EFFECT OF IMPROVED IEEE 802.11 DCF ON THE PERFORMANCE OF MANETs

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BY
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DECLARATION

I declare that the dissertation entitled "EFFECT OF IMPROVED IEEE 802.11 DCF ON THE PERFORMANCE OF MANETs" has been prepared by me under the guidance of Er. Neha Sood, Assistant Professor, Centre for Computer Science and Technology, School of Engineering and Technology, Central University of Punjab.

No part of this dissertation/thesis has formed the basis for the award of any degree or fellowship previously.

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CERTIFICATE

I certify that Shifali Hans has prepared her dissertation entitled “EFFECT OF IMPROVED IEEE 802.11 DCF ON THE PERFORMANCE OF MANETs ", for the award of M.Tech. degree of the Central University of Punjab, under my guidance. She has carried out this work at the Centre for Computer Science and Technology, School of Engineering and Technology, Central University of Punjab.

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ABSTRACT

EFFECT OF IMPROVED IEEE 802.11 DCF ON THE PERFORMANCE OF MANETs

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Wireless networks have become the most crucial aspect of the today's wireless communication and information exchange. The rapid advancements in the wireless networking technologies have drastically modified our communication and networking world and have led us to the new direction of "Infrastructure-less networking i.e. Mobile ad hoc Networks". Mobile ad hoc networks (MANETs) are the wireless infrastructure less networks that do not require any sort of central access point. Nodes in MANETs are connected by the wireless links and they are free to move arbitrarily in any direction. The attractive features of MANETs help to set up a network in emergency situations where the infrastructure is not available or not possible.

Even though MANETs have emerged to be attractive, and they hold great promises for our future, but there are several challenges that need to be addressed. The wireless medium is the open shareable; so many-a-times nodes compete among themselves for the medium access, and the conflict arises. In order to resolve the medium contention among nodes there are medium access control techniques. IEEE 802.11 DCF is the de-facto medium access protocol. However there are some problems in IEEE 802.11 DCF which need to be attended for the better MANET performance. The objective of the dissertation work is to study the IEEE 802.11 DCF performance. The performance of 802.11 have been deduced and analysed by running a simulation in NS2 and then have been comparing to the performance of the modified IEEE 802.11 DCF with AODV and DSR routing protocol.

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LIST OF ABBREVIATIONS

Sr. No.	Full Form	Abbreviation
1.	Access Point	AP
2.	Binary Exponential Backoff	BEB
3.	Carrier Sense Multiple Access with Collision Avoidance	CSMA/CA
4.	Carrier Sense Multiple Access with Collision Detection	CSMA/CD
5.	Clear To Send	CTS
6.	Contention Window	CW
7.	Carnegie Mellon University	CMU
8.	Distributed Coordination Function	DCF
9.	Distributed Interframe Space	DIFS
10.	Direct Sequence Spread Spectrum	DSSS
11.	Floor Acquisition Multiple Access	FAMA
12.	Frequency Hopping Spread Spectrum	FHSS
13.	Institute of Electrical and Electronics Engineers	IEEE
14.	Local Area Network	LAN
15.	Logical Link Control	LLC
16.	Medium Access Control	MAC
17.	Multiple Access with Collision Avoidance	MACA

18.	Multiple Access with collision Avoidance for wireless	MACAW
19.	Metropolitan Area Network	MAN
20.	Mobile Ad hoc Network	MANET
21.	Network Simulator	NS
22.	Orthogonal frequency-division multiplexing	OFDM
23.	Object TCL	OTCL
24.	Open Systems Interconnection	OSI
25.	Power Aware Medium Access Control with Signalling	PAMAS
26.	Point Coordination Function	PCF
27.	Personal Digital Assistant	PDA
28.	PCF Interframe Space	PIFS
29.	Physical Layer	PHY
30.	Short Interframe Space	SIFS
31.	Radio Frequency	RF
32.	Radio Propagation Model	RPM
33.	Request to send	RTS
34.	Tool Command Language	TCL
35.	Transport Control Protocol	TCP

CHAPTER 1

INTRODUCTION

Information sharing and communication are the crucial aspect of today's world. It is impossible to imagine a world without email, online news papers, blogs, chat and the other services offered by the internet. Behind this internet, there is a vast pool of "NETWORKS" which provide the information resources and services.

A network is a cluster of many systems. Basically, it connects various systems and allows them to talk i.e. to communicate, share information, resources, etc. The various systems in the network are also called as nodes, and these nodes can be computers, laptops, mobile phones, PDAs, etc. The nodes in a network can be connected through wired (cable) media or by wireless media. So, the networks can be categorized into wired networks and wireless networks.

A wired network connects the systems using hardware i.e. physical cables and wires whereas the wireless network uses the wireless media to connect the various nodes on the network. Wireless simply means that links among nodes are established through radio waves, i.e. through the air. These wireless networks have their own advantages, as there is no need to lay down expensive cables, free to roam -- need not to tie up your desk or cabin; you can start an online conversation anywhere anytime.

Wireless networking is growing by leaps and bounds, as the past decade has witnessed great progress in the wireless technology and the development of cheap portable devices. Many a times there is a need of spontaneous deployment of a network, and for temporary basis like in the fields of military and rescue operations, crisis management services, virtual class room sessions, emergency operations, enterprise networks, home networks, and location aware services, disaster recovery operations, etc (Aarti & Tyagi , 2013) (Chlamtac, Conti, & Liu, 2003) (Mohapatra, & Krishnamurthy, 2005) (Basagni, Conti, & Gregori, 2004). For such cases, deployment of "MOBILE AD HOC NETWORK" is an appropriate choice.

Mobile Ad hoc Networks (MANETs) are the wireless networks established for a special, extemporaneous service, and do not require pre-existing infrastructure (Chlamtac et. al 2003) (Zhai, Wang, Chen, & Fang, 2006). A MANET uses radio frequency (RF) technology to transmit and receive data over the air medium. These networks are decentralised, self configurable and self healable (Myers & Basagni, 2002). Nodes in MANETS are autonomous, i.e. free to move and organise themselves (Kumar, Raghavan, & Deng, 2006). Nodes share the wireless channel, and because of mobility of mobile nodes topology of network changes dynamically. Communication occurs usually in multi-hop paths, and breaking of communication link is often, as nodes move independently (Jayasuriya, Perreau, Dadej, & Gordon, 2004). Figure 1 shows the MANET.

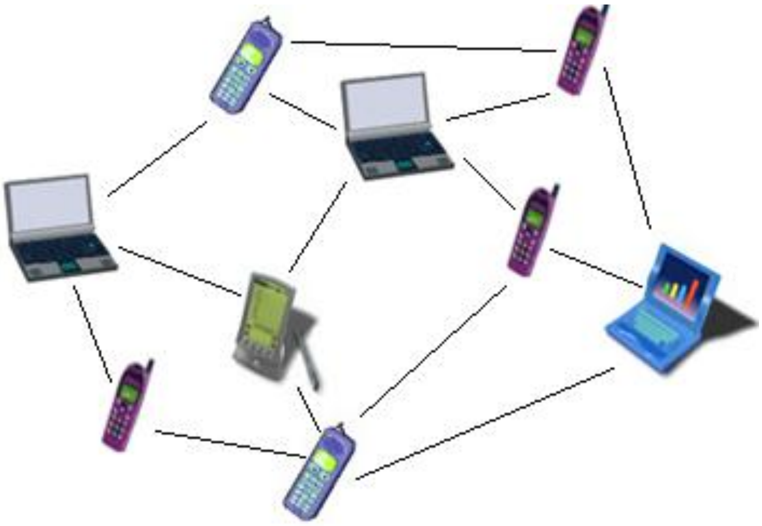

Figure 1: MANET

Some specific attributes of MANETs are listed below (Jayasuriya et al., 2004):

- Decentralised control i.e. nodes are arranged in peer-to-peer fashion, there is no centralized administration or base station.
- Dynamic topology: Nodes are free to roam. They can join or leave the network and they may move randomly, which result in rapid and unpredictable topology.
- Autonomous terminals: Nodes in MANETS can act as host as well as the router.
- Shared medium: Nodes communicate with each other via wireless links. Wireless medium is free and is accessible to all nodes. MAC defines the rules for multiple accesses.
- Multi hop routing: Nodes that lie within each other’s send range can communicate directly but when the receiver and the sender are not in direct transmission range, packets are forwarded by intermediate nodes.

1.1. Medium Access Control (MAC)

Wireless medium is a free open shared medium. All the nodes on MANETs use this open medium. Due to its shared nature, nodes in MANETs often compete for medium access. In order to resolve the problem of medium contention, there are some rules and MAC lays down those rules. These rules are implemented at the MAC sub-layer. MAC is required to provide fair access to resources and efficient utilization of bandwidth. MAC layer is also responsible for providing system authentication, association with an access point, encryption and data delivery (Forouzan, 2008).

In OSI model of networking and in TCP/IP reference model, Link layer is divided in two – LLC and MAC. MAC is the sub-layer of link layer and is sandwiched between LLC and Physical layer (Litwin, 2001). Figure 2 shows the MAC layer in protocol stack. MAC furnishes medium access control mechanisms and addressing, make it possible for several nodes or network terminals incorporated in a shared medium to communicate in a network (Litwin, 2001). MAC protocols regulate access to the shared medium by defining rules that allow the nodes to communicate in an orderly manner. At MAC, IEEE 802.11 is the de-facto protocol.

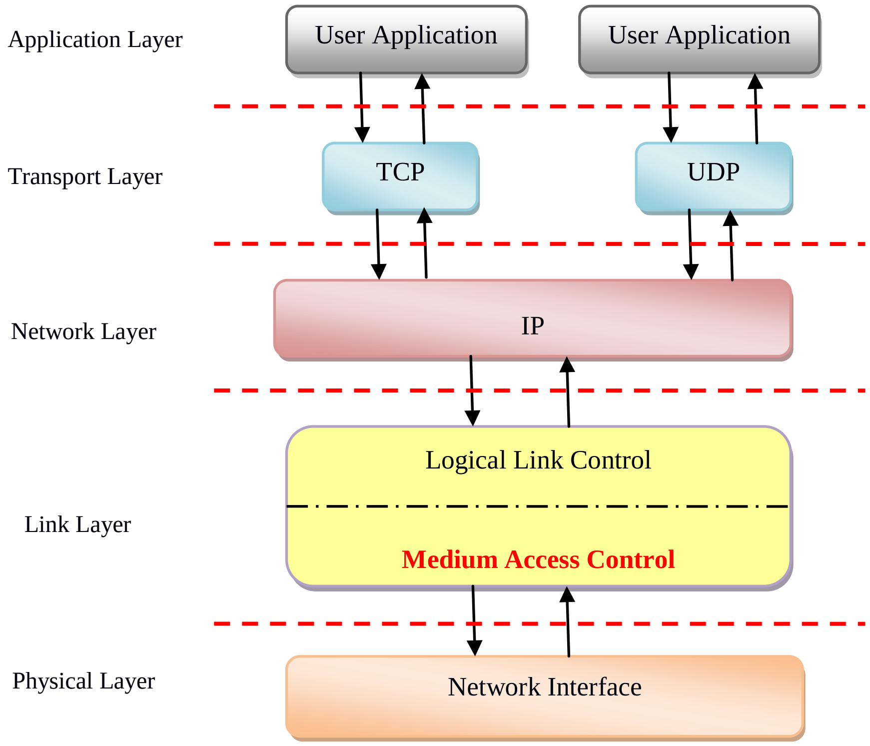

Figure 2: MAC in Protocol Stack (Myers & Basagni, 2002)

1.2. IEEE 802

The Institute of Electrical and Electronics Engineers (IEEE) is a professional organisation that is dedicated to advancing technological innovation and excellence. It is the leading standards making association. IEEE 802 LAN/MAN group of standards which contain the IEEE 802.3 Ethernet standard and the IEEE 802.11 Wireless Networking standard, are the most widely known and remarkable standards of IEEE ("IEEE 802 LAN/MAN Standards Committee”).

