TITLE PAGE

OPTIMUM WLAN PERFORMANCE UNDER SATURATED TRAFFIC LOADING

BY

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APPROVAL PAGE

This is to certify that this project titled ñOptimum WLAN Performance under Saturated Traffic Loadingò was submitted to the Department of Electronic Engineering, Faculty of Engineering, University of Nigeria, Nsukka, for the award of the Degree of Master of Engineering, (M.ENG) in Electronic Engineering (Telecommunication Option)

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CERTIFICATION

I, EKEMEZIE CHIDIEBERE FIDELIS, a postgraduate student of Electronic Engineering Department of the University of Nigeria, Nsukka, declare that this work is my own, and contains no materials presented, published or accepted for publication for the award of any other degree or diploma at any institution except where due acknowledgement is made in the thesis.

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EKEMEZIE CHIDIEBERE F. DATE

DEDICATION

This work is dedicated to GOD ALMIGHTY and to my parents Engr. & Mrs. N. O. Ekemezie for their love and care.

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ABSTRACT

WLAN performance in Nigeria is adversely affected by incessant traffic overloads that constantly lead to congestion, since bandwidth is very limited. This work, therefore, addressed the issue of defining optimum performance parameters in WLAN under traffic saturation. A WLAN model was developed and simulated using MATLAB block oriented simulation package. The model was validated through extensive simulation results related to the simulation result of Nurul I. Sarkar. The relationships between the networks Quality of Service (QoS) parameters under excessive traffic loading were

investigated. Results show that the IEEE 802.11b protocol does not perform well in terms of providing high throughput, low mean delay and low loss rate at saturated traffic load condition. Since the operation of WLAN is highly influenced by the number of workstations that it supports, the IEEE 802.11b optimum parameters under high traffic loadings, at 11Mbps data rate are 4.6 Mbps throughput, 300 ms delay and 0.00017 loss rate. Therefore, a useful control tool was derived for the exploitation of WLAN 802.11b under heavy traffic loadings.

CHAPTER ONE

INTRODUCTION

1.0 Background

In recent years, the family of IEEE 802.11 protocols has become the most popular access method for Wireless LANs (WLANs) [1]. With wireless access, a user can connect its wireless network-equipped laptop or portable devices to the network anywhere and anytime without cumbersome cable or wire connections [1].

The IEEE 802.11 Wireless LAN [2] is the predominant technology for wireless access in local areas. The IEEE 802.11b Wi-Fi networks with data rates up to 11 Mbps in the 2.4 GHz frequency band have been widely deployed as hotspots. Furthermore, The IEEE 802.11a in the 5 GHz band and IEEE 802.11g in dual bands (2.4 GHz and 5 GHz) are being deployed to provide data rates up to 54 Mbps. To further increase data rates and throughput, the IEEE 802.11 work group created a new task group, namely IEEE 802.11n, which focuses on the standardization issues of next-generation WLANs to achieve 100 Mbps net throughput [3]. In other words, the last decade has witnessed rapid growth in the deployment of wireless LANs (WLANs) based on the IEEE 802.11 standard. This growth has been propelled by the high capacity links offered by these networks. Unlike 3G cellular networks, which offer a data rate of 2Mbps, Wi-Fi networks offer 11Mbps (IEEE 802.11b) and 54Mbps (IEEE 802.11a/g) [1]. It is envisioned that this growth would continue till the goals of 4G to offer ubiquitous WLAN services integrated with other wireless technologies like IEEE 802.15, 3G etc are met [1]. Due to the universality in the application of WLANs access protocol in connecting mobile users, an in-depth analysis of WLAN access protocol is necessary.

When nodes or stations are connected to a common link, there is need to coordinate the access to the link. A number of access protocols have been devised to handle access to a shared link. The protocols for WLAN are basically random access protocols which may include ALOHA and Carrier Sense Media Access with Collision Avoidance (CSMA/CA) [4].

Distributed Coordinated function (DCF), Point Coordinated function (PCF) and the combination of DCF and PCF are for IEEE 802.11 WLAN [5].

WLAN performance in Nigeria is adversely affected by incessant traffic overloads that constantly lead to congestion, since bandwidth is very limited. This work, therefore, addressed the issue of defining optimum performance parameters in WLAN under traffic saturation.

1.1 Objective of the Study

The objective of this thesis was to determine the optimum WLAN performance parameters under saturated traffic loading. This is intended to provide a congestion control measure for WLAN in a high traffic loading situation for network service providers.

The said objective is to be realized by pursuing the following sub-objectives:

1. The development of WLAN network model.
2. The conversion of the WLAN network model into a computer simulation model using MATLAB block oriented simulated package.
3. The simulation of the computer model and collection of simulation results.
4. The analysis of the simulation results to establish the set of optimum performance parameters.

1.2 Scope of the Study

The scope of this work covers both the Physical layer architecture and MAC layer architecture. The distributed coordination function (DCF) of WLAN popularly known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), the RTS/CTS mechanism, MAC sub-layer service specifications, physical layer description and specifications, frame structure and addressing, WLAN spectrum allocation and network performance management are also addressed. Logical link control (LLC) layer, Centralized and hybrid coordination function, power management, security etc., are not considered.

1.3 Methodology.

The approach used in the actualization of optimum performance in this project work, is based on the principles of CSMA/CA using the MATLAB Simulink Simevent Block oriented simulation package.

Subsequently, the physical architecture used for the modeling was converted into computer simulation model using MATLAB Block oriented simulation package. The computer simulation model is probed and simulated, for Quality of service parameter collation.

1.4 Thesis Outline.

The rest of this thesis is organized as follows. Chapter 2 presents the literature review of the thesis. Chapter 3 presents the Network model for IEEE 802.11 MAC DCF saturated Traffic Loading for achieving optimum performance. Chapter 4 presents the simulation results and results analysis. Finally, the observations and conclusion were presented in Chapter 5.

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction

A local area network LAN is a data communication network which is geographically limited (typically to 1 km radius) and allows easy interconnection of data terminals, computers and computing systems [7]. A Wireless LAN is a shared ï communication network that broadcast information over wireless link for all stations within the network footprint or within a geographical area approximately 1km radius [8]. A WLAN basically consists of one or more wireless devices connected to each other in a peer-to-peer manner or through APs, which in turn are connected to the backbone network providing wireless connectivity to the covered area [8]. WLAN is widely considered to play a major role in wireless multimedia communications that require high speed transmission. It links two or more devices using some wireless distribution method (typically spread spectrum and OFDM radio), and usually providing a connection through an access point to the wider internet [8].

In this chapter, wireless networks and its variations with emphasis on IEEE 802.11 standard is reviewed. The evolution of IEEE 802.11x series was presented. Significant points were reviewed as the standards evolved from the originally released standard in 1997 to the current state-of-the-art, with more emphasis on IEEE 802.11e (QoS) and IEEE 802.11b. Based on previous work, the IEEE 802.11 architecture, the physical layer, the MAC sub-layer protocols, and the concept of basic access mechanism which is the DCF protocol (CSMA/CA) of the proposed architecture, RTS/CTS mechanism and PCF were described. Furthermore, the frame structure and itôs addressing, general frame format, WLAN RF Allocation were also depicted in this chapter. Finally, the chapter ended with the review of related works.

2.1 Wireless Networks

One of the most promising and discussed technologies in the last decade is the wireless technology which allows users to utilize devices that enable the access to information at any time any place. These needs make wireless networks the best solution for interconnecting devices and people. Wireless networks are comprised of devices that communicate using radio and infra-red signals. Wireless networks are generally classified into two categories: infrastructure-based and ad-hoc wireless networks.

Infrastructure-based wireless network consists of base stations (access points) that are localized at convenient places and predefined infrastructure. They provide wireless connectivity to devices within their coverage area. Examples of this category are Wireless Local Area Networks (WLANs) and cellular networks. In other words, a WLAN is a flexible data communication system implemented as an extension to a wired LAN within a building or campus. [3]

On the other hand, ad hoc wireless networks do not have a pre-established infrastructure. Moreover, nodes connect to each other through automatic configuration when they are in transmission range and willing to communicate. In this way, an ad hoc wireless network is formed which is both flexible and powerful. Therefore, these capabilities make wireless ad hoc networks suitable for many applications where one central node may not be convenient, and where minimal configuration and quick deployment is required in emergency situations.

Wireless ad hoc networks can be further classified by their application in mobile ad hoc networks, wireless sensor networks, and wireless mesh networks [3]. Therefore, mobile ad-hoc network, wireless sensor network, and wireless mesh network make-up the categories of multi-hop wireless networks as illustrated below.

2.2. Multi-hop Wireless Networks

The Multi-hop Wireless Networks consist of wireless networks that primarily use multi-hop wireless relaying. The major categories in the multi-hop wireless networks are (1) Mobile ad-hoc networks, (2) wireless sensor networks, (3) wireless mesh networks, and (4) hybrid wireless networks [3], [9]. In the following subsections, are classifications of multi-hop wireless networks?

2.2.1. Mobile Ad hoc Networks (MANET)

In MANET, devices are mobile nodes which provide the functionality required to connect users allowing them to exchange information in an environment with no pre-established infrastructure. Therefore, MANET is an infrastructure-less network with highly dynamic topology [3]. Devices are free to move randomly and organize themselves arbitrarily; thus, the wireless network topology may change quickly and is unpredictable. Also, some devices may be connected to other resources such as the Internet, file servers, etc., allowing users to gain access to this resources. In the past, these networks have been used for tactical network related applications in battlefield communications and survivability [3], [10]. Military operations generally cannot rely on a fixed communication infrastructure, then MANET allows a suitable framework to overcome issues that radio signals and radio frequency present. In general, MANET also has problems due to wireless communication and wireless networks such as the limited transmission range, channel that is not protected from other signals and has time-varying and asymmetric properties and hidden and exposed terminal problems may occur.

2.2.2. Wireless Sensor Networks (WSN)

Wireless sensor networks are formed by spatially distributed tiny sensor nodes that cooperatively can gather and monitor physical parameters or environmental conditions and transmit to a central monitoring node [3]. In addition, sensor nodes are equipped with a radio transceiver or other wireless communication device, a small microcontroller, and usually a battery as an energy source. WSN can use single-hop wireless communication or a multi-hop wireless relaying [3], [9]. At first, military applications was the motivation for developing WSN. Currently, WSN are used in civilian applications such as environmental and habitat monitoring, traffic control, healthcare applications, home automation, etc. [3]. Fig. 2.1 represents WSN.

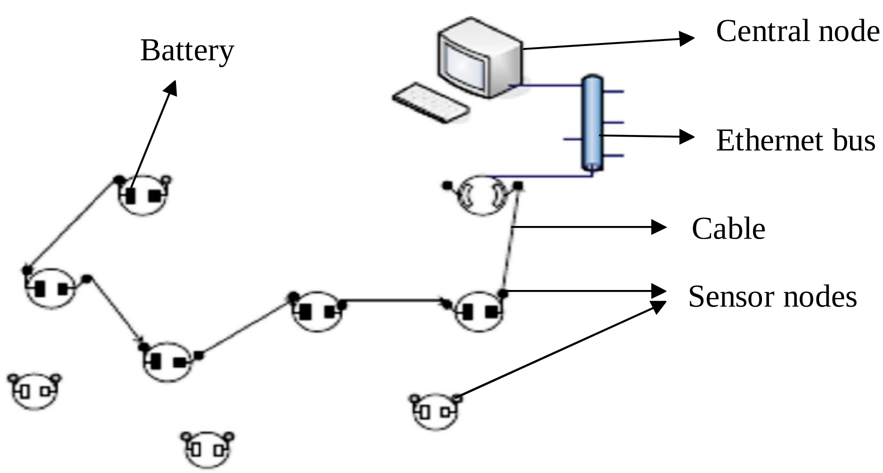


Figure 2.1: Wireless Sensor Network [3]

2.2.3. Hybrid Wireless Networks (HWN)

A Hybrid wireless network is an ad hoc wireless network that contains a sparse wired network of base stations. The resulting network comprises regular nodes and wired connected base stations [3]. In this way, a traditional cellular network and an ad hoc network could be mixed together. The cellular network is an infrastructure based network where data is forwarded through its infrastructure. In figure 2.2, base stations, unlike normal nodes, are neither data sources nor data receivers, but they work as relay nodes, they only engage routing and forwarding data for normal nodes. On the other hand, in an ad hoc network, nodes forward data in a multi-hop fashion [3], [11]. Therefore, hybrid wireless networks utilize both single and multi-hop communication simultaneously within the traditionally single-hop wireless networks [9].

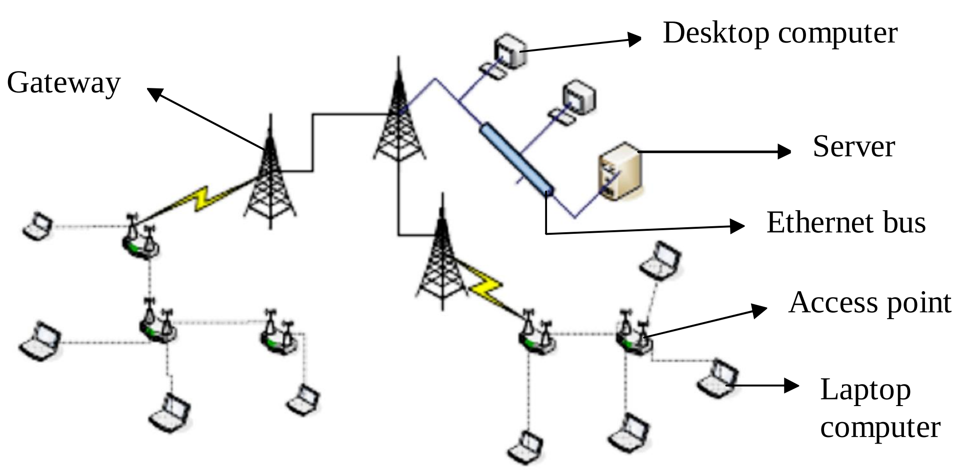


Figure 2.2: A Hybrid Wireless Network [3].

2.2.4. Wireless Mesh Networks (WMN)

Wireless Mesh Network (WMN) is a highly promising technology and it plays an important role in the next generation wireless mobile network. WMNs have emerged as important architectures for the future wireless communication [3], [12]. WMNs consist of mesh routers and mesh clients, and could be independently implemented or integrated with other communication systems such as the conventional cellular systems. In addition, WMN are dynamic, self-organized, self-healed, and self-configured, and enable quick deployment, easy maintenance, low cost, high scalability and reliable service. WMN is an ad hoc network extension and is becoming an important mode complimentary to the infrastructure based wireless networks because they can enhance network capacity, connectivity and resilience [3].

One can define a WMN as a network that has a network topology of either a partial or full mesh topology. In practice, WMNs are characterized by static wireless relay nodes which provide a distributed infrastructure for client nodes over a partial mesh topology. Due to the presence of partial mesh topology, a WMN utilizes multi-hop relaying like other ad hoc wireless networks. According to [12], there are two types of nodes in wireless mesh network: mesh routers and mesh clients. Mesh routers are typically equipped with multiple radio interfaces in order to provide a backbone for routing packets. Mesh clients, on the other hand, incorporates network interface card that connects them to wireless mesh networks through mesh routers [3].

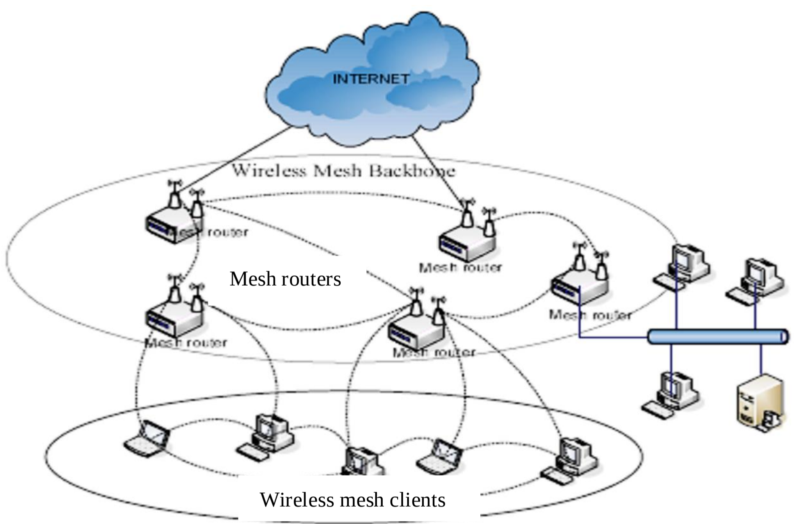


Figure 2.3: Wireless mesh network [3]

In practice, many wireless mesh networks are based on wireless local area network (WLAN) standards, In particular, IEEE 802.11 specifications.

2.3. IEEE 802.11 Standard

In this section, IEEE 802.11a/b/d/g/h/i/j/e are discussed in that order of evolution and the different series of IEEE standard will be represented by x (i.e. IEEE 802.11x). Standards on IEEE 802.11x is still evolving and there are drafts submitted that are not yet ratified. Attempt was made to look at these drafts as they exist.

In considering the evolution of WLAN, both the physical layer and the MAC sub-layers are addressed because they are the layers involved in transmission. The IEEE 802.11 standard was originally released in 1997. Many task groups have since been created to enhance alternately the MAC or PHY layer standardization in order to achieve better performance in the original 2.4 GHz ISM band as well as in the unlicensed 5 GHz UNII band [13].

In 1999, the task group IEEE 802.11 ratified a new standard that revised the IEEE STD 802.11-1997. The Management Information Base according to Open System Interconnectivity (OSI) rule and many redundant management items were removed. This standard worked on the physical layer and MAC sub-layer of the data link layer. IEEE 802.11 deployed infrared, Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS) [13]. Both the infrared implementation and Frequency-Hopping Spread Spectrum that is a radio implementation of the physical layer support 1 Mbit/s data rate with an optional 2 Mbit/s while the Direct Sequence Spread Spectrum supports 1 and 2 Mbit/s data rate [14].

Following the IEEE 802.11 in the same 1999 was the 802.11a that specified a new physical layer for the 5 GHz unlicensed national information infrastructure (UNII). It was designed to operate in the 5.15ï 5.35 GHz and 5.725ï 5.825 GHz bands with a channel space of 20 MHz and orthogonal Frequency Division Multiplexing (OFDM) transmission technique [15]. A combination of OFDM transmission technique, convolution coding and bit interleaving is very robust especially in the non-line-of sight (NLOS) condition [15]. An interesting feature of IEEE 802.11a is the adaptive modulation and coding (AMC) also known as link adaptation. By selecting a constellation from binary phase shift keying (BPSK) to 64-quadrature amplitude modulation (QAM) and a convolutional coding rate (1/2ï 3/4), the data rate on top of the PHY layer can be varied from 6 to 54 Mb/s, which is an improvement over the IEEE 802.11. So far, the largest amount of unlicensed spectrum available at 5 GHz is in Europe, with 19 channels available (5.150ï 5.350 GHz and 5.470ï 5.725 GHZ), compared to only four channels in Japan [15], [16].

IEEE 802.11b has a maximum raw data of 11 Mbps and uses the same media access method defined in the original standard [17]. The IEEE 802.11b is a direct extension of the modulation technique defined in the original standard. The IEEE 802.11b has a higher throughput (compared to the original standard) along with substantial price reductions which led to its acceptance in the market. IEEE 802.11b uses a technology known as complementary code keying (CCK) modulation, which allows for higher data rates with less chance of multi-path propagation interference. (Duplicate signals bouncing off walls) [17]. IEEE 802.11b devices suffer interference from other products operating in the 2.4GHz band. Devices operating in the 2.4GHz range include microwave oven, Bluetooth devices, Baby monitors and cordless telephones.

It should also be noted that IEEE 802.11a radio cards could not communicate with IEEE 802.11 or 802.11b radio cards for two reasons. First, IEEE 802.11a radio cards use a different spread spectrum technology than IEEE 802.11/802.11b devices. Second, IEEE 802.11a devices transmit in the 5 GHz UNII bands, while the IEEE 802.11/802.11b cards operate in the 2.4 GHz ISM band. The good news is that IEEE 802.11a can coexist with IEEE 802.11 or 802.11b/g cards in the same physical space because these cards transmit in separate frequency ranges [13].

In theory, IEEE 802.11a signals are absorbed more readily by walls and other solid objects in their path due to their smaller wavelength and as a result, cannot penetrate as far as those of IEEE 802.11b. In practice, IEEE 802.11b typically has a higher range at low speeds (IEEE 802.11b will reduce speed to 5Mbit/s or even 1Mbit/s at low signal strength). However, at higher speeds, IEEE 802.11a often has the same or greater range due to less interference.

In the same 1999, the IEEE task group published the IEEE 802.11b-1999 that was later corrected as IEEE Std. 802.11b-1999/Cor1-2001. It strictly defined the Direct Sequence Spread Spectrum that is backward compatible with IEEE 802.11. It introduced complementary code keying (CCK) capable of data rates of 5.5 and 11Mb/s in the 2.4 to 2.4835 GHz ISM band [17]. The IEEE 802.11b has a higher throughput (compared to the original standard) along with substantial price reductions which led to its acceptance in the market. IEEE 802.11b uses CCK modulation, which allows for higher data rates with less chance of multi-path propagation interference (Duplicate signals bouncing off walls). IEEE 802.11b devices suffer interference from other products operating in the

2.4GHz band. Devices operating in the 2.4GHz range include microwave oven, Bluetooth devices, Baby monitors and cordless telephones.

IEEE 802.11d is supplementary to the Media Access Control layer in IEEE 802.11 to promote worldwide use of IEEE 802.11 WLANs [16]. It will allow access points to communicate information on the permissible radio channels with acceptable power levels for user devices. The IEEE 802.11 standards cannot legally operate in some countries; the purpose of IEEE 802.11d is to add features and restrictions to allow WLANs to operate within the rules of these countries. The IEEE 802.11d amendment published as IEEE Std. 802.11d-2001 added requirements and definitions necessary to allow IEEE 802.11 equipment operate in areas not served by the original standard. IEEE 802.11d allows conforming equipment to operate in more than one regulatory domain over time. This clause described the mechanism required to implement a capability in IEEE 802.11 stations that supports cross-domain mobility and operation in multiple regulatory domains, when the dot11MultiDomainCapabilityEnabled attribute is true [16].

