.

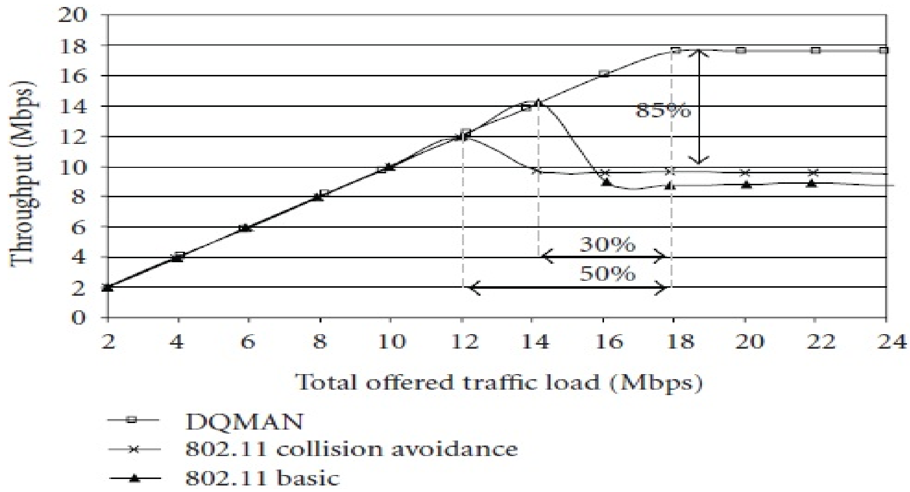

Fig. 6: Throughput Comparison.

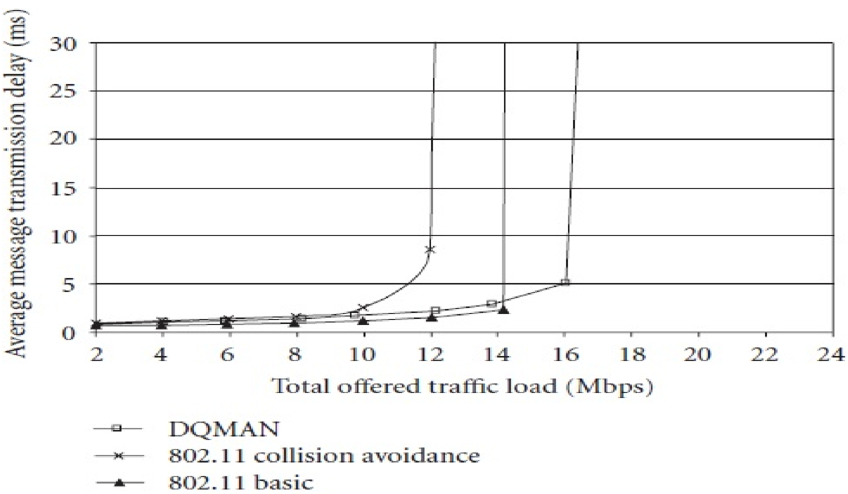

Fig. 7: Average Message Transmission Delay.

The figures 6 and 7 shows the result obtained after the simulation of above mentioned networks.

3.2 Result

From fig. 6 we can observe that DQMAN outperforms IEEE 802.11 in each of the two cases. At the lower traffic rates, DQMAN and IEEE 802.11 protocols show similar performance but at higher traffic load the DQMAN performs 85% better than its counterpart.

From fig.7 we can observe that the average message transmission delay for the network executing DQMAN unbound up to offered traffic loads of 16Mbps whereas COLAV mode unbound at 12 Mbps and Basic mode at 14 Mbps.

3.3 DPCF Performance Analysis

Table 2: System Parameters

Parameter	**Value**
Number of Stations	20
Activation Probability	0.1
Scenario Dimension	X = 600 m, Y = 500 m
Data transmission rate	54Mbps
Control transmission rate	6Mbps
MAC header	34 bytes
PHY preamble	96µs
DIFS, PIFS, SIFS	50µs, 30µs, 10µs
Slot time	10µs
RTS	20 bytes
Beacon	20 bytes
CF_End	20 bytes
Poll Packets	20 bytes
CTS and ACK packets	14 bytes
CW min	16
CW max	256
MTO	3
Polls per beacon	19
Maximum Initial Speed	0 m/s
Maximum Speed	15 m/s
Minimum Speed	0 m/s
Probability of Phase Change	0.5
Maximum Acceleration	10 m/s
Average Speed	0.75 m/s
Mobility model	Random waypoint
Data packet length	1500 bytes
Constant message length	1500 bytes
Simulation time	1 min 10 sec

The scenario details for analysis are tabulated in table 2 above.