IEEE 802 deals with local area networks (LAN) and metropolitan area networks (MAN). IEEE 802 is concerned with the networks carrying variable packet size ("IEEE standard association"). The other networks like Isochronous networks, in which data is forwarded as a steady stream of octets, or in the form of groups of octets, at standard time intervals, are out of the horizon of IEEE 802 standard. The 802 number was simply the subsequent free number IEEE could allot, though sometimes “802” is related to the date the first convention was held — February 1980 ("IEEE standard association"). The protocols and services defined in IEEE 802 maps to the bottom two layers i.e. Data Link and Physical of the OSI networking reference model. Various Active standards of IEEE 802 (“IEEE standard association”) have been given in Appendix A.

1.3. IEEE 802.11

IEEE 802.11 is a MAC layer standard developed by IEEE. IEEE 802.11 is a set of physical layer (PHY) and media access control (MAC) specifications for implementing wireless local area network (LAN) computer communication (Chaudet, Dhoutaut, & Lassous, 2005). IEEE 802.11 defines two medium access techniques - Point Coordination Function (PCF) based on polling, and Distributed Coordination Function (DCF) based on contention. Sometimes when PCF and DCF coexist in a network, the time is divided into sequence of repetition intervals with equal length. In each repetition interval, the system runs first in a PCF mode than in the DCF mode (Feng, Li, & Lin, 2013). Figure 3 shows the PCF and DCF at MAC sublayer.

PCF (Point Coordination Function) is a MAC technique that is implemented in the infrastructure networks (not in Ad hoc networks) and is an optional access method

(Forouzan, 2006). It is used in the time sensitive application and is implemented on the top of DCF (Anastasi, Borgia, Conti, & Gregori, 2003). PCF is a centralised, contention free polling access method. It resides in a point coordinator which is also called Access Point (AP), is for synchronizing the communication between the networks. The AP performs polling for the nodes that are capable of being polled. The terminals are polled one after another, sending data that they have, to AP. The AP waits for PIFS (PCF interframe Space) duration to hold the channel. PCF has priority over DCF as the terminals that only use DCF may not get the medium access (Feng et al., 2013). To remove this priority problem, a repetition interval have been introduced which cover both PCF and DCF. PCF is implemented in some hardware devices as PCF is not a component of the Wi-Fi Alliance's interoperability benchmark ("IEEE 802 LAN/MAN Standards Committee").

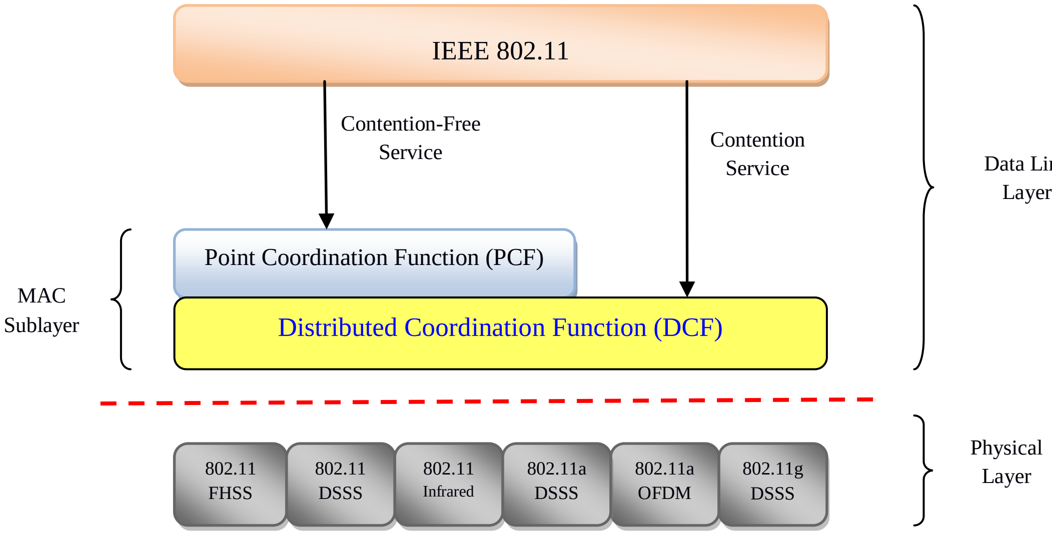

Figure 3: IEEE 802.11 PCF and DCF at MAC Sublayer (Forouzan, 2006)

DCF is the elementary MAC technique used in wireless networks and is the de-facto MAC standard. DCF employs a carrier sense multiple access with collision avoidance (CSMA/CA) and binary exponential backoff algorithm (Bianchi, 2000) (Khalaj, Yazdani, & Rahgozar, 2007). CSMA/CD (carrier sense multiple access with collision detection) cannot be implemented in wireless networks because of signal fading and the hidden station problem, so CSMA/CA is used. Carrier sensing is performed at both air interface as well at MAC layer. Physical carrier sensing at physical layer checks the presence of IEEE 802.11 users on the network by analysing all the detected packets and by detecting activity in the medium via relative signal strength from other sources. Virtual carrier sensing at

MAC layer is performed by the network allocation vector (NAV). The next section explains IEEE 802.11 DCF in detail.

1.4. Distribution Coordination Function (DCF)

The basic MAC is a DCF which allows automatic channel sharing between compatible physical layer through the use of CSMA/CA and a random backoff time following a busy medium condition (LAN/MAN Committee, 1999 Edition (R2003)). All directed traffic uses immediate positive ACK (acknowledgment) but if there is no ACK then retransmission is scheduled by the sender. The following flowchart, Figure 4, explains the mechanism of IEEE 802.11 DCF protocol:

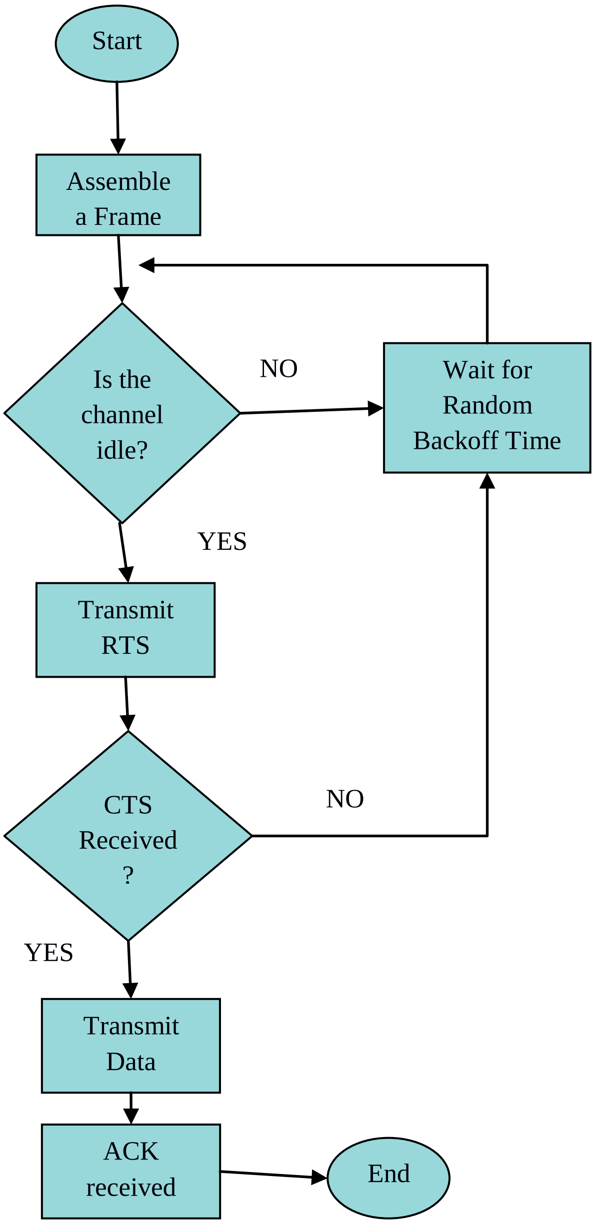

Figure 4: IEEE 802.11 DCF flowcharts

DCF uses four way handshake mechanisms, RTS-CTS-DATA-ACK (Chowdhury, Islam, Jaigirdar, Faruqui, & Al Noor, 2009). Figure 5 show the transmission of data packet between the sender and destination, while other stations maintain their NAV. The interchanging of RTS and CTS frames prior to the actual data frame helps in the distribution of medium reservation information. The RTS and CTS control frames contains a Duration/ID field which defines the time period for which the medium is to be reserved to forward the actual data frame and the returning ACK frame. All nodes within the reception range of either the sender node (which transmits the RTS) or the destination node (which transmits the CTS) shall learn of the medium reservation.

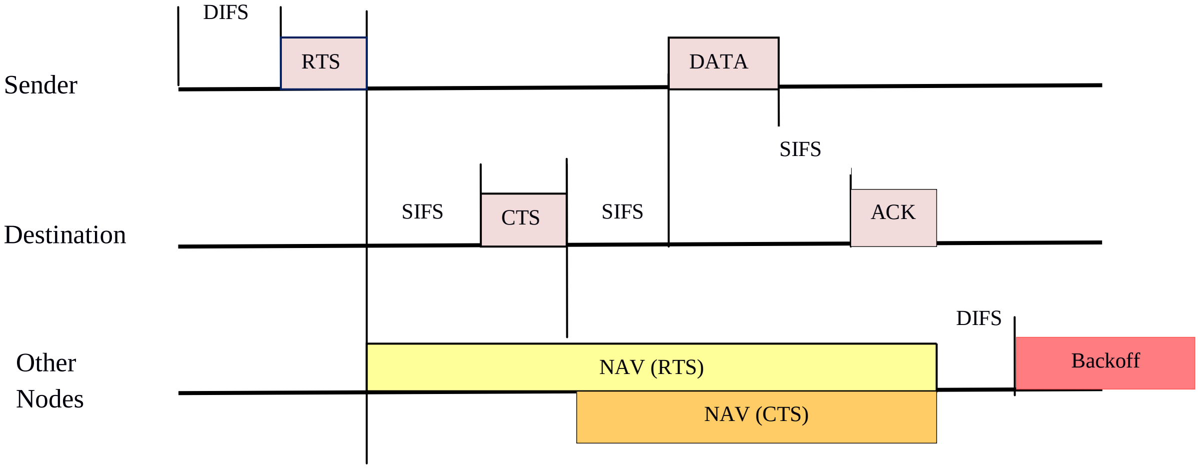

Figure 5: RTS-CTS-DAT-ACK and NAV setting (Anastasi et al., 2003)

The sender node (or terminal) senses the medium, for medium status, whether it is idle or busy, for DIFS interval. If the medium is busy for the DIFS interval, the terminal delays its transmission. If the medium remains idle for a time interval equal to DIFS, the station is allowed to transmit RTS (ready-to-send). Upon receiving the RTS frame, the destination node will wait for certain time period-SIFS and then send CTS (clear-to-send). This will indicate that destination is set to receive the data. Sender after waiting for SIFS time period will then send the data packets. Finally, the destination after waiting for time period SIFS will send the acknowledgement (ACK) to the sender, to show that it has successfully received the data packets. If the medium is busy, the transmission is postponed until the ongoing transmission concludes and BEB procedure is called (Chaudet et al. , 2005).

DIFS (distributed interframe space) and SIFS (short interframe space) are the interframe space (IFS). IFS are the time interval between frames. A node determines that the medium is idle or busy through carrier-sense function for the interval specified.

Carrier sensing is performed both through physical as well as virtual mechanisms. The physical carrier sensing as performed by CSMA/CA helps in diminishing collision between mobile nodes when accessing the channel. The virtual carrier-sense mechanism is attained by disseminating the reservation information, which announces the approaching use of the medium. The nodes can only transmit when the medium is idle. Just after the medium becomes free following a busy medium, it is when the maximum probability of a collision occurs. This is because several nodes could have been waiting for the medium to become free again. This is the situation that required a random backoff procedure to rectify the medium contention conflicts.

The virtual carrier sensing is supported through network allocation vector (NAV). The NAV keeps a forecast of future traffic on the medium based on duration information which is proclaimed in RTS/CTS frames prior to the actual interchange of data frames. So the other node in the environs set the NAV accordingly. NAV signifies the time that must pass before examining the channel for idleness. This will eventually circumvent the collision from other nodes.