In other words, IEEE 802.11d is supplementary to the Media Access Control layer in IEEE 802.11 to promote worldwide use of WLANs. It will allow access points to communicate information on the permissible radio channels with acceptable power levels for user devices. The IEEE 802.11 standards could not legally operate in some countries. IEEE 802.11d was designed to add features and remove the restrictions to allow WLANs to operate within the rules of those countries. Equipment manufacturers do not want to produce a wide variety of country-specific products and users that travel do not want a bag full of country-specific WLAN PC cards. The outcome will be country-specific firmware solutions.

IEEE 802.11f is a ñrecommended practiceò document that aims to achieve radio access point interoperability within a multi-vendor WLAN network. The standard defines the registration of access points within a network and the interchange of information between access points when a user is handed over from one access point to another. IEEE 802.11f will reduce vendor lock-in and allow multi-vendor infrastructures [13].

Another 2.4 GHz PHY layer specification was developed by Task Group G. The IEEE 802.11g PHY layer included a mandatory OFDM mode in order to achieve IEEE 802.11a data rates. Optional 8-PSK and CCK-OFDM modes were also included. Claimed advantages of IEEE 802.11g are backward compatibility with widespread IEEE 802.11b products and a larger cell range than IEEE 802.11a. Nevertheless, the 2.4 GHz ISM band provided only three non-overlapping channels and is already crowded by systems such as Bluetooth [13]. Two additional optional extended rate physical layer and packet binary convolutional code ERP-PBCC modulation with payload 22 and 33Mbit/s were also defined [18]. Although IEEE 802.11/11x used different modulation and coding technique in the physical layer to achieve different data rates, the same MAC sharing technique characterized them all.

IEEE 802.11h defined mechanisms for Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC) that may be used to satisfy regulatory requirements for operation in the 5 GHz band in Europe. IEEE 802.11h comprised of Transmit Power Control (TPC) that is used to control transmitterǿs power sent by Radio Local Area Networks (RLANs) in the 5GHz band involving specification of a regulatory maximum transmit power and a mitigation requirement for each allowed channel to reduce interference with satellite services. It also had Dynamic Frequency Selection (DFS) that implements a mechanism to avoid co-channel operation with radar systems to ensure uniform utilization of available channels [19]. In other words, IEEE 802.11h standard is supplementary to the MAC layer to comply with European regulations for 5 GHz WLANs. European radio regulations for the 5 GHz band require products to have transmission power control (TPC) and dynamic frequency selection (DFS). TPC limits the transmitted power to the minimum needed to reach the furthest user. DFS selects the radio channel at the access point to minimize interference with other systems, particularly radar. Completion of IEEE 802.11h will provide better acceptability within Europe for IEEE compliant 5 GHz WLAN products.

The IEEE 802.11i defined stronger encryption, better authentication and reliable management methods that hide the data flying through the air while at the same time placing a bigger guard at the front door. The IEEE 802.11i security amendment is without a doubt one of the most important enhancements to the original IEEE 802.11

standard due to the seriousness of properly protecting a wireless network by replacing the open system authentication, share key authentication and the Wired Equivalent Privacy which have proven to be vulnerable in IEEE 802.11 with robust security network associations (RSNAs) [20]. In other words, security is a major weakness of WLANs. Weakness of WEP encryption is damaging the IEEE 802.11 standard perceptions in the market. Vendors have not improved matters by shipping products without setting default security features. In 73 additions, the WEP algorithm weakness has been exposed. Solutions will start with firmware upgrades using the Temporal Key Integrity Protocol (TKIP), followed by new silicon with AES (an iterated block chipper) and TKIP backwards compatibility.

In September 2004, IEEE Task Group j (TGj) created extensions to IEEE 802.11 for wireless local area networks (WLANs) by providing mechanisms for operation in the 4.9 GHz and 5 GHz bands in Japan [21]. This standard supports channel spacing of 10MHz and data rates of 3, 4, 5, 6 12, 18, 24 and 27Mbps.

There are some draft amendments yet to be ratified by IEEE; these amendments add different features and new capabilities to the original platform of IEEE 802.11 specification. The different draft amendments and their corresponding roles in the life of the original standard were also presented [18].

The IEEE 802.11k task Group (TGk) provided means for collecting and collating the statistics and radio resource measurement of the physical layer and MAC sub layer.

The IEEE 802.11m task group is charged with the responsibility to clarify and correct technical documentation of IEEE 802.11 standards.

An IEEE 802.11n is described as the state of the art WLAN. IEEE 802.11n is a proposed amendment to the IEEE 802.11 wireless networking standard to improve network throughput over previous standards, such as IEEE 802.11a, and IEEE 802.11b and IEEE 802.11g by adding multiple-input multiple-output (MIMO) and 40 MHz operation to the physical (PHY) layer [3]. The IEEE has approved the amendment and it was published in October 2009 [22]. In this current trend of the WLAN series, organizations can expand their wireless capabilities with this expanding technology to boost network capacity and increase the speed up to 600 Mbps unlike in the 54Mbps of IEEE 802.11a/g networks. This extra capacity and speed allows organizations upgrading to IEEE 802.11n in other to expand the range of applications mobilized over wireless networks. This will help to streamline business processes and foster corporate competitive advantage [12].

The need to handle the higher data rate will create a ripple throughout the entire network. Most of the IEEE 802.11n products provide compatibility with IEEE 802.11g equipment operating on the same channel by reducing the speed to the level of IEEE 802.11g. The speed reduction affects the entire wireless network, not just the IEEE 802.11g equipment.

IEEE 802.11n also supports frame aggregation. Once a station gains the authority to transmit a signal, it can transmit a series of frames without the requirement to release and regain authority for each frame. IEEE 802.11n will also enable high bandwidth applications currently limited to wired networks to migrate to wireless. It will improve wireless VoIP reception. The benefits of higher speed and longer range will guarantee that IEEE 802.11n will be widely adopted, but it is important to prepare for IEEE 802.11n before its deployment [3].

In a previous work [3], the author showed that analytical models have been developed to analyze the performance of packet aggregation mode in various WLAN scenarios. Both analytical and simulation results show that, compared to the traditional approach of sending each upper layer packet individually, packet aggregation mode can significantly reduce the overhead and thus drastically improves the throughput and delay performance of WLAN.

IEEE 802.11p is a standard for traffic class and dynamic multicast filtering. It provides a method to differentiate traffic streams in priority classes in support of quality of service offering. It forms a key part of the IEEE 802.11e proposals for QoS at the MAC level. This applies to IEEE 802.11 physical standards a, b and g. The summary of the drafts given by [17] are summarized as follows:

I. The objective of the IEEE 802.11n supplement is to increase the throughput in both the 2.4 GHz and 5 GHz frequency band. It used multiple-input-multiple-output (MIMO) technology in unison with Orthogonal Frequency Division Multiplexing (OFDM) technology to increase throughput to baseline minimum of 100Mps.

II. The mission of the IEEE 802.11 Task Group p (TGp) also known as Wireless Access and Vehicular Environment (WAVE) is to define enhancements to the IEEE 802.11x standards so that it will support Intelligent Transportation Systems (ITS) applications. IEEE 802.11p is a Dedicated Short-Ranged Communication (DSRC) that provides an extended information horizon to warn the driver or the vehicle systems of (potentially) dangerous situations in a much earlier phase. IEEE 802.11p is an adjustment of the IEEE 802.11a for a low overhead operation in the DSRC spectrum [23].

III. The IEEE 802.11r draft is often referred to as the fast roaming amendment. It establishes a QoS stream and set up security associations with a new access point before actually roaming to the new access.

IV. The IEEE 802.11s Task Group has set forth the pursuit of standardizing mesh networking using the IEEE 802.11X MAC/PHY layers. The IEEE 802.11s amendment proposed a protocol for adaptive, auto configuring systems that supports broadcast, multicast, and unicast traffic over multi-hop mesh topologies in a Wireless distribution System WDS.

V. The goal of the IEEE 802.11t Task Group (TGT) is to develop performance metrics, measurement methods, and test conditions to measure the performance of IEEE 802.11x wireless networking equipment.

VI. The primary objective of the IEEE 802.11 Task Group u (TGu) is to integrate IEEE 802.11x access networks with external networks in a generic and standardized manner. IEEE 802.11u is also often referred to as Wireless Interworking with External Networks (WIEN). This amendment may well address seamless handoff and session persistence with other external networks such as the Internet, cellular networks, and WiMAX.

VII. The main goal of the IEEE Task Group v (TGv) is to make WLAN infrastructure (access points and wireless switches) improved on the control of wireless client stations. The following list includes some of the IEEE 802.11v proposals currently being discussed: wireless client, load balancing and network selection.

VIII. The IEEE Task Group w (TGw) is working on a ñprotectedò management frame amendment with a goal of delivering management frames in a secure manner.

The end result will hopefully prevent many of the layer 2 denial of service attacks that currently exist.

While the physical layers of IEEE 802.11x are different, the MAC remained the same. The basic access mechanism, called distributed coordination function (DCF), is based on CSMA/CA medium sharing mechanism, which is a contention based mechanism [24]. In this mechanism, a station that is ready to transmit first sensed the medium to determine if another station is transmitting. If the station determined the medium to be idle, transmission proceeds otherwise, the station deferred until the end of the current transmission. The station have to select a random back-off interval and decrement the back-off interval counter while the medium is idle after deferral. A refined method that further minimized collision is the exchange of control frames (RTS and CTS) from the transmitting and receiving stations [14].

The MAC also includes an optional mechanism, known as the Point Coordination Function (PCF), which is useful on infrastructure networks. In PCF mechanism, the stations are under the control of a point coordinator (PC) where stations polled by the PC for transmission is allowed to deliver MAC Service data Unit (MSDU). Both the DCF and PCF can be combined in IEEE WLANs.

Researchers identified the standard IEEE medium access control (MAC) protocol as the reason for the poor performance of IEEE 802.11 networks [24]. One of the main weaknesses of the original IEEE 802.11, towards efficient support of multimedia traffic, is the lack of enhanced Quality of Service (QoS) provisioning in the Medium Access Control (MAC) layer [25]. In contention-based networks (e.g., IEEE 802.11x), IP-level service differentiation is not sufficient to efficiently manage the shared resources, and an additional QoS provisioning at the MAC layer is essential in this respect. Clearly, DCF is incapable of adequately supporting the traffic of QoS-sensitive applications [8].

To improve the QoS in IEEE 802.11x, service differentiation such as enhanced DCF (EDCF), persistent factor DCF (PF DCF), distributed weighed fair queue (DWFQ), distributed fair scheduling (DFS) and distributed deficit round robin (DDRR); admission control and bandwidth reservation and link adaptation were proposed. However, these parameters and mechanism are basically station-based and therefore cannot effectively differentiate multiple flows within a station [26]. Furthermore, the effects of tuning these parameters are limited in terms of increasing/decreasing MAC throughput/delay, respectively. Therefore, additional resolutions were demanded to guarantee QoS in IEEE 802.11 [26].

But it is shown that service differentiation methods like EDCF could provide better QoS for multimedia data traffic only under low to medium traffic load conditions. Call admission control (CAC) and bandwidth reservation therefore become necessary in order to support QoS under high traffic conditions, it was recorded that IEEE 802.11 does not support service differentiation and PCF has limited support for IEEE 802.11 [27], [28]. The QoS of IEEE 802.11 DCF cannot be guaranteed in a short term and QoS may also degrade due to congestion, or inter-system interference, as may be experienced in a public common scenario.

In order to address the weaknesses of MAC sub layer as regards QoS, the task group E known as IEEE 802.11e was created. IEEE 802.11e handled quality of service QoS for time-sensitive applications like Voice over IP (VoIP), Voice over Wireless IP (VoWIP) also known as Voice over Wireless LAN (VoWLAN) and as Voice over Wi-Fi (VoWiFi). IEEE Standard IEEE 802.11e defined the Hybrid Coordination Function HCF that comprised of Enhanced Distributed Channel Access (EDCA) an extension to DCF and Hybrid Coordination Function Controlled Access (HCCA) an extension to PCF [29], [30]. Direct Link Service is another mechanism that supports QoS without the station passing through the access point AP. DLC does not apply in ad hoc networks [23].

The EDCA of IEEE 802.11e is an enhanced version of IEEE 802.11 DCF for priority-based QoS support. With EDCA, a station can implement up to four access categories (ACs) [32] corresponding to voice, video, best effort, and background traffic, respectively and thus the higher the throughput [13]. The differences between EDCF and DCF are that in DCF, the back-off counter is decremented at the end of each slot following DIFS while the back-off counter is decremented after AIFS has passed in EDCA scheme. In DCF, transmission can begin if back-off counter makes a transition to

0 and the medium is idle but EDCA station can transmit only if the back-off value is already 0 [30]. The AIFS with the back-off interval for an AC in EDCA is randomly selected from [1, CW], instead of [0, CW-1] as in DCF [28], [33]. The QoS supported in EDCA was provided by the introduction of access categories (ACs) and multiple independent back-off entities. The contention parameters for MSDU delivery by parallel back-off entities are: access category for voice (AC_VO), access category for video (AC_VI), access category for best effort (AC_BE) and access category for background (AC_BK). Other EDCA parameters include arbitration inter-frame space (AIF) [AC], minimum contention window (CW_{min}) [AC], maximum contention window (CW_{max}) [AC], and TXOP limit [AC] [25].

The current DCF is unsuitable for multimedia applications with QoS requirements. Even though the PCF can provide some limited QoS support, it is barely implemented in todayộs products due to its complexity and inefficiency for normal data transmission [31]. The contention window of MAC does not support QoS [25]. Also the binary exponential back-off introduced a heavy-tailed delay distribution for the case of unlimited retransmissions.

In order to optimize the performance of DCF, a number of parameters that are tunable in both the PHY and MAC layers of 802.11 were introduced [26]. These included the beacon interval, request to send RTS threshold, fragmentation threshold and short/long retry limits. There was a suggestion that each traffic class should have its contention window and that the back-off algorithm should be adjusted to follow a multiple increase and multiple decrease procedure [34]. Multiplicative timer back-off (MTB) mechanism, additive timer back-off (ATB) mechanism, and link RTT memorization (LRM) technique were also used to optimize performance of DCF [34].

2.4. IEEE 802.11 Architecture

In this section, the typical IEEE 802.11 standard architecture is presented, see fig. 2.4. The IEEE 802.11 architecture comprises several components such as workstations, the WLAN Access Point (WLAN AP), Distribution System (DS), Server and Very Small Aperture Terminal (VSAT) and services that interact to provide wireless communication to stations which are any devices that incorporates the functionality of the IEEE 802.11 protocol and can connect to the wireless media.

The IEEE 802.11 standard specifies three primary service set topology. They are: the basic service set, extended service set, and the distribution system.

2.4.1. Basic Service Set (BSS)

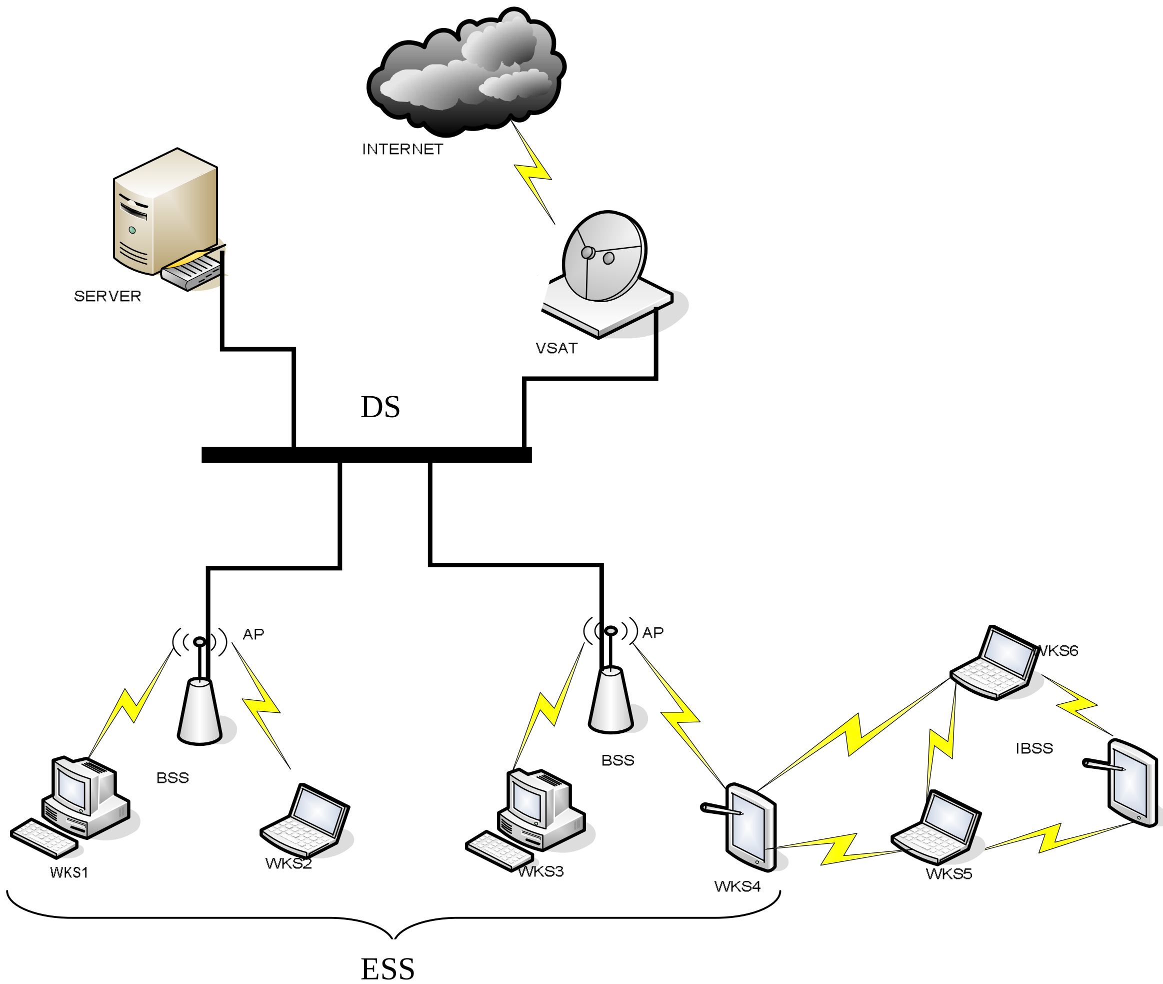
The first service set topology is a Basic Service Set (BSS), which is defined as a group of stations that communicates with each other in a geographical area known as Basic Service Area (BSA), see fig. 2.4. When these stations can communicate without the aid of an infrastructure network, they are referred to as an Independent Basic Service Set (IBSS) which is the formal name of an ad hoc network in the IEEE 802.11 standard. These stations operate in the ñad hoc modeò because they communicate directly with another station in its transmission range [2]. In comparison, in the ñinfrastructure modeò, a station in a BSS communicates with another through a Base Station (BS) which is also called Access Point (AP) if it is connected to a wired network. The BSS operating with a BS is known as the Infrastructure Basic Service.

2.4.2. Extended Service Set (ESS)

An ESS is a set of infrastructure BSSs, where the APs communicate among themselves to forward traffic from one BSS to another and to facilitate the movement of mobile stations from one BSS to another. The APs perform this communication via an abstract medium called the distribution system (DS). Network equipment outside of the ESS, the ESS and all of its mobile stations appears to be a single MAC-layer network where all stations are physically stationary [2]. Thus, the ESS hides the mobility of the mobile stations from everything outside the ESS. In this service set topology, BSs (or APs) provide the integration points for network connectivity among different BSSs. Therefore, a network backbone, also known as distribution system (DS), is formed.

2.4.3 Distribution System (DS):

The distribution system (DS) is an electronic device by which one AP communicates with another to exchange frames for stations in their BSSs, forward frames to fellow mobile stations from one BSS to another, and exchange frames with wired network. The DS is responsible for MAC level transport of MAC data units, and is implementation independent meaning that the DS could be a wired Local area network (LAN), Metropolitan area network (MAN), or another IEEE 802.11 wireless medium [35].



Key:

DS ï Distribution System

AP ï Access Point

Wks ï Workstations

BSS ï Basic Service Set

IBSS ï Independent Basic Service Set

Fig. 2.4**:** IEEE 802.11 [WLAN] ARCHITECTURE [36]

2.4.4. Physical Layers

The IEEE 802.11 LAN has several physical layers defined to operate with its MAC layer. Each physical layer is divided into two sub layers that correspond to two protocol functions as shown below [4], [36], [37].

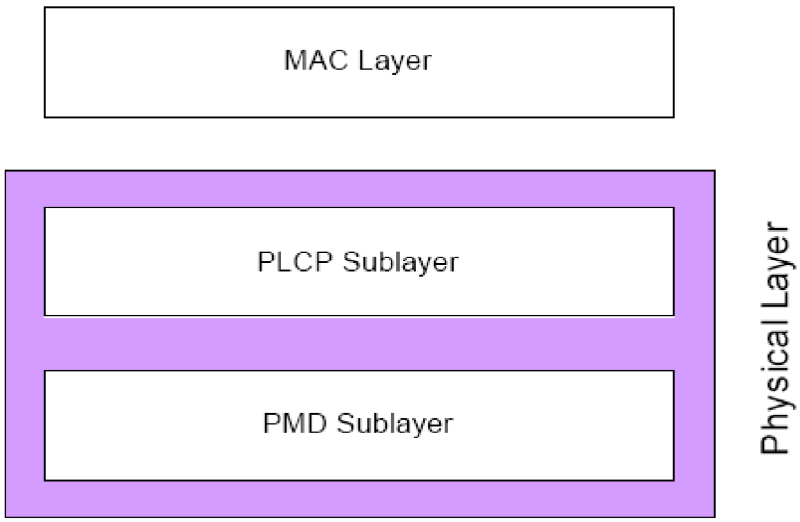


Figure 2.5: IEEE 802.11 Physical layers [38]

The physical layer convergence procedure (PLCP) is the upper sub layer, and it provides a convergence function that maps the MAC PDU into a format suitable for transmission and reception over a given physical medium. The physical medium dependent (PMD) sub layer is concerned with the characteristics and methods for transmitting over the wireless medium [36].

The IEEE 802.11 standard provides three different types of physical layers to be used in wireless LAN networking namely 2.4GHz ISM band frequency hopping (FHSS) spread-spectrum, 2.4 GHz ISM band direct sequence (DSSS) spread-spectrum and infrared (IR)light [4].

