# QUALITY OF SERVICE IN 802.11 NETWORKS (Performance Analysis of the 802.11 Distributed Coordination Function)

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**May 2006**

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Prof. S.N Pradhan

A Dissertation
Submitted to

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This is to certify that the Dissertation entitled

QUALITY OF SERVICE
IN 802.11 NETWORKS
(Performance Analysis of the 802.11
Distributed Coordination Function)

Presented by

Manish Gupta

has been accepted toward fulfillment of the requirement
for the degree of
Master of technology in Computer Science & Engineering

Professor In Charge

Head of The Department

Date: 29/04/06

# *CERTIFICATE*

This is to certify that the work presented here by **Mr.Manish Gupta** entitled "***QUALITY OF SERVICE IN 802.11 NETWORKS(Performance Analysis of the 802.11 Distributed Coordination Function)*"** has been carried out at **Nirma Institute Of Technology** during the period **September 2005 – May 2006** is the bonafide record of the research carried out by him under my guidance and supervision and is up to the standard in respect of the and presentation for being referred to the examiner. I further certify that the work done by is his original work and has not been submitted for award of any other diploma or degree.

Prof. S.N Pradhan

Date: 29/04/06

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Manish Gupta
April 24,2006

# Abstract

The dissertation presents the results of studies , analysis, design and simulations of distribute coordination function performed in the course of the project. As the IEEE 802.11 based internet access is becoming ubiquitous available with simulations we evaluate the MAC protocol modes distribution coordination function (DCF), enhanced DCF (EDCF) and contention free bursting (CFB).We have verified our simulation model by cross-checking it with the results of other researchers. under the assumption of a finite number of stations and ideal channel conditions in a single-hop WLAN. Despite its appealing simplicity, our unified model and analysis are validated very well by simulation results. Ultimately, by means of the proposed model, we are able to precisely evaluate the differentiation effects of EDCF parameters on WLAN performance in very broad settings, a feature which is essential for network design.

In addition to designs of wireless nodes by using ns-2 simulators and this simulator used simulations results describe in this reports. We present quantitative results of the perceptual quality and enhance the precision of performance evaluation. Furthermore, I verified my EDCF extension with the IEEE 802.11e simulation model of Mangold et al. [2]. Mangold used a WARP simulator which differs fundamentally from ns-2. However, both simulation models yield similar results for the same simulation scenarios

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AC | Access category. |
| AP | Access point. |
| ACK | Acknowledgment. |
| AIFS | Arbitration Inter Frame Space (802.11e). |
| AIFSN | Arbitration Inter Frame Space Number (802.11e). |
| BEB | Binary exponential backoff. |
| BSP | Backoff subperiods. |
| CA | Collision avoidance. |
| CD | Collision detection. |
| CI | Confidence interval. |
| CSMA | Carrier-sense multiple access. |
| CTS | Clear to send. |
| CW | Contention window. |
| CWmin | Contention window minimum. |
| CWmax | Contention window maximum. |
| DCF | Distributed coordination function. |
| EB | Exponential backoff. |
| EIFS | Extended interframe space. |
| EDCA | Enhanced DCF (802.11e). |
| HOL | Head of line. |
| LAN | Local area network. |
| MAC | Medium access control. |
| QAP | QoS access point. |
| QoS | Quality of service. |
| RTS | Request to send. |
| SIFS | Short interframe space. |
| TC | Traffic category (802.11e). |
| TXOP | Transmission opportunity. |
| UP | User priority. |
| WLAN | Wireless local area network. |

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# CHAPTER 1 INTRODUCTION

## 1 Introduction

The IEEE 802.11 standard supports two MAC mechanisms, the Distributed (DCF) and the Point Coordination Function (PCF). These mechanisms are to be insufficient for achieving a reasonable quality in scenarios with high background load. Thus, QoS enhancements are vividly studied and evaluated. Currently, the QoS enhanced MAC protocol IEEE 802.11e is under design and in the process . IEEE 802.11e introduces two additional MAC modes: the Enhanced Distributed Coordination Function (EDCF) and the Hybrid Coordination Function (HCF).

In this paper, we present an open-source, verified simulation model of IEEE 802.11e's EDCF mode for the network simulator (ns-2). We verified our model by comparing it with previous published results. Our 802.11e EDCF model includes contention free bursting (CFB=TXOP bursting), which allows the transmission of a train of small packets without intermediate contention.

Our simulation scenario is a Basic Service Set (BSS), which consists of a base station and multiple wireless nodes. IEEE 802.11wireless LANs (WLANs) can operate either in the infrastructure mode or in the adhoc mode. An network is established using Access Points (APs) for each Basic Service Set (BSS). The AP is similar to a base station in a

cellular network. It provides scheduled medium access to all the other stations in the BSS. The BSS is simply a group of stations, which can all communicate directly with each other. Larger networks are built by connecting several Access Points over a Distribution System as shown in Figure[1.2.1]. An ad hoc (single-hop) network is a group of stations within a single BSS (called IBSS) communicating with each other without the aid of an
infrastructure network.

Our simulations solves the following issues:

First, we are interested in the effect of best-effort traffic up to certain number of stations.The Quality of services up to finite numbers of terminals after that the performances degrade.

Secondly, we measure the throughput Vs numbers of stations and the throughput of the b traffic is lower because of the offered load increases up to certain number of terminals and packets drop rate increases .In case of my result the best effort services up to 17 terminals and the load is maximum up to this terminal after that suddenly the packet drop rate increases

Third, we consider another parameter Latency as the packets rate increases obviously the The latency also increases .Here the Latency is the difference of sending of packets and receiving of packets.

Fourth ,we consider the TXOP limit an interval of time when a station has the right to initiate transmissions, defined by a starting time and the maximum

Fifth , comparision of Mangold results vs our result .In case of Mangold results best .Effort up to 15 station but ion my case best effort up to 17 terminal after that the wrost effort start.

Furthermore, the article addresses issues that arise when end-to-end QoS has to be guaranteed in today's pervasive heterogeneous wired-cum-wireless networks.

Next, we present our simulation results, which are finally concluded. We present early results from a systematic study of throughput and delay behavior of mobile networks based on the IEEE 802.11 standard. Measurements, in test based as well as in simulations, have shown that the throughput values obtained in multi-hop networks are only a small fraction of the raw channel of individual stations. To try and understand the causes of this, we began by studying single-hop ad hoc networks, and the results presented in this paper are confined to these. We have simulated throughput and delay as a function of load, varying packet sizes and the number of stations in the network. This we have done for the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF) modes of operation of the IEEE 802.11 WLAN, and we present a comparison.

## 1.1 AN OVERVIEW OF IEEE 802.11

IEEE 802.11 is the leading standard for wireless LAN [2]. It adopts the standard 802 logical link control (LLC) protocol but provides optimized physical layer PHY) and medium access control (MAC) sub layers for wireless communications.11 specifies two physical layers: direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS). Based on the transmission technologies and operating spectrum, the later revisions of 802.11 can be classified into three categories: 802.11a (orthogonal frequency-division multiplexing, OFDM, 5 GHz), 802.11b (high-rate DSSS, HR/DSSS, 2.4 GHz), and 802.11g (OFDM, 2.4 GHz). 802.11b is based on HR/DSSS and operates at the 2.4 GHz industrial, scientific, and medical (ISM) band with transmission rate from 1 to 11 Mb/s. 802.11a is based on OFDM and uses 5 GHz unlicensed national information infrastructure (U-NII) band in America with a transmission rate of 6–54 Mb/s. 802.11g is also based on OFDM but uses the 2.4 GHz ISM band and was formally ratified by the IEEE Standards Association’s Standard Board in June 2003. This standard specifies a maximum transmission rate of 54 Mb/s, the same as 802.11a. However, since 802.11g uses the same spectrum between 2.4 and 2.4835 GHz and is inherently backward compatible with 802.11b, it may attract more attention from industry than the earlier.11a. Nevertheless, 802.11a possesses one noteworthy advantage: the unlicensed radio spectrum (5.15–5.35 and 5.725–5.825 GHz) it operates within is rarely used, while the 2.4 GHz spectrum for 802.11b and g has already been taken by many home electronic devices such as cordless phones, microwave ovens, and garage door openers. The family of IEEE 802.11 standards is shown in Table 1.

The 802.11 MAC supports two basic medium access protocols: contention-based distributed coordination function (DCF) and optional point coordination function (PCF). When PCF is enabled, the wireless channel is divided into superframes. Each superframe consists of a contention- free period (CFP) for PCF and a (CP) for DCF. At the beginning of CFP, the point coordinator (usually the access, AP) contends for access to the wireless channel.

Once it acquires the channel, it polls high-priority stations and grants them the privilege of transmitting. Although the optional PCF is designed for delay-bounded services, it is centralized and can only be used in the network of infrastructure mode. In addition, the loose specification of PCF leaves many issues m unsolved [10]:

- PCF experiences substantial delay at low load; stations must always wait for polling, even in an otherwise idle system;
- Since the AP needs to contend for the channel using DCF at the beginning of a CFP, the effective period of contention-free polling may vary.
- It is very difficult for the point coordinator to manage the polling of a large number of interactive streams without harming the applications using DCF contention.

In addition, PCF is a centralized approach that suffers from location-dependent errors. Therefore, PCF has not drawn much attention from either the research or industry, and most existing schemes focus on the enhancement of DCF, which is a fully distributed protocol. DCF is based on carrier sense multiple access with collision avoidance (CSMA/CA) instead of CSMA with collision detection  /CD) because stations cannot listen to the channel for collision while transmitting. In IEEE 802.11, carrier sensing (CS) is performed at both PHY and MAC layers: physical CS and MAC layer virtual CS. If the MAC frame length (including the payload and 34 bytes of MAC header) exceeds the RTS_threshold, request-to-send (RTS) and clearto- send (CTS) are used by stations to solve the hidden terminal and capture effect problems. A MAC protocol data unit (MPDU) contains header information, payload, and a 32-bit cyclic redundancy check (CRC). The duration field indicates the amount of time after the end of the present frame the channel will be used to complete successful transmission of the data or  frame. Stations use the information in the duration field to adjust their network allocation vector (NAV), which indicates the amount  of time that must elapse until the current  session is complete and the channel can be sensed again for idle status.

| S.N0 | Task Groups | Responsibility |
|---|---|---|
| 1 | 802.11a-OFDM in 5 GHZ Band | Specification enabling up to 54 Mb/s to be achieved in the 5 Ghz unlicensed radio band by utilizing OFDM |
| 2 | 802.11b-HR/DSSS in 2.4 GHZ Band | Specification enabling up to 22 Mb/s to be achieved in the 2.4 ghz unlicensed radio band by utilizing HR/DSSS |
| 3 | 802.11c-Bridge Operation Procedures | Provides required information to ensure proper bridge operation, which is required when developing access points |
| 4 | 802.11d- Global Harmonization | Cover additional regulatory domains, which is explicitly important for operation in the 5 GHZ bands because the use of these frequencies differ widely from country to another. As with 802.11c, the 802.11d standards mostly appliers to companies developing 802.11 product |
| 5 | 802.11e- MAC Enhancements QOS | Covers issues of MAC enhancements for quality of services, such as EDCF services differentiation and hybrid coordination function (HCF) |
| 6 | 802.11f –Inter Access Point protocol (IAPP) | Provide interoperability for users roaming from one access point to another of different vendor |
| 7 | 802.11g-OFDM in 2.4 GHZ band | Specification enabling high data rates(3.6 or 54 Mb/s to be achieved in the 2.4GHZ unlicensed radio band |
| 8 | 802.11h-Dynamic Frequency | Dynamic channel selection and transmission power control |

| | | |
|---|---|---|
| | Selection(DFS) | |
| 9 | 802.11i- security | Specification for WLANE security to replace the weak wired Equivalent Privacy(WEP) |

Table1. The Family of IEEE 802.11 standards OFDM:orthogonal frequency division Multiplexing)

## 1.2 Architecture

The Basic Service Set (BSS) is the basic building block of the IEEE-802.11 architecture. A BSS is a set of stations controlled by a single coordination function. There are two coordination functions defined in the IEEE-802.11: Distributed Coordination Function (DCF) and Point Coordination Function (PCF), which are described below.

The independent BSS (IBSS) is the most basic type of IEEE-802.11 instantiation. An IBSS is a BSS in which any station can establish a direct communication session with any other station in the BSS without the aid of an infrastructure network. Figure-1.2.1 shows an example of an IBSS, which is often referred to as an ad hoc network [14].

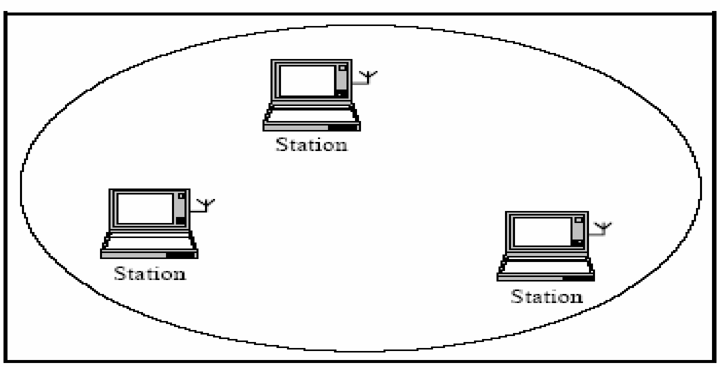



Fig 1.2.1 Sketch of IBSS

In contrast to an IBSS, infrastructure networks are defined to provide coverage area extension and specific services. An infrastructure network is built with multiple BSSs, which are interconnected by a common Distribution System (DS). Each BSS in an infrastructure network has an Access Point (AP), which provides access to the DS, for all associated stations, via the wireless medium. The DS can be thought of as a backbone to transfer MAC-level packets between different BSSs in an infrastructure network. The DS, as specified by IEEE-802.11, is implementation independent. Therefore, the DS could be any network type such as IEEE-802.3 Ethernet LAN or another IEEE-802.11 WLAN. With the DS, the coverage area can be extended to the limitations of the DS. The infrastructure architecture can integrate with a wired network to provide specific services such as Internet access. A logical entity, a portal, is specified as the integration point on the DS where the IEEE-802.11 network integrates with a non- IEEE-802.11 network. Figure-1.2 illustrates an example of an infrastructure network built with two BSSs, a DS, and a portal access to a wired LAN [13].