1.4.1. BEB Algorithm

In a MANET, numbers of nodes compete for the medium, if multiple nodes sense the medium and defer their communication, they will essentially at same time find the medium being released and try to capture the medium. So in order to avoid such collision, nodes need to be displaced in time, and to displace them temporally, backoff algorithm called binary exponentially backoff (BEB) algorithm is used. In BEB whenever a node is involved in collision, a random waiting time is allotted to the node and the node has to wait for that time before trying again. If the node is again not successful in its attempt, then its contention window size will be doubled. But, if the node successfully transmits its packet, the CW is reset to its minimum value. Under BEB, the CW controls the medium access. The contention window (CW) parameter shall take an initial value of CWmin. The CW shall take the subsequent value in the series every time when there is an unsuccessful attempt. Figure 6 shows the exponential increase of CW. Once it reaches CWmax, the CW will stay at the value of CWmax till it is retuned.

BEB algorithm uses uniform random distribution function to generate a random backoff value for the node. Backoff time is a random integer of uniform distribution over the interval [0, CW], multiplied by the slot time size. The backoff value increases exponentially if the channel is busy or there is a collision. But if the channel is idle and there is successful transmission, then backoff value is set to minimum CW size (Khalaj et al., 2007). Backoff time is calculated as:

$$\text{BackoffTime} = \text{random}()*\text{aSlotTime}$$

where Random() = Pseudorandom integer which is drawn from a uniform distribution over the period [0,CW], where CW is an integer in the range values of the PHY characteristics CWmin and CWmax, CWmin ≤CW ≤CWmax.

aSlotTime = The value of the correspondingly named PHY characteristic.

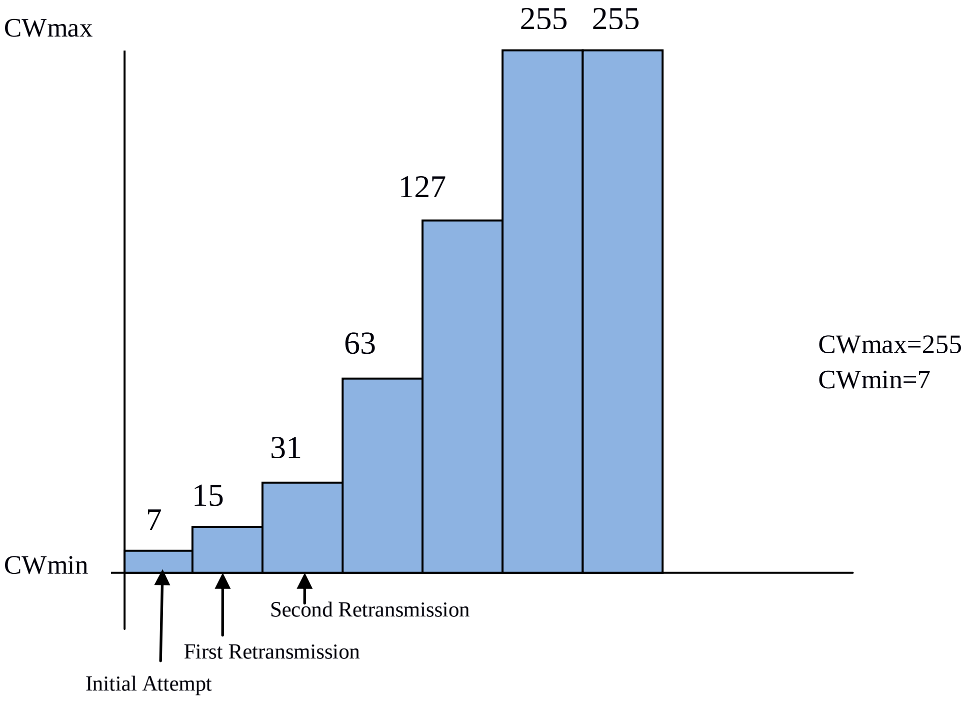

Figure 6: An example of exponential increase of CW

The backoff procedure shall be invoked for a node to transfer a frame when the node finds medium busy as indicated by either the physical or virtual carrier-sense mechanism. The backoff procedure shall also be invoked when a transmitting node infers a failed transmission. To begin the backoff procedure, the node will set its Backoff Timer to a random backoff time using the above equation. A node performing the backoff procedure uses the carrier-sense mechanism to decide whether there is an activity at some point in each backoff slot. If there is no medium activity for the particular backoff slot, then the backoff procedure will decrement its backoff timer by aSlotTime. Transmission shall commence whenever the Backoff Timer reaches zero (Khalaj et al., 2007).

The consequence of this procedure is that when the multiple nodes are deferring and go into random backoff, then the node having smallest backoff time will win the contention.

IEEE 802.11 DCF Algorithms:

Basic scheme followed in IEEE 802.11 DCF is shown below:

```
{
BO = 0;                         // initial backoff is zero.
CHECK medium_status;
IF medium == idle, then
            Wait for DIFS time period;
            Send_RTS;
            Wait SIFS;
            IF (CTS_Received && BO = 0)
            {
                  Send_DATA
                  }
            ELSE
                  Call BEB_ALGO;
ELSE medium == BUSY
            Defer the transmission, till current transmission ENDS
            Call BEB_ALGO
```

BEB Algorithm:

```
      Assign backoff time to the contending node.
      {BO= random ()*aSlotTime}
      WHEN BO gets over
      Check medium status
```

```
While (Medium == BUSY && CW! = CWmax)
{
        CW= 2*CW}
IF medium = idle && BO! =NIL
{
        BO=BO_old - aSlotTime}
ELSE (medium = IDLE && BO = 0)
        {
                Start_transmission
                }
```

CHAPTER 2

LITERATURE REVIEW

Misra et al. (2013) provide a comprehensive guide to fundamental concepts, new ideas and various results in the area of mobile ad hoc networks. They have discussed the properties of general multihop networks, and the important issues relating to simulations, testbeds and theoretical studies in these type of networks. They have presented trendier issues like integration of mobile ad hoc networks into IP-based access networks. They have concluded that the quality of service, delay management and security in these networks is a challenging task in wireless networking.

Kumar et al. (2006) presented a comprehensive survey of various MAC Protocols in wireless Local Area network. They have presented the thorough categorization of MAC protocols. They have provided their concise description, based on their functioning principles and underlying features. The various protocols discussed are MACA, MACAW, PAMAS, D-MAC, Multi-Hop RTS MAC, etc. These protocols are of considerable importance since the wireless communication channel is intrinsically prone to various errors and unique problems like hidden nodes problem, the exposed nodes problems, and the signal fading effects.

Razfar & Abedi (2011) have discussed various MAC protocols that have been developed to combat the MAC problems. The comparison was made between the single channel and multichannel MAC protocols considering several factors affecting the design of the MAC layer The busy tone multiple access (BTMA) protocol was the first scheme to combat the hidden-node problems of CSMA. Then, MACA was proposed to address the hidden nodes problem in single-channel networks. Later, MACA was extended by V. Bharghavan, and was named MACAW, it provided improved fairness and throughout by adding the acknowledgement after the transmission is over. The IEEE 802.11 committee proposed another MAC protocol based on RTS-CTS handshake. Finally, they have realized that the single channel schemes did not perform well in the MAC layer due to the hidden and exposed terminal problems and the multichannel schemes solved these problems on the cost of additional channel usage.

Myers & Basagni (2002) have provided the comprehensive view of the role and details of the wireless media access protocols. They have highlighted the distinguished characteristics of the wireless systems and their impact on the design and implementation of MAC protocols. They have presented the MAC solutions for ad hoc networks, like network architectures with decentarlised control, characterised by the mobility of all the nodes.

Zhai et al. (2006) discussed several important issues in MAC protocol design in IEEE 802.11 wireless LANs and mobile ad hoc networks, such as severe MAC layer contention and collision in multihop environment, traffic flows contentions, rate adaptation with dynamic fragmentation, multiple input link diversity and multiple output link diversity. They have proposed novel scheme to address the flow level related issues by optimizing the cross layer interaction between the MAC layer and the higher layer. The scheme of rate adaptive fragment bursts MAC shows better results as it provide better throughput than the existing.

Jayasuriya et al. (2004) have evaluated the relative throughput performance of ad hoc networks with and without predata control schemes, such as RTS/CTS mechanism in 802.11 systems. They have carried out network simulations through OPNET. The nodes were distributed in a grid pattern evenly throughout the network. The analytical and simulation results suggest that throughput performance degrades by pre-data handshake mechanisms like RTS/CTS. But, their study does not take into account all the effect of hidden and exposed terminals on the transmission patters of ad hoc networks.

Dubey et al. (2008) have discussed the pros and cons of RTS/CTS packets by comparing CSMA (does not use RTS/CTS) and IEEE 802.11 (uses RTS/CTS packets). Firstly they have developed theoretical model of WLAN and have calculated the maximum possible throughput. Finally the comparison between theoretical and simulation results were made, using the variation of throughput with the variation of packet arrival rate and variation of average end to end delay with throughput. Their results show that in terms of delay and throughput CSMA/CA is better because it is providing maximum throughput while taking minimum end to end delay.

Fu et al. (2005) have studied TCP performance in multihop wireless networks that uses IEEE 802.11 as channel access control. They have stated that network overload is connoted by packet drops due to wireless link-layer disputation, rather than buffer overflow-induced losses as observed in the wired Internet. Moreover as the offered load increases, the prospect of packet loss due to link contention also get amplify and ultimately saturates. Their results show that it is only when the buffer is unrealistically small, buffer overflow induced packet drop dominate. But in most scenarios packet loss due to link-layer contention dominates.

Chaudet et al. (2005) have presented the serious performance issues of IEEE 802.11. The performance offered by 802.11 is often low and directly impacts the performance of higher-layer protocols. They presented the main known elementary topologies that lead to performance issues and classify performance issues into three categories: long-term, short-term unfairness situations, and overall throughput decrease. The long-term fairness issues are those which some network flows suffer from starvation problem while other flows detain the whole channel bandwidth. In short-term fairness issues, the frames are emitted in bursts. The configurations that result in overall throughput decrease, where a portion of the network capacity is not utilised and thus wasted.

Wu, Peng, Long, Cheng, & Ma (2002) proposed a scheme named DCF+ for IEEE 802.11 DCF, which is compatible with DCF, and enhance the performance of reliable transport protocol over WLAN. They have also proposed a new and simple analytical model based on Markov chain to compute the throughput performance of IEEE 802.11 DCF and proposed DCF+. This model can be used for both the basic access method and the RTS/CTS access method in DCF. They have concluded that the DCF+ can be used to enhance the performance of TCP over WLAN.

Khalaj et al. (2007) have discussed the problem IEEE 802.11 DCF that it can’t support QoS for real time traffic. They have modified the contention window size for successful transmissions by applying different schemes i.e. making the size of contention window half of the range [0, CW], minimizing it to the lowest point [CW_{min}] etc. Results of simulation show that when CW size remains larger, the throughput becomes better, but lead to higher jitter. Hence, keeping CW larger is better for data traffic while using the original DCF method is better for multimedia traffics in heavy loads. DCF even causes starvation for low priority traffics when load increases, while the schemes which keep CW larger provide better fairness among priority classes.

Chen, Zeng, & Agrawal (2003) have discussed that the basic access method is the DCF which is based on the CSMA/CA. The IEEE 802.11 adopts exponential backoff. In this paper, they have used fixed contention window instead of the exponentially increased contention window. They have employed the "linear feedback model" to compute the throughput and the delay for CSMA/CA. Based on their analytical equations they have got the optimal contention window size. Their results show that optimal contention window scheme can greatly improve the performance as compared to IEEE 802.11 CSMA/CA MAC protocol.

Elarbaoui & Refai (2008) have presented a new approach to alleviate retransmission rate in IEEE 802.11 DCF. In this approach, simultaneous transmissions have been spread more evenly and with better flexibility relative to the legacy DFC access mechanism of 802.11 MAC protocol. They have proposed that after successful transmission, backoff window preference is dependent on the number of retransmissions; in other words, it is adaptable according to the traffic condition of the network. And under the assumption of a finite number of terminals and ideal channel conditions, the system performance shows an enhancement in both throughput and delay parameters.