IEEE 802.11 FHSS

IEEE 802.11 FHSS uses a frequency-hopping spread spectrum (FHSS) method. FHSS uses the 2.4-Ghz ISM band. The band is divided into 79 sub-bands of 1MHz (and some guard bands). A pseudorandom number generator selects the hopping sequence.

The modulation technique in this specification is either two-level FSK or four-level FSK with 1 or 2 Mbps.

IEEE 802.11 DSSS

IEEE 802.11 DSSS uses the direct sequence spread spectrum (DSSS) method. DSSS uses the 2.4-Ghz ISM band. The modulation technique in this specification is PSK at 1 Mbaud/s. The system allows 1 or 2 bits/baud (BPSK OR QPSK), which results in a data rate of 1or2 Mbps [4].

IEEE 802.11 Infrared

IEEE 802.11 Infrared uses infrared light in the range of 800 ï 950 nm. The modulation technique is called pulse position modulation (PPM).For a 1-Mbps data rate, a 4-bit sequence is first mapped into 16-bit sequence in which only one bit is set to 1and the rest are set to 0. For a 2-Mbps data rate, a 2-bit sequence is first mapped into a 4 bit sequence in which only one bit is set to 1 and the rest are set to 0.the mapped sequences are then converted to optical signals; the presence of light specifies 1,the absence of light specifies 0 [4]. The advantages of each of the PHY layers can be exploited by users who want an IEEE802.11 complaint wireless LAN. The disadvantage also is that two users need to specify additionally the type and data rate of their wireless LAN system to permit interoperability.

2.5. Medium Access Control (MAC) Layer

The IEEE 802.11 draft standard, defines a single MAC protocol for use with all of the aforementioned physical layers. The use of a single MAC protocol enables chip vendors to achieve a better high-volume production, which will help to keep the cost low for these systems. There was considerable debate and compromise preceding the adoption of the current IEEE 802.11 MAC protocol. The MAC protocol defined in the IEEE 802.11 draft is sophisticated and entails considerable complexity. The protocol has few options, as well as several features that can be turned on and off, and combines most of the functionality that was contained in the standard considered by the committee [39].

The IEEE 802.11 standard not only defines a Medium Access Control (MAC), but also the related management protocols and services, and the physical layer. Also, important timing intervals are specified by the standard.

- **Short Inter-frame space (SIFS**). It is the shortest time interval. It is used between a frame and its acknowledgment. It is long enough for the sender to switch to the receiver mode.
- **Slot time (Slot).** A little longer than SIFS, it is the basic time unit for the binary exponential back-off algorithm spelled out in the standard.
- **PCF inter-frame (PIFS).** It is equal to the SIFS plus one Slot. It is used by the Point Coordinator to get higher priority in accessing the medium.
- **Distributed inter-frame space (DIFS).** It is equal to the SIFS plus two Slots. It is used before starting a new transmission.[3]

Below are the functions of the MAC layer:

a. On transmission, assemble data into a frame with address and error detection fields.
b. On reception, disassemble frame and perform address recognition and error detection.
c. It governs access to the LAN transmission medium.

2.5.1. IEEE 802.11 MAC Protocol Architecture

The dominant standard for WLANs is IEEE 802.11 which provides specifications for both the physical layer and the medium access control (MAC) layer. The physical layer is the interface between the MAC and the wireless media where data is transmitted and received, while the MAC layer provides functionality to allow reliable data delivery for the upper layers over the wireless physical media [39]. The MAC sub layer is responsible for the channel access procedures, protocol data unit (PDU) addressing, frame formatting, error checking, and fragmentation and reassembly of MSDUs. The MAC sub layer also provides options to support security services through authentication and privacy mechanisms. MAC management services are also defined to support roaming within an ESS and to assist stations in power management.

The IEEE 802.11 MAC protocol is specified in terms of coordination functions that determine when a station in a BSS is allowed to transmit and when it may be able to receive PDUs over the wireless medium. Subsequently, The IEEE 802.11 MAC layer offers two types of service, the Distribution Coordination Function (DCF), and the Point Coordination Function (PCF) [2], [37], [40], [41].

The IEEE 802.11 DCF MAC protocol is basically a Carrier Sense Multiple Access with Collision Avoidance protocol (CSMA/CA). Carrier sensing function is performed at both the MAC and Physical Layer. Physical carrier-sensing functions are provided by the physical layer by using channel sensing function called Clear Channel Assessment (CCA) [36]. CCA analyzes all detected packets from other nodes and detects activities in the channel by analyzing relative signal strength. Virtual Carrier Sensing functions are provided by the MAC layer by using the Network Allocation Vector (NAV). The NAV is a timer that decrements irrespectively of the status of the medium and is updated by frames transmitted on the medium. Figure 2.6 shows the comparison between IEEE 802.11 protocol architecture and OSI Reference Model.

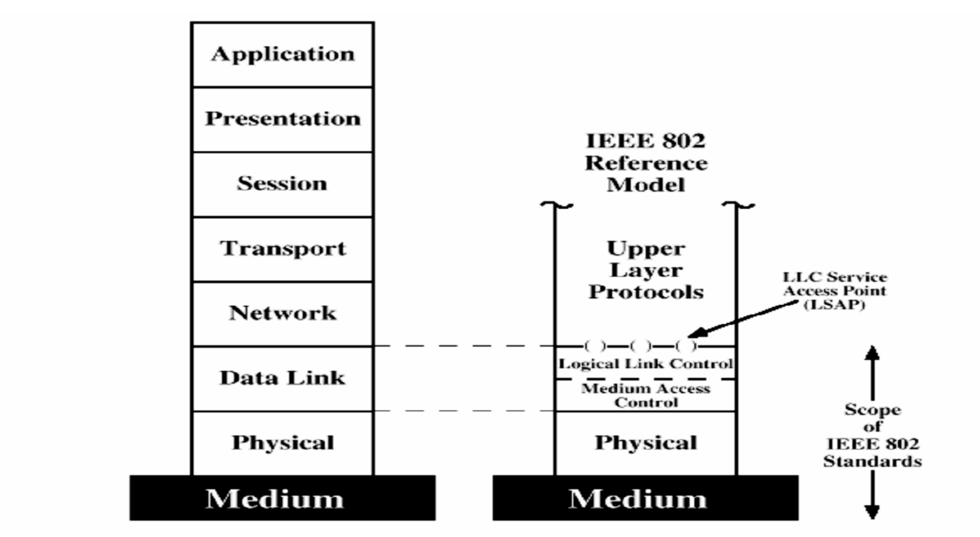


Figure 2.6**:** IEEE 802.11 Protocol architecture and OSI Model. [2]

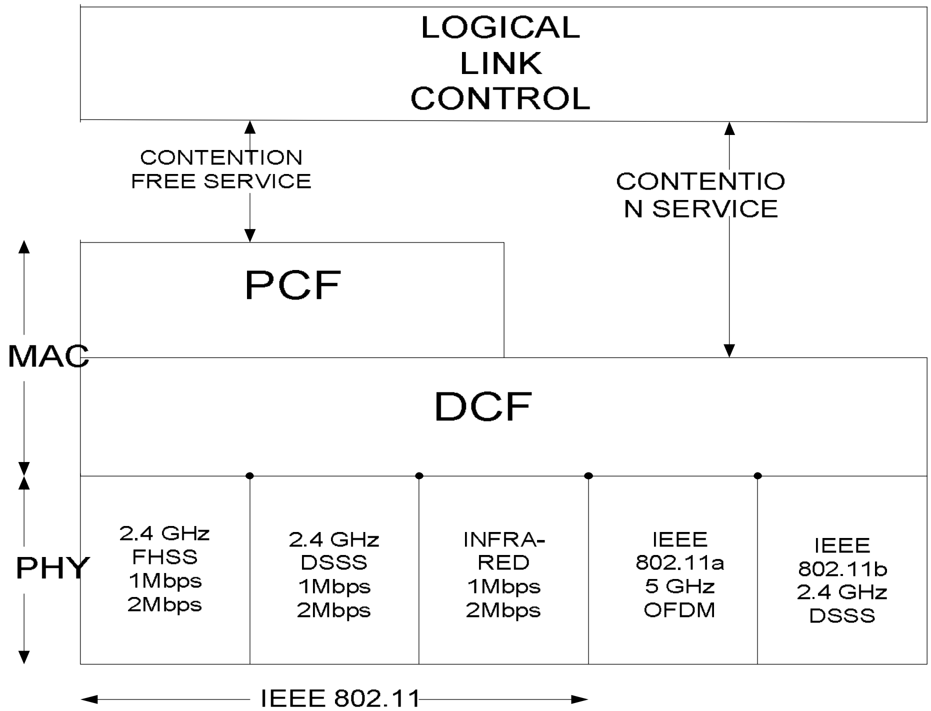


Figure 2.7: GENERAL IEEE 802.11 PROTOCOL ARCHITECTURE [4]

2.5.2. The Distributed Coordination Function (DCF)

The DCF protocol allows stations to access the medium in a distributed manner. There is no central entity controlling the use of the shared channel. The DCF is the basic access method used to support asynchronous data transfer on a best-effort basis [36]. All stations are required to support the DCF. The access control in ad hoc networks uses only the DCF. Infrastructure networks can operate using just the DCF or a coexistence of the DCF and PCF. The IEEE 802.11 MAC architecture is depicted in Figure 2.7, which shows that the DCF sits directly on top of the physical layer and supports contention services. Contention services imply that each station with an MSDU queued for transmission must contend for the channel and, once the given MSDU is transmitted, must re-contend for the channel for all subsequent frames. Contention services are designed to promote fair access to the channel for all stations. [36]

The DCF defines two access mechanisms:

- The Basic Access and
- The RTS/CTS [3]

2.5.2.1. Basic Access Mechanism

The Basic Access scheme is carrier sense multiple access with collision avoidance (CSMA/CA). The CSMA/CA media access control (MAC) protocol of IEEE WLAN is a unique way of avoiding the collision of the user packets when the traffic sources transmit bursty packets [2], [37], [40], [41]. When the MAC needs to transmit a frame, it physically senses the medium to check that the medium remain free. If it is still free, the station sends its frame. Otherwise, the MAC selects a back-off value randomly from a contention window. Figure 8 below shows this scheme. If a collision happens the contention window is set to twice its size and a back-off value is chosen from the new interval. After a successful transmission, the contention window is reset to a pre-set minimum value. The random back-off is also called after each successful transmission and each retransmission to reduce the probability of collisions. The IEEE 802.11 MAC uses a positive acknowledgement scheme to detect collisions. Each unicast frame sent by the MAC has to be acknowledged by the receiver; otherwise the frame is retransmitted by the MAC layer. Broadcast packets are not acknowledged. Also, retransmissions are limited to a maximum number of tries which is 4 by default, after which the packet is dropped [3].

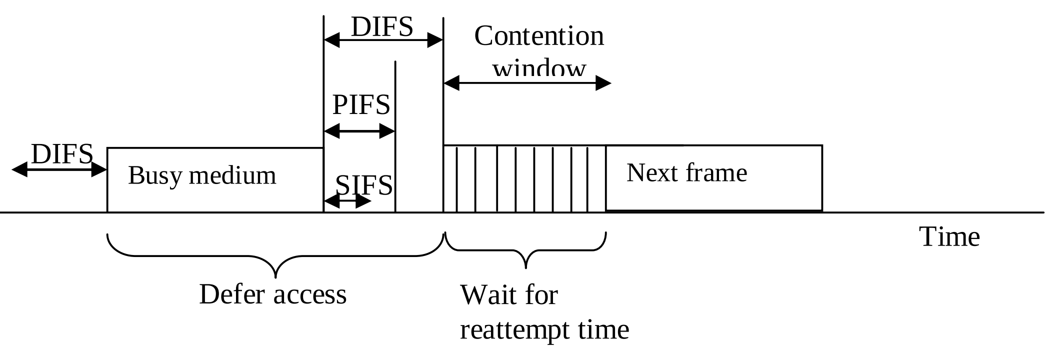


Figure 2.8: Basic CSMA-CA operation [4]

Figure 2.8 shows the basic CSMA-CA operation. All stations are obliged to remain quiet for a certain minimum period after a transmission has been completed, called the inter frame space (IFS). The length of the IFS depends on the type of frame that the station is about to transmit. High-priority frames must only wait the short IFS (SIFS) period before they contend for the channel. Frame types that use SIFS include ACK frames, CTS frames, data frames of a segmented MSDU, frames from stations that are responding to a pool from an AP, and any frame from an AP during the CFP. All of these frame types complete frame exchanges that are already in progress. The PCF inter frame space (PIFS) is intermediate in duration and is used by the PCF to gain priority access to the medium at the start of a CFP. The DCF inter frame space (DIFS) is used by the DCF to transmit data and management MDPUs [36].

In other words, Carrier sensing involves monitoring the channel to determine whether the medium is idle or busy. If the medium is busy, it makes no sense for a station to transmit its frame and cause a collision and waste band-width. Instead the station should wait until the channel becomes idle. When this happens, there is another problem: Other stations may have also been waiting for the channels to become idle, then collisions are likely to occur; and because collision detection is not possible, the channel will be wasted for entire frame duration [36]. A solution to this problem is to randomize the times at which the contending stations attempt to seize the channel. This approach reduces the likelihood of simultaneous attempts and hence the likelihood that a station can seize the channel [36].

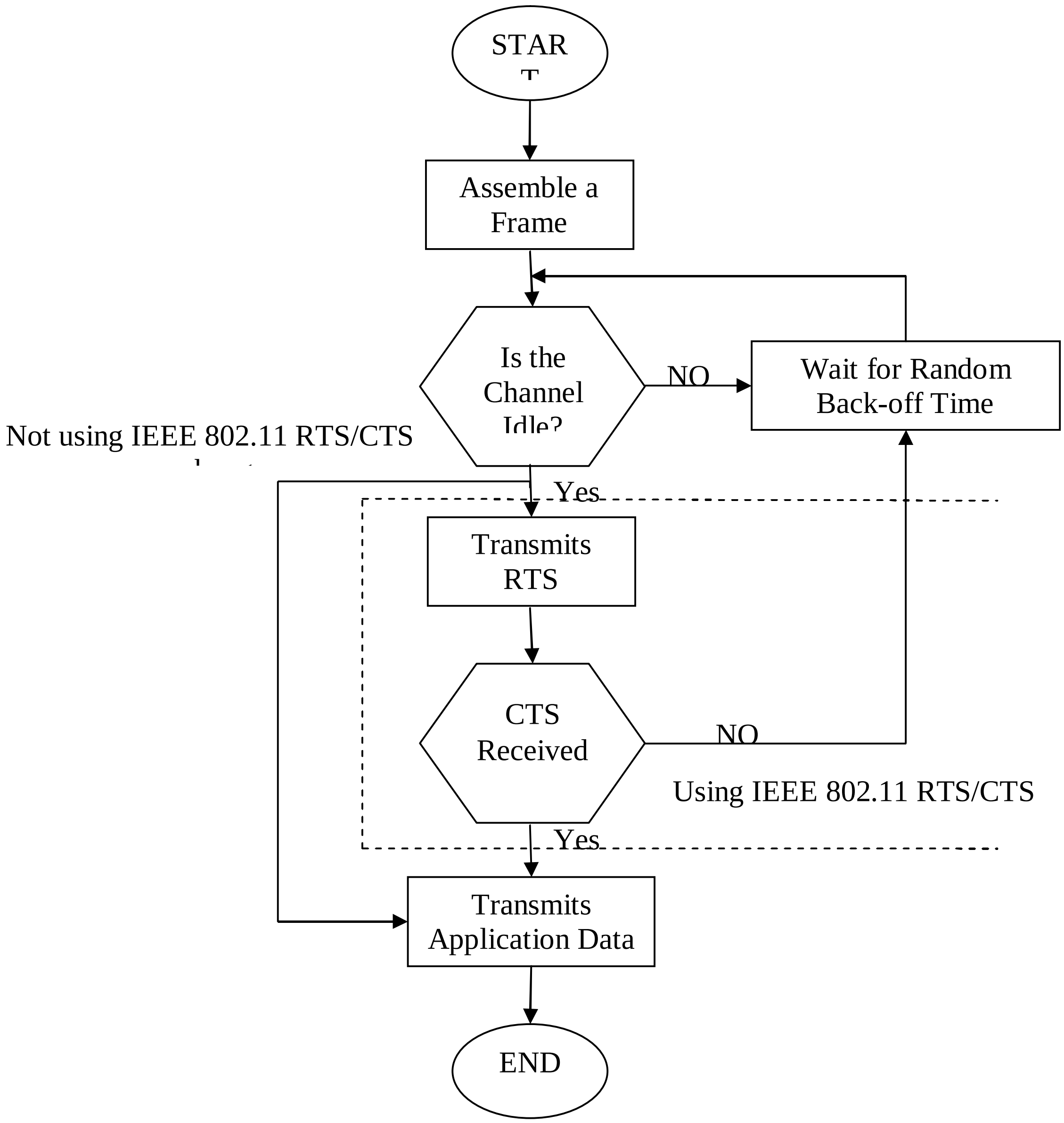


Fig. 2.9: IEEE 802.11 Simplified Algorithms of CSMA/CA [42]

2.5.2.2. The RTS/CTS Mechanism

In a wireless network, the sender node cannot detect a collision because it occurs at the receiver side. When a packet collides at the receiver, the whole packet still needs to be transmitted and then retransmitted if an acknowledgment packet is not received. In addition, stations in the receiverûs surrounding may not sense a transmission from the sender. If any of these stations transmits, there will be a collision at the receiver. This is referred to as the Hidden Terminal problem [36]. To overcome this issue and enable faster collision detection, the MAC specifies a prior hand-shake. Whenever a station has data to send, it first sends a Request to Send (RTS) frame. The destination replies with a Clear to Send (CTS) frame. These two frames contain information about the duration of the next data frames. All neighbor stations hearing these frames set a variable called Network Allocation Vector (NAV) to keep track of the availability of the medium [36]. Checking the NAV before a transmission is also called a Virtual Carrier Sense mechanism. This protocol is depicted in Figure 2.10. The attribute dot11RTSThreshold in the management information base (MIB) specifies the minimum size of the frame requiring a RTS/CTS exchange [3].

A handshake procedure was developed to operate with CSMA-CA when there is a hidden-station problem [36]. It showed that if a station, say, A, wants to send a data frame to station B, station A first sends a request-to-send (RTS) frame. If station B receives the RTS frame, then B issues a clear-to-send (CTS) frame. All stations within range of B receive the CTS frame and are aware that A has been given permission to send, so they remain quiet while station A proceeds with its data frame transmission. If the data frame arrives without error, station B responds with an ACK. In this manner CSMA-CA coordinates stations, even in the presence of hidden stations, so that collisions are avoided. It is still possible for two stations to send RTS frames at the same time so that they collide at B. In this case the stations must execute a back off to schedule a later attempt. Note that having RTS frames collide is preferable to having data frames collide, since RTS frames are much shorter than data frames. For example, RTS is 20 bytes and CTS is 14 bytes, whereas an MPDU can be 2300 bytes long [36], [43].

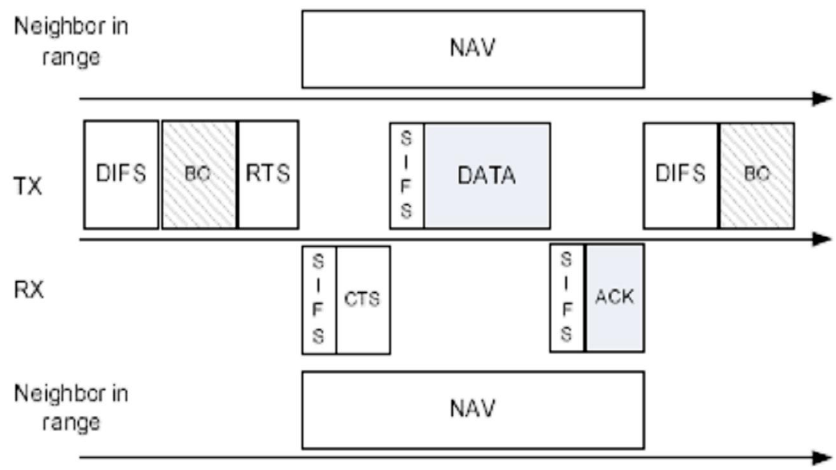


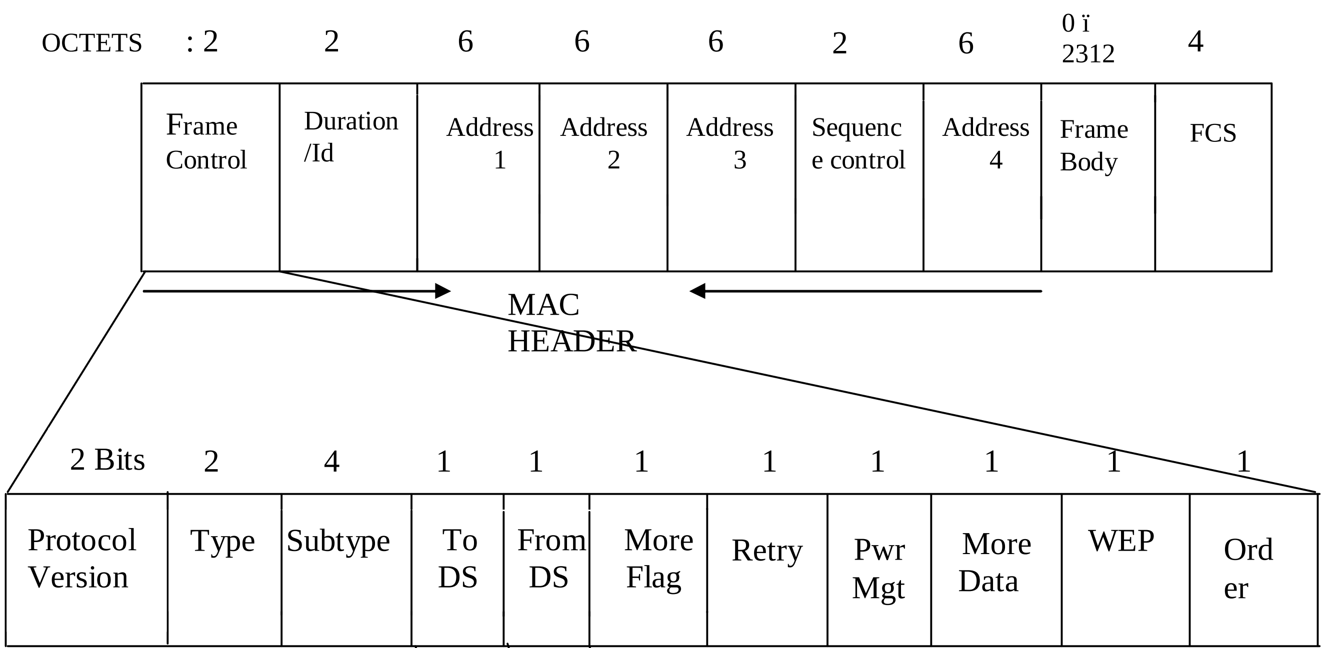
Figure 2.10: The RTS/CTS Mechanism [3]

2.5.3. Point Coordination Function

IEEE 802.11 also defines an optional point coordination function (PCF), which may be implemented by an AP, to support connection-oriented time-bounded transfer of MAC SDUs. Under PCF, the medium can alternate between the contention period (CP), during which the medium uses contention mode, and a contention-free period (CFP). During the CFP, the medium usage is controlled by the AP, thereby eliminating the need for stations to contend for channel access [36], [42]. The important characteristics of the IEEE 802.11 MAC protocol, which are likely to remain unchanged in the final standard, are its ability to support the access-point-oriented, ad hoc networking topologies, synchronous and time-critical traffic (called time bounded services in IEEE 802.11) and finally the power management.