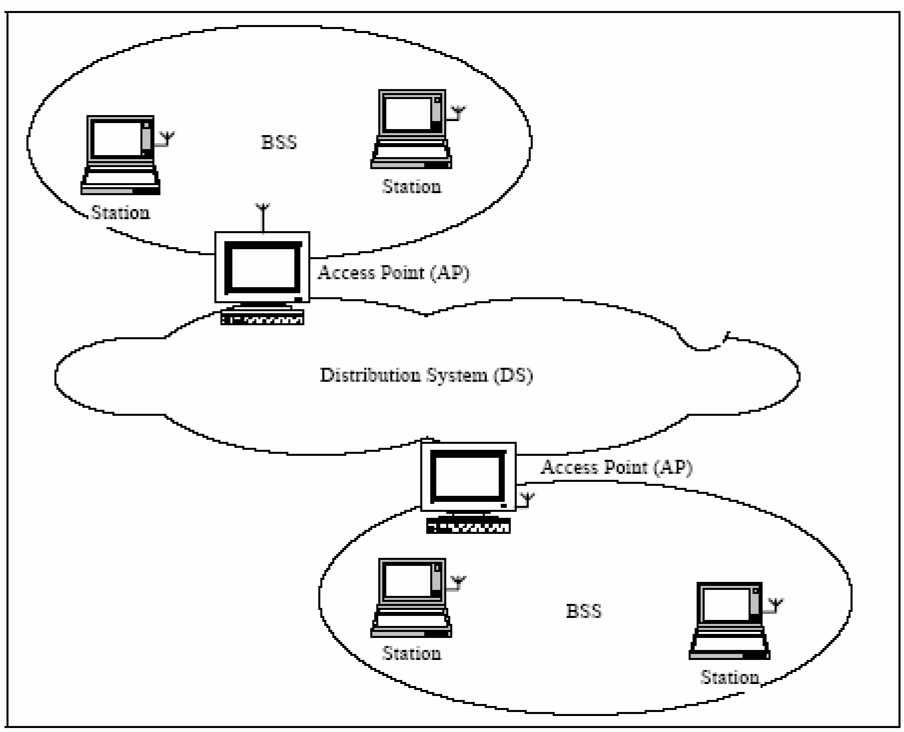



Fig 1.2.2 Architecture of wireless nodes

## 1.3 Wireless can be divided into three categories:

**Fixed Wireless**—wireless devices or systems that are established in homes and offices, especially equipment connected to the Internet via specialized modems.

**Mobile or Portable Wireless**—wireless devices or systems that can be used aboard moving vehicles; As wireless communication systems evolve, service quality and capacity are of primary importance. To ensure reliable communication over a mobile radio channel, a system must overcome multipath fading, polarization mismatch, and interference. The trend towards low power hand held transceivers increases all of these challenges. Even as more spectrum is allocated, demand for higher data rate services and steadily increasing numbers of users will motivate service providers to seek ways of increasing the capacity of their systems. Antenna arrays can improve reliability and capacity in two ways. First, diversity combining or adaptive beamforming techniques can combine the signals from multiple antennas in a way that mitigates multipath fading. Second, adaptive beamforming using antenna arrays can provide capacity improvement through interference reduction. The use of adaptive arrays is an alternative to the expensive approach of cell splitting, which increases capacity by increasing the number of base station sites. Most adaptive arrays that have been considered for such applications are located at the base station and perform spatial filtering. They cancel or

coherently combine multipath components of the desired signal and null interfering signals that have different directions of arrival from the desired signal. Multi-polarized adaptive arrays, sometimes called polarization-sensitive adaptive arrays, can also match the polarization of a desired signal or null an interferer having the same direction of arrival as the desired signal, if the two signals have different states. If base stations or mobile units in a peer-to-peer system can match the polarization states of hand-held transceivers, link quality and reliability will be enhanced, and power consumption in the hand-held units will be reduced, increasing battery life. It is possible that 100% or greater increase in system capacity can be achieved through a combination of spatial and polarization reuse. Because they offer large untapped potential performance gains, multi-polarized adaptive arrays should be studied extensively to determine what performance improvements are feasible. Currently, however, little is known about the performance of multi-polarized adaptive arrays in mobile communication systems.
eg. Cell phones, PCS phones, BlackBerry devices.

**IR Wireless**—devices that transfer information via infrared radiation; some computers and Palm devices can communicate with each other via IR. Some engineers consider Infrared Radiation (IR) technology to be a sub-specialty of optical technology. The hardware is similar, and the two forms of energy behave in much the same way. But strictly speaking, "optical" refers to visible electromagnetic radiation, while "infrared" is invisible to the unaided eye. To compound the confusion, IR is sometimes called "infrared light." IR wireless is used for short- and medium-range communications and control. Some systems operate in lineof- sight mode; this means that there must be a visually unobstructed straight line through space between the transmitter source and receiver destination. IR wireless technology is used in intrusion detectors; home-entertainment control units; robot control systems; cordless microphones, headsets, modems, printers and personal digital assistants (PDA). Unlike radio-frequency wireless links, IR wireless cannot travel through walls. Therefore, IR communication or control is generally not passed between different rooms in a building or between different buildings on a street (unless they have facing windows). This might seem like a disadvantage, but IR wireless is more private than radio frequency (RF) wireless. Some IR wireless schemes offer a level of security comparable to that of hard-wired systems. It is difficult, for example, to eavesdrop on a well-engineered, line-of-sight, IR laser communications link (Searchingnetworking.com 2002).

I am working on fixed wireless

**Fixed Wireless**

Fixed wireless services at broadband rates involve the delivery and return of  via radio transmissions from fixed towers. Each tower is hard wired to an ISP and thus the Internet. To reach last mile clients, fixed wireless companies use  cellular and PCS tower infrastructure but have to augment the existing network. This is because broadband, unlike voice, needs clear line-of-sight between the antennas. But the current role of fixed wireless technologies is more as a means of expanding wire-based networks. Fixed wireless services at broadband rates involve the delivery and return of Internet traffic via radio transmissions from fixed towers. Each tower is hard wired to an ISP and thus the Internet. To reach last mile clients, fixed wireless companies use existing cellular and PCS tower infrastructure but have to augment the existing network.

This is because broadband, unlike voice, needs clear line-of-sight between the antennas. The current state-of-the-art is Multipoint Multichannel Distribution System (MMDS) technology. It can provide asymmetric data transmission at nearly 2 Mbps for downstream traffic and 256K upstream. Like cable this is a shared resource so that all users attached to an antenna will have to contend with crowding and 2 privacy issues. In the near future, third generation (3G) wireless will address the slow rates on the upstream and increase the downstream rates to 2.5 Mbps. As a standalone business model for the last mile clients, fixed wireless in the US involves a monthly charge of US$40 per residential user. This is slightly higher than wire-based solutions because there is little overlap in coverage among wireless data, DSL and cable. As a result, the wireless companies can charge a premium to underserved areas. But the current role of fixed wireless technologies is more as a means of expanding wire-based networks. The fixed wireless companies see a revenue generating opportunity in filling the gaps left by the wire line services. Consequently, they are targeting commercial accounts on city outskirts and existing networks that wish to expand their coverage quickly. Alternatively, large wire-based network companies install fixed wireless systems themselves as a means of expanding their reach beyond their wire nets. Like the other terrestrial networks, fixed wireless services to last-mile clients from the telcos and existing wireless telecom companies will rollout in populated areas first. This helps amortize the infrastructure cost quickly. Transmission to remote areas is more difficult because of line-of-sight and the availability of backbone services to which to connect the towers. Residential areas have the added problem of sight pollution caused by the towers (Sector, 2001). Look Communications Inc. introduced Look ULTRAFAST™ Wireless high-speed Internet access to small and medium-sized enterprises (SME) in the Greater Toronto and Montreal markets. Look ULTRAFAST™ Wireless is a unique last mile solution, offered in two high-speed options – 750 Kbps and 1.5 Mbps. Look's primary targets are SMEs located in underserved pockets of Ontario and Quebec, including industrial parks and commercial districts where there are currently no or few alternative for highspeed connections. The wireless connection is provided through a small antenna and modem at the customer location, which receives and transmits signals via the provider's local tower.

The company's bandwidth management system monitors the connection, ensuring consistent performance and offering dedicated business service priority during business hours. The wireless solution is mplemented with wireline 1.5 Mbps and 3.0 Mbps ADSL and ISDN high-speed Internet access where required (Canada Newswire, 2002).

**Communication Exchange**

The 802.11 standard specifies nine services to support frame delivery, access control and privacy. These nine services are authentication, association, de authentication, disassociation, distribution, integration, privacy, re association, and frame delivery.

In an infrastructure network, wireless clients and APs must establish a relationship, or an association, prior to data communication. Only after an association is established can the two wireless stations exchange data. The synchronisation process is a two-step
process involving three states:

1. Unauthenticated and unassociated,
2. Authenticated and unassociated, and
3. Authenticated and associated.

The process of a wireless client finding and associating with an AP transmit a beacon management frame at fixed intervals a client listens for beacon messages to identify the APs within range, which is also known as passive scanning.

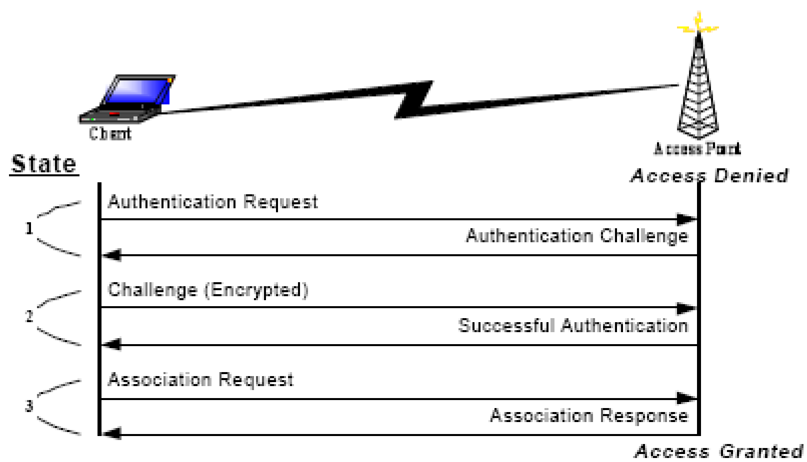



Figure 1.3.1

After identifying an AP, the client and the AP perform authentication by exchanging several management frames as part of the process. After successful authentication, the client moves into the second state, authenticated and unassociated.Moving from the second state to the third and final state, authenticated and associated,involves the client sending an association request frame, and the access point responding with an association response frame.

## 2.1 Existing IEEE 802.11 MAC in ns-2.28

The ns-2 MAC simulation model can be found in the directory ../ns-2.28/mac/. The LLC hands packets to the MAC through a priority interface queue. It is an advanced drop-tail queue which facilitates the insertion of routing packets at its head. The MAC itself consists of the IEEE 802.11 DCF but not of the PCF. There is a PCF patch available on the Internet, but I have never tested it. Beacons and super frame structures are not really included due to the lack of the PCF.
In ns-2 beacons are only realized by routing update messages which have intervals in a range of several seconds, so the notation "beacon" may be a little far-fetched.

The DCF MAC protocol is RTS/CTS/DATA/ACK and broadcast capable. is able to scan the medium by virtual and physical carrier sense. The MAC provides the inter frame spaces SIFS, PIFS, DIFS as well as EIFS. The EIFS is applied after every detected transmission attempt. It assures that a station may be able to answer with an ACK.

### 2.1.2 LEGACY 802.11

Here we briefly summarize the 802.11 MAC protocol and discuss its limitations in QoS support. We consider an infrastructure Basic Service Set (BSS) of IEEE .11 is imposed of an Access Point (AP) and a number of stations associated with the AP. The AP connects its stations with the infrastructure

### 2.1.3 Distributed Coordination function (DCF)

When a station has data to send it first senses the channel. If the channel is idle it waits for a time interval called the DIFS period and then samples the channel again. If the channel is still idle it transmits either an RTS frame or a data frame, depending on whether it is using RTS/CTS or not. The receiving station waits for a time interval called the SIFS time and replies with either a CTS for the RTS or an ACK for the data.

Carrier sensing is performed at the air interface, called physical carrier sensing, as well as at the MAC sublayer, called virtual carrier sensing. A source station assists virtual carrier sensing by sending duration information relating to the packet in the header of RTS/CTS/Data frames. The duration field in the header indicates the amount of time in microseconds required to successfully send the data frame. Stations in the BSS, other than the source and the destination, use this information to set their Network Allocation Vector (NAV). The latter indicates the amount of time for which the station must defer access, after which the channel can be sampled again for idle status. The channel is marked busy if either the physical or virtual carrier sensing mechanism (NAV) indicates a busy status. Fig.2 also illustrates the setting of the NAV by stations depending on whether they receive the RTS or the CTS frames.