Elhag & Othman (2007) have studied and proposed a new adaptive contention window adjustment algorithm, ACW, for DCF in 802.11 Wireless local area networks (WLAN). Simulation results depicts that the new algorithm better than the legacy 802.11 window adjustment algorithm. They have found that the throughput performance is strongly dependent on the number of actives nodes and the total load offered to the system. The modification in the initial contention window size is relative to the number of contention nodes, which can be obtained from the routing table in each node. They have found via the simulation results the expression of the optimal CWMin as the function of the active stations in order to maximize the throughput of the system.

Garg (2002) have studied the impact of altering the minimum contention window size parameters (CWmin) of the standard IEEE 802.11 on average back-off, throughput and the channel behaviour of the wireless network. Their simulation results show the effect of various CWmin sizes on channel throughput and the frame loss. They have suggested the adaptive use of CWmin value, which dynamically depends on the number of active stations and have presented interoperability issues associated with the using non-standard values.

Deng, Ke, Chen, & Huang (2008) have presented that the backoff parameters in the IEEE 802.11 DCF access method are far from being optimal in a heavy-loaded and error-prone WLAN environment. This gives up a high collision probability and degraded channel utilization in bursty arrival or congested scenarios. So they have proposed a pragmatic solution to solve the problem. The proposed scheme works at each station in a distributed way, and it can be implemented in IEEE 802.11 networks with relatively minor modifications. Their results show that the proposed scheme works satisfactorily in many cases, offering a remarkable performance improvement in a congested and noisy wireless environment.

Ksentini, Nafaa, Gueroui, & Naimi (2005) have proposed a novel backoff mechanism, namely “Determinist Contention Window Algorithm (DCWA)”, which further separates between the different backoff ranges associated to the different contention stages. Instead of just doubling the upper bound of the CW, DCWA increases both backoff range bounds (i.e., upper and lower bounds). On the other hand, after each successful transmission the backoff range is readjusted by taking into account current network load and past history. Simulation results show that DCWA outperforms both the Distributed Coordination Function (DCF) and the Slow Decrease (SD) scheme in terms of responsiveness to network load fluctuations, network utilization, and fairness among active stations.

Chen, Schmidt, Jiang, Torrent, Delgrossi & Hartenstein, (2007) presented a spotless and modular architecture for IEEE 802.11 simulations in NS-2. The roles, functions and signalling interfaces of all major modules in the MAC and PHY have been described in their paper. They have mentioned that the current NS2 distribution code has some major deficiencies both in the overall architecture and in the modelling details of the standard IEEE 802.11 MAC and PHY modules. The authors have developed a absolute new revised architecture and design for these two modules. They have carried out the simulation and have shown the effects of IEEE 802.11 modeling updates under different node density scenarios.

CHAPTER 3

SIMULATION WORK

3.1. Simulator

Simulation is the most widely used method for the validation of wireless networking protocols, but several assumptions are made regarding the node placement, wireless signal propagation, and traffic type (Misra et al., 2013).

NS-2 (Network Simulator version 2) is a discrete event driven, object-oriented network simulator developed at UC Berkely as a part of Virtual Internet Testbed (VINT) project, written in C++ and OTcl. A discrete event scheduler is that in which the advance of time dependent on the timing of the events which are maintained by the scheduler. NS is principally useful for simulating wide and local area networks. It supports different networking protocols such as TCP and UPD, traffic source behaviour such as FTP, UDP, Telnet, CBR, Web and VBR, router queue management mechanism such as Drop Tail, routing algorithms such as Dijkstra, and more (Greis, 2007).

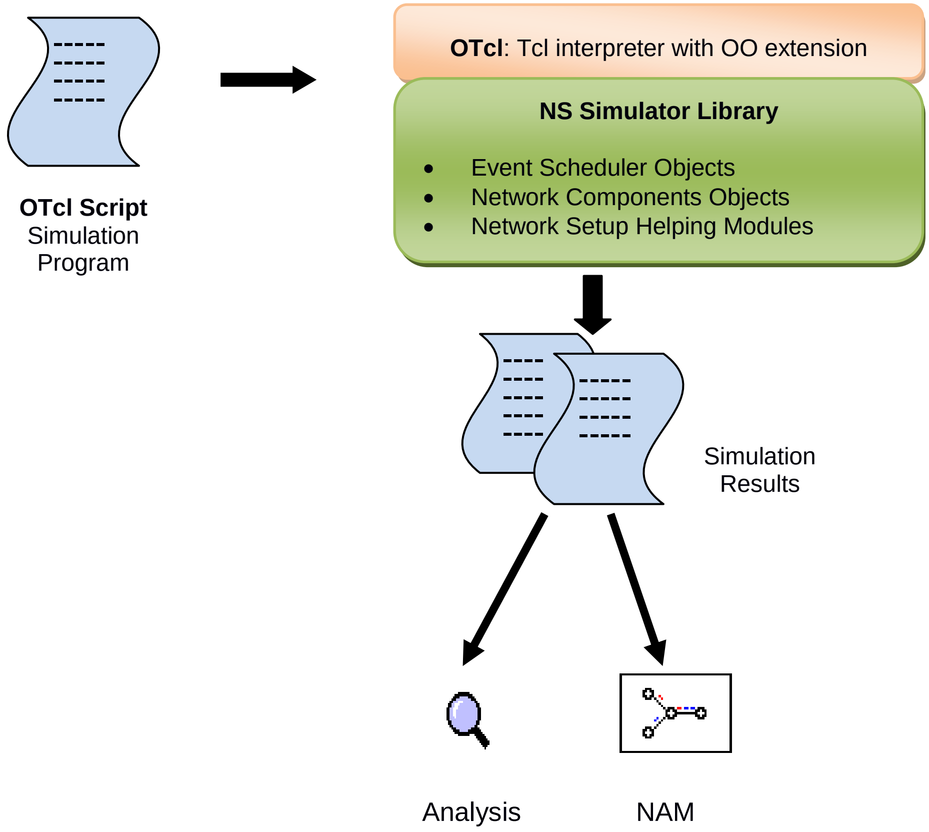

Figure 7: Simplified User's View of NS (Greis, 2007)

NS2 acts as a TCL interpreter where the end user should write the code in TCL and then pass it to NS2. The simulation output is a trace file, which includes all the detailed information of each packet. The simulation results are sent to the Network animator (NAM) which is an animation tool for screening network simulation traces and the real world packet traces. NAM supports topology layout, packet level animation, and various data inspection tools (Samhan & Khoulani, 2010). Figure 7 shows the simplified user's view of NS2. Various elements related to NS2 are described below:

Tool Command Language (Tcl) Script

Tcl is a dynamic programming language used to write the Tcl scripts. Object Tcl(OTcl) is an object oriented extension of Tcl.

Network Animator (NAM)

NAM is a GUI interface to generate NS scripts. It is basically Tcl based animation tool for presenting network simulation traces and packet traces.

Trace files (tr)

Trace file contains all information required for animation purposes such as packet arrivals, departures, drops and link failures. A trace file data format includes fields like source address, destination address, sequence number, unique packet identifier, simulation time of event occurrence, packet type, packet size, IP flow identifier etc.

Awk scripts

AwkScripts are used in processing the data from the trace files. It processes the data column wise.

Installation of NS2 on Ubuntu 12.04

Step 1: Download ns-allinone-2.34.tar.gz from http://www.isi.edu/nsnam/ns/ in /home/ns folder.

Ns-allinone is a package containing required components of NS2 and some of the optional components that are used in running NS.

Step 2: Then extract ns-allinone-2.34 from its tar file by using the command

tar –zxvf ns-allinone-2.34.tar.gz in terminal.

Step 3: To install NS2 use the command $**sudo apt-get install ns2**

sudo is a program which allows a permitted user to execute a command as the superuser or another user that require root privileges.

Step 4: To install X – graph use the command **$sudo apt-get install xgraph.**

To execute the Tcl script use the command **$ ns filename.tcl**

To view the NAM use the command **$ nam filename.nam**

To execute the awk script use the command **$awk –f awk-filename.awk trace-filename.tr**

3.2. Problem Statement

IEEE 802.11 DCF uses BEB algorithm to calculate the backoff time. Backoff time is a random integer of uniform distribution over the interval [0, CW], multiplied by the slot time size. This random function leads to performance degradation. Moreover, after successful transmission the CW resets to CWmin, this leads to unfairness among nodes, as BEB chooses the last contention winner, and the new contending nodes over those nodes that have been waiting for long time, as transmission is possible when the backoff is zero and CW is minimum. The rapid changes in CW lead to higher delay, much higher jitter and degrading bandwidth.

3.3. Objective

- To simulate the existing random function based BEB algorithm of IEEE 802.11 DCF for analysing the performance parameters- throughput, delay, PDR, energy and jitter.
- To modify IEEE 802.11 DCF using logarithmic approach and by resetting CW to CW/2 on successful transmission.
- To analyse and compare the performance parameters for modified IEEE 802.11 DCF with the existing IEEE 802.11 DCF.

3.4. Methodology

The simulation is based on NS2.34 where the legacy 802.11 DCF is already defined. The improved 802.11 "802.11mod" is implemented by applying some changes in the existing files and by adding some new files. The work flow of this dissertation work has been divided into two phases:

Phase1: Simulation of legacy IEEE 802.11 DCF.

As already explained, that in MANETs, node desiring to initiate transfer of data shall invoke the carrier-sense mechanism of 802.11 to determine the busy/idle state of the medium. If the channel is found to be idle, then the node is granted access to start transmission. Otherwise, the node waits for an inter-frame space and the backoff mechanism is invoked. Backoff time is set using the equation

Backoff Time = Random() × aSlotTime.

So, BEB algorithm of DCF protocol is implemented in NS-2. The parameters taken in simulation are listed below.

Table 1: Simulation Parameters

Parameters	**Value**
Interface Queue Type(IFQ)	PriQueue
IFQ Length	200
Propagation Model	Two Ray Ground
Routing Protocol	AODV, DSR
Packet size	500 bytes
Packet Interval	5 ms
Flow rate	100 Kbps
Topology area	500*500 sq. m
Simulation time	100s

The simulation scenario consists of 10 to 60 nodes, where some nodes act as sink, some as agent. CBR (Constant Bit Rate) traffic pattern over TCP has been used in the simulation, which generates traffic. The simulation is carried on two different routing protocol AODV (Ad hoc On-demand Distance Vector) and DSR (Dynamic Source Routing). Both DSR and AODV are demand-driven protocols which forms a route on demand when a transmitting node desires a route. The basic difference between DSR and AODV is the source routing feature of these two protocols. The DSR is based on source routing in which entire routing information is maintained at the mobile nodes, whereas AODV rely on the routing table at each intermediate device.

The Tcl scripts were written, containing the 10 to 60 nodes and node configuration options as mentioned in Table-1 were laid. The trace file and NAM file was created in that Tcl script, so as to record the various parameters and to show the animation. A topology object was created that keeps track of movements of the mobile nodes within the topological boundary. Flatgrid topology was set and topology object was provided with the x and y coordinates value. Each simulation runs for 100s. When each simulation is completed, NS2 produces trace file. The trace file contains the detail information about every packet send during the simulation time. The awk scripts are used to extract the information from the trace file. The five awk scripts i.e throughput.awk, delay.awk, jitter.awk, pdr.awk, energy.awk were used to calculate the throughput, delay, jitter, PDR and energy of the network. The results were then depicted using graphs. AWK Scripts have been given in Appendix C.

The above scenario was applied to the legacy 802.11 defined in NS2, which is already defined in the NS2. The same scenario was then applied to the improved 802.11 “802.11mod”. In order to implement 802.11mod in NS2, several files were added and changed, that is described in next section.

Phase 2 : Modifying the BEB algorithm of IEEE 802.11 DCF by the logarithmic function.

In order to modify or to add a new protocol in NS2, firstly we need to understand the existing implementation of the protocol. Figure 8 shows the various MAC protocols in NS2.