2.6. Frame Structure and Addressing

IEEE 802.11 supports three types of frames: management frames, control frames, and data frames [36]. The management frames are used for station association and disassociation with the AP, timing and synchronization, and authentication and de-authentication. Control frames are used for handshaking and for positive acknowledgements during the data exchange. Data frames are used for the transmission of data. The MAC header provides information on frame control, duration, addressing, and sequence control. Figure below shows that the format of the MAC frame consists of a MAC header, a frame body, and a CRC checksum [36], [38].



		Add1	Add2	Add3	Add4
0	0	DA	SA	BSSID	N/A
0	1	DA	BSSID	SA	N/A
1	0	BSSID	SA	DA	N/A
1	1	RA	TA	DA	SA

DA ï Destination Address
RA ï Receiver Address
SA ï Source Address
DS ï Distribution system
TA ï Transmitter Address
BSSID ï Basic service set Identification.
Add - Address

Figure 2.11: IEEE 802.11 frame structure [36]

The frame control field in the MAC header is 16 bits long, and it specifies the following items: [36] [38]

- The 802.11 protocol version: two bits representing the protocol version. Currently used protocol version is zero. Other values are reserved for future use.
- The type of frame: two bits identifying the type of WLAN frame. Control, Data and Management are various frame types defined in IEEE 802.11, that is, management (00), control (01), or data (10).
- The subtype within a frame type; Four bits providing addition discrimination between frames. Type and Sub type together to identify the exact frame for example, type = ñcontrolò, subtype=ñACK.ò
- The To DS field is set to 1 in Data type frames destined for the distribution system, including Data type frames from a station associated with the AP that have broadcast or multicast addresses.
- The From DS field is set to 1 in Data type frames exiting the distribution system. Control and management frames set these values to zero. All the data frames will have one of these bits set. However communication within an IBSS network always set these bits to zero.
- The more fragments field is set to 1 when a packet is divided into multiple frames for transmission. Every frame except the last frame of a packet will have this bit set. Or set in frames that have another fragment of the current MSDU to follow.
- The retry field is set to 1 in Data or Management type frames that are retransmissions of an earlier frame; this helps the receiver deal with duplicate frames.
- The power management bit is set to indicate the power management mode of a station.
- The more data field is set to 1 to indicate to a station in power save mode that more MSDUs are buffered for it at the AP.
- The Wired Equivalent Privacy (WEP) field is set to 1 if the frame body field contains information that has been processed by the cryptographic algorithm.

The duration/id field in the MAC Header is 16 bits long and is used in two ways. It usually contains a duration value (net allocation vector) that is used in the MAC algorithm. The only exception is in control type frames of subtype PS-Poll, where this field carries the id of the station that transmitted the frame. [36]

The use of the four address fields is specified by the To DS and From DS fields in the frame control field. Addresses are 48 bits long and can be individual or group (multicast/broadcast).The address 1 field in this case contains the destination address. The BSS identifier (BSS ID) is a 48 bits field of the same format as IEEE 802 MAC addresses, uniquely identifies a BSS, and is given by the MAC address of the station in the AP of the BSS. The destination address is an IEEE MAC individual or group address that specifies the MAC entity that is the final recipient of the MSDU that is contained in the frame body field. The source address is a MAC individual address that identifies the MAC entity from which MSDU originated. The receiver address is a MAC address that identifies the intended immediate recipient station for the MPDU in the frame body field. The transmitter address is a MAC individual address that identifies the station that transmitted the MPDU contained in the frame body field [36].

- To DS=0, From DS=0. This case corresponds to the transfer of a frame from one station in the BSS to another station in the same BSS.
- To DS=0, From DS=1. This case corresponds to the transfer of a frame from the distribution system to a station in the BSS.
- To DS=1, From DS=0. This case corresponds to the transfer of a frame from a station in the BSS to the distribution system.
- To DS=1, From DS=1. This special case applies when we have wireless distribution system transferring frames between BSSs.

The sequence control field is 16 bits long, and it provides 4 bits to indicate the number of each fragment of an MSDU and 12bits of sequence numbering for a sequence number space of 4096. The fame body field contains information of the type and subtype specified in the frame control field. For data type frames, the frame body field contains an MSDU or a fragment of an MSDU. Finally, the CRC field contains the 32 bit cyclic redundancy check calculated over the MAC header frame body field [36], [38].

2.6.1. The General Frame Format

The MAC frame format comprises a set of fields that occur in a fixed order in all frames. Figure below depicts the general MAC frame format. The Frame Control, Duration/ID, and Address, and the FCS constitute the minimal frame format and are present in all frames.

The field Address 2, Address 3, Sequence Control, Address 4, QoS Control, and Frame Body are only present in certain frame types and subtypes.

The Frame Body field is of variable size. The maximum frame body size is determined by the maximum MSDU size (2304 octets) plus any overhead from security encapsulation [38].

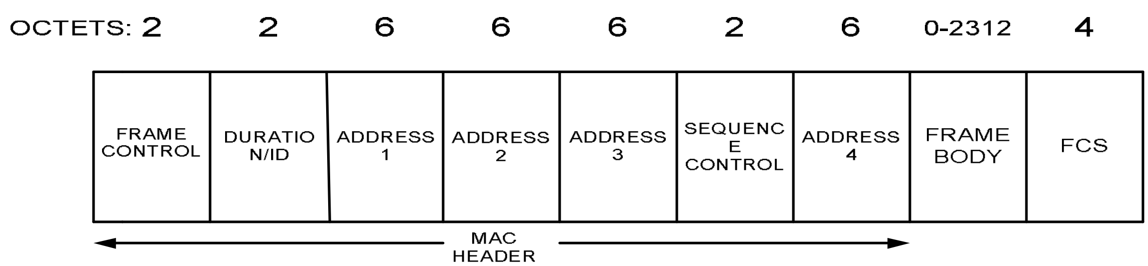


Figure 2.12**:** MAC Frame Format [38]

2.6.2 Format of Individual Frame Types

2.6.2.1. Control Frames.

Control frames facilitate in the exchange of data frames between stations.

The subfields within the frame control field of control frames are set as illustrated below [36], [38].

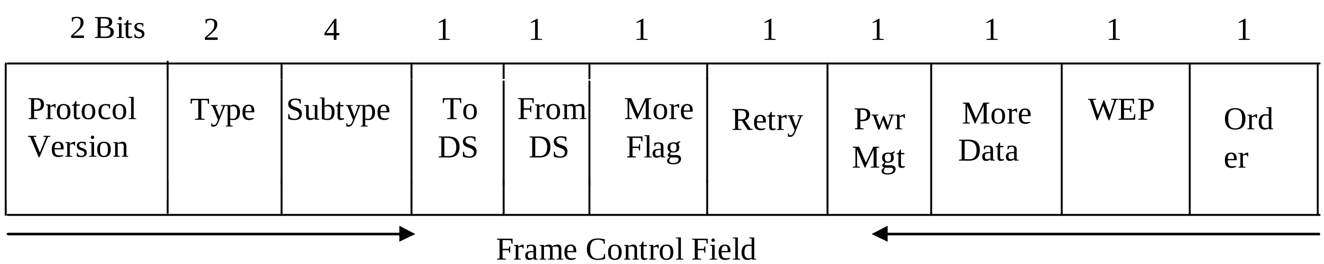


Figure 2.13: Frame control field subfield values within control frames [38].

Some common IEEE 802.11 control frames include:

Request To Send (RTS) frame format

The frame format for the RTS frame is as defined in figure

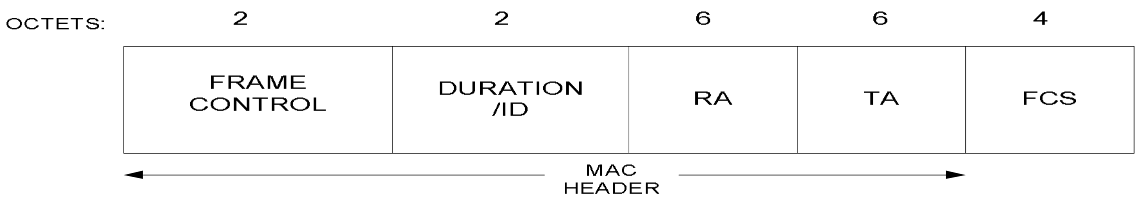


Figure 2.14: RTS Frame. [38]

The RA of the RTS frame is the address of the station (STA), on the wireless medium (WM), that is the intended immediate recipient of the pending directed data or management frame. The TA is the address of the station transmitting the RTS frame.

For all RTS frames sent by n station, the duration value is the time, in microseconds, required to transmit the pending data or management frame, plus one CTS frame, plus one ACK frame, plus three SIFS intervals. If the calculated duration includes a fractional microsecond, that value is rounded up to the next higher integer [29], [44].

Clear To Send (CTS) frame format

The frame format for the CTS frame is as defined in figure below

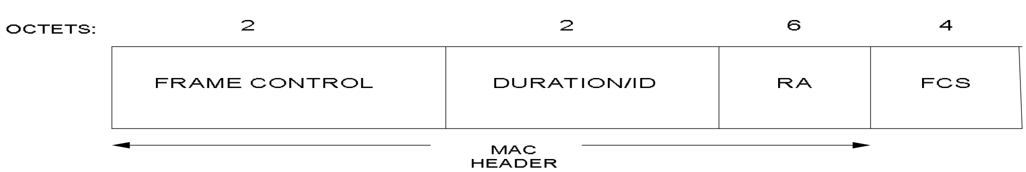


Figure 2.15: CTS Frame [38]

For all CTS frames sent in response to RTS frames, the RA of the CTS frame is copied from the TA field of the RTS frame to which the CTS is a response. The duration value is the value obtained from the duration field of the immediate previous RTS frame, minus the time, in microseconds, required to transmit the CTS frame and its SIFS interval. If the calculated duration includes a fractional microsecond, that value is rounded up to the next higher integer [29], [44].

Acknowledgement (ACK) frame format

The frame format for the ACK frame is as defined in the figure below

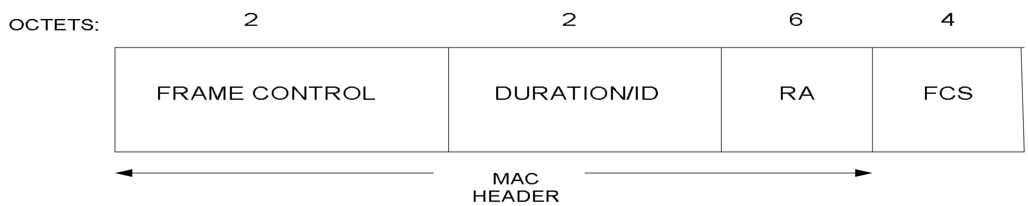


Figure 2.16: Acknowledgment frame [38]

The RA of the ACK frame is copied from the Address 2 field of the immediate previous directed data, management, block AckReq control, or BlockAck control, or PS-Poll control frame.

For ACK frames sent by n stations, if the more fragment bit was set to 0 in the frame control field of the immediately previous directed data or management frame, the duration value is set to 0. In all other ACK frames, the duration value is the value obtained from the duration field of the immediately previous data, management frame PS-Poll, block AckReq control, or Block Acknowledgement minus the time, in microseconds, required to transmit the ACK frame and its SIFS interval. If the calculated duration includes a fractional microsecond, that value is rounded up to the next higher integer [29], [44].

Block Acknowledgement Request (BlockAckReq) frame format

The frame format of the BlockAckReq frame is defined in figure below

Octets:	2	2	6	6	2	2	4
	Frame Control	Duration ID	RA	TA	BAR Control	Block Ack Starting Sequence Control	FCS

MAC Header

Figure 2.17: BlockAckReq frame [29]

The Duration/ID field value is greater than or equal to the time, in microseconds, required to transmit one ACK or BlockAck frame, as applicable, plus one SIFS interval. If the calculated duration includes a fractional microsecond, that value is rounded up to the next higher integer. The RA field of the BlockAckReq frame is the address of the recipient QSTA. The TA field is the address of the QSTA transmitting the BlockAckReq frame.

Block Acknowledgement frame format

The frame format of the BlockAck frame is defined in Figure 2.18 below

Octets:	2	2	6	6	2	2	123	4
	Frame Control	Duration ID	RA	TA	BA Control	Block Ack Starting Sequence Control	Block Ack Bitmap	FCS

MAC Header

Figure 2.18: BlockAck frame [29]

If the BlockAck frame is sent in response to the BlockAckReq frame, the Duration/ID field value is the value obtained from the Duration/ID field of the immediate BlockAckReq frame, minus the time, in microseconds, required to transmit the BlockAck frame and its SIFS interval. If the BlockAck frame is not sent in response to the BlockAckReq, the Duration/ID field value is greater than (subject to the TXOP limit) or equal to the time for transmission of an ACK frame plus a SIFS interval. If the calculated duration includes a fractional microsecond, that value is rounded to the next higher integer.

The RA field of the BlockAck frame is the address of the recipient QSTA that requested the Block Ack. The TA field is the address of the QSTA transmitting the BlockAck frame. The BlockAck Starting Sequence Control field and is set to the same value as in the immediately previously received BlockAckReq frame.

2.6.2.2. Data Frames

The frame format for a Data frame is dependent on the QoS subfield of the subtype field [44] and is as defined in figure below

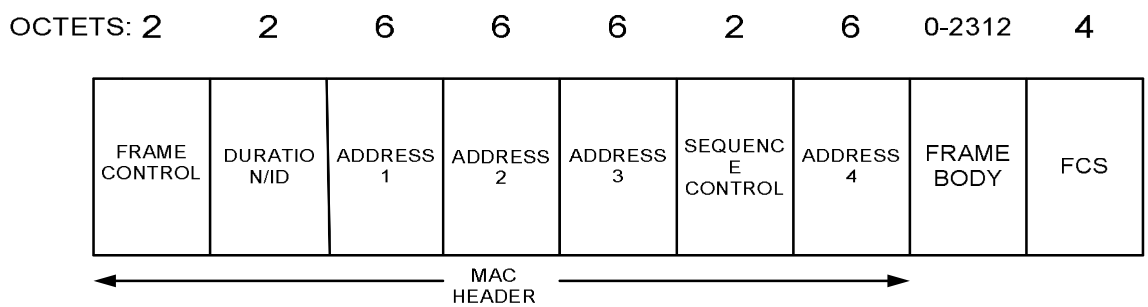


Figure 2.19: Frame format [29].

Data frames carry packets from web pages, files, etc. within the body [29].

2.6.2.3. Management Frames

Management Frames allow for the maintenance of communication. Management frames uses the format shown in figure 2.20; it uses only the three Address fields which do not vary upon specific frame sub-types [29]**.** It makes up a majority of the frames types in an IEEE 802.11 network. Management frames are used by wireless stations to join and leave the network.

Fame control 2 octets	Duration 2 octets	Destination Address 6 Octets	Source Address 6 Octets	BSSID 6 Octets	Sequence Control 2 Octets	Frame Body 0-2312 octets	FCS 4 Octets

→ MAC Header ←

Figure 2.20: Management frame [29].

Frame format

- In management frames of subtype Probe Request, the BSSID is either a specific BSSID, or the broadcast BSSID.
- Within all management type frames sent during the CFP, the Duration field is set to the value 32768. Within all management type frames sent during the contention period, the Duration field is set according to following rules:

✓ If DA is a group address, the duration value is set to 0.

✓ If More Fragment bit is set to 0 in FC field and DA is individual address, the duration value is set to the time, in microseconds, required to transmit one ACK frame, plus one SIFS interval.

If the More Fragment bit is set to 1 in the Frame Control field of a frame, and the DA contains an individual address, the duration value is the time, in microseconds, required to transmit the next fragment of this management frame, plus two ACK frames, plus three SIFS intervals [38].

2.7. Spread Spectrum Allocation for WLANs

The combined function of the transmitting and receiving physical medium dependent PMD sub layers results in a data stream, timing information, and receive parameter information being delivered to the receiving convergence sub layer. The IEEE Std.802.11 [14] made used of FHSS to provide 1 and 2 Mbps RF communication for 2.4 ISM. The IEEE specification is shown in the figure below. The bandwidth is 1MHz

Table 2.1: Operating frequency ranges [14]

Lower Limit	Upper Limit	Regulatory range	Minimum	Hopping set	Geography
2.402 GHz	2.480 GHz	2.400-2.4835 GHz	75	79	North America
2.402 GHz	2.480 GHz	2.400-2.4835 GHz	20	79	Europe
2.473 GHz	2.495 GHz	2.471-2.497 GHz	Not applicable	23	Japan
2.447 GHz	2.473 GHz	2.445-2.475 GHz	20	27	Spain
2.448 GHz	2.482 GHz	2.4465-2.4835 GHz	20	35	France

NOTE - The frequency ranges and the number of required hopping channels in this table are subject to geographic-specific regulatory authorities.
Excluding France and Spain

IEEE 802.11 divides each of the above-described bands into channels, analogously to how radio and TV broadcast bands are sub-divided. For example the 2.4000ï 2.4835 GHz band is divided into 13 channels each spaced 5 MHz apart, with channel 1 centered on 2.412 GHz and 13 on 2.472 GHz to which Japan adds a 14th channel 12 MHz above channel 13. Since IEEE 802.11g OFDM signals use 20 MHz there are only four non-overlapping channels, which are 1, 5, 9 and 13. The previous standard IEEE 802.11b was based on DSSS waveforms which used 22 MHz and did not have sharp borders, as OFDM waveforms do, due to the way the signal was generated.

Thus only three channels did not overlap. Even now many devices are shipped with channels 1, 6 or 11 as the preset option, slowing the adoption of the newer four channel scheme. Such devices should be simply reconfigured to channel 1, 5, 9 or 13 by the user. Availability of channels is regulated by country, constrained in part by how each country allocates radio spectrum to various services. At one extreme, Japan permits the use of all

14 channels (with the exclusion of IEEE 802.11g/n from channel 14), while other countries like Spain initially allowed only channels 10 and 11, and France only allowed 10, 11, 12 and 13 (now both countries follow the European model of allowing channels 1 through 13) [17], [45]. Most other European countries are almost as liberal as Japan, disallowing only channel 14, while North America and some Central and South American countries further disallow 12 and 13. Besides specifying the centre frequency of each channel, IEEE 802.11 also specify (in Clause 17) a spectral mask defining the permitted distribution of power across each channel. The mask requires that the signal be attenuated by at least 30 dB from its peak energy at ±11 MHz from the centre frequency, the sense in which channels are effectively 22 MHz wide [45]. One consequence is that stations can only use every fourth or fifth channel without overlap, typically 1, 6 and 11 in the Americas, and in theory, 1, 5, 9 and 13 in Europe although 1, 6, and 11 is typical there too. Another is that channels 1ï 13 effectively require the band 2.401ï 2.483 GHz, the actual allocations being, for example, 2.400ï 2.4835 GHz in the UK, 2.402ï 2.4735 GHz in the US, etc.

Since the spectral mask only defines power output restrictions up to ±11 MHz from the center frequency to be attenuated by -50 dBr, it is often assumed that the energy of the channel extends no further than these limits. It is more correct to say that, given the separation between channels 1, 6, and 11, the signal on any channel should be sufficiently attenuated to minimally interfere with a transmitter on any other channel. Due to the near-far problem a transmitter can impact a receiver on a "non-overlapping" channel, but only if it is close to the victim receiver (within a meter) or operating above allowed power levels.