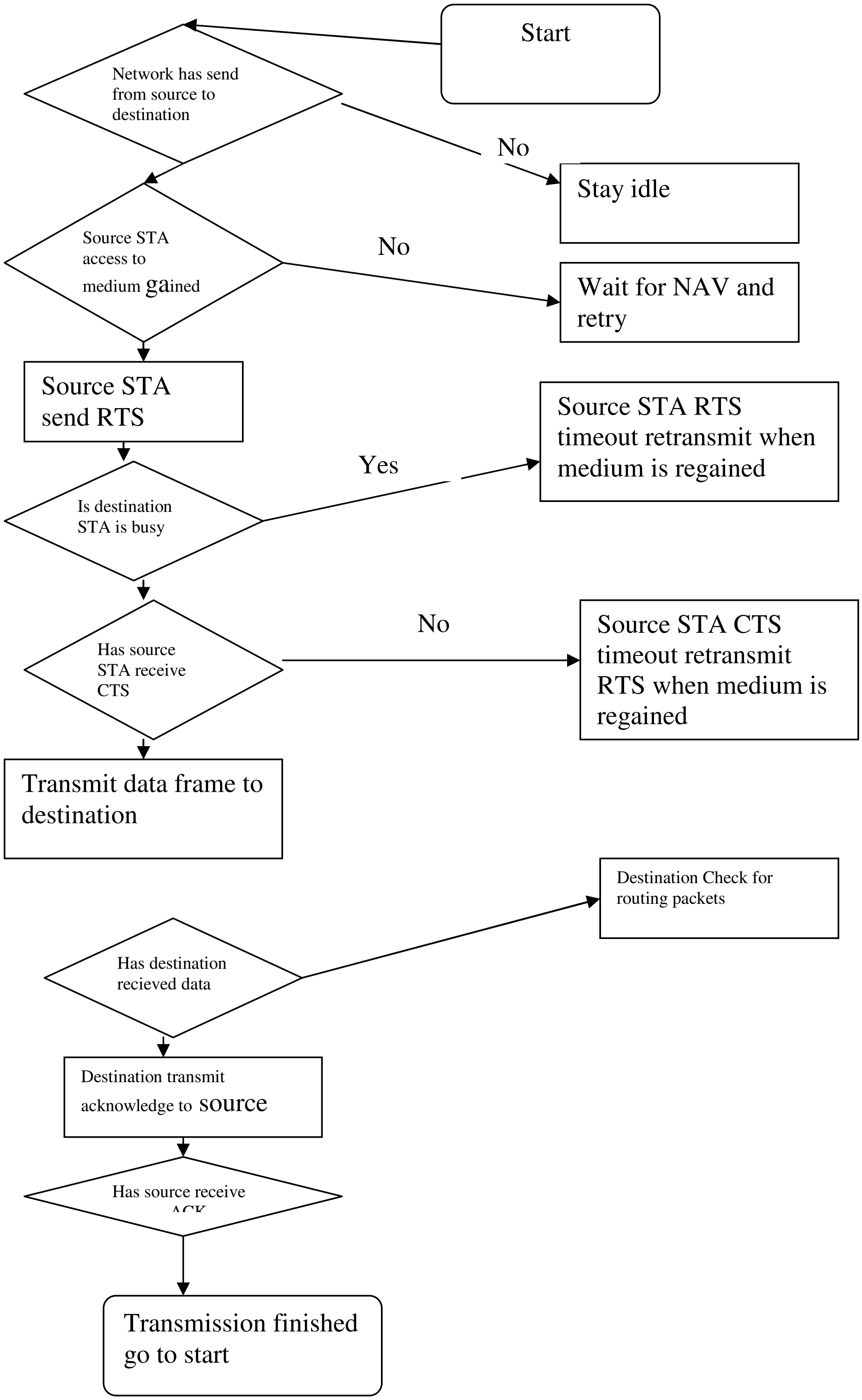



Fig 2 .1.3.1 Flow chart for DCF method Access

### 2.1.4 PCF

The PCF can only be used in an infrastructure-based network because it requires an access point (AP). Usually the Point Coordinator (PC) is installed on this AP. The PC manages the access to the medium in the CFP by polling stations sequentially. The PCF comes up with a higher complexity than the DCF. It is mostly implemented in currently installed infrastructured BSS but it is not used very often due to the lack of an optimized scheduling / polling.

### 2.1.5 HCF

The HCF controls both the CFP and CP. It uses a polling scheme to control the medium access. To grant and to administrate polled-TXOP requests a kind of scheduling management, which introduces a lot of complexity, is needed at the AP (denoted as Hybrid Coordinator (HC)). The HCF is still a moving target in the IEEE draft. It is very difficult to model and to verify without an exact definition. Generally, the HCF as well as he PCF in 802.11 requires an infrastructured BSS. For ad hoc networks an additional MAC mode beside HCF/PCF is required (e.g EDCF). On the other hand, if EDCF works well in both ad hoc and infrastructured networks, HCF is not needed.

## 2.2 The ns MAC includes several timers:

**Defer timer**: is used when the MAC has to sense the medium being idle for the public period of DIFS or if the MAC has to wait a period of SIFS

_ **Backoff timer**: counts down the residual time of a backoff

_ interface timer: indicates, how long the interface will be in transmit mode when sending a packet

_ Send timer: is used for the indication of the time up to which an ACK should be received after a transmission attempt

**Nav timer**: is started

– for EIFS if a collision has been detected

– for the period contained in the duration field of a successful received data frame for the duration of a RTS/CTS/DATA/ACK exchange

These timers have start, stop, pause, resume and handle methods are implemented in ../ns-2.28/mac/mac-timers.cc/h. The event for the point of time is added to the scheduling list in the start method (resp. in resume() after a timer was paused and should be restarted again). Descheduling of events is realized in pause() and stop().

## 2.3 Contention Free Bursting

Tourrilhes  proposed the idea of Contention Free Bursting (CFB) to improve the performance for small packets (of timebounded services) in Wireless LANs. CFB  increcreases the overhead and delay and increases the throughput. CFB sends multiple small packets as a burst without intermediate contention as soon as the station gains  access to the medium (see figure 2.3). It is possible to send packets to different estinations in one burst frame. Between an ACK and the following packet only a time  nterval of SIFS is required.

Therefore the station keeps control over the medium for the whole burst. Sending multiple small packets in a burst avoids contention for each single packet and increases the efficiency. However, the medium access time might be increased because packet bursts occupy the medium for a longer period.

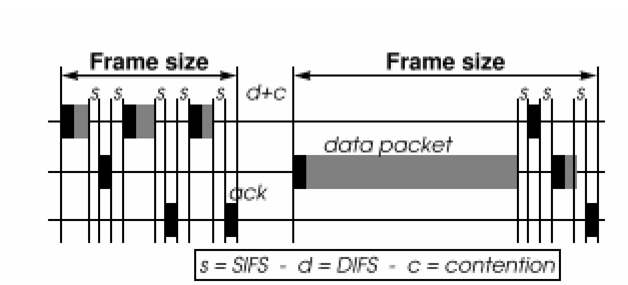



figure 2.3.1

## 2.4 Related Work

One primary design goal of the IEEE 802.11 wireless LAN standard has been to define a way to connect wireless computers in local area networks. The main traffic in a LAN consists of file services or Internet traffic. But it has always been of high interest, how well the data centric WLAN technology can transmit interactive voice. The DCF and PCF modes provide inadequate performance and various performance improvements have been proposed and evaluated .In the following we concentrate on papers that cover WLAN as well as QoS to enhance voice flows. Veeraraghavan et al. [11] have analyzed how many voice flows can be transmitted simul- taneously in an IEEE 802.11 network if the PCF polling mode is applied. D. Chen et al. [14] studied the capacity of IEEE 802.11b's PCF mode to transmit variable bit rate (VBR) VoIP calls. The capacity is up to 17 respective 10 voice calls in the considered modulation of 11 Mbps respective 2 Mbps.

In K¨opsel et al. simulated whether the DCF and PCF MAC mechanism can transmit real-time traffic.In the DCF mode stringent delay requirements are fulfilled only in low load scenarios. In a high load scenario or in a scenario with a high number of nodes, DCF fails to wireless channel. In case of an audio stream with 64 kbit/s coding rate and 20ms packetization, the capacity is 12 stations in the DCF mode and 15 in the PCF mode. As a minimal quality level, the provide a low delay and low jitter. Therefore, the authors suggests to switch in those cases from the DCF to the PCF mode. In [15], the audio flows are transmitted over a 2 M Bit/s authors have chosen a maximum transmission delay of 250ms and maximal 5% packet loss. The usage of PCF, however, decreases the overall throughput because of unsuccessful polling attempts. In a follow-up publication [16], K¨opsel studies the benefit of higher data rates. An increase of the data rate (up to 54 MBit/s) leads only to limited quality improvements. This effect can be explained because of the packet overhead of the IEEE 802.11 PHY and MAC protocol, containing large protocol headers at a low rate, immediate acknowledgements (ACK) and large spaces between the packet transmissions (interframe spaces). Instead, to improve delay and jitter the authors suggest to use a transmit queue that supports two priorities. The high priority is reserved for interactive voice flows whereas the low priority is considered for best effort traffic.

If the priority queue is present, the author does not see an immediate need for an extended DCF mode. In S. Garg et al. experimentally studied the capacity of IEEE 802.11b to determine the maximum number of VoIP calls. The maximum number depends on the packetization of VoIP (reciprocal of the packet frequency), the geographic distribution of the wireless client, and the distance between wireless client and base station. The authors measured quality of the VoIP calls by using packet delay, packet jitter and loss rate. Using 10ms packet sizes six simultaneous calls were possible. Starting the seventh, the wired-to-wireless streams failed to meet the obligation regarding the packet loss. The authors concluded that lowering the packet frequency is the most efficient solution to increase the number of VoIP calls in an WLAN cell.
P. Garg at all. simulated the ability of IEEE 802.11e’s EDCF and HCF coordination function to support a better QoS and higher channel efficiency [14]. They transmitted various flow types (audio,

video and ftp) over a basic service set and measure delay distribution and bandwidth. The simulation is an extended version of Atheros Communication's 802.11e model for ns-2.Their findings lead to the conclusion that both coordination functions are highly sensitive to the chosen parameters. However, both can reach the desired QoS requirements but HCF has a higher bandwidth efficiency than EDCF.

Choicte all. compared IEEE 802.11 DCF with IEEE 802.11e's EDCF and CFB accord- ing to throughput, dropped data rate and delay in an IEEE 802.11b PHY. In their scenarios, they used a combination of unidirectional voice, video and data traffic. They noticed a large decrease in dropped packets and delay as well as a more constant throughput for voice and video transmission in the EDCF simulations. CFB in addition to EDCF increased the throughput of voice and video only marginally but decreased the data dropping rate for both significantly. Because of the interaction of voice and video, the delay of video transmissions was reduced by CFB due to less contention overhead while it was increased for the voice flows.

## 2.5 Motivation

The number of nodes increases the performances or best effort certain number of terminals but the performances get degraded heavy load. When the number of nodes accessing such information become large, a bottle neck is reached.To alleviate this problem we have to analysis of nodes and packet size also constant bit rate of packet sending. We can however take advantage that different nodes need the data at different resolution i.e, each may be interested in the same varying data at varying levels of coherency. For example, system administrator may be interested at the packet level traffic statistics of the traffic while a casual user might be happy with average traffic levels of the network over a longer period of time .Even each of repositories that replied that replied the data have their own coherency requirements . Having understood the problem, we shall develop the problem of defining the Algorithms and architectures for realization of service that advantage of above properties When the number of nodes accessing such information become large, a bottle neck is reached.To alleviate this problem we have to analysis of nodes and packet size also constant bit rate of packet sending Here I am using ns-2 simulator open source tool kit for simulation. After that I compare my result with previous published results. For example consider a situation when three people bring there laptop and start communication After some times number of user increases but finite number of users and start sending packets to access point and I have to analysis for up to which number of terminals the load increases and we get the best effort Services after that the performances degraded. And for verification point of view I compare my result with previous publish Mangolds results

# CHAPTER 3 SIMULATION AND EVALUATION

## 3.1 IEEE 802.11 EDCF Simulation Model

We used the discrete event simulator ns-2.28 for our work where an 802.11 DCF model is already included. The ns-802.11 model does not provide the PCF as well as any MAC- Management mechanisms like Association/Reassociation, Authentication/Deauthentication. We did not use an error model but the ns' TwoRayGround Propagation model, which considers the line-of-sight path and a ground reflection path. Further details about the implementation of the Simulation model can be found in its open-source distribution .

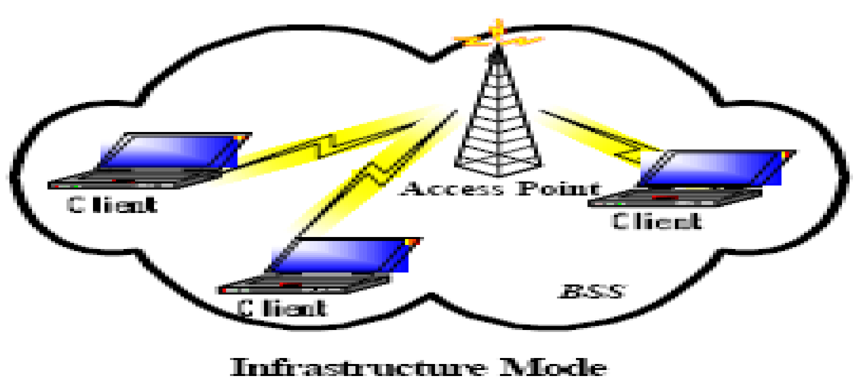



Fig 3.1.1

## 3.2 Verification

During the implementation of our model we found a couple of errors in ns-2 and removed them. To ensure the correctness of our simulation model we compared it with the work of Mangold [3]. Mangold has implemented an EDCF simulation model in WARP and conducted some performance evaluations. If our simulation model achieves similar results to Mangold's work we assume it as verified and as "correct". Mangold [3 utilized the IEEE 802.11a-PHY with a data rate of 24Mbps, therefore we had to adopt the PHY parameters of our model, too. At first we considered and compared the maximum achievable throughput in ns-2.28 with the simulations in [3]. The scenario is a BSS consisting of a QoS AP (QAP) and only one wireless station. On this station one flow is sent to the QAP. [3]performed separate simulations for each TC with an increased generation rate respective a larger MSDU. The throughputs in Mbps are listed in table 3.1. We reached similar results with only minor differences. We took the following scenario (figure 3.1.1) out of [3 to verify our model. The number of the wireless stations increases from 1 to 15.

In the Mangold results and our results are describe below as shown in table. The results of are shown in figure 6 while our results are displayed in figure 7. In our simulations, traffic only up to a number of 1 respective 17 stations .Afterwards the curves drop faster and much more down in our simulations. In our results traffic only up to 17 stations (in terms of throughput per station) then it decreases slightly. Our results differ to Mangold in that respect. However, we explain this effect due to the different retransmission and packet drop behavior of both simulation models.

In our simulation model packets are dropped after the seventh collision. Retransmissions due to a collision occur often if many stations compete for the medium. Also, the overall throughput reaches an upper limit if the number of stations increases. Even after extensive checking of our simulation code, we see no indications to doubt the results of our simulation model and its implementation.

## 3.3 What is Adhoc Mode?

Adhoc mode is a networking framework by which wireless devices or stations communicate directly with each other, without the need for an access point (AP). Ad-hoc mode can be referred to as peer-to-peer mode or an Independent Basic Service Set (IBSS). This Mode is useful when you want to communicate among many computers locally without the need to connect to printers or file servers on a wired LAN.