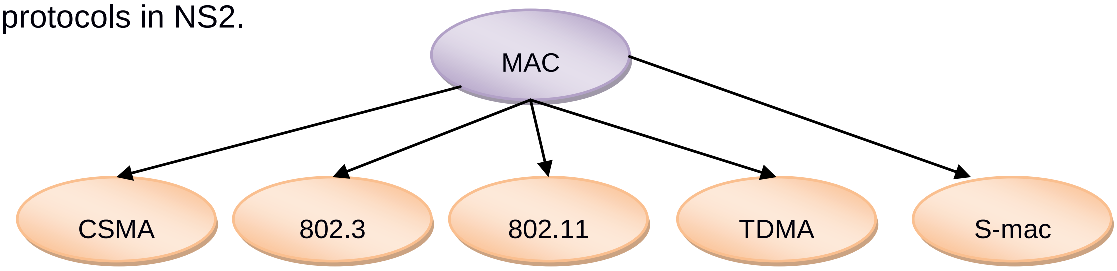

Figure 8: MAC in NS2

The schematic of mobile node is shown in Figure 9; it shows how MAC is used. 802.11 is a MAC layer protocol in NS2 developed by CMU. Only the DCF mode is implemented (not PCF). It is a subclass of MAC, which itself is a subclass of Bi-connector class. 802.11 is implemented in:

~/ns-allinone-2.34/ns-2.34/mac/mac-802_11.cc

~/ns-allinone-2.34/ns-2.34/mac/mac-802_11.h

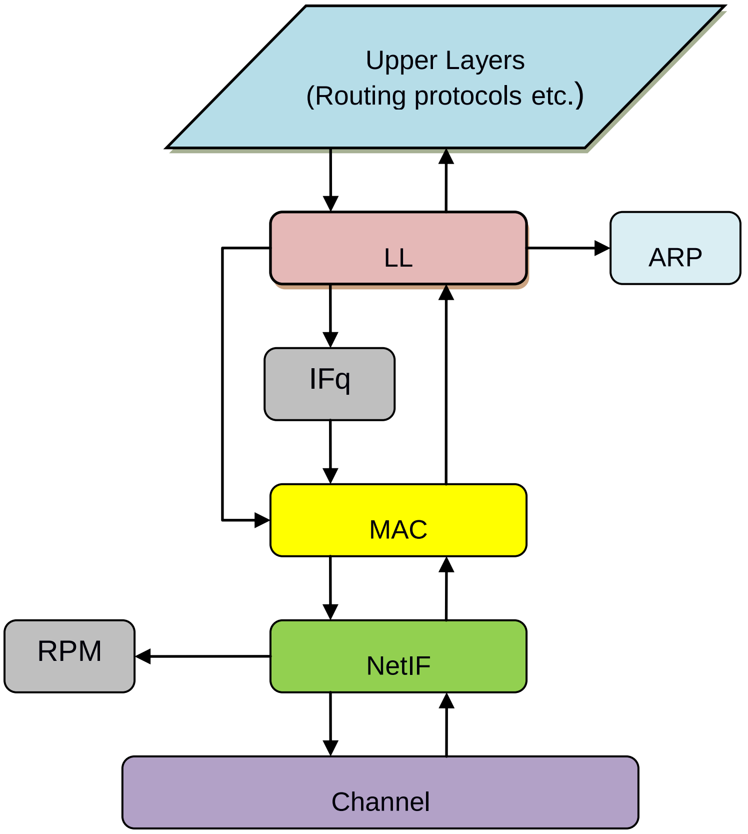

Figure 9: Schematic of a mobile node in NS2 (Hautakorpi, 2005)

Channel

The function of class WirelessChannel (channel.cc) is to deliver packets to its neighbours within sensing range (Wang & Yue, 2012).

NetIF (WirelessPhy)

The function of class WirelessPhy (wireless-phy.cc) is to send packets to Channel and receive packet from Channel. The basic functions used are sendDown() and sendUp() (Wang & Yue, 2012).

MAC Layer (802.11)

The functions of 802_11 (mac-802_11.cc) provide the medium control access. It has two main functions sending and receiving. On sending it uses CSMA/CA channel access mechanism. Timers are very important in 802.11 for triggering channel access. State transition diagram explains the network programs. The state transition diagram of MAC 802.11 (Wang & Yue, 2012) has been given in Appendix B.

Modifying MAC Protocol 802.11

The modified 802.11 has used the logarithmic function instead of random exponential function in backoff, and resets the CW to CW/2 on successful transmission.

Backoff= (log (backoff)) * (backoff) old* aSlotTime

Transmission=successful, CW= CW/2

In order to modify a protocol several original files have to be changed and some have to be added new. For ease, modified MAC protocol has been named - 802.11mod. The various files that were modified and created new are as follow:

Files that were modified:

ns-allinone-2.34\Makefile

ns-allinone-2.34\dei80211mr-1.1.4\src\InitTCL.cc

ns-allinone-2.34\ns-2.34\tcl\lib\ns-mobilenode.tcl

ns-allinone-2.34\ns-2.34\tcl\lib\ns-default.tcl

ns-allinone-2.34\ns-2.34\tcl\lan\ns-mac-802 11.tcl

ns-allinone-2.34\ns-2.34\tcl\lan\ns-mac.tcl

Files that were added:

ns-allinone-2.34\ns-2.34\mac\mac-802 11mod.cc

ns-allinone-2.34\ns-2.34\mac\mac-802 11mod.h

ns-allinone-2.34\ns-2.34\mac\mac-timersmod.cc

ns-allinone-2.34\ns-2.34\mac\mac-timersmod.h ns-allinone-2.34\nam-1.14\log.h

ns-allinone-2.34\nam-1.14\log.cc

Recompilation and Performance check of 802.11mod

After modifying and adding new files in the NS2, the NS2 is recompiled. The following command is used to recompile:

. /configure : the makefile will be replaced by the modified one.

make clean: this will recompile the whole NS2. It removes all the object files in NS2.

make: this will make all object files which are missing.

After recompiling the NS2, the modified 802.11 is tested using Tcl scripts. The performance of the modified 802.11mod is checked using the awk scripts.

3.5. Performance Parameters

The various parameters analysed and measured in this simulation are throughput, delay, jitter, PDR, energy.

Throughput: The throughput of the protocols can be defined as percentage of the packets received by the destination among the packets sent by the source. The throughput is measured in bits per second (bit/s or bps). The number of bits per second must be high for a better system performance.

Packet Delivery Ratio: The data packet delivery ratio is the ratio of the number of packets generated at the source to the number of packets received by the destination. It is obtained by dividing the number of data packets received by the destination node with the number of data packets originated by the source node.

Delay: Transmission delay is average time required by packet to reach the destination. It is basically the interval between the frame arrival time at the MAC layer of a transmitter and the time at which the transmitter realizes that the transmitted frame has been successfully received by the receiver.

Jitter: It is defined as the measure of time variability of the packet latency across the network. A network with constant latency has no variation i.e. no jitter. In simpler words, jitter is referred as variation of the packet arrival time. The latency between the different packets needs to be low for better performance in Mobile Ad hoc networks.

Energy Consumption: This is the total energy consumed by the network. Energy consumption of the MANET is a very important issue that determines the efficiency of a MANETs protocol.

The comparative analysis of performance of 802.11 and 802.11mod with routing protocols AODV and DSR, using above parameters have been depicted in next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

Simulation of BEB algorithm of IEEE 802.11 DCF and 802.11mod was evaluated with two routing protocol AODV and DSR. The basic scenario with different mobile nodes in area size of 500*500 sq. m. is set. The following performance metrics -- Delay, Throughput, Jitter, Packet Delivery Ratio and Energy were analysed.

4.1. IEEE 802.11 Simulation

4.1.1. Throughput

The number of bits received per second must be high for a better system performance. Figure 10 depicts that the value of throughput is higher when the number of nodes is less but when the number of nodes are increased, throughput value is declining. Moreover, IEEE 802.11 DCF with DSR routing protocol shows better throughput than the IEEE 802.11 DCF with AODV routing protocol. The decrease in the throughput is not steady because of random topology of the network and the transmission of packets varies from time to time.

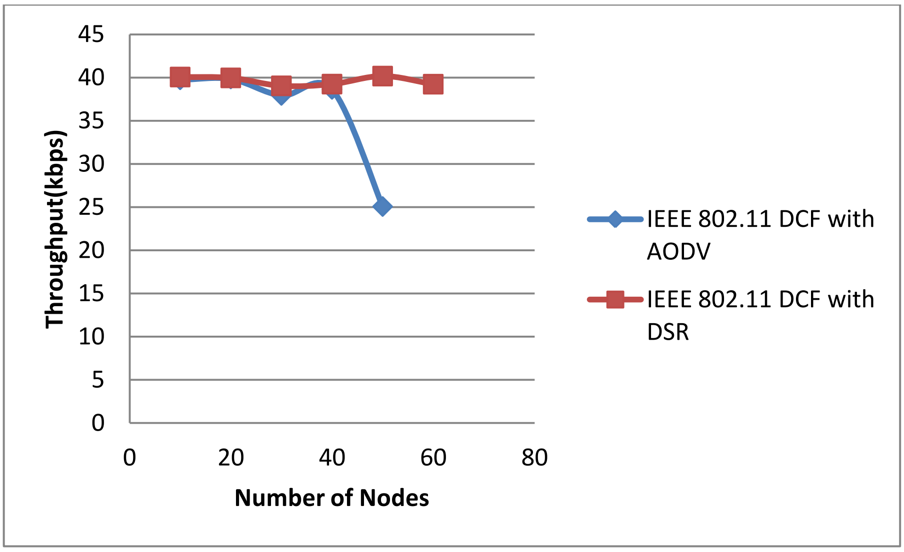

Figure 10: Graph- Throughput v/s no. of nodes

4.1.2. Delay

Delay is calculated by subtracting time at which first data packet is transmitted by source, from the time at which first data packet arrived at destination.

Delay must be less for good performance. Figure 11 shows that the average delay increases enormously, after 50 nodes in case of IEEE 802.11 DCF with AODV routing protocol. But when IEEE 802.11 is used with DSR routing protocol delay is quite less. Less delay in DSR is due to the reason that the DSR uses single request reply cycle as compare to the AODV.

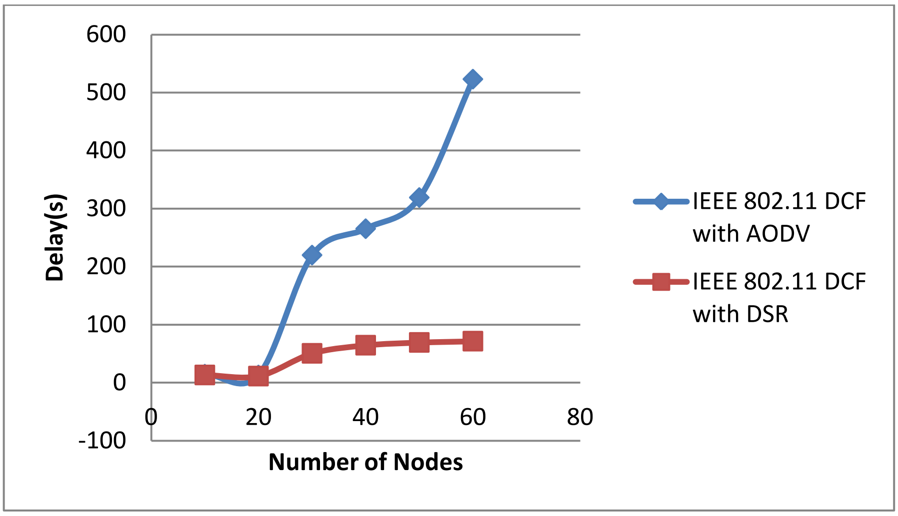

Figure 11: Graph- Delay v/s no. of nodes

4.1.3. PDR

Packet Delivery Ratio must be high for better network performance. Figure 12 shows that PDR goes on decrease with an increase in number of nodes. IEEE 802.11 DCF with AODV shows much decrease in PDR as compare to IEEE 802.11 DCF with DSR routing protocol. The routing overhead is less in the DSR as compare to AODV.