Although the statement that channels 1, 6, and 11 are "non-overlapping" is limited to spacing or product density, the 1ï 6ï 11 guideline has merit. If transmitters are closer together than channels 1, 6, and 11 (for example, 1, 4, 7, and 10), overlap between the channels may cause unacceptable degradation of signal quality and throughput [45]. However, overlapping channels may be used under certain circumstances. This way, more channels are available [45]. The most widely used non-overlapping channels that avoids interference in WLANs are 1, 6 and 11 for North America and 1, 7 and 13 for Europe. The figure below shows the non-overlapping channels

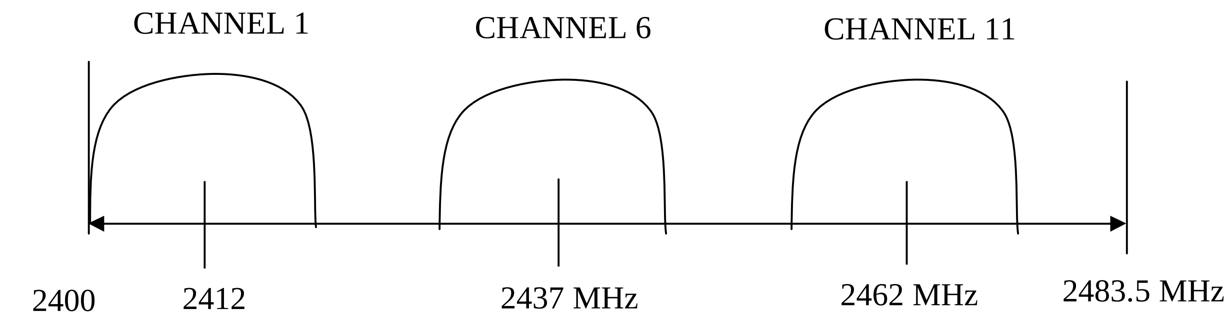


Figure 2.21: North American Channel selections non-overlapping [17]

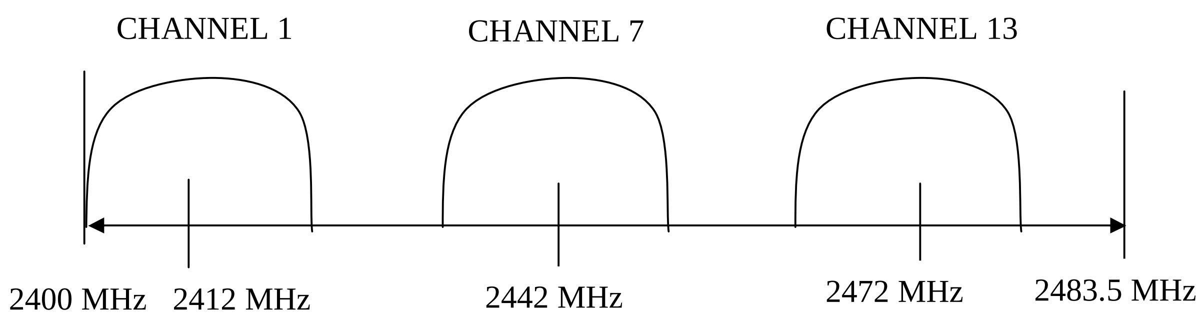


Figure 2.22: Europe Channel selections non-overlapping [17]

2.8. Network Performance Management

Managing performance of networks involves optimizing the way networks function in an effort to maximize capacity utilization, minimize latency and offer high reliability regardless of bandwidth available and occurrence of failures [51]. Network performance management consists of tasks like measuring, modeling, planning and optimizing networks to ensure that they carry traffic with the speed, capacity and reliability that is expected by the applications using the network or required in a particular scenario. Networks are of different types and can be categorized based on several factors. However, the factors that affect the performance of the different networks are more or less the same. These involve parameters like Latency, Packet Loss and Throughput. In order to design high performance networks or guarantee performance of any type of network, detailed analysis of the above factors is a crucial step. Often the foremost step in such an analysis is the study of the traffic on the network. As a consequence, the type of traffic model used to understand the flow of traffic in the network, and how closely the model depicts the real-time characteristics of the network, become vital parameters. Choosing a model that doesn't describe the real-time characteristics of the traffic in the network can be as disastrous as not analyzing the traffic at all.

2.9. Related Works

The IEEE 802.11 DCF uses a combination of physical / virtual carrier sensing and RTS/CTS channel reservation. While these mechanisms are generally effective in reducing frame collisions, the protocol is rather pessimistic and not very efficient in channel use because it does not encourage enough concurrent transmissions. My observation concurs with the views of many other researchers, who have also proposed modifications to the DCF for the purpose of increasing the number of concurrent transmissions in the network. Authors in [46] manipulate the timing of the original RTS-CTS- DATA-ACK frame sequence and attempts to synchronize the states among one hop neighbors so that if the receivers of two frames transmitted by two neighbors are far apart enough, these two transmissions are scheduled to occur concurrently. [47] observes that in an ñoveractive RTS/CTSò situation, in which the RTS/CTS exchange reserves way too much space than needed, just hearing RTS or CTS but not both does not justify for assessing the channel as busy. Thus a bystander to a pair of data transmitter and receiver should only block its own transmission if it receives both RTS and CTS. One issue with both approaches is that they do not fully address the complexity of capture effect. Thus the proposed solutions only work for certain scenarios.

The Interference Aware (IA) method proposed by [48] and [49] share the same philosophy as in [43] proposal, in the way that stations report channel condition by piggybacking condition information in the frame exchange sequence. In IA, a receiver of a RTS embeds the Signal to Interference Ratio (SIR) observed while receiving the RTS in its returning CTS frame. This way other stations, also taking into account the SIR observed while receiving the CTS frame, are able to calculate if their own transmissions may cause enough interference to the receiver in question. The approach makes assumptions about the participating stations such as same transmission power, same antenna characteristics, etc. The authors mainly rather keep their model simple than make their solution more generalized. In addition, the proposal only concerns about the receiver of RTS frame, not the sender of the RTS frame, which also is the receiver of the subsequent ACK frame. If a nearby station indeed decides not to block and its transmission collide with the ACK frame, the DATA frame transmission still needs to be rescheduled. In addition to the above issues that are particular to each individual proposal, I have noticed some rather common problems. The first is that these proposals rely on the RTS/CTS handshake. In reality, the RTS/CTS handshake is turned off in most deployments, which makes these proposals inapplicable in such environments. The next issue is that these proposals do not take the aforementioned ñcapture frameò vs. ñcapture signalò problem into consideration. As a result, many concurrent transmissions will not be received by their intended receivers, not because the signals are not strong enough, but because the received bits are cast into the wrong frame, the ongoing DATA frame that these receivers have already engaged in receiving.

Subsequently, in the IEEE 802.11 standard for wireless LAN networks, there have been remarkable studies on IEEE 802.11 MAC protocol to improve system throughput or support differentiated services. Providing QoS requirements like good throughput and minimum access delay are challenging tasks with regard to IEEE 802.11 WLAN protocols and Medium Access Control (MAC) functions. IEEE 802.11 MAC layer supports two main protocols: DCF (Distributed Coordination Function) and EDCF (Enhanced Distributed Coordination Function). The primary medium access scheme is calledò distributed coordination functionò (DCF) and it is based on a CSMA/CA protocol with binary exponential back-off (BEB) retransmission rules. Since the introduction of the standard, many works have been interested in the analytical evaluation of its performance; most of them were based on the model of Bianchi [22], and consider saturation throughput and delay analysis [42], [50], [51].

A. Queuing Analysis

In real networks, packets may be queued at nodes buffer before being handled by the MAC protocol, and typical data traffics are bursty or streamed at low rates so that stations do note operate usually in saturated regime. Recent works have addressed the finite load performance of IEEE 802.11 DCF with queuing at nodes buffer (queues with infinite capacity) [52], [53], [55] or with simplifying assumptions [54]. The analysis of queuing model of MAC protocols is a challenging task, and generally do not permit to obtain closed-form expressions of quantities of interest. In [56], they used a two-stage technique to analyze a queuing model of DCF protocol. In order to acquire closed-form expression of system performance, a Markov chain model is first used to analyze the non-queuing operation of the system. The traffic load in this case is modeled as a Probability of having a packet to transmit q; this probability is taken into account whenever the protocol is able to handle a new packet. In this way, q allows them to consider the fact that packet arrivals may occur anytime during the operation of the system. From the non-queuing model, they obtain the service-time statistics corresponding to a given q. In the second phase, they also consider a queuing model of the system with a given arrival process _ (t) and queue length K. Thus, the probability of having a packet to transmit q corresponds to the probability of having at least one packet in the queue q0. In order to link the two models, they use a recursive algorithm that update the q value used in the Markov model to specify the service time statistics, to match the resulting q0 from the queuing model.

B. Back-off Scheme Optimization

It is well recognized that the key optimization issue of random access protocols is the design of an optimal retransmission scheme that keeps access rate to the multiple-access channel around its capacity. Obviously, an optimal retransmission scheme must achieve this capacity under all network conditions and must be distributed. The optimality of the scheme depends on how accurate is the information that is, has about the multiple access channel state. IEEE 802.11 DCF uses a BEB retransmission scheme. The BEB scheme has the advantage of being simple and does not require cooperation among users or any information about the channel state, it tries to blindly adapt the contention window to the channel congestion level based only on its experience, i.e., the contention window is increased in case of collision and it is reset to its initial value in case of success. Its performances however are shown to be sub-optimal, in term of the achieved throughput as it needs several attempts to find approximately the best contention window, and also in term of short-term fairness as it favors the first successful user to compete again for the channel with small contention window against potentially others users with much higher contention window, Works in [57], [58], [59] have derived specific fairness metric to illustrate this. The enhancement of the DCF based BEB have been extensively addressed in the literature, the schemes may be categorized into two classes:

(1) Blind schemes: as in BEB, there is no need to sense the channel activity; the change of the contention windowȏs length is made upon collision or success but in a different manner than BEB [60], [61], and [62] in order to reach better the optimal back-off window and increase short-term fairness.

(2) Coherent schemes: here the optimization is made in order to dynamically adapt the contention window to meet directly some objective optimization condition. The objective condition is derived from an analytical model and its verification is made by measuring some specific performance metrics, [63], [64], [65], [66]. Even if these schemes identify and try to reach an optimal operating point of the system, the way they update the back-off window is not optimal as in the blind schemes.

Early in the work of Bianchi [22], the notion of optimal back-off window that optimizes the saturation network throughput has been introduced. Unfortunately, the calculation of this optimal window requires information about the network size n and the average duration of collisions E [Tcol]. Even if n could be easily obtained in single-hop network, channel activity sensing is required to estimate E [Tcol] in case of heterogeneous networks where users employ different physical rates and packet sizes. As DCF provides equal long-term access rate to different users, several studies have shown that DCF is unable to fairly and efficiently manage heterogeneous networks [67], [53], [63], [68], [69], [70]. As solution, time-based scheduling [68] have been shown to increase both the throughput and fairness of the MAC protocol. In order to achieve trivially time-based scheduling with DCF, it is sufficient to normalize the packet duration by normalizing the packet-size/physical-rate ratio, i.e., each physical rate is to be used with a corresponding packet size in order to get unique packet duration on the channel and hence, a prioritized, fair input to the system.

Obviously, many studies have appeared in this literature investigating the performance of the IEEE 802.11 DCF protocol since the standard has been proposed. One of the most important studies was proposed by Bianchi [22]. He proposed a Markov chain model to compute the saturation throughput performance and the probability that a packet transmission fails due to collision. The back-off mechanism of IEEE 802.11 was studied under heavy traffic condition. In addition, the proposed analytical model was for a simplified version of IEEE 802.11 DCF MAC protocol. The proposed model in [22] has been extended in [84] by including the discarding of the MAC frame when it reaches the maximum retransmission limit. In [42], the authors analyzed the throughput and delay of CSMA/CA protocol under maximum load conditions by using a bi-dimensional discrete Markov chain. Also, they extended the proposed model in [22] by taking into account the busy medium conditions when invoking the back off procedure. They introduced an additional transition state to bianchiǿs model in order to model the freezing of the back off counter. To simplify the analysis of the proposed model, they assumed that the access probability and station collision probability are independent of channel status. Moreover, they didnǿt validate their work using simulation. Tickoo and Sikdar [71] proposed an analytical model based on a discrete time G/G/1 queue to study the performance of IEEE 802.11 MAC based wireless networks. They introduced a different approach to model the unsaturated traffic using a probability generating functions that allow the computation of the probability distribution function of the packet delay. Unfortunately, most of previous researches didnǿt address the problem of hidden nodes, despite of its importance in wireless networks. This is because it complicates the mathematical analysis of the IEEE 802.11 based systems. A small number of analytical studies [72], [73], [74], [75] have been proposed considering the effect of the hidden nodes on the performance of IEEE 802.11 DCF protocol. Hou et al [72] presented an analytical study to compute the normalized throughput of the IEEE 802.11 DCF protocol with hidden nodes in a multi-hop ad hoc network. The drawback of this work is that it doesnǿt consider the state of retransmission counters for obtaining the collision probability. In [73], the throughput of the IEEE 802.11 DCF scheme with hidden node problems in multi-hop ad hoc networks was analyzed assuming that the carrier sense range is equal to the transmission range, which isnǿt applicable in real world. Jayaparvathy et al [76] introduced an SRN model to evaluate the average system throughput and delay of the IEEE 802.11 DCF protocol. Although they succeeded to model the effect of freezing of back-off counter, they failed to model the retransmission retry counter. In addition, the proposed model didnꞌt take into account RTS/CTS handshake and was only verified for light load conditions. Neither [77] nor [76] model the effect of the hidden node problem. In [78], Osama et al investigated the performance of the IEEE 802.11 DCF MAC protocol, for both the BA and RTS/CTS methods, in multi-hop ad hoc networks in the presence of hidden nodes using SRN models. The proposed models capture most features of the MAC protocol. The influences of system parameters, such as traffic load, packet size, and number of nodes, have been demonstrated. The proposed SRN models for both the BA and RTS/CTS methods have been validated through extensive comparisons between analytical and simulation results. Comparisons showed that the proposed models succeeded to provide an accurate representation of the dynamic of the IEEE 802.11 DCF MAC protocol under several different settings of the system parameters. Analytical results show that in light load condition there is not much difference between the performance of the BA and RTS/CTS methods. Conversely, in heavy load conditions the performance of RTS/CTS method is much better than the BA method. Also, the packet size, number of neighbor nodes, and number of hidden nodes have a great effect on the performance of ad hoc networks especially in the case of the BA method under saturated load conditions. Nadeem, T. [79] proposed an enhancement to the existing IEEE 802.11 DCF MAC function named the Location Enhanced DCF (LED) for IEEE 802.11, which incorporates location information in the RTS-CTS-Data-ACK handshakes of the IEEE 802.11 DCF so that other stations sharing the channel are able to make better interference predictions and blocking assessments and thus improves channel spatial reuse efficiency and data throughput. They study how LED may improve channel efficiency in normal ad hoc networks as well as its effectiveness in the newly emerging application of mesh networking.

Subsequently, the international standard IEEE 802.11Wireless LAN protocol is a popular standard for wireless local area networks. Its medium access control layer (MAC) is a carrier sense multiple access with collision avoidance (CSMA/CA) design, although collisions cannot always be prevented, randomized exponential back off rule is used in the retransmission scheme to minimize the likelihood of repeated collisions. To work around this problem, [80] identify state transition of the protocol that can be used to simplify the models and make verification feasible. It also explains the state transition model of two way handshake mechanism of IEEE 802.11 standard for MAC DCF. The proposed model has been validated using network simulator 2.The use of modeling state transition diagram allows them to model asynchronous behavior of stations. There is no service differentiation policy associated with different flows, so the delay for real time multimedia flows should be reduced for better performance. So, when the no of station increases, the throughput of two flow decreases and delay increases. So this simulation clearly shows that there is neither throughput nor delay differentiation between the different flows. The reason is that all flow shares the same queue. So DCF cannot provide QoS, rather it provides only best-effort services. Also, during the evaluation of EDCF, [56] showed that the performance of various access categories was the determining factor. Two scenarios, with same Physical and MAC parameters, one implementing the DCF and other EDCF, were created in the network simulation tool (OPNET) to obtain the results. The results showed that the performance of EDCF was better in providing QoS for real-time interactive services (like video conferencing) as compared to DCF, because of its ability to differentiate and prioritize various services. Whereas the DCFôs overall performance was marginally better for all kinds of services taken together. The modeling of IEEE 802.11 DCF has been a research focus since the standard has been proposed. The analysis model proposed in [22] simplifies the back off behavior of IEEE 802.11 DCF by using a discrete Markov chain. Using the model, the author of [22] demonstrates that the performance of DCF strongly depends on the system parameters, mainly, the minimum contention window and the number of stations. It motivates a significant amount of subsequent analysis work. Cali et al. [81] derive a theoretical upper bound by approximating DCF with a p-persistent protocol. They also propose a dynamic and distributed algorithm, IEEE 802.11, which allows each station to estimate the number of competing stations and to tune its contention window to the optimal value at run time. H. Kim et al. [82] have derived an analytic model and developed a model-based frame scheduling scheme, called MFS, to enhance the capacity of IEEE 802.11 WLANs. In MFS, each station estimates the current network status and utilization, and then based on the estimation, it determines a scheduling delay that is introduced before a station attempts for transmission of its pending frame. Several recent proposals [83], [84] improve the throughput of DCF by either modifying the back off mechanism or tuning the various inter-frame spacing time. The Fast collision resolution (FCR) is a new contention-based MAC protocol [83]. It actively redistributes the back off timer for all competing nodes, thus allowing more recent successful stations to use smaller contention window, and allowing other stations to reduce back-off timer exponentially when they continuously meet some idle time slots. Due to this operation, each station can more quickly resolve collisions and obtain higher throughput than DCF when there are a large number of active stations. DCF, proposed in [84], is a new ACK-integrated mechanism that combines the TCP ACK with MAC-level ACK, and enhances the performance of TCP over WLANs. Several schemes that dynamically alter the value of CW have been proposed and can be found in [81], [85], [86]. Bianchi and Tinnirello [85] show that the number n of competing stations can be expressed as a function of the collision probability encountered on the channel, and hence it can be estimated based on run-time measurements, and propose a methodology to estimate the number of competing stations, based on an extended Kalman filter coupled with a change detection mechanism. The authors of [87] proposed a distributed MAC scheme, called Black burst, with the main goal of minimizing delay for real-time traffic. With this scheme, real-time stations contend for access to the channel in a distributed manner by sending a black burst signal with duration proportional to the time the station has been waiting. After transmitting the black burst, the station listens to the medium for a short period of time, and transmits its pending frame only if the medium is idle. This scheme basically ensures that the longest-waited station transmits a frame without collision.

Piggybacking mechanisms are used in many systems to support various purposes. For example, in [88], when a base-station sends a packet to a mobile station, the base-stationĝs scheduler piggybacks the information about the time eligible for the next packet to be transmitted. The enhanced collision avoidance algorithm proposed in [86] similar to [89] applies piggybacking mechanism to the back off scheme of DCF. The algorithm involves advertising the transmitting stationĝs next back off value and tracking the back off values of other stations in the network. It also employs a dynamic value for CW based on the result obtained by tracking the number of unique station addresses that have transmitted over the last few seconds [88]. Refer to this piggyback scheme as the basic algorithm. However, [86] gives only a rough description about the algorithm without considering how it works and performs in various situations such as the existence of newly-arriving stations and power-saving stations. Also, [89] proposed a novel distributed reservation-based MAC protocol that can be used for the enhanced IEEE 802.11 WLAN. The proposed EBA is a simple MAC with a minor modification of the IEEE 802.11 DCF. Since the proposed EBA is backward compatible with the legacy DCF, both EBA and DCF stations can co-exist smoothly in the same WLAN.

Foh and Tantra [90] proposed an analytical model that improves the model introduced in [42] by relaxing its assumptions. They modeled the effect of post-DIFS (the time slot immediately following the DIFS guard time after a successful transmission). In addition they improved the modeling of the back off freezing mechanism and maximum retry limit specified by IEEE 802.11 standard. But this model assumes that medium access probability depends on whether the previous period is busy or idle which makes the model more complicated. All previous researches assumed that all stations in the network work in heavy traffic conditions (saturated traffic), where every station always has a data frame to transmit, which is rarely found in real-life applications. In addition, their proposed models are only for single-hop networks where every station can communicate with all other directly. Because of complexity, a few researches have been proposed to study the performance of IEEE 802.11 DCF protocol under general traffic condition [71], [91], [92]. In [91], the model is based on the presentation of the system with a pair of one-dimensional state diagrams which accommodate different input parameters. But, the model deviated from IEEE 802.11 protocol standard because it assumed that all stations collide or succeed at the same time. In [92], the authors modified Bianchiôs markov models to calculate the transmission probability of a station that may have different traffic loads, but the proposed model failed to capture some aspects of the standard, e.g. the station enter the back off state if it received a frame when the channel is busy.

In WLANs, the medium access control (MAC) protocol is the main element that determines the efficiency in sharing the limited communication bandwidth of the wireless channel. According to [33], the distributed congestion reaction adopted in the IEEE 802.11 DCF is obtained with a variable time-spreading of the usersô accesses. Channel utilization wastage is caused both by collisions and by the idle periods introduced by the spreading of accesses. To optimize the network performance (channel utilization), the access protocol should balance these two conflicting costs [41], [93]. Since these costs change dynamically, depending on the network load, the access protocol should be adaptive to congestion variations in the system.

Another important issue is the Bandwidth of wireless networks. The bandwidth of wireless local area networks is limited as compared to that of wired local area networks which provide a large bandwidth. This limitation is due to the error prone physical medium (air). The methods like tuning the physical layer related parameters [94], tuning the IEEE 802.11 parameters and using enhanced link layer (media access control) protocol were used to improve the performance of WLANs. The IEEE 802.11 standard operates far from theoretical throughput limit depending on the network configuration [95]. An analytical model was proposed by [95] to achieve maximum protocol capacity (theoretical throughput limit), by tuning the window size of the IEEE 802.11 back-off algorithms. The main reason why the capacity of the standard protocol is often far from theoretical limit is that during the overload conditions, a station experiences a large number of collisions before its window has a size which gives a low collision probability. It was cited that proper tuning of the back-off algorithm can derive the IEEE 802.11 protocol close to the theoretical throughput limit.

The growing popularity of wireless networks has led to cases of heavy utilization and congestion. In heavily utilized wireless networks, the wireless portion of the network is a major performance bottleneck. Understanding the behavior of the wireless portion of such networks is critical to ensure their robust operation. This understanding can also help optimize network performance. In [96], they used link layer information collected from an operational, large-scale, and heavily utilized IEEE 802.11b wireless network deployed at the 62nd Internet Engineering Task Force (IETF) meeting to study congestion in wireless networks. They motivated the use of *channel busy-time* as a direct measure of channel utilization and show how channel utilization along with network throughput and good put can be used to define *highly congested*, *moderately congested*, and *uncongested* network states. Their study correlates network congestion and its effect on link-layer performance.

The throughput performance of WLANs is affected by the mobility of the users [97]. The wireless data connections have high bit error rates, low bandwidth and long delays. The physical and MAC layer were fine tuned to improve the performance of WLAN. The performance metrics like slot time, short Inter-frame spacing (SIFS), minimum contention window (CWmin), Fragmentation Threshold (FTS) and Request to send (RTS) thresholds were focused upon to reduce collisions and media access delay. Hence an increase in throughput and channel utilization occurs, which can improve the performance of Wireless networks under heavy load conditions (high BER values).

Another major problem exists in the form of network congestion. To overcome the problem of congestion, Fiber Distributed Data Interface and Asynchronous Transfer Mode type high-performance networks along with the bucket congestion control mechanism were modeled and simulated [98]. The effect of variation in attributes like traffic load on the performance metrics like end-to-end delay and throughput was analyzed. It was shown that the increase in traffic load affects the network performance.
The initial efforts to understand the performance of heavily congested wireless networks is described in a previous paper [99]. My work therein proposes a reliable WLAN model to address the issue of congestion, packet loss rate, packet delay and throughput towards actualizing optimum performance standard under network saturation.