## 3.3 What is Infrastructure Mode?

Infrastructure mode is a networking framework by which devices communicate with each other by first going through an Access Point (AP). Infrastructure mode, lets wireless devices communicate with each other or with a wired network. Two possible types of service can exist while in Infrastructure mode:

**Basic Service Set (BSS)**

Basic Service Set is when an Access Point is connected to a wired network
and a set of wireless stations.

**Extended Service Set (ESS)**

Extended Service Set is a set of two or more Basic Service Sets BSSs that
form a single subnet.

Ad-Hoc and Infrastructure Mode

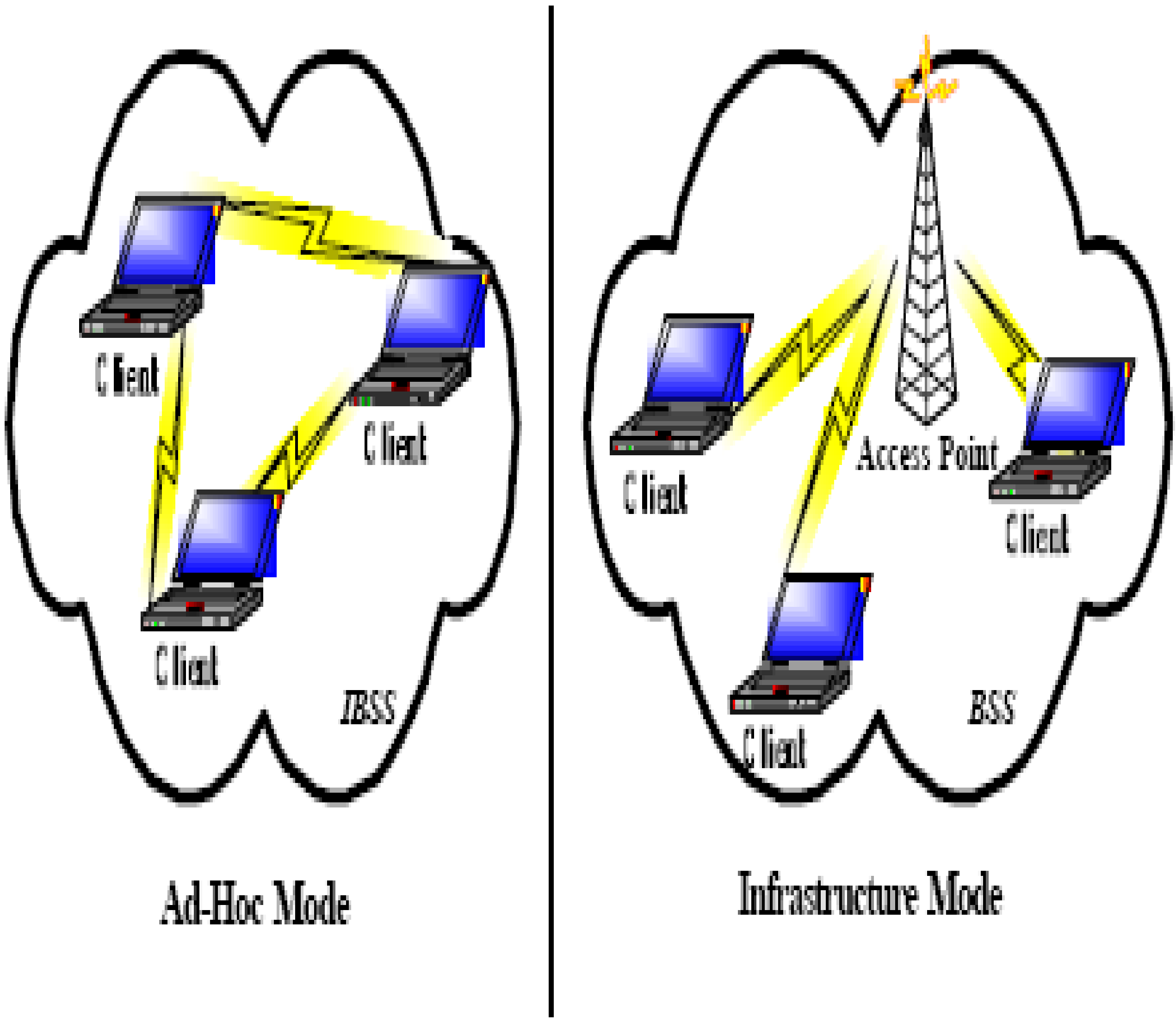



Fig 3.3.1

## 3.4 Simulation Scenario

Our simulations are done using the public domain network simulator ns-2 2.28 [1]. Support for wireless simulations in ns was added as a part of the Mangolds Results [3]. We have used the default values for all the physical and MAC layer parameters like simulation time and SlotTime (20ms) etc. The simulation start time and the transmission range is 550m.

NS-2 scenario

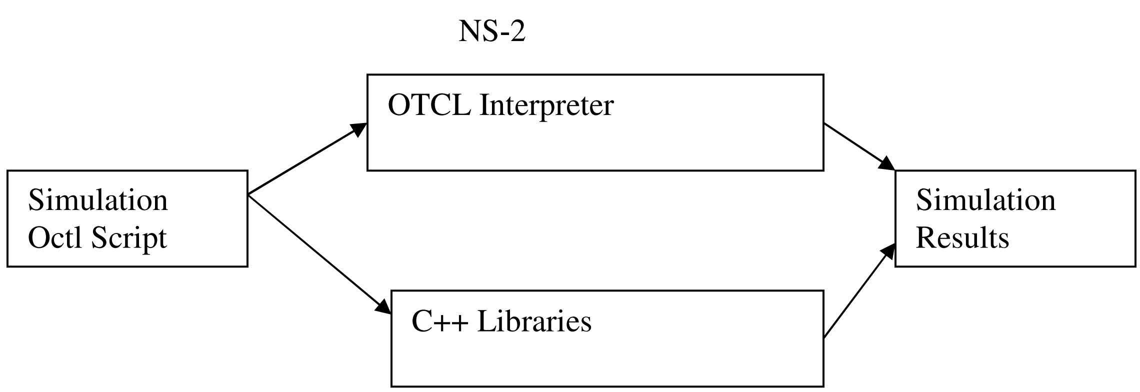



Fig 3.4.1

## 3.5 Software Architecture (SA) specification formalism

Software Architecture (SA) specification formalism is a means to represent the design of a system from a designer's point of view. It is usually a simple graphical representation of the design. Several different formalisms have been developed to help the designer represent the system in a manner that is natural to him, yet easily convertible to the model used by performance analyst. It is increasingly clear that effective software engineering requires facility in architectural software design. First, it is important to be able to recognize common paradigms so that high-level relationships among systems can be understood and so that new systems can be built as variations on old systems. Second, getting the right architecture is often crucial to the success of a software system design; the wrong one can lead to disastrous results. Third, detailed understanding of software architectures allows the engineer to make principled choices among design alternatives. Fourth, an architectural system representation is often essential to the analysis and description of the highlevel properties of a complex system.

When systems are constructed from many components, the organization of the overall system—the software architecture—presents a new set of design problems. This level of design has been addressed in a number of ways including informal diagrams and descriptive terms, module interconnection languages, templates and frameworks for systems that serve the needs of specific domains, and formal models of component integration mechanisms.

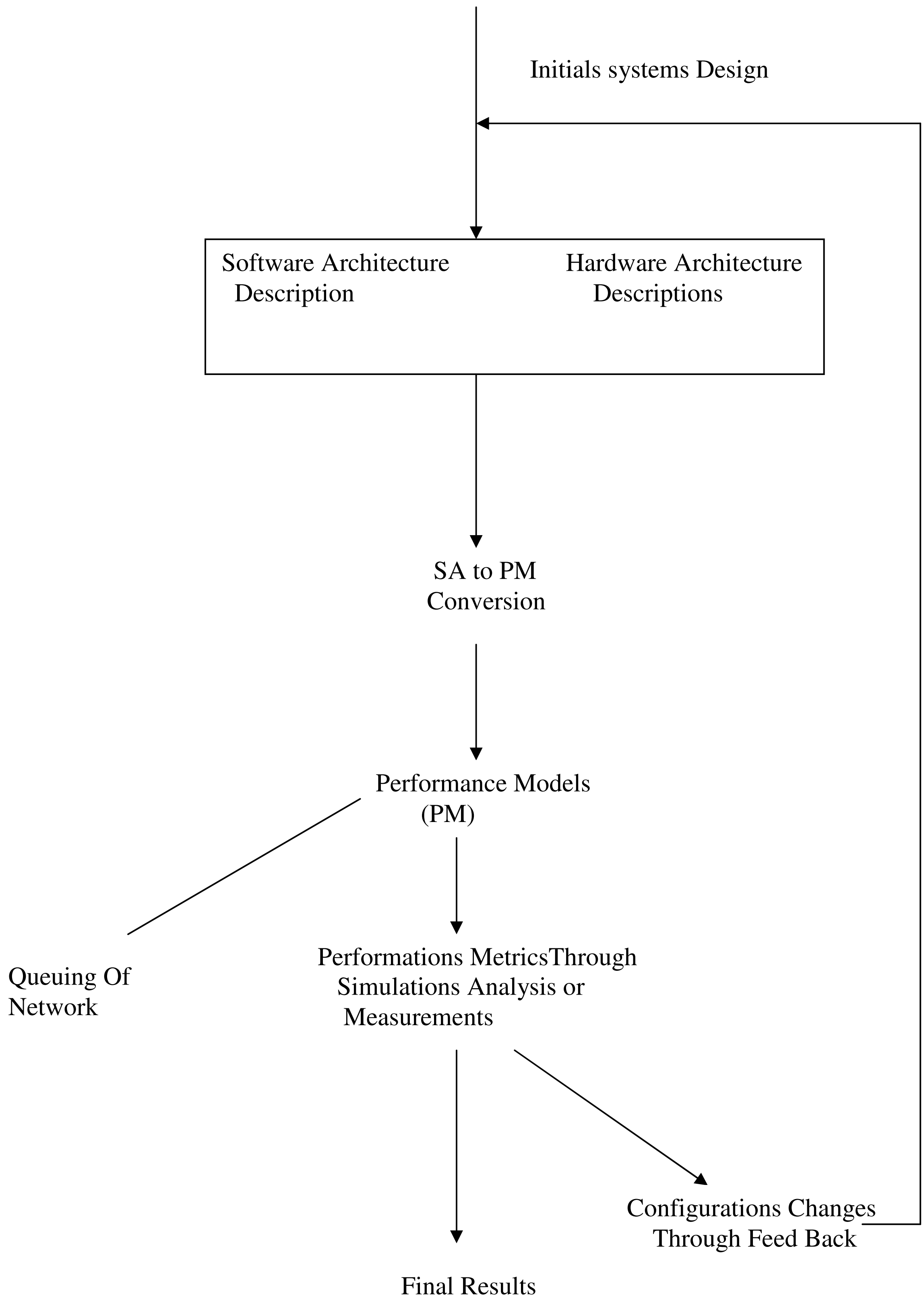



Fig 3.5.1 Software Architecture Specification

# CHAPTER 4 IMPLEMENTATION ISSUES

## Methodology

Network Simulator - Toolkit

**Simulator Initialization**

When a new simulation object is created the initialization procedure performs the following operations:

_ initialize the packet format (calls create_packetformat)

_ create a scheduler (defaults to a calendar scheduler)

_ create a "null agent" (a discard sink used in various places)

## How to work in ns toolkit

■ [root@manish ns-allinone-2.28]# ls

```
bin            include        man        README      tk8.4.5
cweb           install        nam-1.11   sgb         xgraph-12.1
cygwin-cd1.iso INSTALL.WIN32  ns-2.28    tcl8.4.5    zlib-1.1.4
gt-itm         lib            otcl-1.9   tclcl-1.16
```

[root@manish ns-allinone-2.28]# cd ns-2.28/

## 4.1 Contention Free Burst (CFB)

For enabling or disabling the CFB I introduced the cfb_ flag which is set in ../ns-2.28/tcl/lan/ns-mac.tcl. The May-2003 802.11e draft [11] defines a maximum duration of a transmission opportunity (TXOPLimit) for each priority. TXOPLimit is given in milliseconds and should take different values dependent on the Physical Layer.

In my model the TXOPLimits are defined in ../ns-2.28/mac/802_11e for each priority . RecvACK() is called when a station  an ACK on time for its last transmitted packet. If this ACK is error free, it has to be checked if this station should have the chance to send the next packet without contention.

## 4.2 DCF Parameters

DCF (Distributed Coordination Function)

- Latency
- TXOP
- Only support best-effort services
- Throughput degradation in the heavy load

## 4.3 QoS Limitations of 802.11

- DCF (Distributed Coordination Function)
- No guarantee in bandwidth
- packet delay and jitter

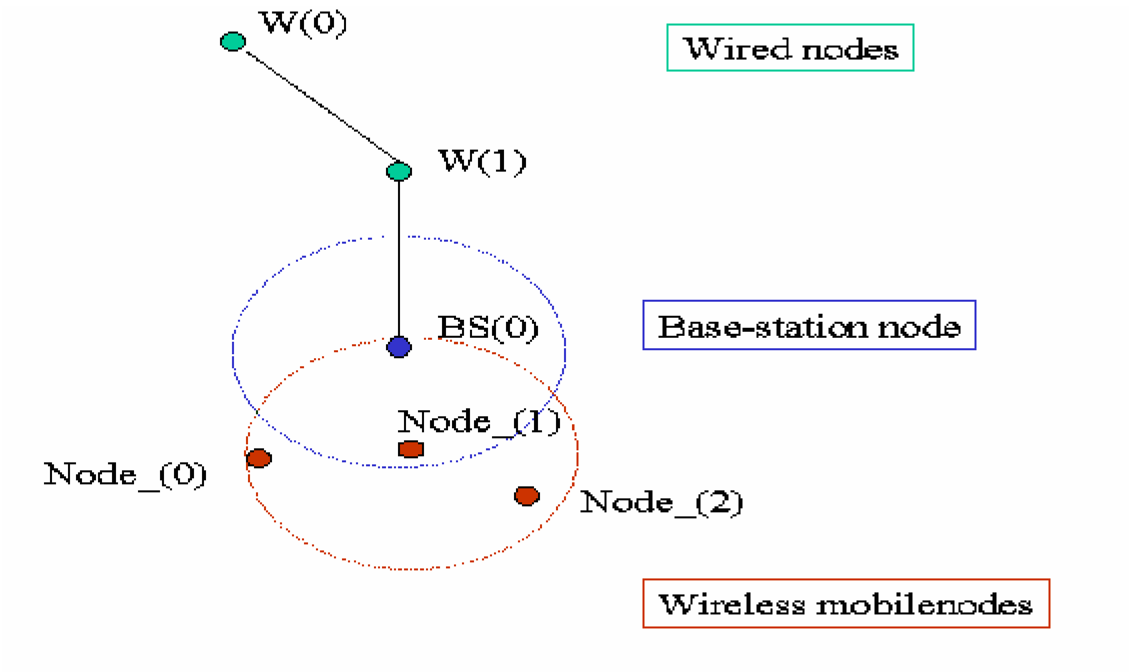



Fig 4.4 Topology for wired cum wireless nodes

These are the examples wired –cum-wireless simulation . similar related to my work one acess point wired nodes and number of wired nodes connected to acess point for sending a packets .