3.4 Result

The throughput of three different networks is plotted below as function of total offered load to the network. All the curves grow linearly until they reach the saturation throughput. All the plots remain flat for very high traffic loads indicates that three protocols are stable for heavy traffic conditions without entering in congestion. The plot shows the improvement in the saturation throughput in comparison to DCF. Collisions and back off periods are reduced in DPCF. Analysis from the other values obtained through simulation gives following plots.

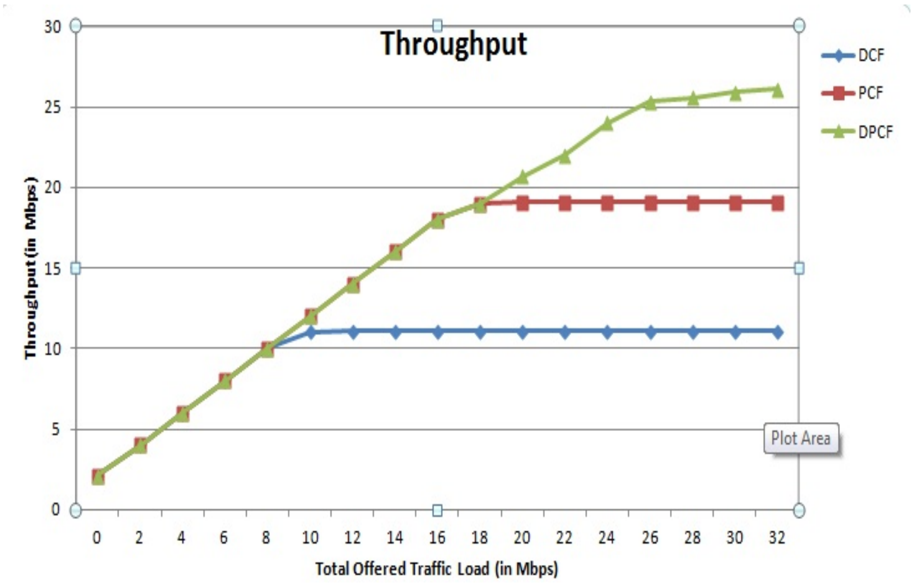

Fig. 8: Throughput Comparison.

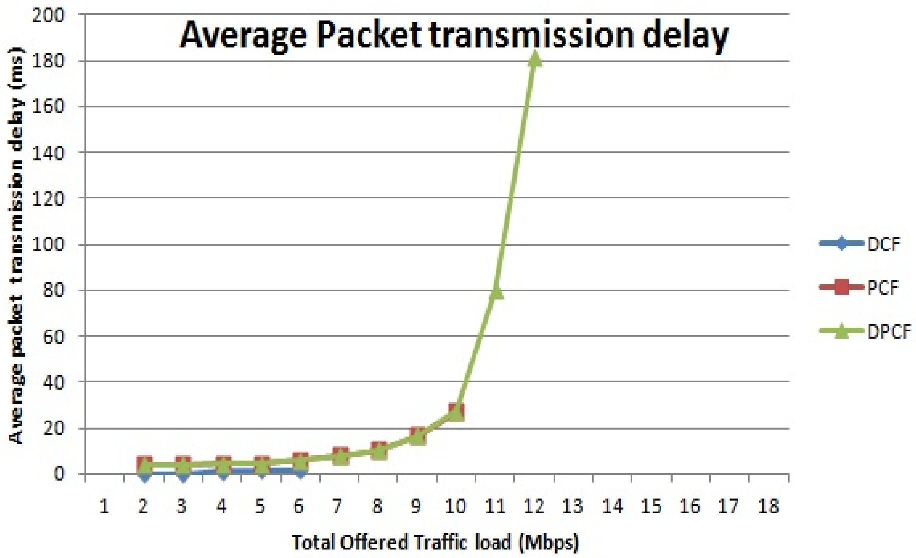

Fig. 9: Average Packet Transmission Delay.

4. Conclusions

Performance evaluation of the protocols through link level computer simulation shows the improved performance of ad hoc networks when compared to current standards only based on random access. The results achieved also prove that the designs of protocols used are very efficient in extending the operation of PCF and DCF to be executed in networks without infrastructure. The throughput performance of DPCF in comparison to PCF increases by around 250% as obtained in result graph whereas DQMAN performs 85% better. The throughput performance of DPCF in comparison to DCF increases by 45% as obtained in result graphs. So depending upon the load offered in the network of the application, we can select from either of the two DQMAN or DPCF.

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