CHAPTER THREE

WIRELESS LOCAL AREA NETWORK (WLAN) MODEL

3.0 Introduction

The performance of a given network can be analyzed using two approaches ï analysis on a real life system and on a model [100]. Analysis on a real-world system is possible, but may have due consequences. In this case, carrying out WLAN performance analysis under saturated traffic loading on a practical network could result in the disruption of network operation. Therefore, such an approach may be costly. As a result of this, a modeling approach was adopted. A model will therefore be designed and implemented using MATLAB block oriented simulation package. Many types of modeling techniques exist; these include descriptive, physical, mathematical, flowchart, schematics, and computer program [100]. There are three basic classifications of models commonly used in communication engineering; they are analytical, graphical and computer program model. The network model for this thesis is computer program model and is based on the adopted WLAN architecture.

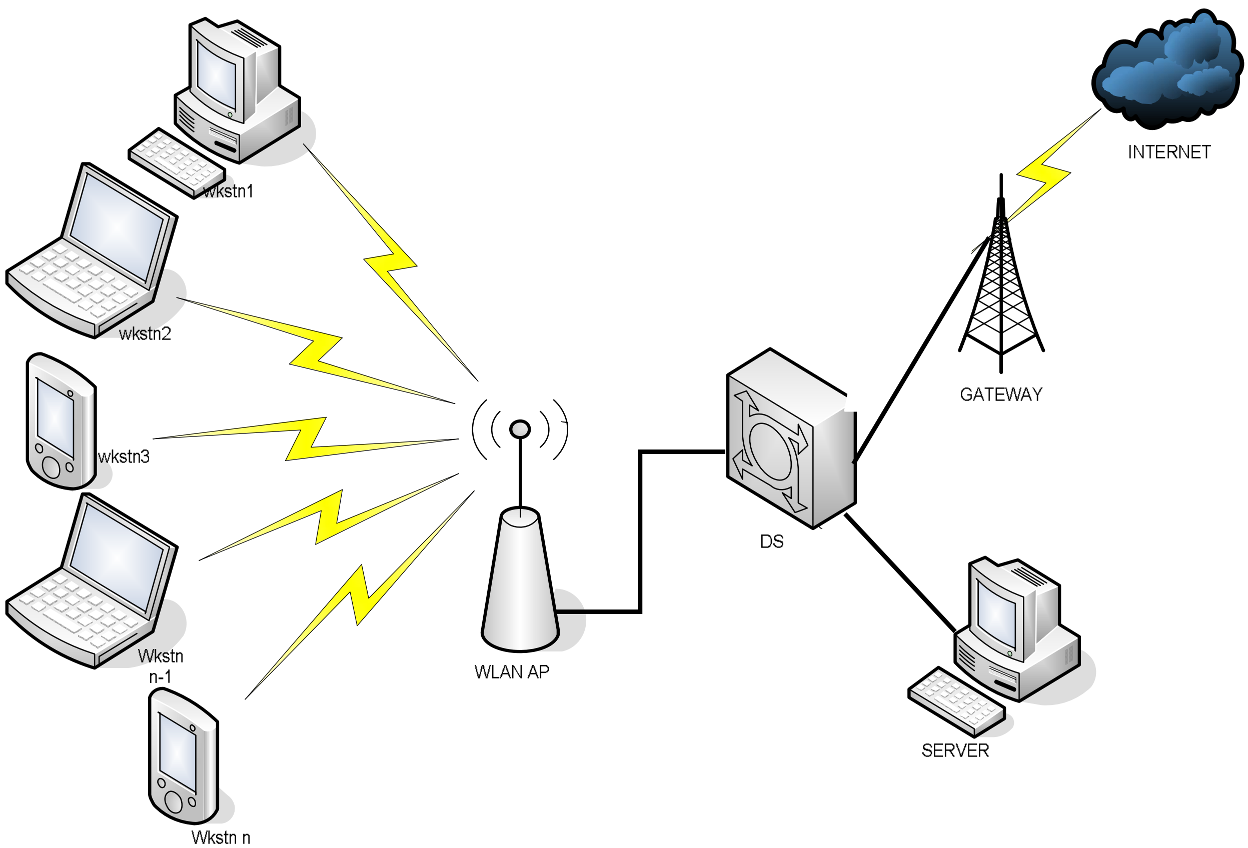
In this chapter, the adopted typical WLAN architecture is presented in figure 3.1. The DCF access mechanism is implemented on MATLAB Simevent Environment as shown on figure 3.2 and figure 4.9.

3.1 Adopted Typical WLAN Architecture

The WLAN architecture intended for infrastructure mode of operation as recommended by IEEE 802.11 standard [2] is adopted for this project as illustrated in figure 3.1. The architecture is comprised of WLAN Access Point (WLAN AP), Distribution System (DS), Server, Very Small Aperture Terminal (VSAT) and the attached Workstations (Wkstn).

In the infrastructure mode, a station needs to join a BSS to communicate. It obtains synchronization information from periodic beacons from the BS. It can either obtain this information by requesting it from the BS (active probing), or it can wait for the periodic beacon from the BS. Before being able to send and receive data, the station has to go through an authentication and association process [3]. The distribution system connects BSS to the Server and the VSAT through the access point and then to the internet.

All components that can connect into a wireless medium in a network are referred to as stations. All stations are equipped with wireless network interface cards. Access points (APs), normally routers, are base stations for the wireless network. They transmit and receive radio frequencies for wireless enabled devices to communicate with. A distribution system (DS) connects access points in an extended service set or connect an access point in a basic service set. The concept of a DS can be used to increase network coverage through roaming between cells. DS can be wired or wireless. VSAT provides access to the internet.



Key:

Wkstn - Workstation

WLAN AP - Wireless LAN Access Point

DS ï Distribution system

VSAT - Very small Aperture Terminal

Figure 3.1 Adopted Typical WLAN Architecture

3.2 WLAN Model

The performance of a WLAN may be defined by the QoS parameters. The QoS parameters considered in the modeling of the WLAN in this project are packet delay, packet loss rate and throughput. These QoS parameters influence the operation of the network and specifically the resource assignment to the traffic load.

The network model was based on an isolated IEEE 802.11b MAC DCF protocol of the network architecture which operates on the principles of CSMA/CA. The figure 3.2 represents the network model.

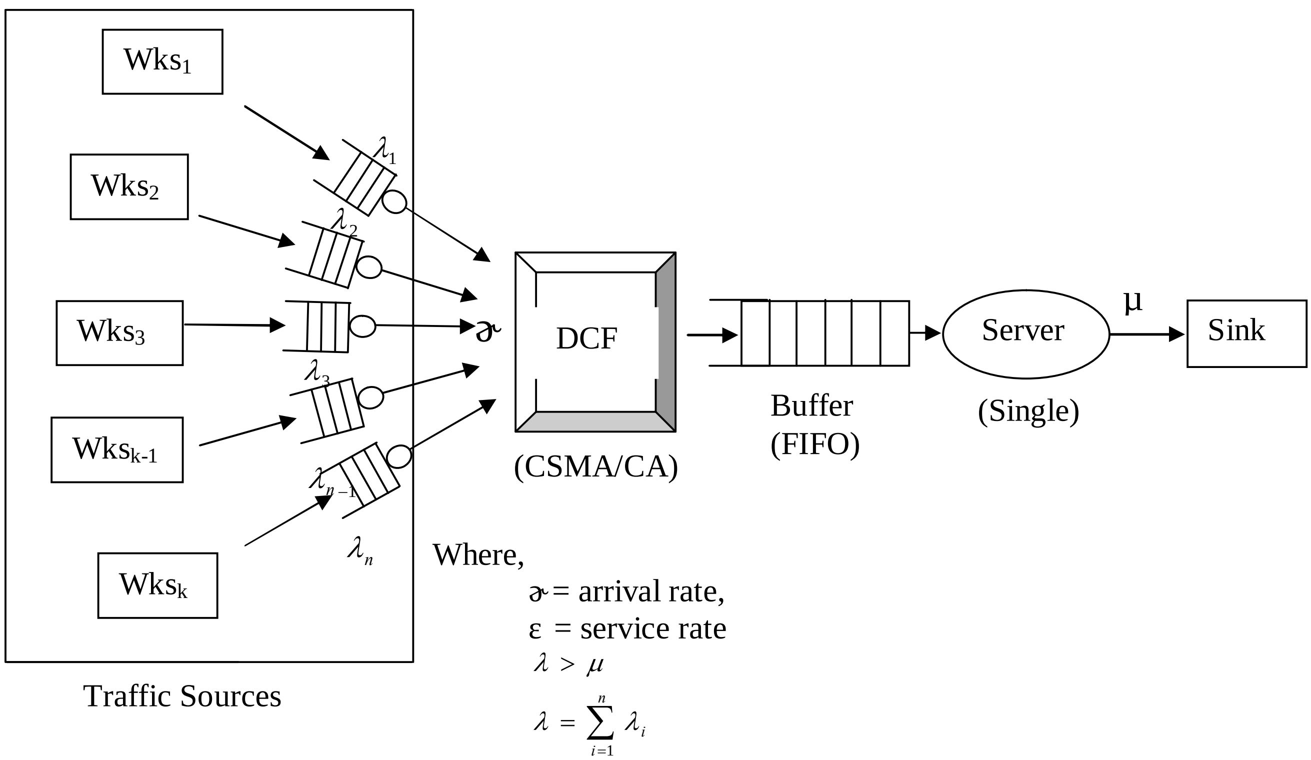


Figure 3.2: WLAN Model

Also, the entire communication network has severally been shown to be modeled as a single network node [102], [103]. The WLAN model was defined to simply consist of workstations (traffic source (generators) and sinks), MAC DCF communication (CSMA/CA) protocol, single server and a buffer system. The source generators were developed on the basis that packet arrival process is randomly distributed and Poisson in nature with intensity. Also, random exponentially distributed packets lengths were implemented at the WLAN access point. The rate of packet transmission through the wireless medium was represented by μ (Bps).

The MAC DCF communication protocol was employed in the simulation modeling in order to ensure that the arriving traffic has equal probability of being served in a random manner.

The WLAN server was modeled based on the principle of CSMA/CA. The WLAN server serves packets for a period through the output port on a sequence of First-In-First-Out (FIFO). The pattern of services follows exponential distribution. The server utilization was enhanced by the application of buffering system that controls packet arrivals from the sources. Collisions occur when two sources send data at the same time. The workstations use random back-off procedure to avoid probability of two or more workstations accessing the channel at the same time. The traffic intensity and the traffic trends of the WLAN were probed during and after simulation time.

The sink terminates packets transmitted from the source generators via the single server. The sink has stop time attached to it. The stop time gives the delay or time elapsed of the packets transmitted.

Probes were strategically implemented in the model to gather the necessary information (data) on the desired quality of service (QoS) parameters as shown in figure 4.9.2. In other words, the WLAN QoS parameters such as packet loss rate, packet delay and throughput are also calculated and they can be displayed graphically or numerically.

3.2.1 Traffic Model

The design of robust and reliable networks and the provisioning of quality services do not go without challenges. One of paths to achieve this goal is to develop a detailed understanding of the traffic characteristics of the network.

Analysis of the traffic provides information like the average load, the bandwidth requirements for different applications, and numerous other details. Traffic models enables network designers to make assumptions about the networks being designed based on past experience and also enable prediction of performance for future requirements [100].

Data network traffic model was well characterized using ON-OFF process mainly because it reflects the notion of self-similarity [104], [105]. Therefore, in this thesis, traffic modeling was based on the ON-OFF process. The packet generated during the ON period is random and is assumed to have been distributed following Poisson distribution law [100]. The ON and OFF intervals distribution follow the exponential service distribution [100]. The modeling of the data traffic consists of two parts-the arrival process at the access point and the traffic within the network [101]. Figure 3.3 below represents the Traffic Model.

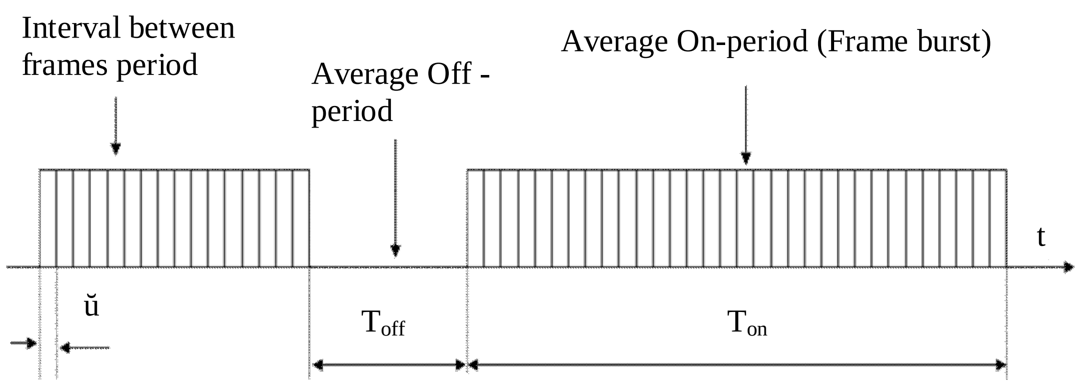


Figure 3.3: Traffic Model

In this thesis, it is assumed that the packet arrivals at the access point follow the Poisson process or distribution with average arrival rate. The source generators were intended to generate bursty packets with fixed length randomly.

For most of the data applications, the arrival process has been modeled using the ON-OFF process or the Poisson process. The activity phase model differs from one application to the other. The traffic model was designed and translated into computer simulation model using the MATLAB block oriented simulation package. The traffic model is translated into the simulation model in figure 3.3

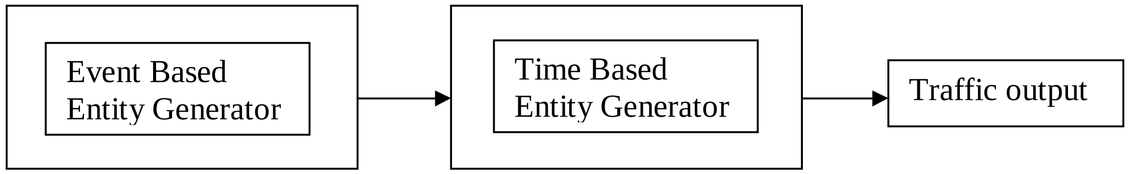


Figure 3.4: ON-OFF Traffic Generator [103]

Event-based entity generator blocks were employed and the distribution needed for the model specified to be Poisson. Although it is subject to change from the drop ï down menu, it could be binomial, Gamma or lognormal traffic distribution. The generator blocks (event based) in each case, was connected to time based entity generator which produces the required output traffic [103]. Therefore, the workstation traffic generator in the network model in each case encompasses both the event-based entity generator and the time based entity generator of the traffic model.

3.2.2 CSMA/CA As Realized In the Model.

This section summarizes the operation of the IEEE 802.11 Distributed Coordination Function (DCF) protocol. The scope of the protocol description is limited to aspects that are essential for a better understanding of the operation and functions discussed in chapter 2. The IEEE 802.11b DCF protocol is designed to manage and reduce contention in the wireless communication medium in a fair manner. The algorithm used by the protocol is known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). According to the algorithm, when a node wants to transmit a frame, the station is required to first sense if the communication medium is busy. If it is, the station waits for a specific period of time known as the Back-off Interval (BO) and then tries to sense the medium again. If the channel is not busy, the station transmits the frame to the intended destination. The destination sends an acknowledgment message to the source of the frame upon successful reception of the frame. If the source does not receive an acknowledgment within a specific period of time, it tries to re-send the frame. Broadcast messages do not require the destination to send an acknowledgment of reception. In other words, Broadcast packets are not acknowledged. Also, retransmissions are limited to a maximum number of tries, which is 4 by default, after which a packet is dropped. Figure 3.5 shows this scheme.

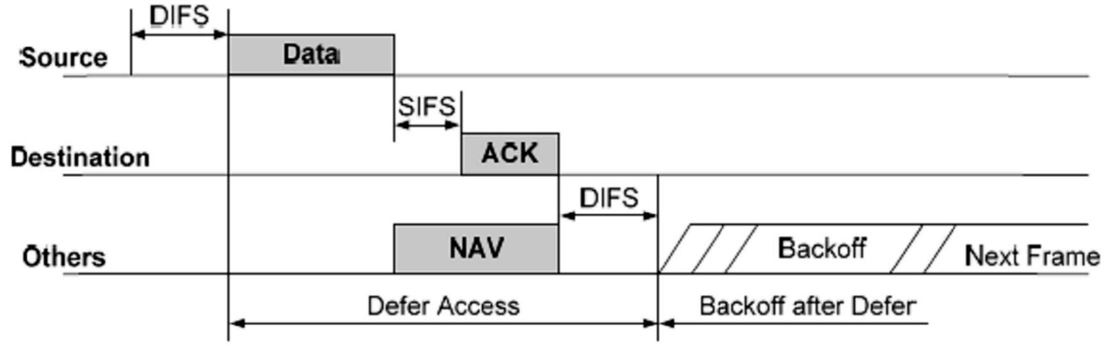


Fig. 3.5: Basic access mechanism in DCF [33]

3.2.3 Queuing Model

Many applications are sensitive to end-to-end delay and queue characteristics such as average queue length, waiting time, queue blocking probability and service time. Thus, it is necessary to investigate the queuing modeling and analysis for wireless LANs in order to obtain the required performance metrics. A queue model can be characterized by the arrival process and the service time distribution with certain service discipline. The packet transmission process at each station is modeled as a single ‗server' simply because the entire communication network has severally been shown to be modeled as a single network node. The buffer size at each station is K and the service discipline is based on FIFO (First in First Out) procedure. Thus, the queuing model for each station is modeled as an M/M/1/K/FIFO when Poisson arrivals of packets are assumed.

In other words, the Kendall's notation is standard for the specification of queuing system and it is also used to express the model. Generally, it is given in this form.

M/M/C/K/N/Z

Where M stands for - Inter arrival time distribution. Arrival is markov, M

M - Service discipline. Departure is also markov, M.

C - Number of servers is 1

K - System capacity (maximum queue length of buffer size)

N - Number of potential customers in a given source population

Z - The queuing discipline (FIFO)

Hence for Kendall, i have: M/M/1/K/FIFO.

3.3 Timing Sequence:

The figure 3.6 below shows the timing sequence of frames and delays used by the IEEE 802.11 protocol [106]. The delays that precede and follow the transmission of control frames (RTS, CTS or ACK) or data frames are called Inter-Frame Spacing (IFS). Before the transmission of an RTS, stations are required to wait for a time equal to the Distributed IFS (DIFS). On the other hand, a destination station is required to send a CTS or an ACK frame within a Short IFS (SIFS) amount of time after the reception of RTS and DATA frames from the source, respectively. If the sending station senses the medium busy during the DIFS interval, it chooses a BO from a range and then an associated timer starts counting down to zero. If the channel is sensed busy during the BO, the sending station stops the countdown and resumes the countdown when the channel is idle again. When the timer counts down to zero the sending station attempts to transmit the frame, if the channel is idle for a period of DIFS. If the channel is busy, another BO is chosen from an exponentially increased range and the process repeats.

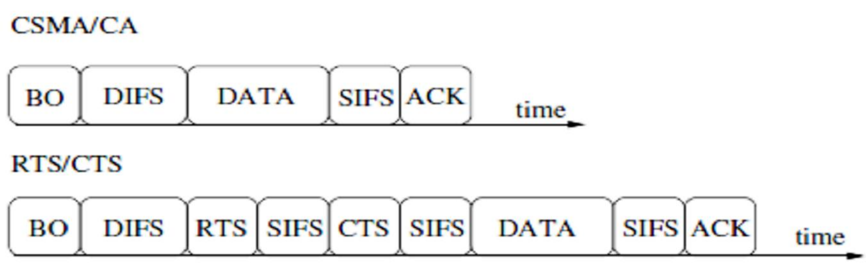


Figure 3.6: Frame and delay sequence diagram for CSMA/CA and RTS.CTS [106].

CHAPTER FOUR
SIMULATION RESULTS AND RESULTS ANALYSIS

4.0 Introduction

The model presented in chapter three (figure 3.2) is intended to be simulated under varying and different traffic conditions. The traffic considered includes Lognormal, Binomial, and Bernoulli traffic distributions. The implication is that all users always have packets available for transmission and enough to flood the network. Throughput under saturated traffic situation is the upper limit of the throughput achieved by the system, and it represents the maximum load the system can carry in the stable condition.

In this chapter, the model, figure 3.2 was converted into MATLAB Computer Simulation Model as presented in figure 4.9 on page 80. The model was simulated in order to determine the relationships between varying traffic intensity, delay, loss and throughput.

4.1 Computer Simulation Model

Computer simulation is a very useful technique that allows us to model different kinds of systems including network computers leveraging inherent characteristics of computers such as its computational power. In this manner, we can simulate and experiment with multiple real or future scenarios in order to compare and develop solutions to improve systems performance. Computer Simulation is a powerful and important tool because it provides a way in which alternate designs, models and methods can be evaluated without having to experiment on a real system, which could be costly or simply impossible because elements may not exist right now, but can be built in the future if feasible. Network designers and developers want assurances that their designs will achieve the desired goal prior to actual production and deployment. Network operators want assurances that the introduction of a new device type into their networks will have no unintended consequences. The available methods that provide these types of assurances include analysis, prototype development, empirical testing, low-scale trial deployments, modeling and simulation (M&S) [107]. Modeling and simulation (M&S)

are critical elements in the design, development, test and evaluation (T&E) of any network product or solution. While not sufficient unto themselves, M&S are particularly valuable methods due to the fact that they (M&S) are, in most cases, the only viable methods to gain insight into the performance of the eventual product or solution in a large-scale environment prior to actual deployment. They are used for design trade studies and deployment decisions. A simulation represents the execution of a model. It consists of a typical set of inputs, algorithms and routines that model the system behavior and a set of outputs that provide insight into the system performance. The systems can be as simple or as complex as the user desires [108].

Modeling and simulation (M&S) methods are employed by scientists and engineers to gain insight into systemsô behavior that can lead to faster product time-to-market and more robust designs. These advantages come at the cost of model development time and the potential results are questionable as a result of the fact that the model represents limited attributes of the actual system. M&S techniques are used to characterize complex interactions and performance at various layers of the protocol stack. Therefore, the computer simulation realized from figure 3.2 is as shown in figure 4.9.