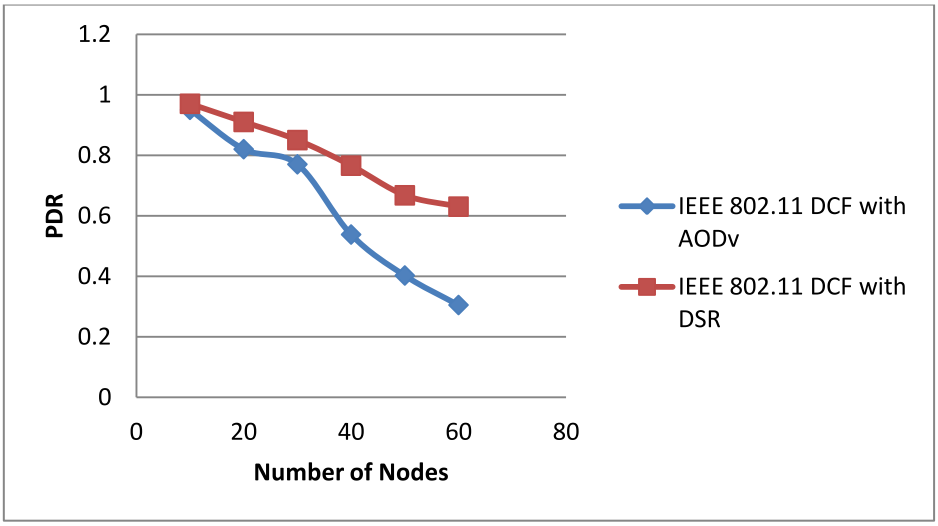

Figure 12: Graph- PDR v/s no. of nodes

4.1.4. Energy

A huge amount of energy is consumed in MANETs as the nodes are mobile. Figure 13 depicts that the energy consumption by MAC protocol IEEE 802.11 shows more fluctuations in DSR than AODV. Energy consumption of network which uses 802.11 with DSR is much more than the network using 802.11 with AODV. The overall energy consumed in case of DSR is much higher as compare to the DSR this is because routing information is greater in DSR routing protocol and is lesser in AODV.

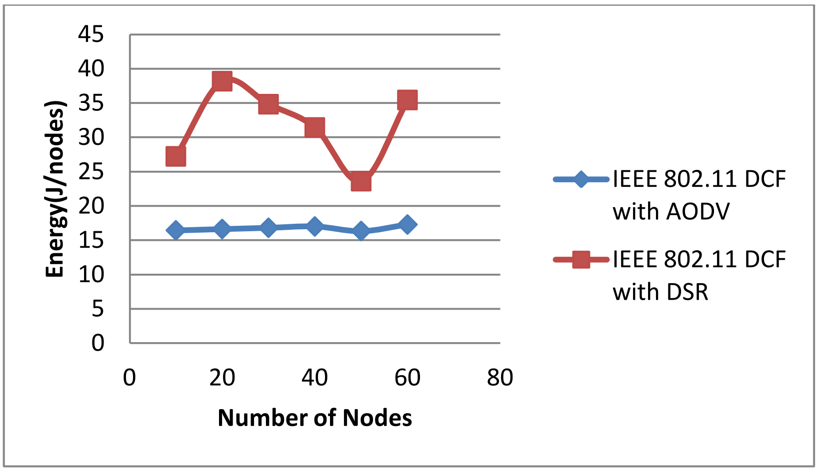

Figure 13: Graph- Energy v/s Number of Nodes

4.1.5. Jitter

Jitter must be less for the efficient performance of the network. Figure 14 shows that the jitter for 802.11 with DSR is almost around 40s. In case of 802.11 with AODV, value of jitter is also high. Jitter should be low for the better performance of the network, as it severely affects the interactive appications.

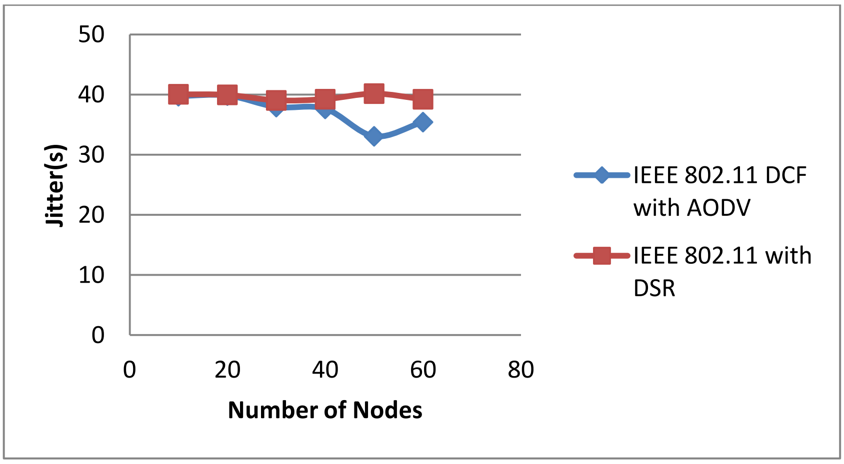

Figure 14: Graph- Jitter v/s Number of Nodes

4.2. IEEE 802.11mod Simulation

4.2.1. Throughput

Figure 15 shows the performance of 802.11and 802.11mod with AODV. It shows that the modified 802.11 relatively gives better throughput than existing one. Figure 16 shows the performance of the 802.11 and 802.11mod with DSR. 802.11mod with DSR gives better throughput as compare to the 802.11 with DSR. But as the numbers of nodes are increasing, the performance is degrading in both cases.

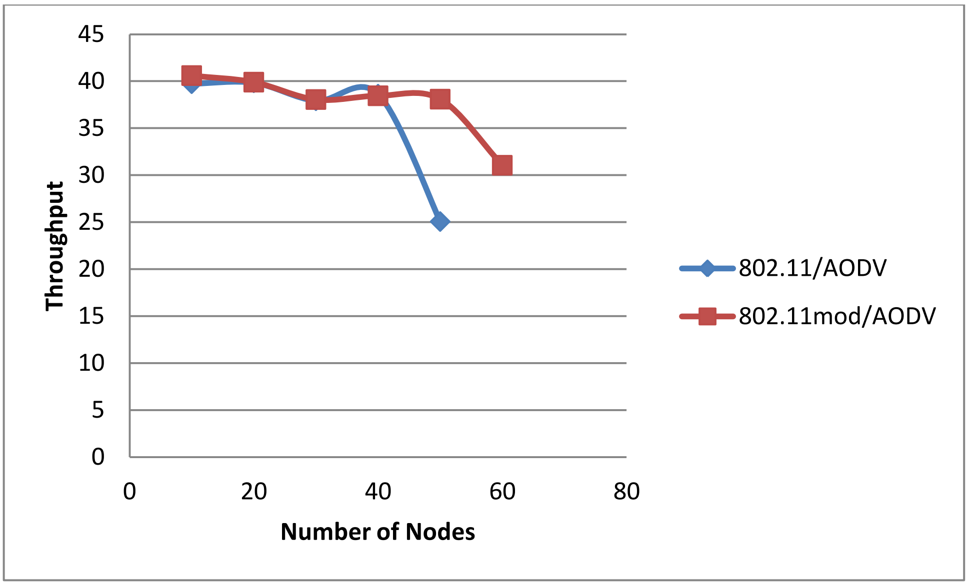

Figure 15: Throughput of 802.11 and 802.11mod with AODV

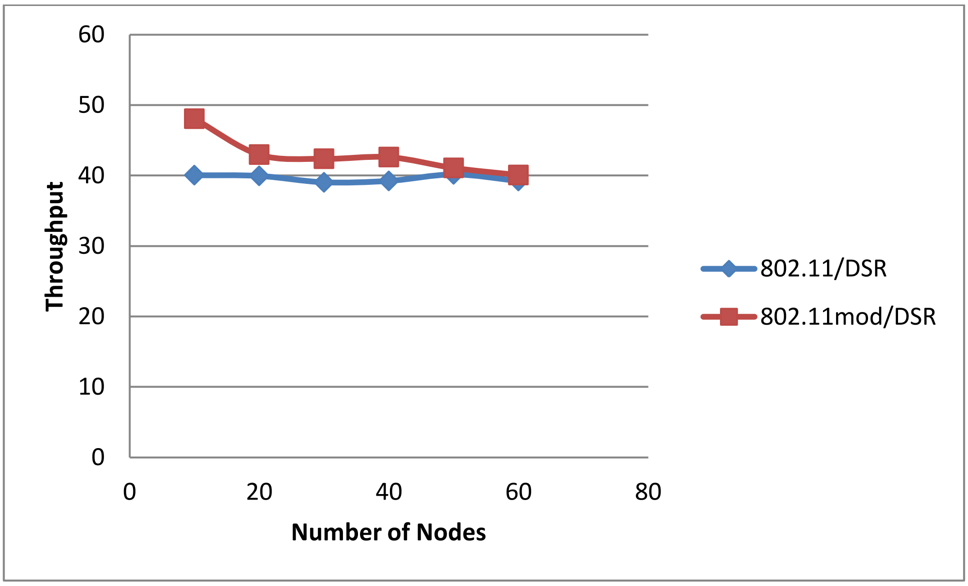

Figure 16: Throughput of 802.11 and 802.11mod with DSR

4.2.2. Delay

The delay of 802.11mod is good initially but as the nodes are increasing the delay is also increasing. Figure 17 shows that when routing protocol is AODV 802.11mod gives less delay as compared to 802.11. While Figure 18 show that the when DSR routing protocol is used, initial delay of 802.11mod is high comparatively but after 40 nodes the delay of 802.11mod is less as compare to 802.11.

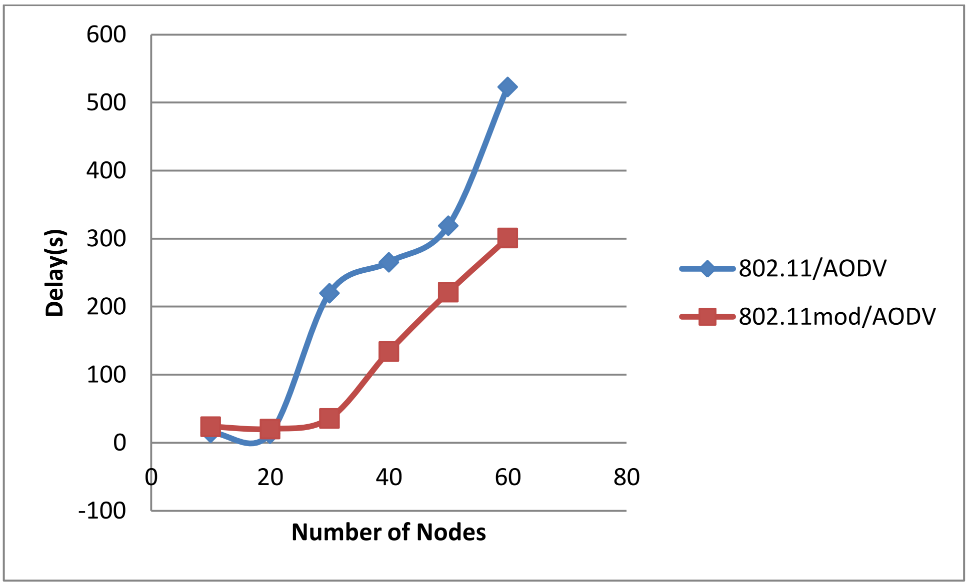

Figure 17: Delay of 802.11 and 802.11mod with AODV

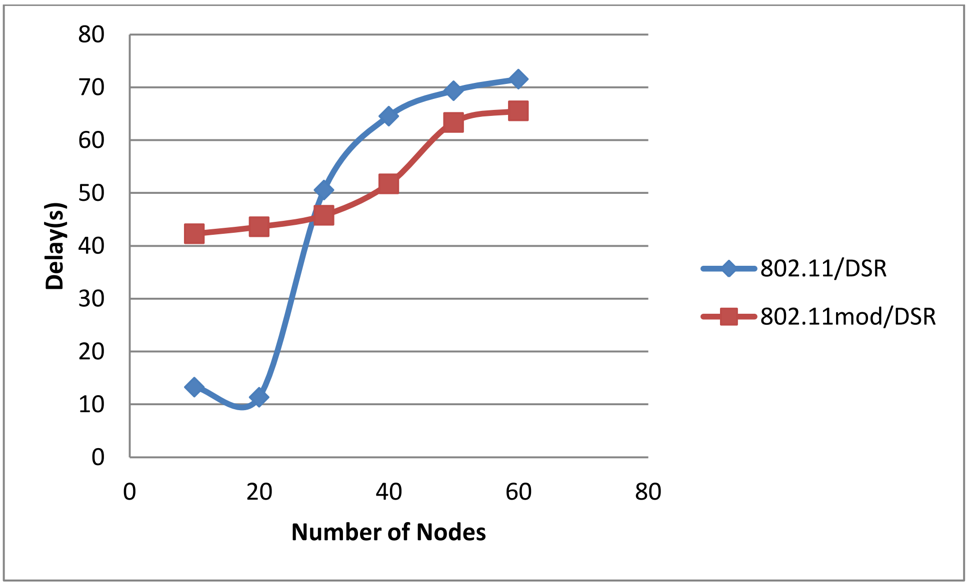

Figure 18: Delay of 802.11 and 802.11mod with DSR

4.2.3. PDR

The packet delivery ratio of the 802.11mod is fairly better as compare to the existing. Figure 19 shows that with AODV, the 802.11 PDR is low as nodes are increasing but 802.11mod is providing better PDR. Figure 20 shows that till 20 nodes, the 802.11mod PDR is low as compare to the 802.11, but when nodes are increased the 802.11mod PDR is better than 802.11.