## 4.5 Simulation setup

| | |
|---|---|
| Simulator | ns-2 |
| Examined protocols | DSDV |
| Simulation duration | 250 seconds |
| Simulation area | 500 m x 500 m |
| TXOP | 3 s |
| Traffic type | CBR |
| Data payload | 512 bytes/packet |
| Packet rate | 4 packets/sec |

Table 4.5 for simulation setup

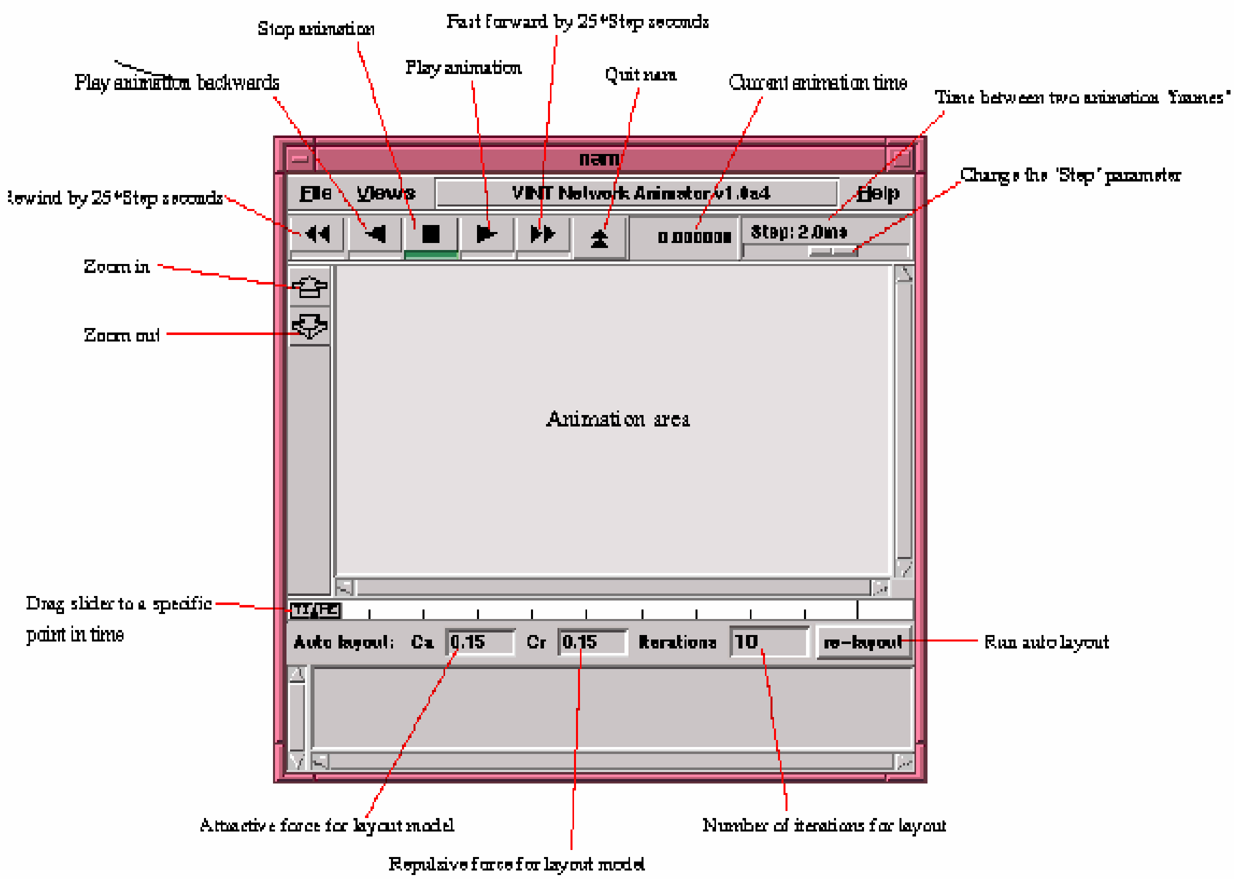



Fig 5.1 Animation file where you visualize simulation scenario

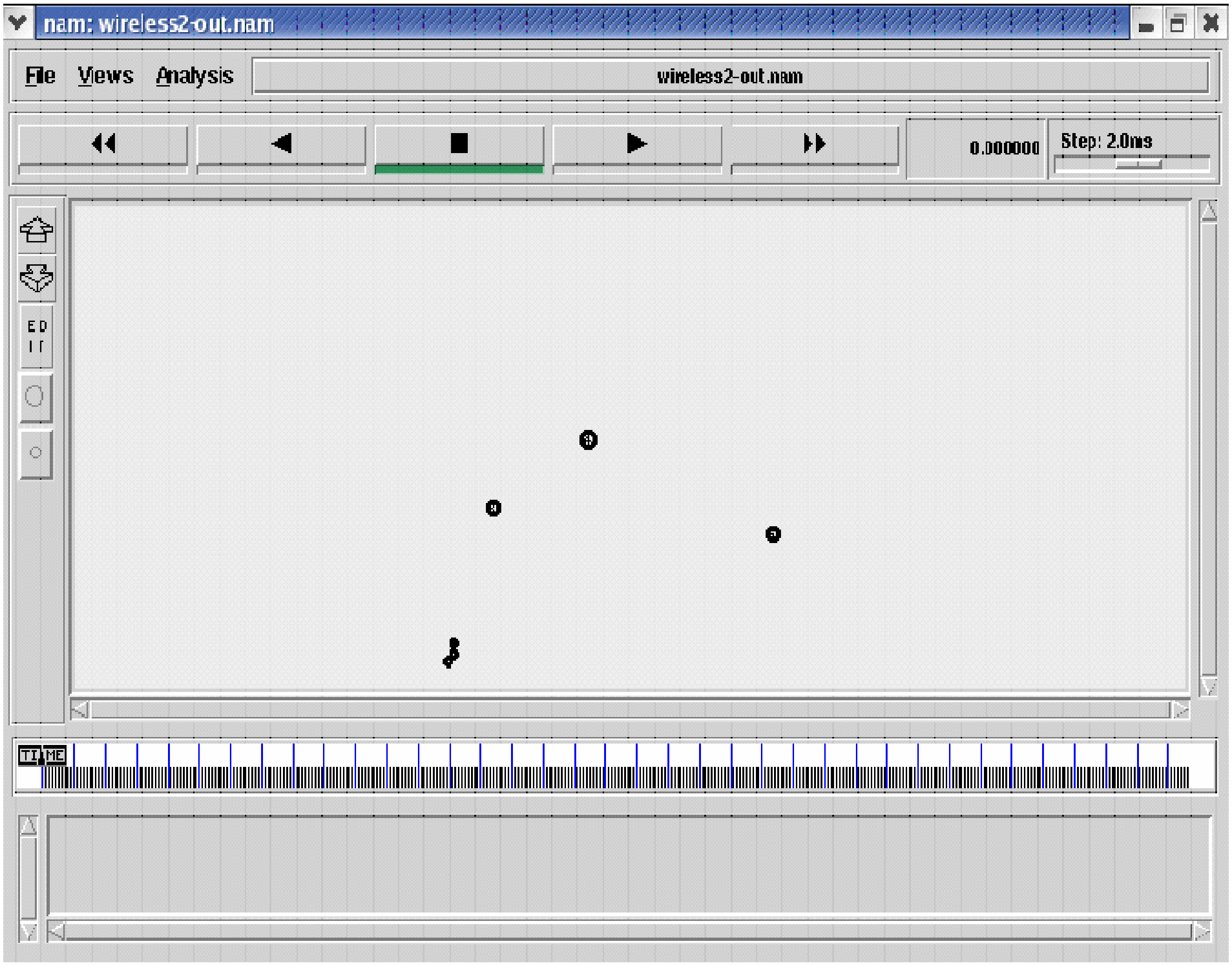
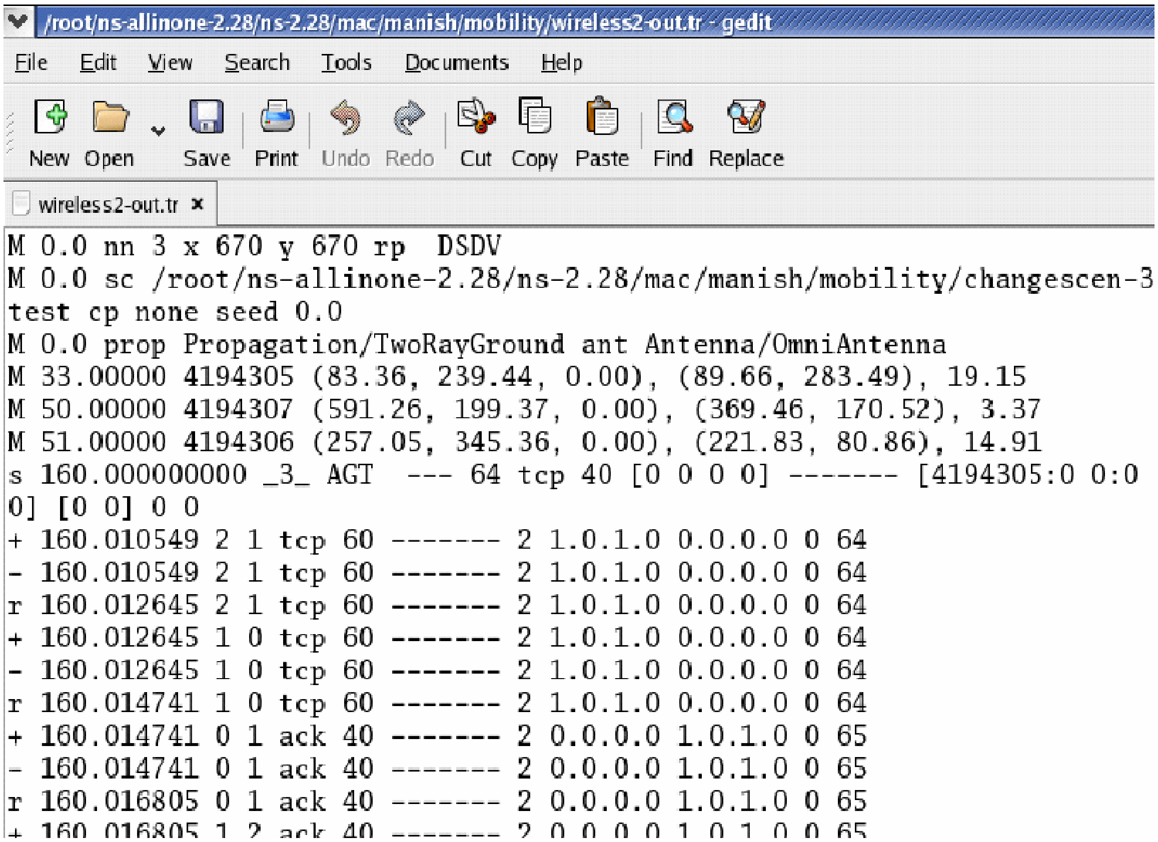



Fig 5.2 Our animation file where you visualize simulation scenario




```
M 0.0 nn 3 x 670 y 670 rp  DSDV
M 0.0 sc /root/ns-allinone-2.28/ns-2.28/mac/manish/mobility/changescen-3
test cp none seed 0.0
M 0.0 prop Propagation/TwoRayGround ant Antenna/OmniAntenna
M 33.00000 4194305 (83.36, 239.44, 0.00), (89.66, 283.49), 19.15
M 50.00000 4194307 (591.26, 199.37, 0.00), (369.46, 170.52), 3.37
M 51.00000 4194306 (257.05, 345.36, 0.00), (221.83, 80.86), 14.91
s 160.000000000 _3_ AGT  --- 64 tcp 40 [0 0 0 0] ------- [4194305:0 0:0
0] [0 0] 0 0
+ 160.010549 2 1 tcp 60 ------- 2 1.0.1.0 0.0.0.0 0 64
- 160.010549 2 1 tcp 60 ------- 2 1.0.1.0 0.0.0.0 0 64
r 160.012645 2 1 tcp 60 ------- 2 1.0.1.0 0.0.0.0 0 64
+ 160.012645 1 0 tcp 60 ------- 2 1.0.1.0 0.0.0.0 0 64
- 160.012645 1 0 tcp 60 ------- 2 1.0.1.0 0.0.0.0 0 64
r 160.014741 1 0 tcp 60 ------- 2 1.0.1.0 0.0.0.0 0 64
+ 160.014741 0 1 ack 40 ------- 2 0.0.0.0 1.0.1.0 0 65
- 160.014741 0 1 ack 40 ------- 2 0.0.0.0 1.0.1.0 0 65
r 160.016805 0 1 ack 40 ------- 2 0.0.0.0 1.0.1.0 0 65
+ 160.016805 1 2 ack 40 ------- 2 0.0.0.0 1.0.1.0 0 65
```