4.2 Parameters Considered for Simulation

The key parameters considered for the modeling of WLAN access point under network saturation are the packet loss rate, mean packet delay and network throughput.

In this thesis, MATLAB is used to implement IEEE 802.11b MAC DCF Saturated traffic loading. The model is converted into a computer simulation model using MATLAB block oriented simulation package. Insight into the systemôs performance was provided by the probes strategically positioned to collect data for the calculation of the mean packet delay, and packet loss rate as expressed in equations (8) and (9) above. Byung-jack wak etal defined medium access delay as the time taken from the moment a packet is ready to be transmitted to the moment the packet starts its successful transmission [59]. Transmission of bits from workstations (sources) to the destination (sink) via the medium access-CSMA/CA controller was observed for n intervals and the average delay was taken. Network packet delay was considered as being comprised of packet access delay, propagation delay and processing delays. The average delay was processed as expressed in equation (8) below [4], [18], [19]. Network packet loss was considered to consist of packet loss due to access blockage, collision, packet unacknowledgement and buffer overflow. The network packet loss rate is defined as the ratio of the number of packets lost to total number of packets offered for transmission during the simulation period. The network packet loss rate formula is depicted in the equation (9) below [4], [18], and [19].

$$\text{Average delay} = \frac{\sum_{i=1}^{M} \text{delay}_i}{M} \quad - \quad - \quad - \quad - \quad - \quad - \qquad (1)$$

Where,

Delay $_i$ = Time taken to transmit bits from UTs to medium access controller +

Time taken to send the bits from medium access controller to the destination +

Time taken to retransmit bits due to collision

= Time taken to offer bits ï time taken to serve the bits

M = Total number of packets transmitted.

$$\text{Average loss} = \frac{\text{Total loss}}{\text{K}} = \frac{\sum_{i=1}^{K} loss_i}{\text{K}} \quad - \quad - \quad - \quad - \quad - \quad - \qquad (2)$$

Where,

K = Total number of packets offered for transmission.

Loss$_i$ = Total offered packets - Total served packets - Total packets pending

= Total packets that collided + Total unacknowledge packets retransmitted

$$Loss\ rate = \frac{\sum_{i=1}^{K} \text{loss}_i}{\text{Total packets offered}} \quad - \quad - \quad - \quad - \quad - \quad - \qquad (3)$$

Traffic intensity can be defined as the total number of simultaneous packets in progress at a given instant (time). It is measured in Erlang.

Traffic intensity, a = ঌ * t - - - - - - - (4)

Where;

ঌ = Arrival rate = 45 per minute.

t = holding time = 2.35s.

Arrival rate = No of arrivals/ time

Arrival rate = 45/60 =0.75 per sec.

Traffic intensity = 0.75 *2.35 = 1.763 Erlang.

So, the traffic intensity for 1 data source, a = 1×1.763 = 1.763 Erlang.

The traffic intensity for n data source, a = n ×1.763 =1.763n Erlang.

In the analysis, it is assumed that traffic intensity and number of workstations (data sources) follows the same pattern.

Throughput is defined as the number of bits passing through a point in a second or it is defined as the number of packet passing through the network in a unit time. [4]

Throughput =Total number of bits offered by Wktns ï number of bits pending ï number of bits dropped.

= (bits_offered) - (bits_pending) - (bits_dropped) - - (5)

4.3 Modeling Assumptions and Configuration

A simulation model has been developed using MATLAB block oriented simulation package to study the network throughput, mean packet delay, and packet loss rate performance of the IEEE 802.11b DCF protocol.

To simplify the simulation model, a perfect radio propagation environment, in which there is no transmission error due to interference and noise on the system, was assumed. The following assumptions were made regarding the data traffic:

1) No hidden stations and exposed station problems are considered.

2) The network consists of a finite number of stations, *n*.

3) Each station always immediately has a packet available for transmission (saturation conditions).

4) Packet Generation**:** Streams of data packets arriving at stations are modeled as independent Poisson processes with an aggregate mean packet generating rate » packets/s.

5) Packet Size: Packets are of fixed length. The time axis is divided into slots of equal length, and the transmission of one packet takes one slot time.

6) Buffer size: Each station in the network has a buffer, modeled as a buffer of finite size, to store packets. This assumption means that packets can be lost due to buffer overflow when the system is under unmanageable input loads.

7) Destination addresses: it is assumed that packet arrival at a station is uniformly destined to N ï 1 other station in the network.

Table 4.1: Parameters used in simulation and calculations

Parameter	Values
Data rates	1, 2, 5.5, 11 Mbps
SIFS	10 ε sec
DIFS	50 ε sec
Slot time	20 ε sec
Packet size	1500 bytes
Traffic distribution	Poisson (Validation), Lognormal, Binomial, and Bernoulli
PHY modulation	DSSS
CWmin	31
CWmax	1023
Simulation time	60 seconds

Table 2 above lists the parameter values that was used in the simulation, The simulation was run for 60 seconds in other to achieve the required stability during which throughput and mean packet delay were computed for varying number of workstations and network resources (medium transmission rate - bandwidth). The workstations generate packets with exponential time distribution; the exponential parameter has 0.15 mean values. Network loading was varied from 5 to 100 workstations. The workstations have a finite buffer capacity while the transmission rate was varied from 1Mbps to 11Mbps. the figure 4.1 below presents the pattern of traffic generation that was employed for the simulation. The pattern was from a single source and depicts a typical bursty ON-OFF packet generation. These arrival patterns are random in nature and they depict real time scenarios.

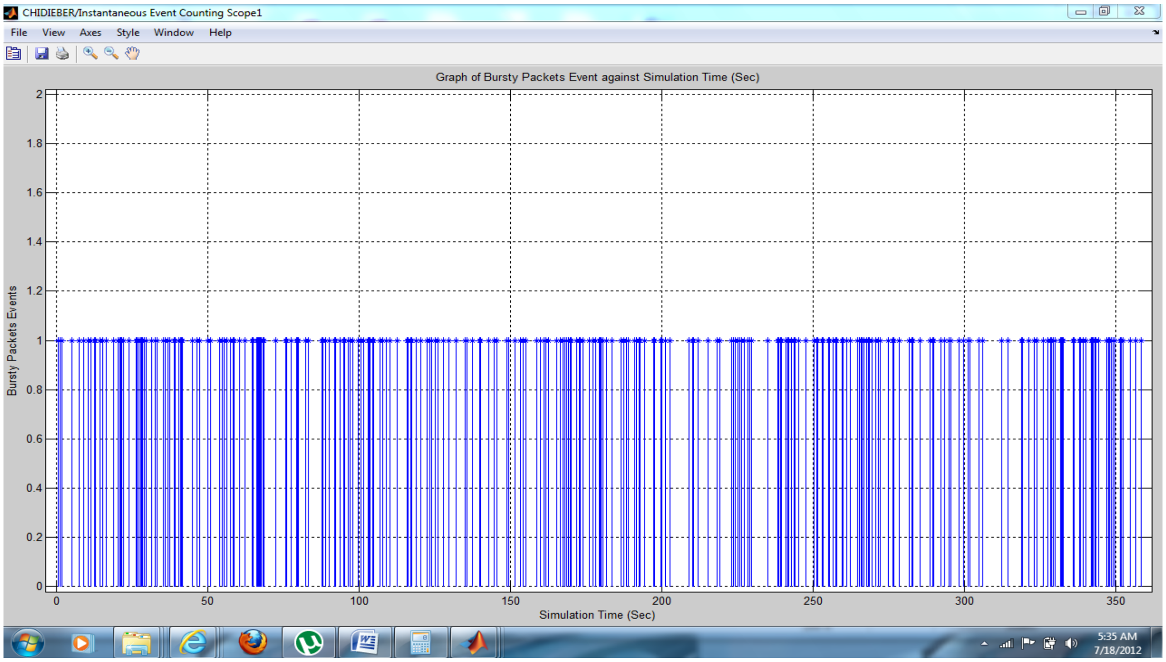


Figure 4.1: Bursty Packet arrivals vs. simulation time generated from MATLAB Simulink environment.

4.4 Model Validation.

The accuracy of the model presented was verified using MATLAB simulation results. The network parameters used in these results are shown in Table 2 above, and it is assumed that every station was able to listen to each other and there are no hidden terminals in the systems. To validate the model, we compared our proposed model simulation results with the ns ï 2 simulation results of [6] obtained from IEEE 802.11 DCF. A close match between MATLAB simulation results and Model [6] simulation results validates our models. The simulation results of the IEEE 802.11b protocol are discussed next.

4.5 Simulation Results

In this thesis, three important network performance metrics were considered: (1) Network throughput; (2) mean packet delay, and (3) packet loss rate for both individual stations and the overall network. The throughput (measured in Mbps) is defined as the fraction of the total channel capacity that is used for data transmission. The mean packet delay at station is defined as the average time (measured in seconds) from the moment the packet is generated until the packet is fully dispatched from that station. A packet arriving at station *i* experiences several components of delay including queuing delay, channel access delay (i.e., contention time) and packet transmission time. Fairness in channel access might mean that all active stations on the network have an equal opportunity in accessing a shared wireless channel for packet transmission.

In this section, the simulation results obtained from simulation runs for the IEEE 802.11b were presented. The performance of the IEEE 802.11b by considering infrastructure networks with Poisson traffic distribution, operating under uniform loads (in which the packet arrival rate is same for all stations) was examined. Poisson packet arrivals and a packet length of 1,500 bytes (a realistic figure close to the wired Ethernet protocol) were also considered. The simulation results report the steady-state behavior of the network and have been obtained with the relative error less than 15%, at the 85% confidence interval for figure 4.2 below. (For Validation)

The need for communication networks capable of providing an ever increasing spectrum of services for efficient techniques for the analysis, monitoring, evaluation and design of the networks. Analyses are perpetually faced with ever increasing user demands and uncertainty about the evolution of the network systems. To meet the requirements of users, three different traffic distributions were employed, in order to ascertain the best traffic distribution for the proposed model. They are Lognormal, Binomial, and Bernoulli traffic distribution. Since, Traffic Analysis is a vital component to understand the requirements and capabilities of a network. Consequently, the study of traffic models to understand the features of the models and identify eventually the best traffic model, for a concerned environment has become a crucial and lucrative task. Good traffic modeling is also a basic requirement for accurate capacity planning. The result of the three traffic distributions, shows that lognormal traffic distribution has the best performance in terms of high throughput, low packet delay and low packet loss rate whereas Bernoulli traffic distribution has the least performance with its QoS parameters as follows; low throughput, high packet delay and high packet loss rate and Binomial traffic distribution is slightly above Bernoulli traffic distribution in terms of performances.

Subsequently, comparing critically the maximum throughput point and the minimum throughput point of the IEEE 802.11b, for the three traffic distributions at different data rate, especially at 11Mbps. As seen in Fig. 4.3, the maximum achievable throughput is 4.6 Mbps for N = 5 station at 80% offered load. This throughput is around 42% of the maximum theoretical bandwidth of 11 Mbps. The minimum throughput is 1.7 Mbps which is around 15% of the maximum theoretical bandwidth of 11 Mbps for N= 80 stations at 80% offered load for lognormal traffic distribution. Whereas in figure 4.3.1 and figure 4.4, where Binomial and Bernoulli traffic distribution results were depicted, there maximum and minimum achievable throughput especially at 11Mbps are slightly below when compared to that shown in figure 4.3. under this circumstancesq, comparism were made, for both the packet delay and packet loss rate, and then it was realized that lognormal traffic distribution has a more considerable performance when compared to Binomial and Bernoulli traffic distribution.

In other words, lognormal traffic distribution was used, for the proposed model analysis because of its high performance amongst the three traffic distribution listed above.

4.6 Throughput Result Analysis:

4.6.1 Effect of workstations on network throughput performance:

In Fig. 4.3, network throughputs versus number of workstations for infrastructure networks were plotted. Considering the lognormal traffic distribution, which has the best performance and slightly different behaviour from the three distributions. it showed that throughput is higher and increases with continous increase in data rate and vice versa but decreases slightly with increase in the number of workstations from 5 ï 80 workstations at 1, 2, 5.5, 11 Mbps data rate. In order words, it was observed that the network throughput decreases with corresponding increase in the number of workstations, from N = 5 to 80 stations at 80% offered load. It was also observed that the network throughput under the infrastructure network is reasonable, especially for N > 30 stations. Under the infrastructure network, the throughput is saturated at around N Ó 80 stations. Now let us examine the maximum and minimum throughput of the IEEE 802.11b as stated earlier. As seen in Fig. 4.3, the maximum achievable throughput is 4.6 Mbps for

N = 5 station at 80% offered load. This throughput is around 42% of the maximum theoretical bandwidth of 11 Mbps. The minimum throughput under the infrastructure network is 1.7 Mbps which is around 15% of the maximum bandwidth of 11 Mbps for N= 80 stations at 80% offered load. Figure 4.3 illustrates that the throughput performance strongly depends on the number of stations or traffic intensity for all data rates when basic access mechanism is employed. On the other hand, if basic access is used, the throughput decreases as the number of stations increases because more collisions take place at that point. Moreover, the throughput is reduced when the data rate increases. The situation is explained by considering that the time spent for frame transmission is decreased as the data rate increases but the time overhead spent on DIFS, SIFS and the back off delay remains the same.

In other words, the data rate of a signal is based on the time it takes to send information and overhead data bits when transmitting. Therefore, the aggregate data rate (throughput) is actually much lower because of delays between transmissions.

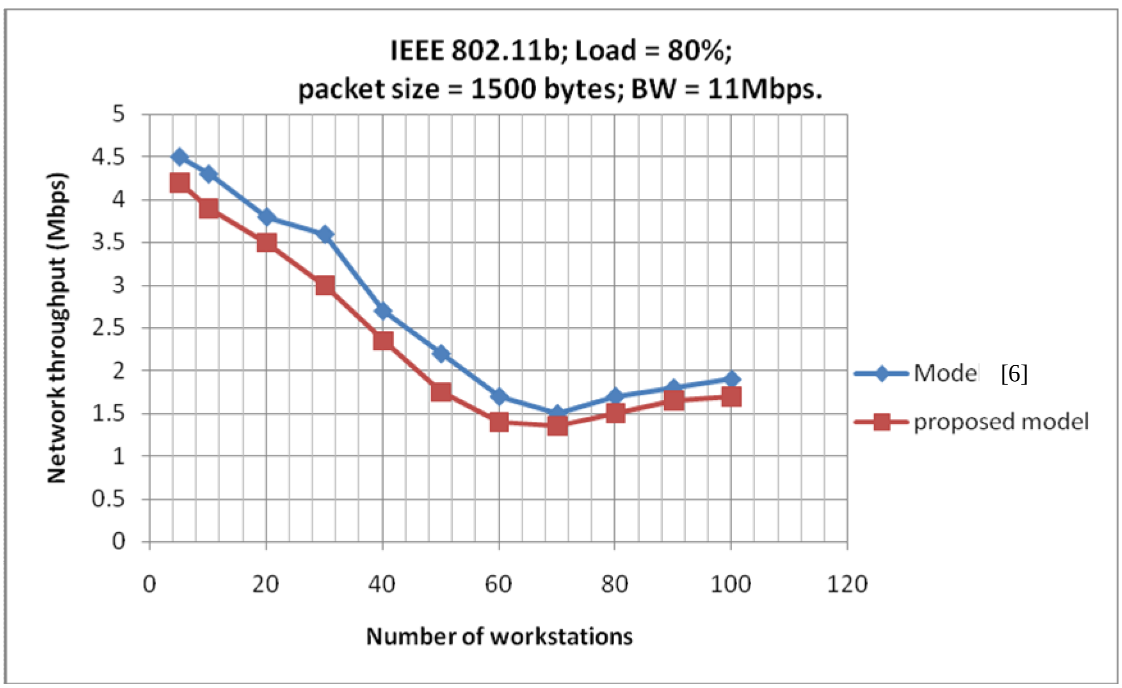


Figure 4.2. Effect of number of workstations on network throughput performance of IEEE 802.11b infrastructure networks. (load = 80%) and comparism between the proposed model and Model [6] at 11Mbps data rate using Poisson traffic distribution.

Fig.4.2. compares my proposed model simulation result and Model [6] simulation results of IEEE 802.11 DCF, by plotting the network throughput against number of

workstations at 11Mbps packet data rate. In this graph, at minimum number of stations and low traffic, the proposed model network throughput significantly increases under network load of 80%, whereas at medium to maximum number of stations and high traffic, the proposed model network throughput significantly decreases under network load of 80%. In other words, the simulation results report the steady-state behavior of the network and have been obtained with the relative error less than 15%, at the 85% confidence interval.

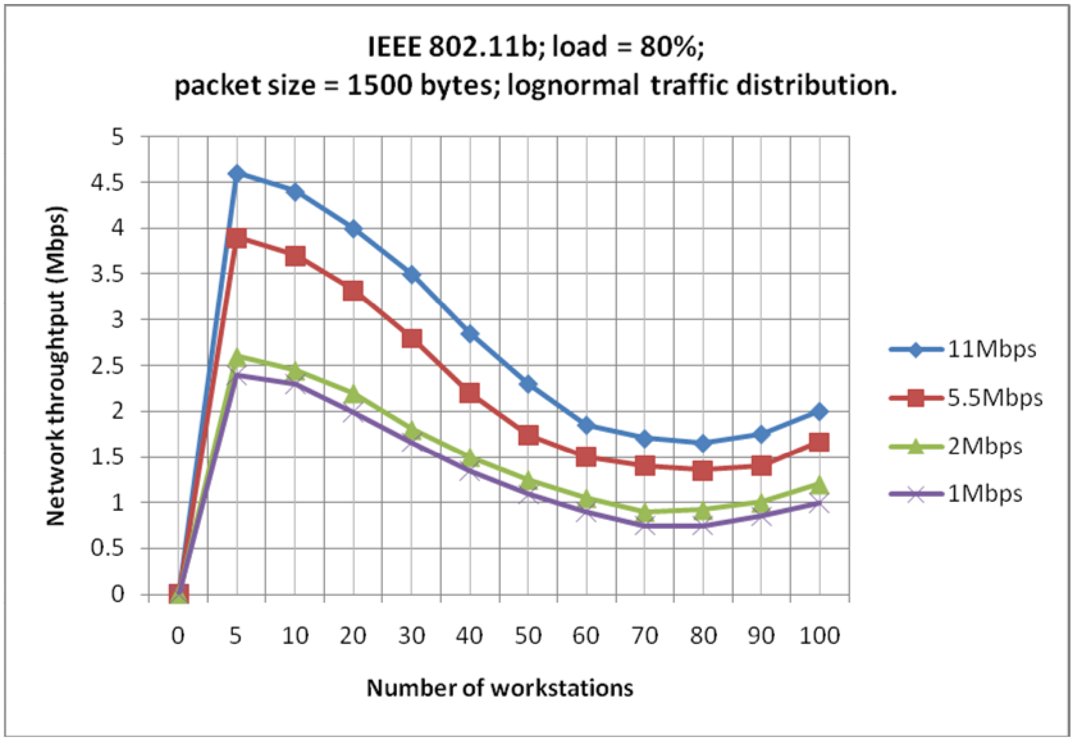


Figure 4.3: Network throughput for basic access mechanism as a function of the number of workstations for four different data rate using lognormal traffic distribution

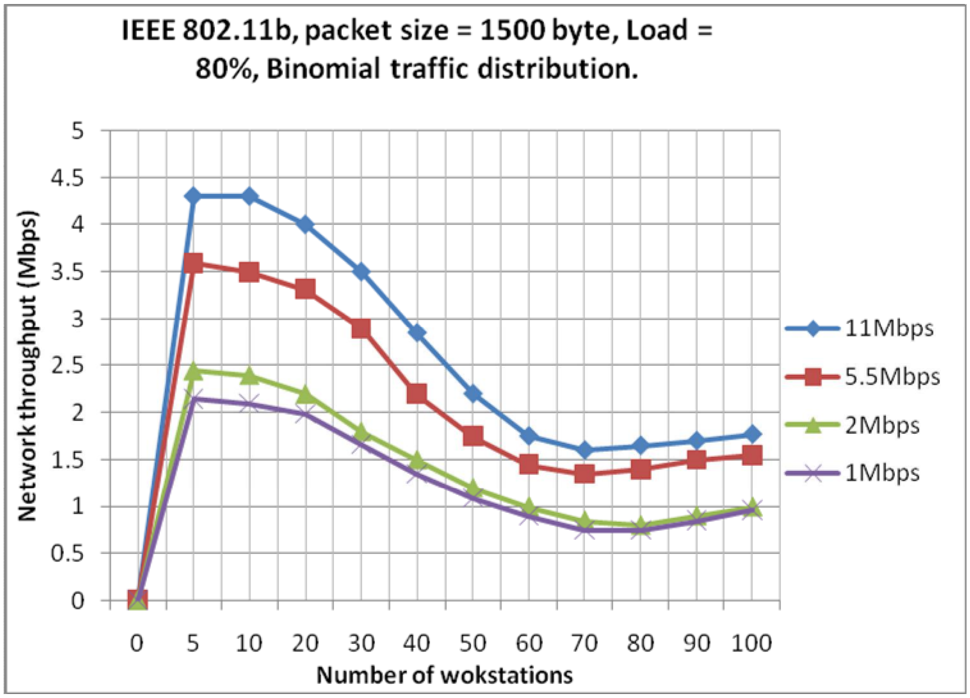


Figure 4.3.1: Network throughput for basic access mechanism as a function of the number of workstations for four different data rate using binomial traffic distribution

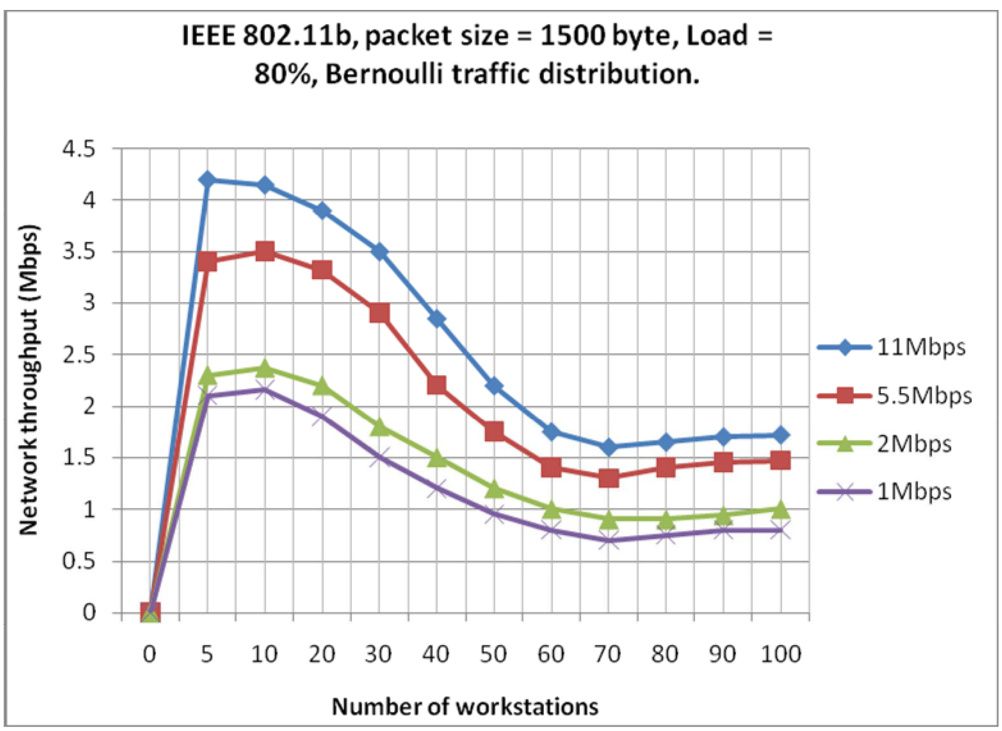


Figure 4.4: Network throughput for basic access mechanism as a function of the number of workstations for four different data rate using Bernoulli traffic distribution

4.6.2 Throughput performance of selected stations: In this thesis, an IEEE 802.11b infrastructure network with N = 1, 5, 10, 20 and 40 workstations was considered. As seen in Fig.4.3, the throughput performance of the IEEE 802.11b decreases significantly with increase in the number of workstations on the network, especially for N = 10 to 40 stations. Also In fig. 4.5., it was observed that throughput increases sharply with increasing offered load from 10 to 40%. For the offered load greater than 40%, the increase in throughput is not very significant. The main conclusion drawn from Figures 4.3 and 4.5 is that the network throughput performance under the IEEE 802.11b WLAN deteriorates for N > 10 stations, especially at medium-to-high offered loads. This throughput deterioration is due to the wastage of transmission capacity in the back off state of IEEE 802.11b protocol.