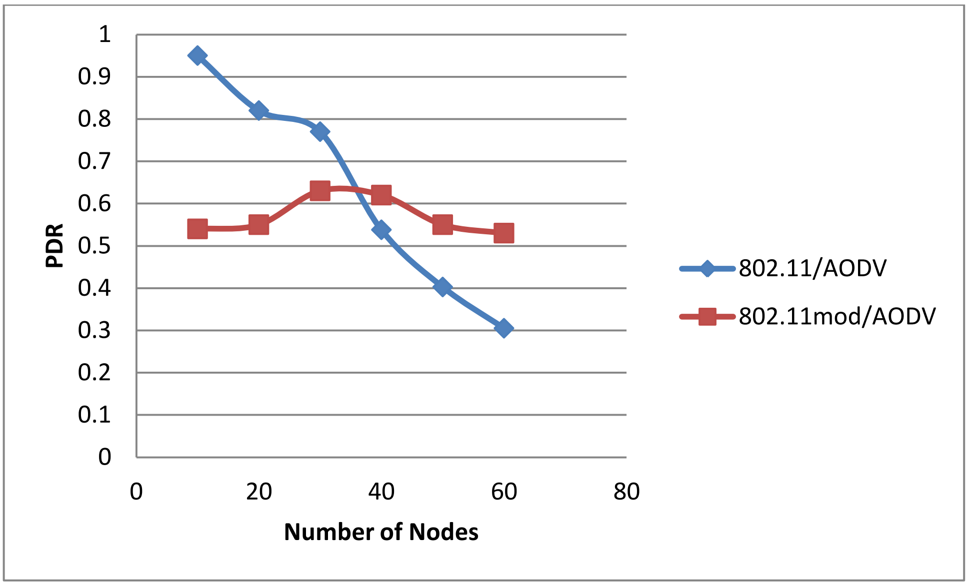

Figure 19: PDR of 802.11 and 802.11mod with AODV

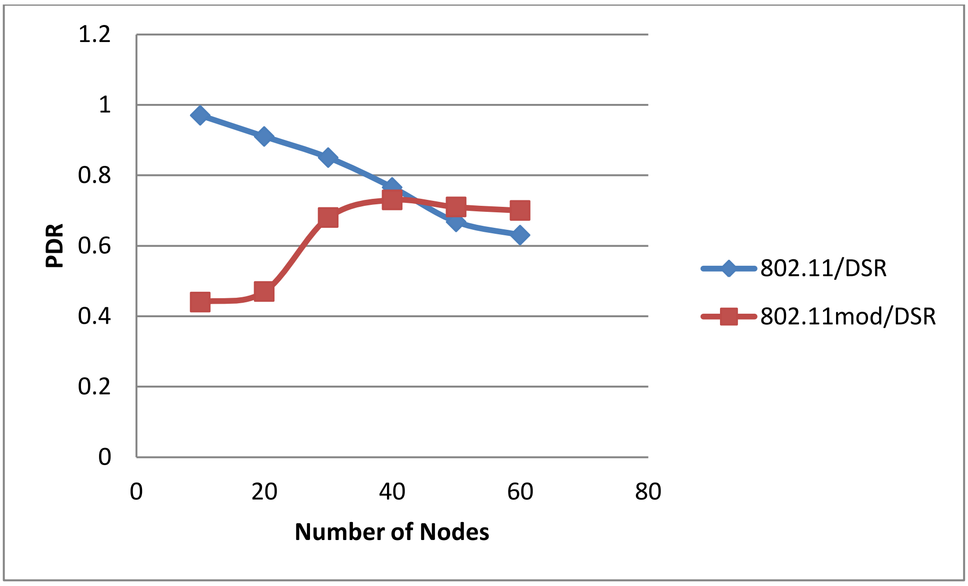

Figure 20: PDR of 802.11 and 802.11mod with DSR

4.2.4. Energy

Energy graph shows that the energy consumption in case of 802.11mod is high as compare to the 802.11. Figure 21 and 22 show that the energy consumption of 802.11mod with AODV and DSR is very high as compare to 802.11.

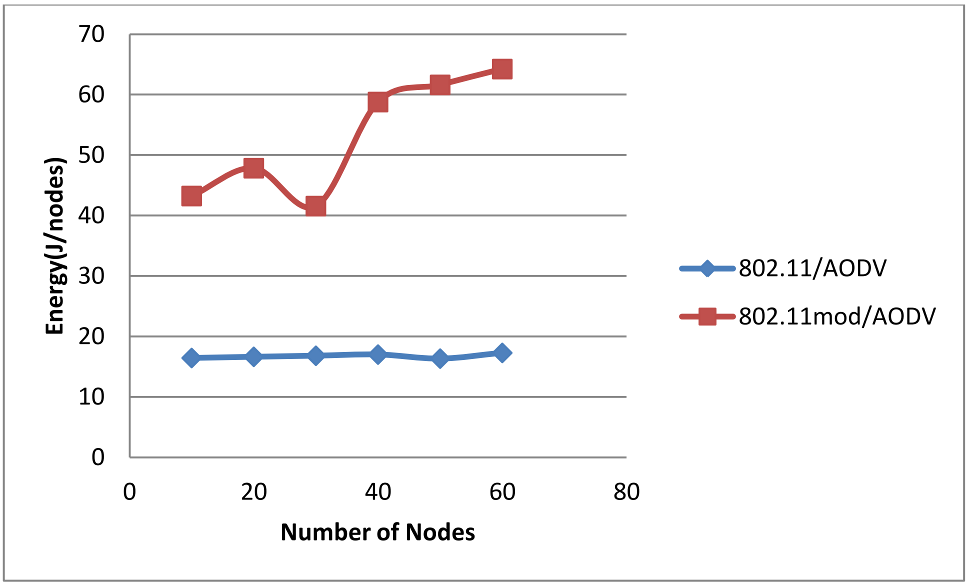

Figure 21: Energy of 802.11 and 802.11mod with AODV

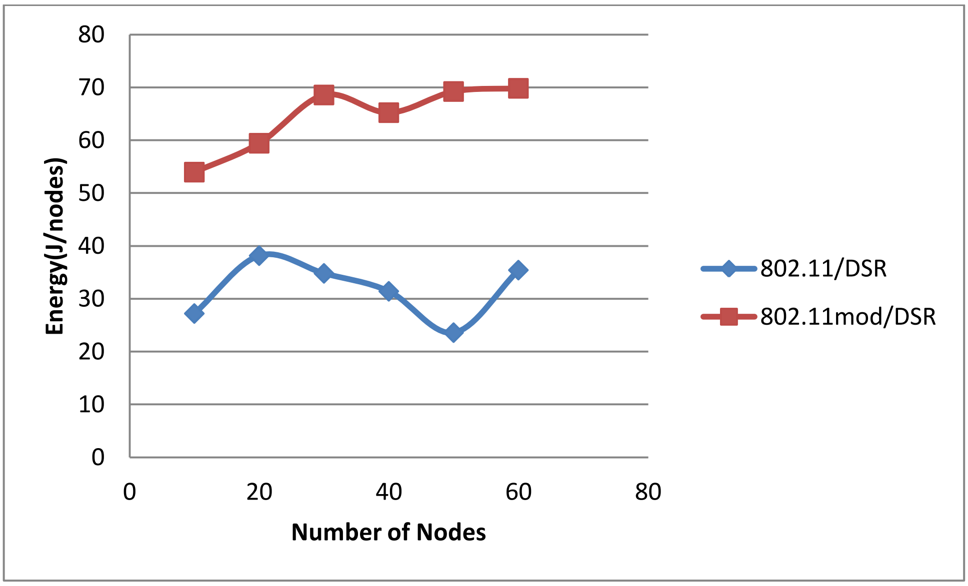

Figure 22: Energy of 802.11 and 802.11mod with DSR

4.2.5. Jitter

Jitter of the 802.11mod is high in both AODV and DSR. Figure 23 shows that initially 802.11mod gives less jitter, but as nodes are increasing jitter is also growing. Figure 24 shows that with DSR routing protocol, the jitter of 802.11mod is higher than 802.11.