Fig 5.3 Trace file of sending and receiving of packets

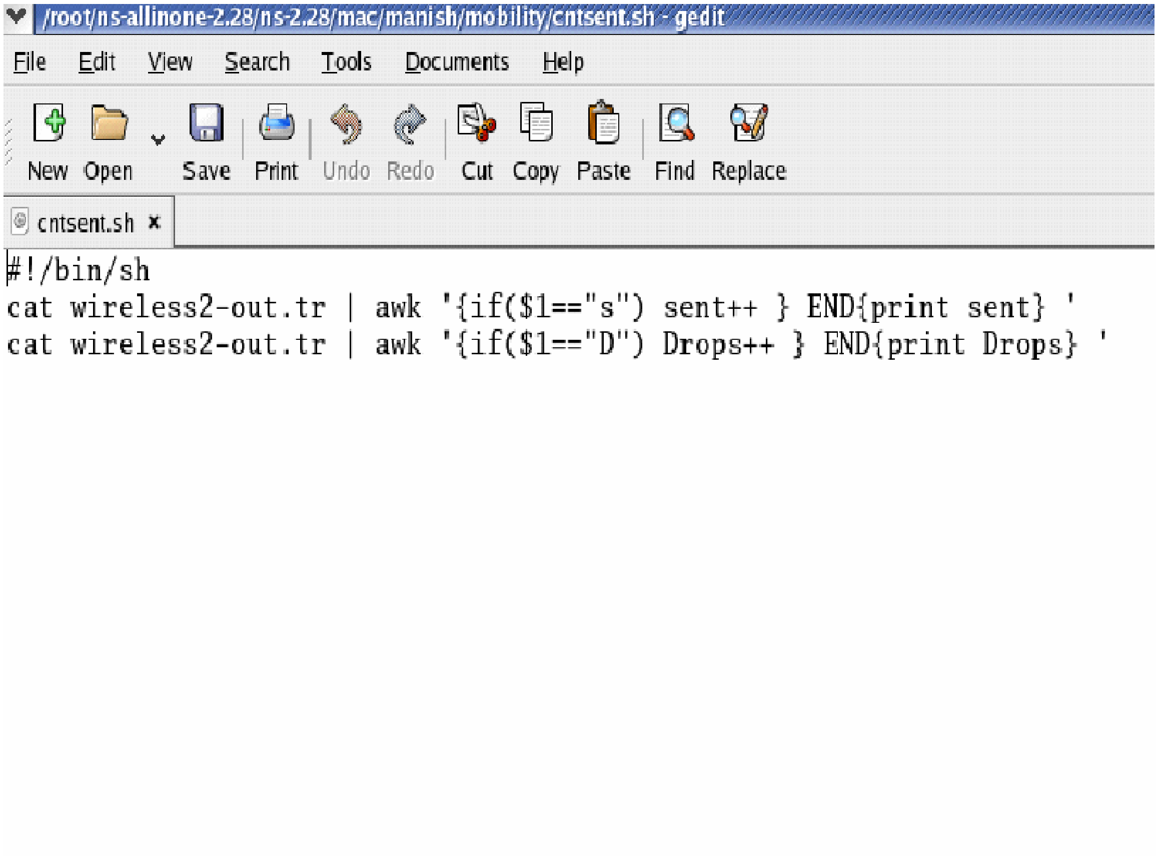



Fig 5.4 Count the number of packets send and dropping of packets

# CHAPTER 6 HIDDEN TERMINAL

## 6.1 Hidden Terminal Problem

- Two nodes, hidden from one another (out of transmission range), attempt to send information to the same receiving node.
- Packet collisions.

- Exposed Node Problem
  - A node is inhibited from transmitting to other nodes on overhearing a packet transmission.
  - Wasted bandwidth