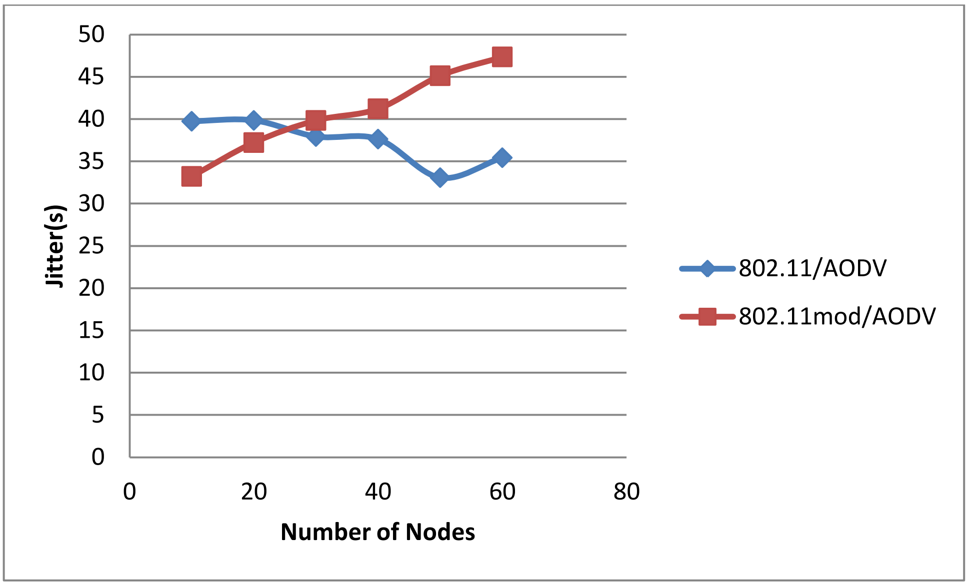

Figure 23: Jitter of 802.11 and 802.11mod with AODV

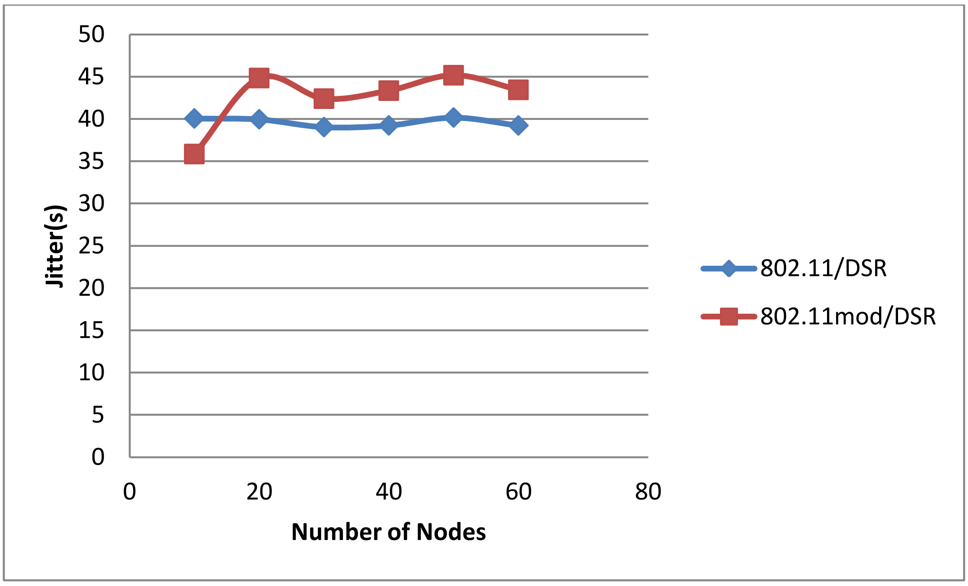

Figure 24: Jitter of 802.11 and 802.11mod with DSR

CHAPTER 5

CONCLUSION

No doubt, MANETs have heralded a new era of extemporaneous and infrastructure-less networking, but still they are in their adolescence, requiring more detailed exploration and study. Wireless medium is an open sharable medium, which has lead to new problem of contention between mobiles nodes and collision of data packets. It is the need of hour to carry out more in-depth research on MAC techniques of wireless networks, so as to reduce the contention among nodes and collision of packets. The default MAC standard IEEE 802.11 DCF employ carrier sensing with binary backoff algorithm. The current backoff method used in DCF leads to higher delay, higher jitter, wasting bandwidth and low PDR, when numbers of nodes are increased in MANET. When CW is reset to its minimum size after a large value, the next packet delays will be too low in comparison to delays before the CW size reduction. These rapid changes in the CW size cause variations in delay or jitter. This ultimately affects the quality of service (QoS) of the entire MANET.

The modifications of BEB algorithm of IEEE 802.11 DCF using logarithmic approach have been done using NS2 simulator. Then the performance comparison of 802.11 and 802.11mod was done using AODV and DSR routing protocols. Results show that throughput, PDR and delay improves but jitter and energy utilisation is still high as compared to legacy 802.11 DCF. Moreover, overall analysis of results reveals that small MANET with less number of nodes have better performance as compare to the bigger MANET.

Work doesn’t stop here. We still need to work on the problems of designing efficient MAC protocols as bandwidth-greedy applications are growing fast nowadays and the available RF (radio frequency) spectrum is still very narrow.

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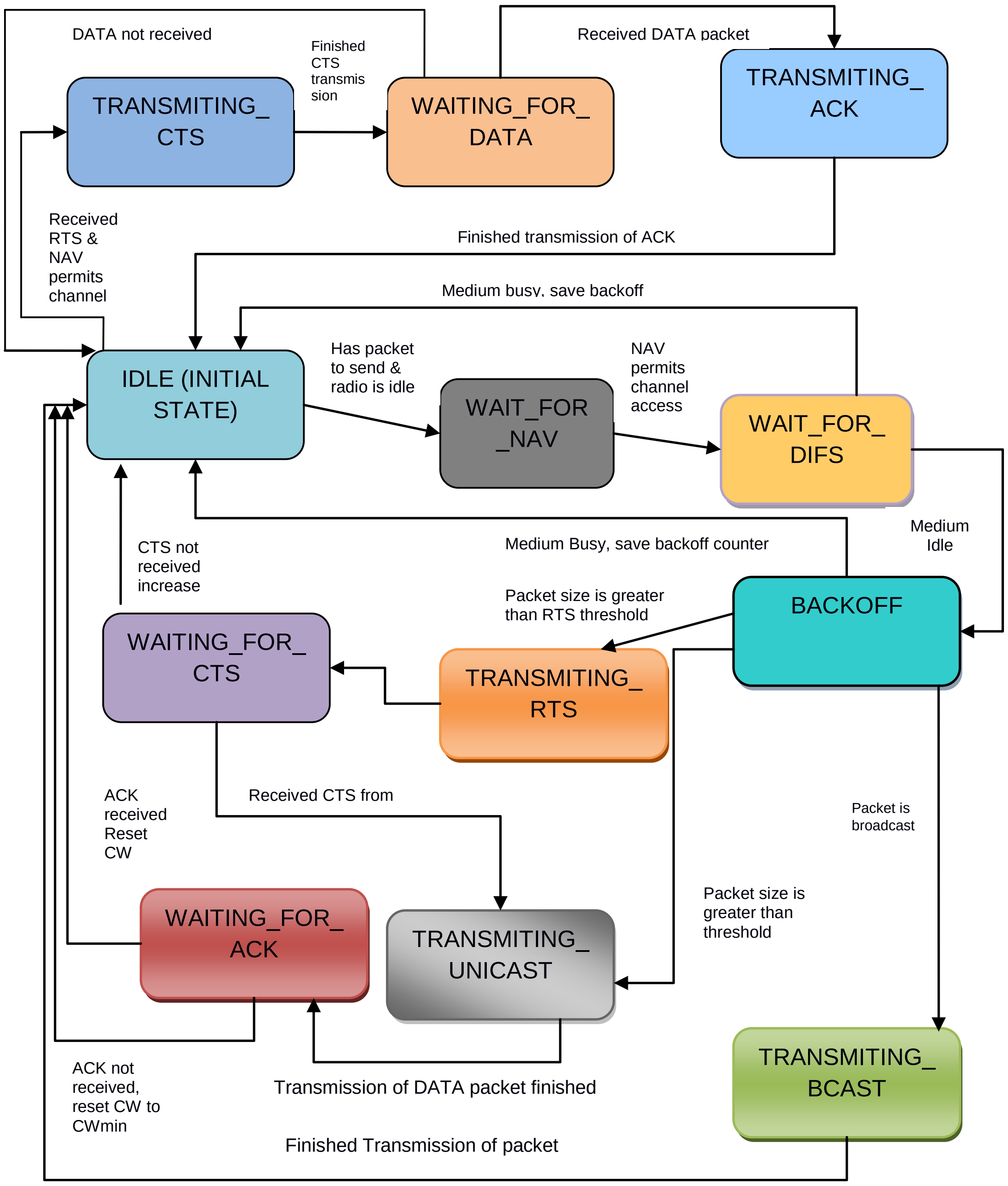
APPENDIX A

Various Active Standards of IEEE 802

Standards	**Description**
802.1	Internetworking
802.2	Logical link control
802.3	Ethernet
802.4	Token bus
802.5	Token ring
802.6	Metropolitan area network (MAN)
802.7	Broadband technology
802.8	Fiber-optic technology
802.9	Voice and data integration
802.10	Network security
802.11	**Wireless LAN**
802.15	Wireless Personal Area Network (WPAN)
802.16	Broadband Wireless Access
802.18	Radio Regulatory TAG
802.19	Wireless Coexistence Working Group
802.21	Media Independent Handover Services Working Group
802.22	Wireless Regional Area Networks
SG ECSG	Smart Grid Executive Committee Study Group

APPENDIX B

STATE TRANSITION DIAGRAM OF MAC 802.11



APPENDIX C

AWK SCRIPTS

THROUGHPUT.AWK

```
BEGIN {
       recvdSize = 0
       txsize=0
            drpSize=0
       startTime = 400
       stopTime = 0
       thru=0

  }

  {
             event = $1
             time = $2
             node_id = $3
             pkt_size = $8
             level = $4

  # Store start time
  if (level == "AGT" && event == "s" ) {
    if (time < startTime) {
             startTime = time
             }
# hdr_size = pkt_size % 400
 #       pkt_size -= hdr_size
       # Store transmitted packet's size
       txsize++;

       }

  # Update total received packets' size and store packets arrival time
  if (level == "AGT" && event == "r" ) {
       if (time > stopTime) {
             stopTime = time
             }
       # Rip off the header
     #  hdr_size = pkt_size % 400
      # pkt_size -= hdr_size
       # Store received packet's size
       recvdSize++
      # thru=(recvdSize/txsize)
# printf(" %.2f %.2f \n" ,time,thru)>"tru2.tr"


       }
 if (level == "AGT" && event == "D" ) {
# hdr_size = pkt_size % 400
 #       pkt_size -= hdr_size
       # Store received packet's size
```

```
      drpSize++

  }
   }
  END {
      printf("AverageThroughput[kbps]=
%.2f\t\ts=%.2f\td=%.2f\tr=%.2fStartTime=%.2f\tStopTime=%.2f\n",(recvdSize/(stopTime-
startTime)),txsize,drpSize,recvdSize,startTime,stopTime)

  }
```

DELAY.AWK

```
BEGIN  {
        seqno=-1;
        dp=0;
        rp=0;
        cnt=0;
}
{
        if($4=="AGT"&&$1=="s"&&seqno<$6)
{
        seqno=$6;
}
        else if(($4=="AGT")&&($1=="r"))
{
        rp++;
}
        else if($1=="D"&&$7=="tcp")
{
        dp++;
}
#end_end delay
        if($4=="AGT"&&$1=="s")
{
        start_time[$6]=$2;
}
        else if(($4=="AGT")&&($1=="r"))
{
        end_time[$6]=$2;
}
        else if($1=="D"&&$7="tcp")
{
        end_time[$6]=-1;
}
}
END{
        for(i=0;i<=seqno;i++)
{
        if(end_time[i]>0)
{
        delay[i]=end_time[i]-start_time[i];
        cnt++;
}
        else
{
        delay[i]=-1;
```

```
}
}
            for(i=0;i<=seqno;i++)
{
            if(delay[i]>0)
{
            ssdelay=ssdelay+delay[i];
}
}
            ssdelay=ssdelay/(cnt+1);
printf( "average ssdelay= %.2f" ,ssdelay*1000);
            print "\n";
}
```

PDR.AWK

```
BEGIN {
        sendLine = 0;
        recvLine = 0;
        fowardLine = 0;
}

$0 ~/^s.* AGT/ {
        sendLine ++ ;
}

$0 ~/^r.* AGT/ {
        recvLine ++ ;
}

$0 ~/^f.* RTR/ {
        fowardLine ++ ;
}

END {
        printf "r/s Ratio:%.4f\n", (1-recvLine/sendLine);
}
```

ENERGY.AWK

```
BEGIN {
initialenergy = 90
maxenergy=0
n=50
nodeid=999
}
{
17
# Trace line format: energy
event = $1
time = $2
if (event == "r" || event == "d" || event =="s"|| event=="f") {
node_id = $9
energy=$17
}
```

```
if (event=="N"){
node_id = $5
energy=$7
}
# Store remaining energy
finalenergy[node_id]=energy
}
END {
# Compute consumed energy for each node
for (i in finalenergy) {
consumenergy[i]=initialenergy-finalenergy[i]
totalenergy +=consumenergy[i]
if(maxenergy<consumenergy[i]){
maxenergy=consumenergy[i]
nodeid=i
}
}
###compute average energy
averagenergy=totalenergy/n
####output
for (i=0; i<n; i++) {
print("node",i, consumenergy[i])
}
print("====================")
print("average",averagenergy)
print("====================")
print("total energy",totalenergy)
print("====================")
}
```

JITTER.AWK

```
BEGIN {
      last_seqno = 0
      txsize=0
           pkt_seqno=0
      startTime = 400
      end_Time = 0
      packet_duration=0
}
{
            seqno_diff = $1
            time = $2
            packet_id = $3
            pkt_size = $8
            level = $4
  if (level == "AGT" && seqno_diff == "s" ) {
    if (time < startTime) {
            startTime = time
            }
      txsize++;
      }
  if (level == "AGT" && seqno_diff == "r" ) {
      if (time > end_Time) {
            end_Time = time
            }
      last_seqno++
      }
```

```
 if (level == "AGT" && seqno_diff == "D" ) {
       pkt_seqno++
   }
}
  END {
       printf("Jitter=%.2f\t",(last_seqno/(end_Time-
startTime)),txsize,pkt_seqno,last_seqno,startTime,end_Time)
}
```