Hidden and Exposed terminal problem

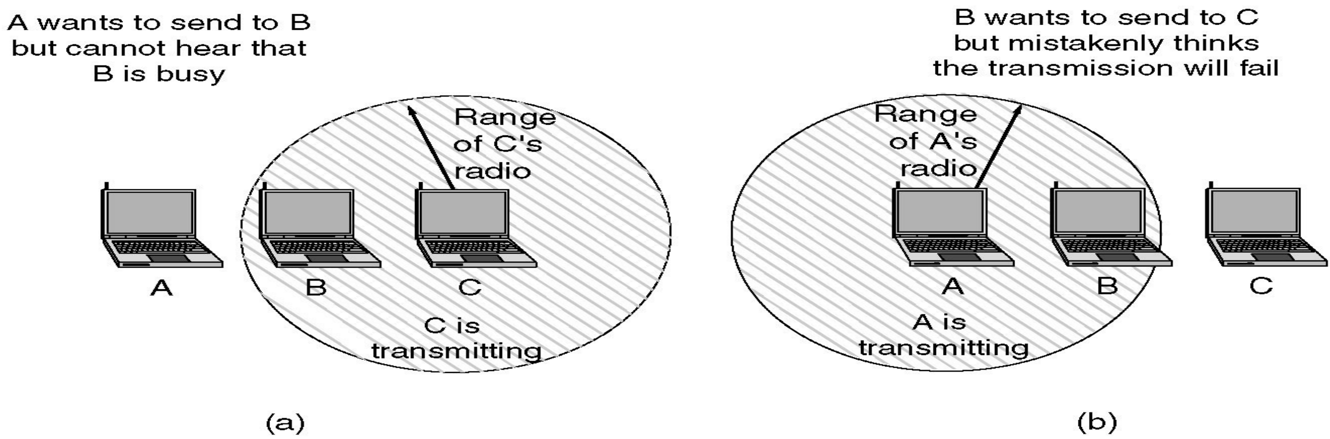



Figure 6.1 .(a)The hidden station problem.
(b) The exposed station problem

6.2 Hidden and Exposed terminal problem solved up to some extend

Solution to exposed node problem

- Use of separate control
- TXOP limit
- Syncronization

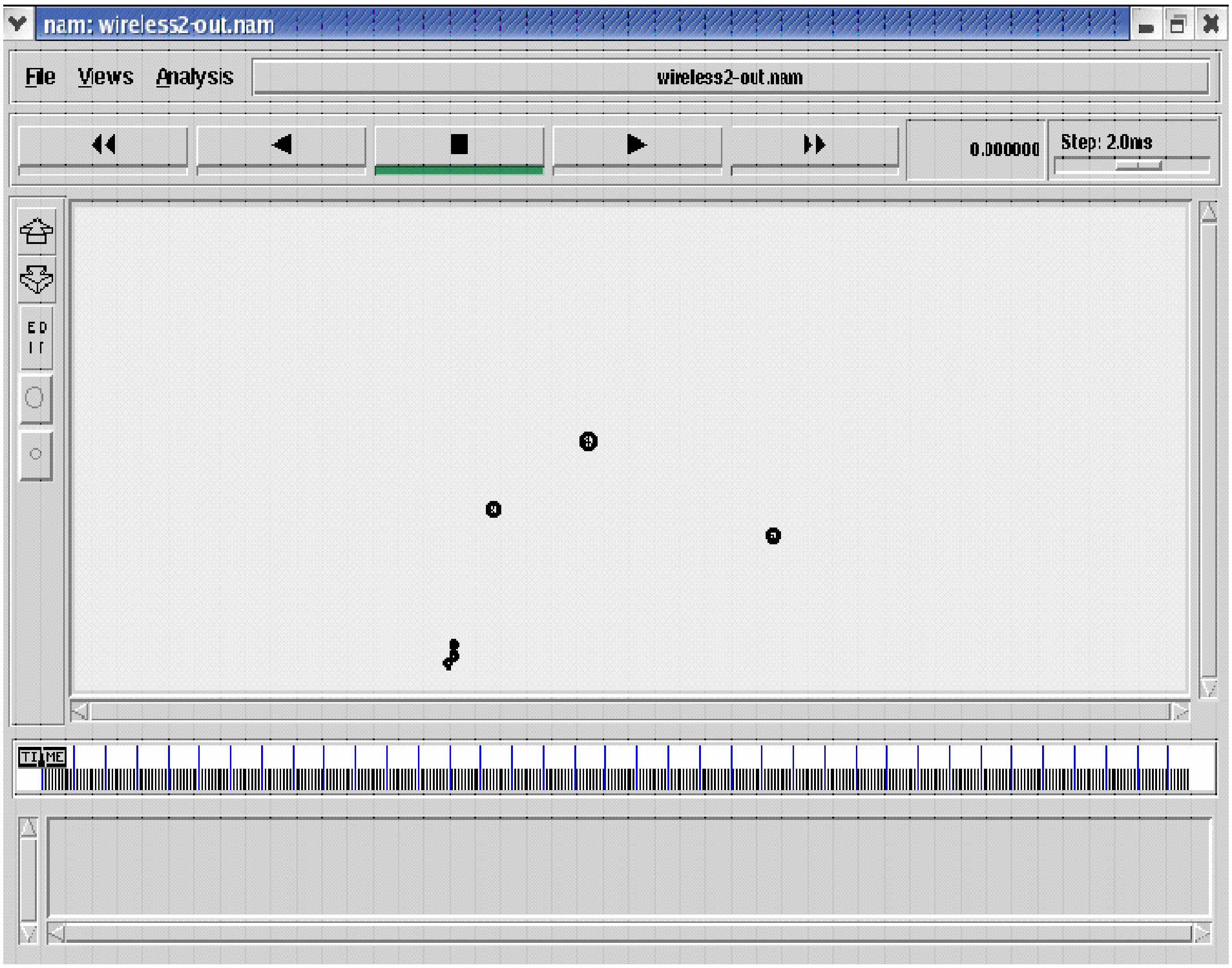



Fig 6.2

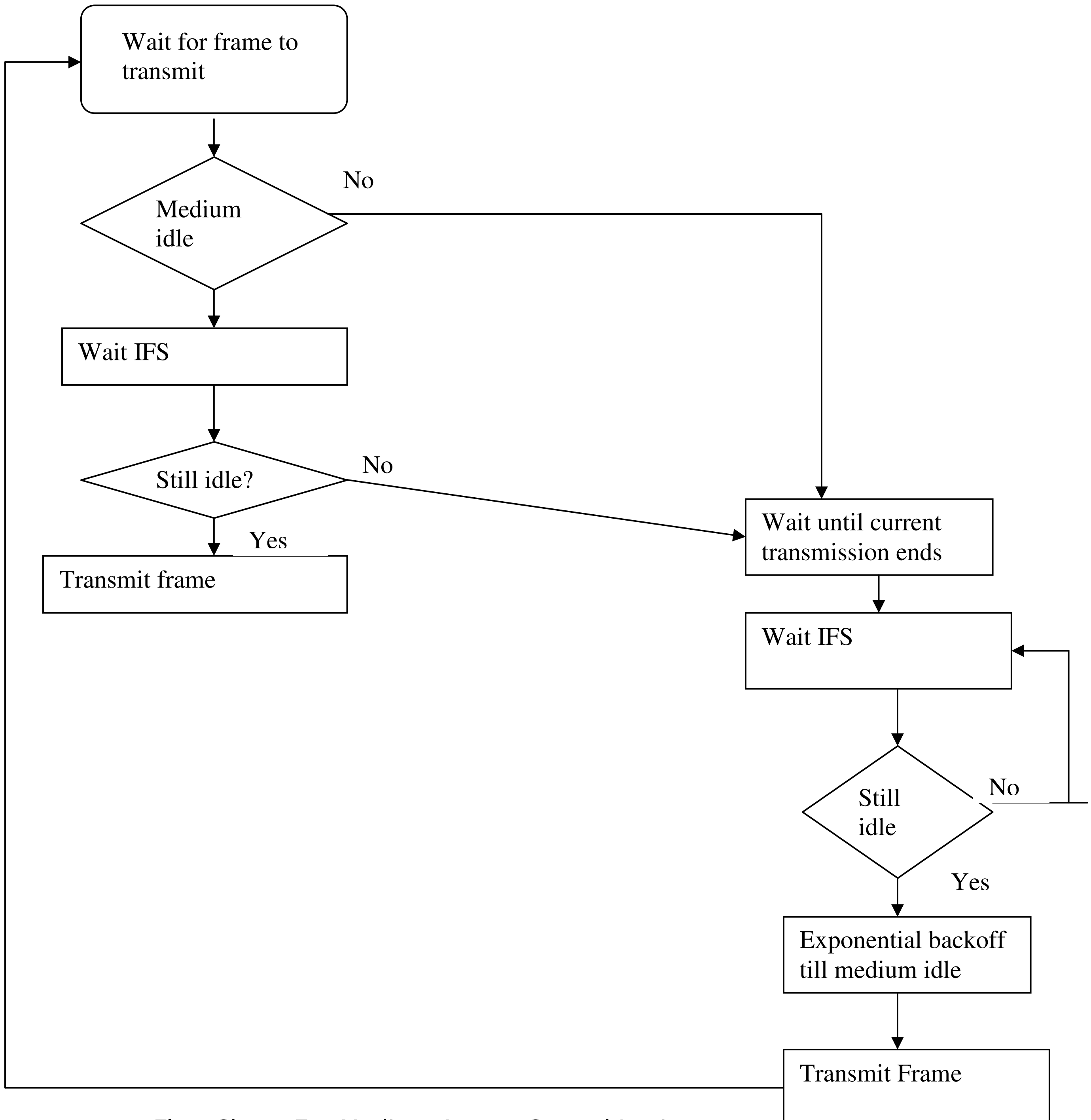



Fig 6.3 Flow Chart For Medium Access Control Logic

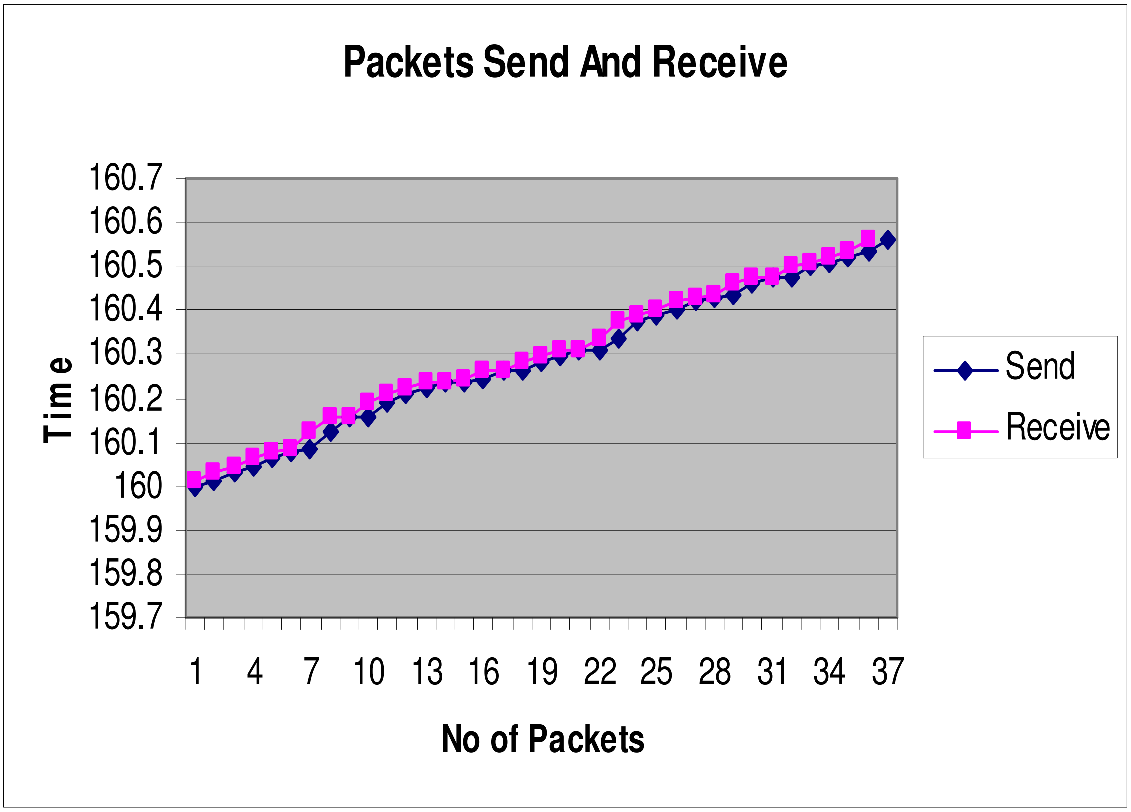



Fig 7.1 Packet sending and receiving rate

Table 7.1 For Sending and Receiving Of Packets

| No Of Packets | Packets Sends | Packets Receive |
|---|---|---|
| 1 | 160 | 160.0105 |
| 2 | 160.0105 | 160.0328 |
| 3 | 160.0328 | 160.0438 |
| 4 | 160.0448 | 160.056 |
| 5 | 160.0668 | 160.0782 |
| 6 | 160.0791 | 160.0906 |
| 7 | 160.0809 | 160.0926 |
| 8 | 160.1238 | 160.1357 |
| 9 | 160.1559 | 160.168 |
| 10 | 160.1577 | 160.1898 |
| 11 | 160.1898 | 160.2024 |
| 12 | 160.212 | 160.22 |
| 13 | 160.22 | 160.235 |
| 14 | 160.235 | 160.2379 |
| 15 | 160.2379 | 160.2399 |
| 16 | 160.2399 | 160.262 |
| 17 | 160.262 | 160.2639 |
| 18 | 160.2639 | 160.2859 |
| 19 | 160.2859 | 160.297 |
| 20 | 160.2979 | 160.3099 |

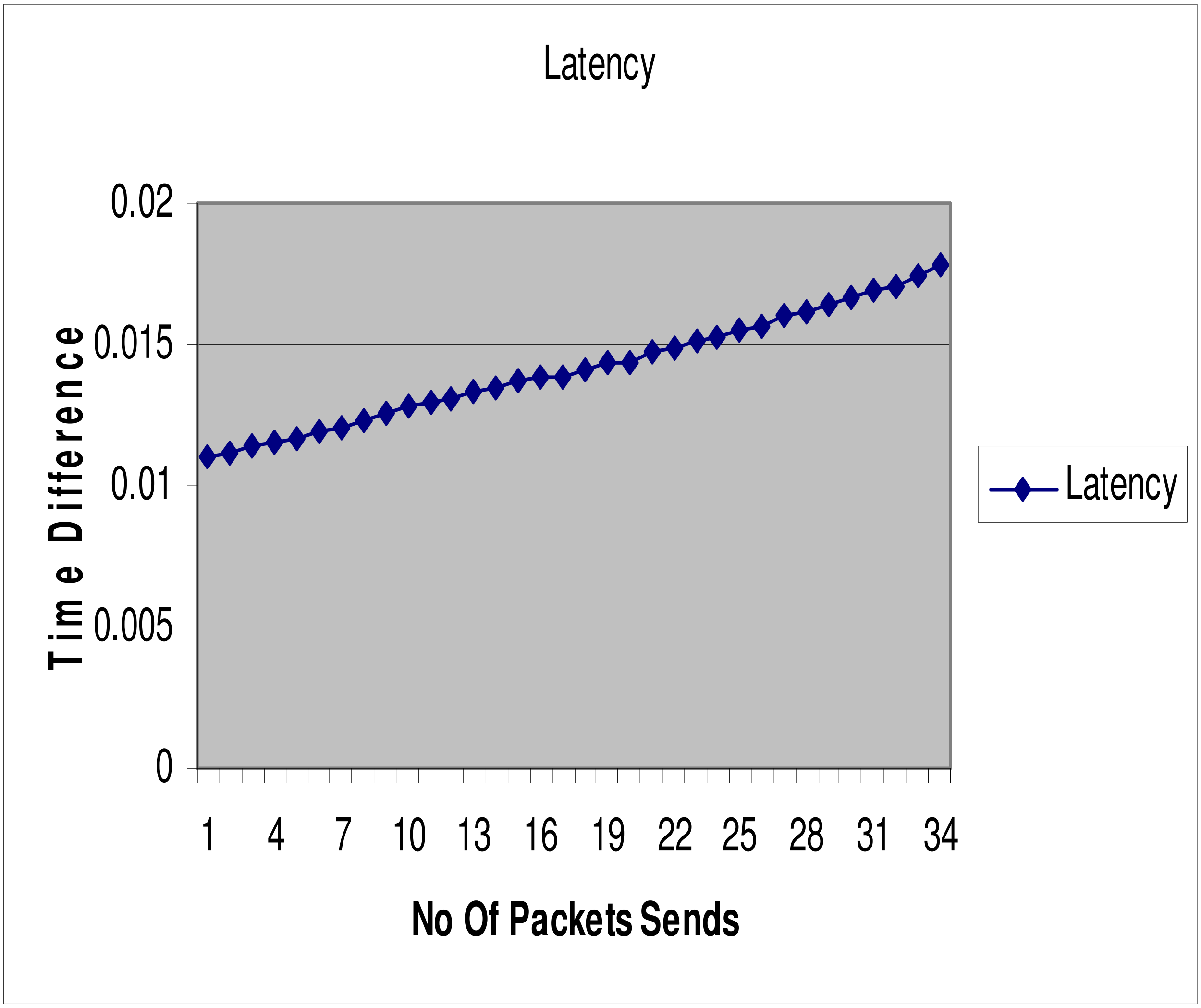
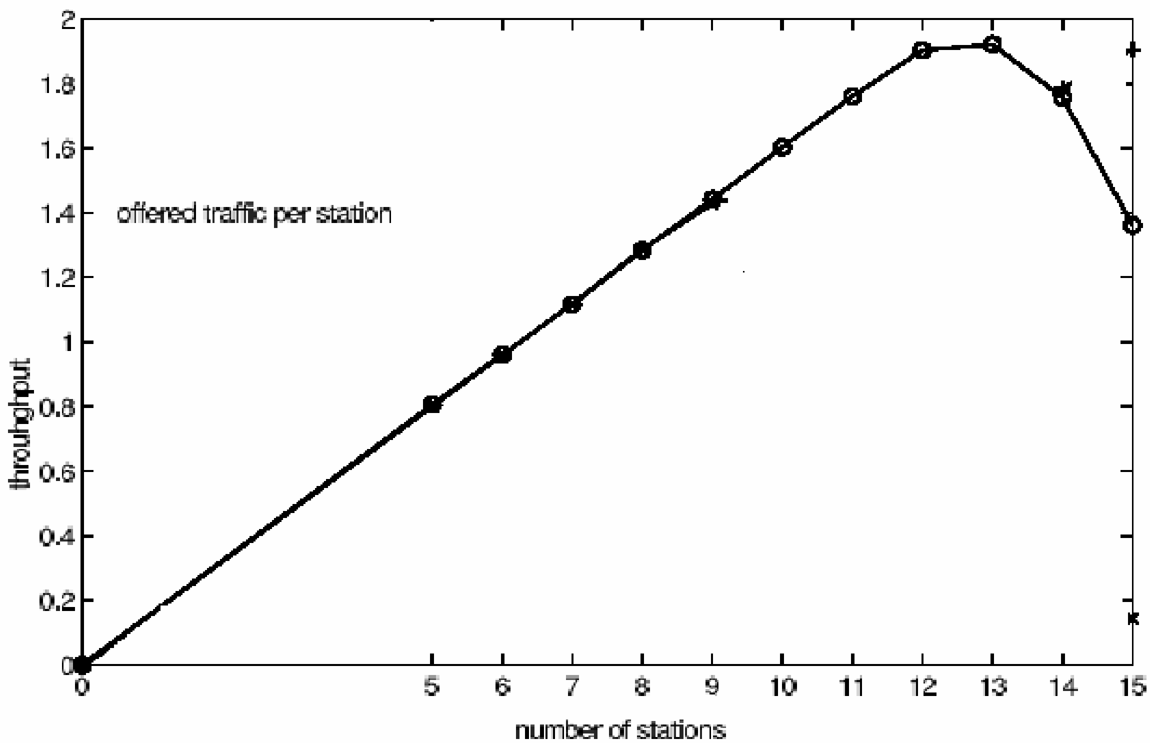


Fig 7.2 Latency

Table 7.3 for latency

| No Of Packets | Packets Sends | Packets Receive | Latency |
|---|---|---|---|
| 1 | | 160.0105 | 0.0105 |
| 2 | 160.0105 | 160.0328 | 0.0109 |
| 3 | 160.0328 | 160.0438 | 0.011 |
| 4 | 160.0448 | 160.056 | 0.0112 |
| 5 | 160.0668 | 160.0782 | 0.0114 |
| 6 | 160.0791 | 160.0906 | 0.0115 |
| 7 | 160.0809 | 160.0926 | 0.0117 |
| 8 | 160.1238 | 160.1357 | 0.0119 |
| 9 | 160.1559 | 160.168 | 0.0121 |
| 10 | 160.1577 | 160.1898 | 0.0123 |
| 11 | 160.1898 | 160.2024 | 0.0126 |
| 12 | 160.212 | 160.22 | 0.0128 |
| 13 | 160.22 | 160.235 | 0.0129 |
| 14 | 160.235 | 160.2379 | 0.0131 |
| 15 | 160.2379 | 160.2399 | 0.0133 |
| 16 | 160.2399 | 160.262 | 0.0135 |
| 17 | 160.262 | 160.2639 | 0.0137 |
| 18 | 160.2639 | 160.2859 | 0.0138 |
| 19 | 160.2859 | 160.297 | 0.0139 |
| 20 | 160.2979 | 160.3099 | 0.0141 |



Mangold's results for increasing number stations vs. throughput

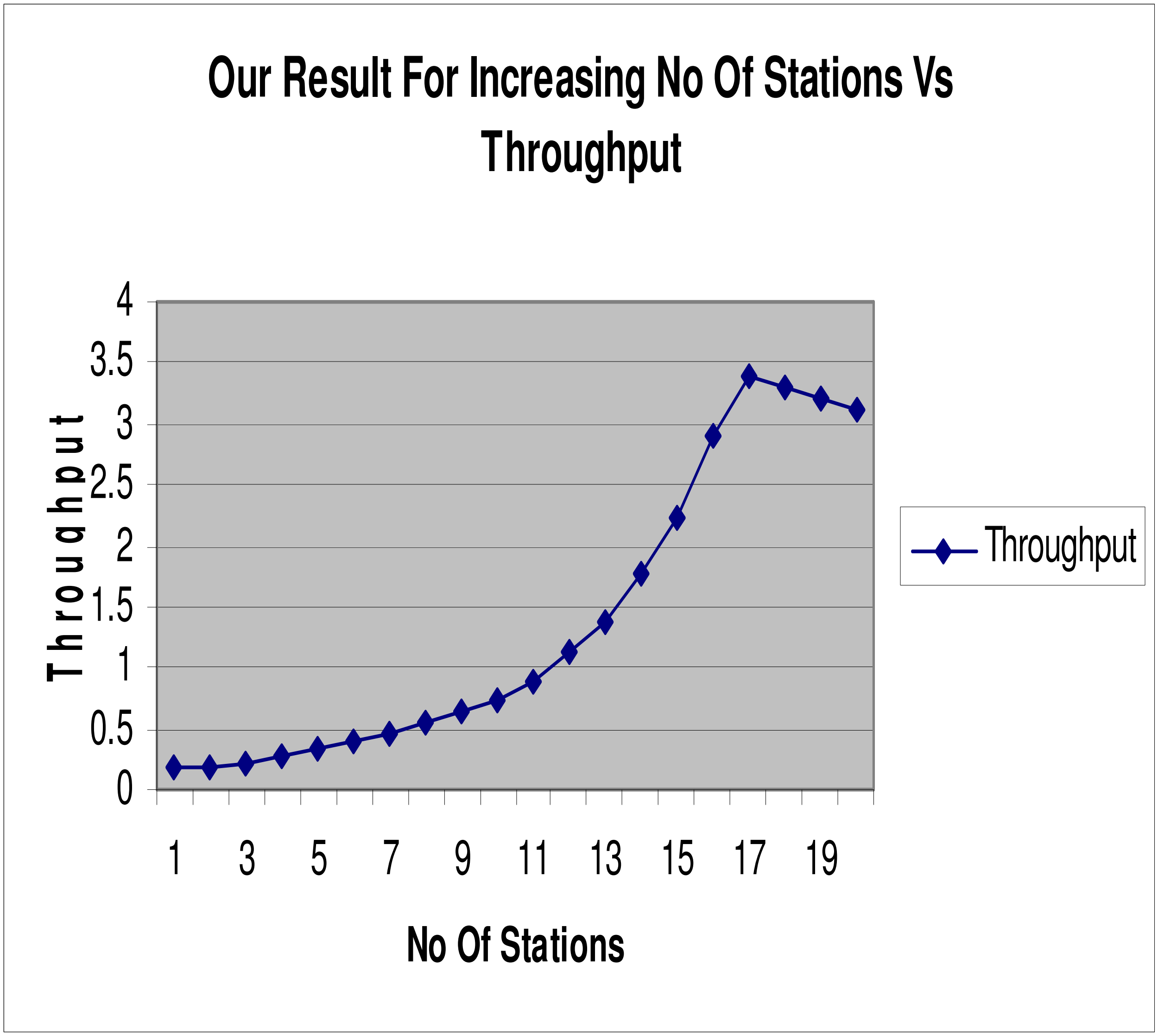



Fig 7.5 Our simulation result vs Throughput

| No Of Stations | Throughput | Designation |
|---|---|---|
| 1 | .1832 | Best Effort |
| 2 | .1925 | Best Effort |
| 3 | .2127 | Best Effort |
| 4 | .2834 | Best Effort |
| 5 | .3339 | Best Effort |
| 6 | .3945 | Best Effort |
| 7 | .4652 | Best Effort |
| 8 | .5460 | Best Effort |
| 9 | .6369 | Best Effort |
| 10 | .7379 | Best Effort |
| 11 | .87321 | Best Effort |
| 12 | 1.1376 | Best Effort |
| 13 | 1.37346 | Best Effort |
| 14 | 1.7789 | Best Effort |
| 15 | 2.22781 | Best Effort |
| 16 | 2.898 | Best Effort |
| 17 | 3.3912 | Best Effort |
| 18 | 3.2892 | Wrost Effort |
| 19 | 3.20032 | Wrost Effort |
| 20 | 3.12111 | Wrost Effort |

- Table 7.5 Design of IEEE 802.11e EDCf Simulation Model

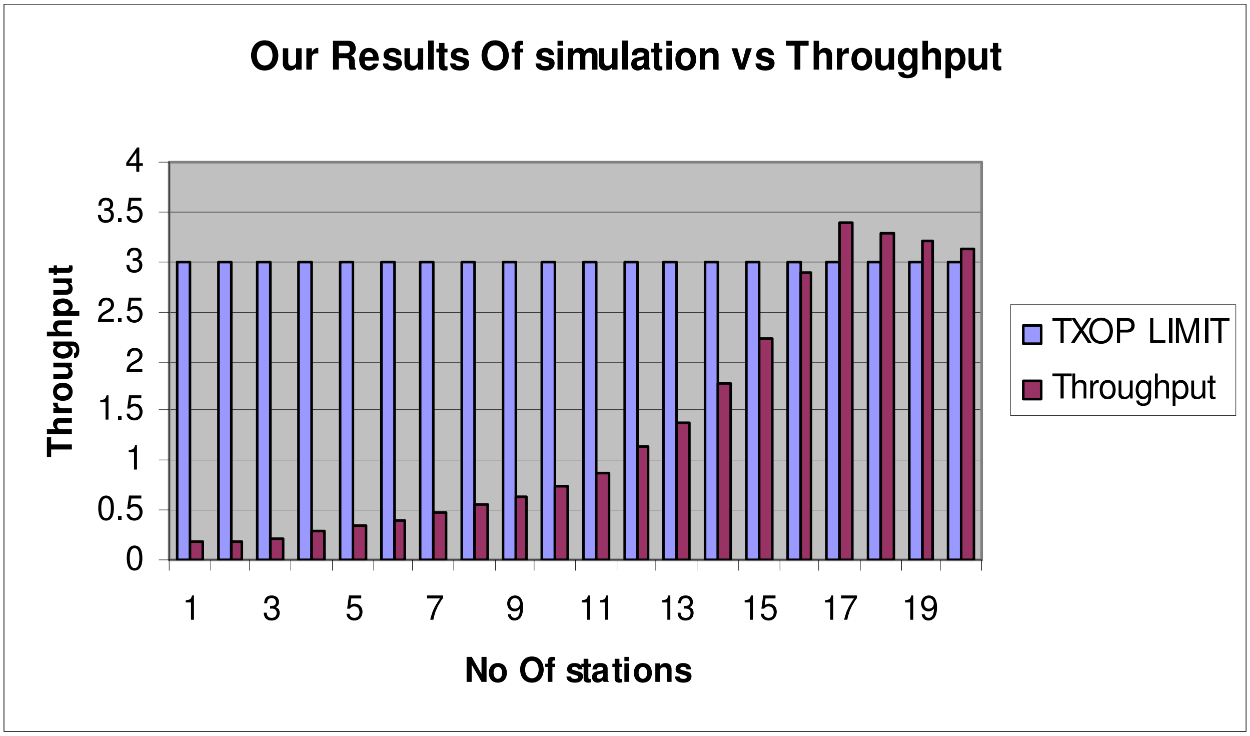
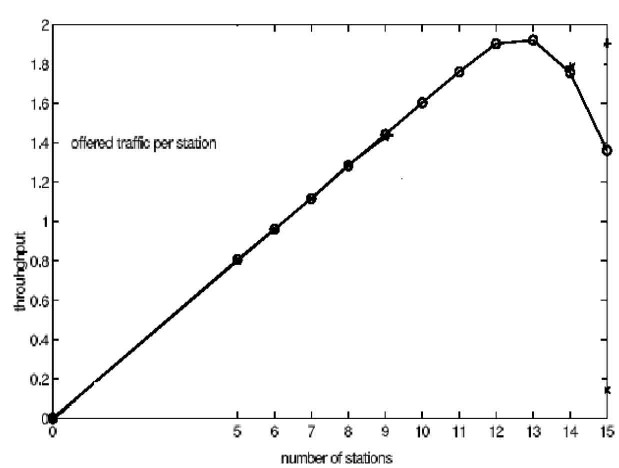



Fig 7.6 TXOP LIMIT




Mangold's results for increasing number stations vs. throughput

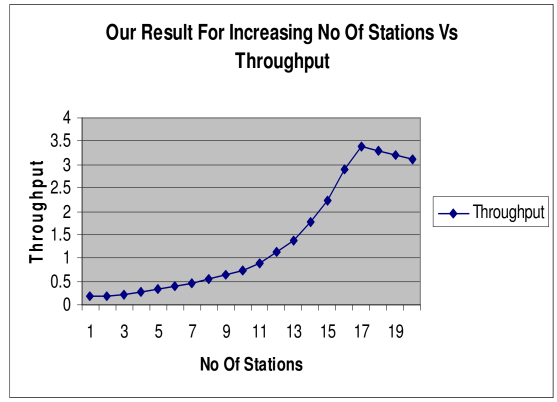



Fig 7.7 Comparision of our result with mangolds results

| No Of Stations | Throughput | Mangolds Results | Our Result |
|---|---|---|---|
| 1 | .1832 | Best Effort | Best Effort |
| 2 | .1925 | Best Effort | Best Effort |
| 3 | .2127 | Best Effort | Best Effort |
| 4 | .2834 | Best Effort | Best Effort |
| 5 | .3339 | Best Effort | Best Effort |
| 6 | .3945 | Best Effort | Best Effort |
| 7 | .4652 | Best Effort | Best Effort |
| 8 | .5460 | Best Effort | Best Effort |
| 9 | .6369 | Best Effort | Best Effort |
| 10 | .7379 | Best Effort | Best Effort |
| 11 | .87321 | Best Effort | Best Effort |
| 12 | 1.1376 | Best Effort | Best Effort |
| 13 | 1.37346 | Best Effort | Best Effort |
| 14 | 1.7789 | Best Effort | Best Effort |
| 15 | 2.22781 | Wrost Effort | Best Effort |
| 16 | 2.898 | Wrost Effort | Best Effort |
| 17 | 3.3912 | Wrost Effort | Best Effort |
| 18 | 3.2892 | Wrost Effort | Wrost Effort |
| 19 | 3.20032 | Wrost Effort | Wrost Effort |
| 20 | 3.12111 | Wrost Effort | Wrost Effort |

Table 7.7 Comparision of our result with mangolds results

# CHAPTER CONCLUSION AND OUTLOOK

## Conclusions and Outlook

In this paper, a performance evaluation of the 802.11e MAC has been presented. We first introduced the new mechanisms the 802.11e standard provides in order to increase QoS performance and protocol efficiency, First, we are interested in the effect of best-effort traffic up to certain number of stations.The Quality of services up to finite numbers of terminals after that the performances degrade. Secondly, we measure the throughput Vs numbers of stations and the throughput of the b traffic is lower because of the offered load increases up to certain number of terminals and packets drop rate increases .In case of my result the best effort services up to 17 terminals and the load is maximum up to this terminal after that suddenly the packet drop rate increases

Third, we consider another parameter Latency as the packets rate increases obviously the The latency also increases .Here the Latency is the difference of sending of packets and receiving of packets. Fourth ,we consider the TXOP limit an interval of time when a station has the right to initiate transmissions, defined by a starting time and the maximum Fifth , comparision of Mangold results vs our result .In case of Mangold results best .Effort up to 15 station but ion my case best effort up to 17 terminal after that the wrost effort start and then we evaluated those techniques via ns-2 simulations over different scenarios. Simulation results clearly showed that, in heavily loaded conditions, legacy MAC is unable to preserve QoS constraints for all flows, especially for delay sensitive flows. This fact highlighted the need to regulate traffic access to the wireless medium on the basis of

QoS rules. By introducing traffic differentiation, 802.11e improves performance. To increase the MAC efficiency further, the IEEE 802.11e standard introduces some new features (i.e., continuation TXOP) in order to reduce protocol overheads . Simulation results demonstrated that the new approaches produce benefits in terms of network performance.

During the implementation of our model we found a couple of errors in ns-2 To of our simulation model we compared it with the work of Mangold. Mangold has implemented an EDCF simulation model in WARP and conducted some performance evaluations. If our simulation model achieves similar results to Mangold's work we assume it as verified and as "correct". Another area of research can be to find closed-form solutions for a simplified performance model and then perform a formal sensitivity analysis of each parameter, finally providing a dynamic turning of parameters according to the desired QoS level.

# BIBLIOGRAPHY

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# APPENDIX

A APPENDIX

**#Define mobileNode**

set node [$*opt(rp)*-create-node *$id*] ;

$opt(rp) defines what ad hoc routing protocols ;

are, either “dsdv” is acceptable so far. ;

$id defines the node

**# Define node location**

$*node* set X_ 12.0 ;set node coordinate (x,y,z) to

$*node* set Y_ 27.0 ; (12.0, 27.0, 0.0)

$*node* set Z_ 0.0;

**#Create 3 nodes with dsdv routing**

for {set i 0} {$i < 3} {incr i} {

dsdv-create-node $i

**#Include traffic scenario files**

source traffic-scenario-files

**#Define simulation stop time**

$*ns_* at 100.0 “stop” ; stop simulation at time 100.0

**#Start your simulation**

*$ns_* run

# B APPENDIX

## Position of Nodes

```
set god_ [God instance]
$ns_ at 36 "$node_(18) setdest 1 2 "
$ns_ at 37 "$node_(17) setdest 1 2 "
$ns_ at 38 "$node_(16) setdest 1 2 "
$ns_ at 39 "$node_(15) setdest 1 2 "
$ns_ at 40 "$node_(14) setdest 1 2 "
$ns_ at 41 "$node_(13) setdest 1 2 "
$ns_ at 42 "$node_(12) setdest 1 2 "
$ns_ at 43 "$node_(11) setdest 1 2 "
$ns_ at 44 "$node_(10) setdest 1 2 "
$ns_ at 45 "$node_(9)  setdest 1 2 "
$ns_ at 46 "$node_(8)  setdest 1 2 "
$ns_ at 47 "$node_(7)  setdest 1 2 "
$ns_ at 48 "$node_(6)  setdest 1 2 "
$ns_ at 49 "$node_(5)  setdest 1 2 "
$ns_ at 50 "$node_(4)  setdest 1 2 "
$ns_ at 51 "$node_(3)  setdest 1 2 "
$ns_ at 52 "$node_(2)  setdest 1 2 "
$ns_ at 53 "$node_(1)  setdest 1 2 "
$ns_ at 55 "$node_(0)  setdest 1 2 "
$ns_ at 56 "$node_(19) setdest 1 2 "

$node_(19) set Z_ 0
$node_(19) set Y_ 420
$node_(19) set X_ 280
$node_(18) set Z_ 0
$node_(18) set Y_ 120
$node_(18) set X_ 280
$node_(17) set Z_ 0
$node_(17) set Y_ 120
$node_(17) set X_ 80
```

```
$node_(16) set Z_ 0
$node_(16) set Y_ 410
$node_(16) set X_ 100
$node_(15) set Z_ 0
$node_(15) set Y_ 175
$node_(15) set X_ 250
$node_(14) set Z_ 0
$node_(14) set Y_ 175
$node_(14) set X_ 50
$node_(13) set Z_ 0
$node_(13) set Y_ 175
$node_(13) set X_ 180
$node_(12) set Z_ 0
$node_(12) set Y_ 250
$node_(12) set X_ 80
$node_(11) set Z_ 0
$node_(11) set Y_ 250
$node_(11) set X_ 30
$node_(10) set Z_ 0
$node_(10) set Y_ 50
$node_(10) set X_ 386
$node_(9) set Z_ 0
$node_(9) set Y_ 550
$node_(9) set X_ 100
$node_(8) set Z_ 0
$node_(8) set Y_ 50
$node_(8) set X_ 200
$node_(7) set Z_ 0
$node_(7) set Y_ 70
$node_(7) set X_ 321
$node_(6) set Z_ 0
$node_(6) set Y_ 270
$node_(6) set X_ 321
$node_(5) set Z_ 0
$node_(5) set Y_ 170
$node_(5) set X_ 521
$node_(4) set Z_ 0
$node_(4) set Y_ 150
```

```
$node_(4) set X_ 441
$node_(3) set Z_ 0
$node_(3) set Y_ 150
$node_(3) set X_ 300
$node_(2) set Z_ 0
$node_(2) set Y_ 200
$node_(2) set X_ 591
$node_(1) set Z_ 0
$node_(1) set Y_ 345
$node_(1) set X_ 257
```