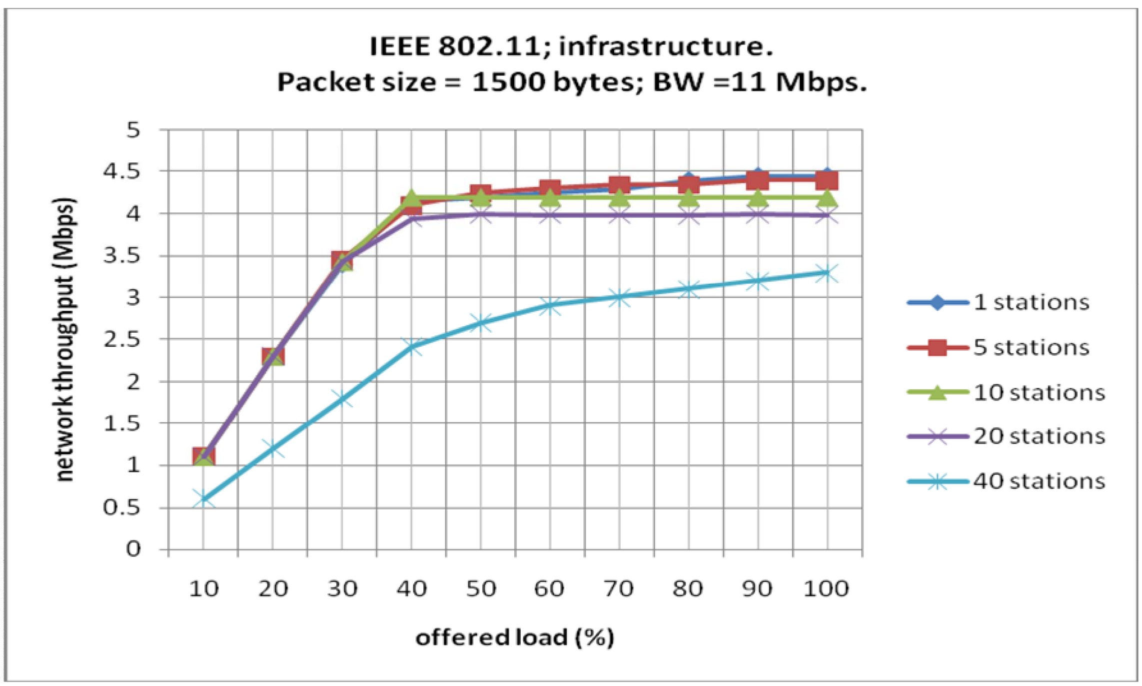


Figure 4.5. Effect of increasing number of workstations on network throughput performance of IEEE 802.11b infrastructure network.

4.7 Delay Result Analysis:

4.7.1 Effect of workstations on network mean delay performance: In Fig. 4.7.2, network mean packet delays versus number of workstations was plotted. It was observed that under infrastructure networks, the mean packet delay increases with corresponding increase in the number of workstations for N Ó 10 stations for infrastructure network, operating at 80% offered load. It was also observed that mean packet delay under the infrastructure network, especially for N > 10 stations, has more delay, and that average delay decreases with corresponding increase in data rate and vice versa.

In figure 4.6, 4.7, 4.7.1, and 4.7.2, when critically examined, it was found that lognormal traffic distribution possesses a better performance when compared to Binomial and Bernoulli traffic distribution, in the sense that the delay for lognormal traffic distribution gradually increases with corresponding increase in the number of workstations and intensity of the traffic, at different data rate. Specifically, at data rate = 1Mbps, the delay for lognormal traffic distribution gradually increases from 110ms to 390ms with corresponding increase in the number of workstation from 10 to 60 workstations, Whereas the delay for Binomial and Bernoulli traffic distribution follows the same patterns but at different delay levels.

Also, the maximum and minimum delay of the IEEE 802.11b was examined. As seen in Fig. 4.7.2, the maximum achievable delay is 300 ms for N = 100 station at 80% offered load. While the minimum delay under the infrastructure network is 40 ms for N = 10 stations at 80% offered load and so on. The main conclusion drawn from Fig. 4.7.2 is that mean packet delay performance of IEEE 802.11b WLAN deteriorates with increase in the number of workstations on the network, especially at high offered load. Therefore, the IEEE 802.11b WLAN may not be a suitable standard for real-time applications (e.g. multimedia communication) because the mean packet delay is very large for N Ó20 stations at high traffic loads. The reason is that the frame delay in each station originates from the back off defer periods in a significant portion, as well as from the periods when the station participates in collisions. Also, it is shown that Data rate mostly affects the delay performance of a WLAN. The higher the data rate, the lower the delay when sending data from one point to another. Subsequently, higher data rates can increase the capability to support a larger number of users. Data rate alone is not a good measure for the performance of the system.

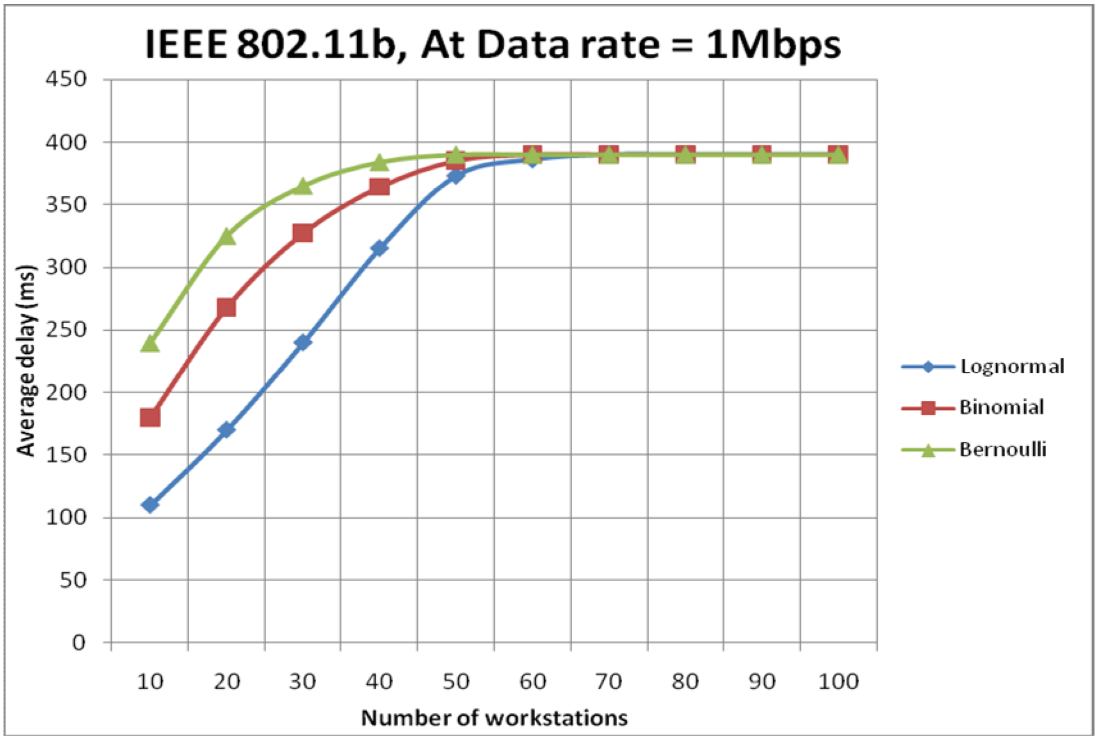


Figure 4.6. Effect of increasing number of workstations on delay performance of IEEE 802.11b network (load = 80%) and at different traffic distribution using 1 Mbps data rate.

Considering the lognormal traffic distribution, which has the best performance and slightly different behaviour from the three distributions. It was showed that the mean packet delay increased continously at medium traffic load from 10 ï 70 workstations at both 5.5 and 11 Mbps and at 1 and 2 Mbps, mean delay increased from 10 ï 60 workstations and 10 ï 70 workstations respectively, whereas at high traffic load, the mean delay at different data rate behave alike from 70 ï 100 workstations at 11 Mbps, 80 ï 100 workstations at 5.5Mbps, and 60 ï 100 workstations at 1 and 2 Mbps.

Figure 4.7. Effect of increasing number of workstations on delay performance of IEEE 802.11b network (load = 80%) and at different traffic distribution using 2 Mbps data rate.

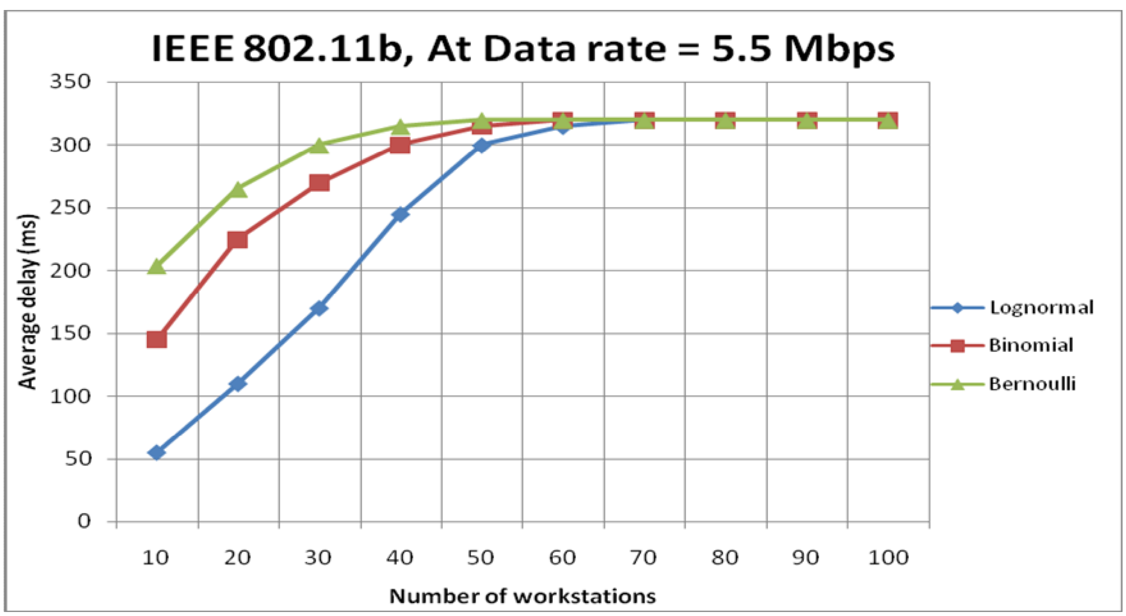


Figure 4.7.1. Effect of increasing number of workstations on delay performance of IEEE 802.11b network (load = 80%) and at different traffic distribution using 5.5 Mbps data rate.

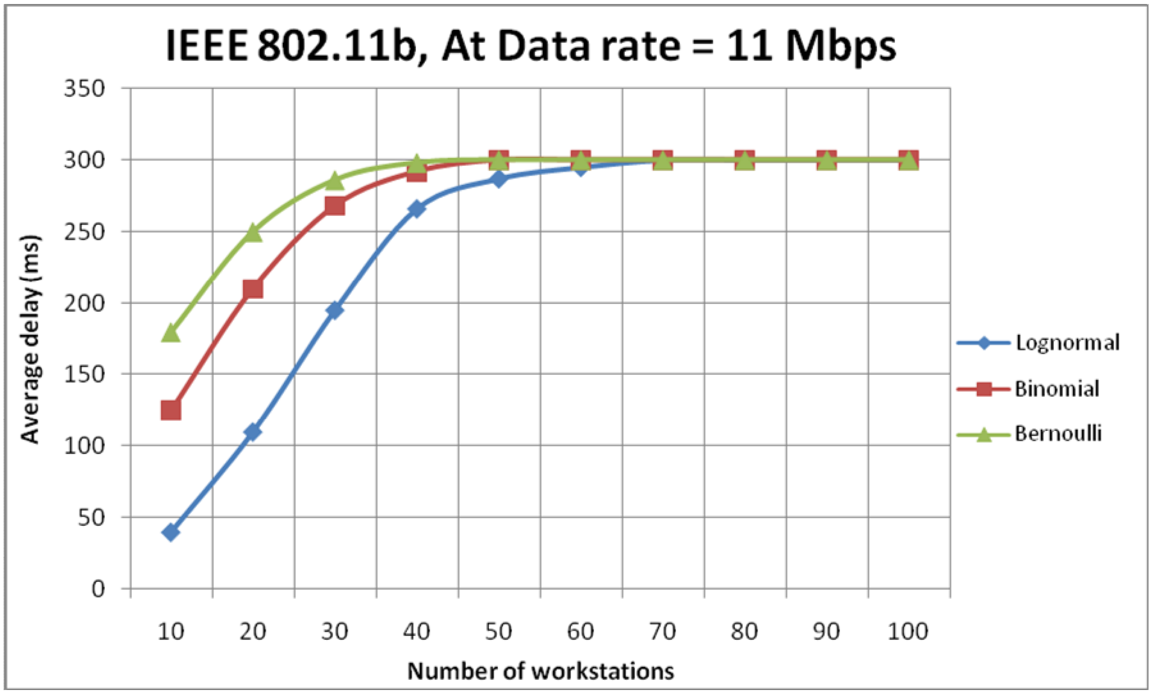


Figure 4.7.2. Effect of increasing number of workstations on delay performance of IEEE 802.11b network (load = 80%) and at different traffic distribution using 11 Mbps data rate.

4.8 Packet Loss Rate Result Analysis

Figure 4.8 below depicts the relationship between packet loss rate and number of workstations; it shows that increase in the network traffic loadings has no immediate effect on the packet loss rate performance. For the different data rates up to 40 workstations. The number of workstations that may be allowed into the basic service vicinity at zero packet loss rate increases with increase in the data transmission rate. It was showed that at 40 workstations and above, the packet loss rate at 1 and 2 Mbps data rates increases, with further increase in the number of workstation, whereas when the number of workstation is at 60, packet loss rate gradually increases at both 5.5 and 11 Mbps. The above statement proved that packet loss rate increases with decrease in the data rate and decreases with increase in data rate. But increases in the transmission rate values beyond 5.5 Mbps could not result in further creation of more number of workstations within the BSV at zero and unity packet loss rates. The reason being that at 5.5 Mbps transmission rate and above, buffer occupancy remained constant for all traffic loading. Subsequently, the above recorded maximum number of workstations for given data rate values may be exceeded if packet loss rate greater than zero and unity is permitted in the network. It was also observed that packet loss rate under the infrastructure network, especially for N Ò 40 stations, has no loss recorded. Also, the maximum and minimum loss rate of the IEEE 802.11b was examined. As seen in Fig. 4.8, the maximum achievable loss rate is 0.0006 for N = 100 station at 80% offered load. The minimum loss rate is 0 for N= 10 stations at 80% offered load.

The main conclusion drawn from Fig. 4.8 is that network packet loss rate performance of IEEE 802.11b WLAN deteriorates with increase in the number of workstations on the network, especially at high offered load. The reason is that the packet loss rate in each station originates from the buffer overflow and, as well as from the periods when the station participates in collisions.

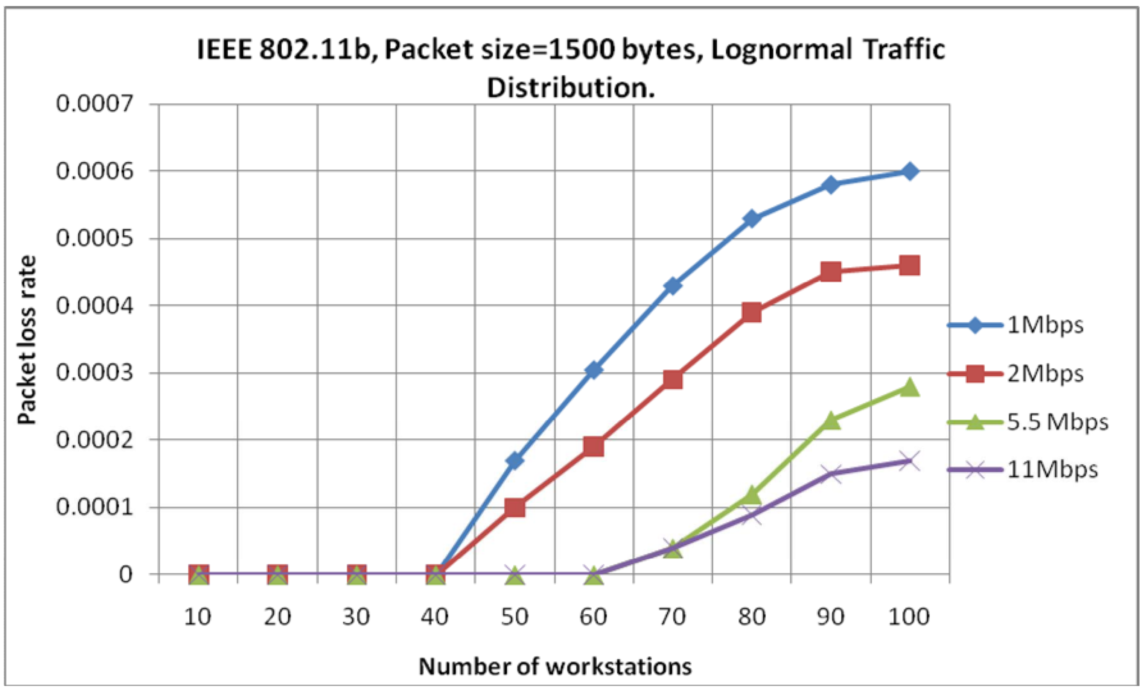


Figure 4.8. Effect of increasing number of workstations on packet loss rate performance of IEEE 802.11b network and at four different network data rate using lognormal traffic distribution.

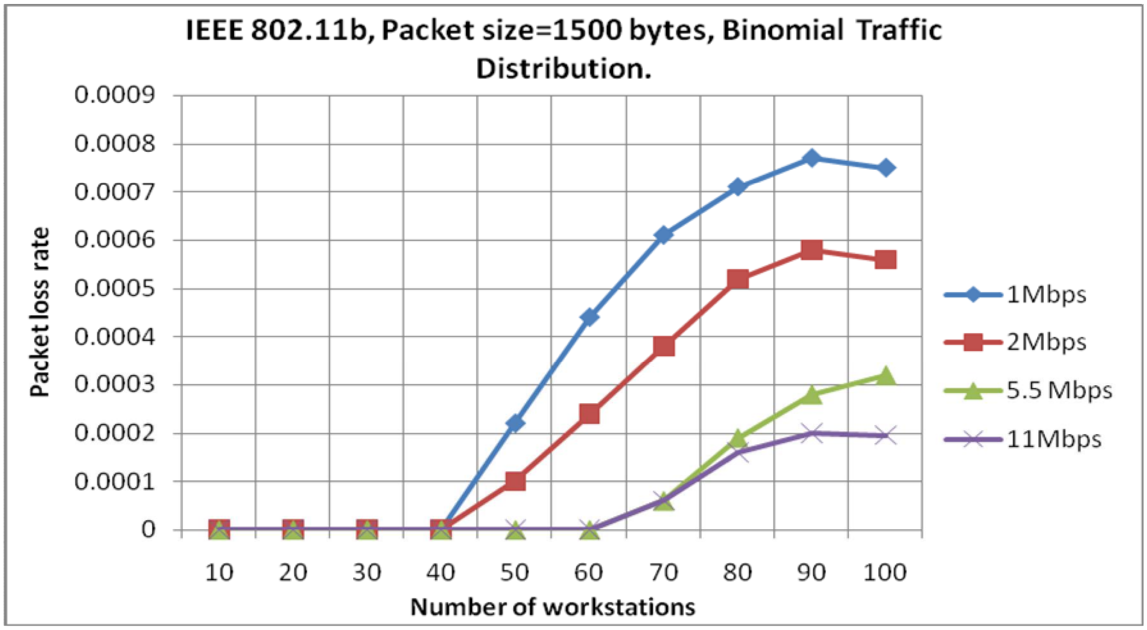


Figure 4.8.1. Effect of increasing number of workstations on packet loss rate performance of IEEE 802.11b network and at four different network data rate considering Binomial traffic distribution.

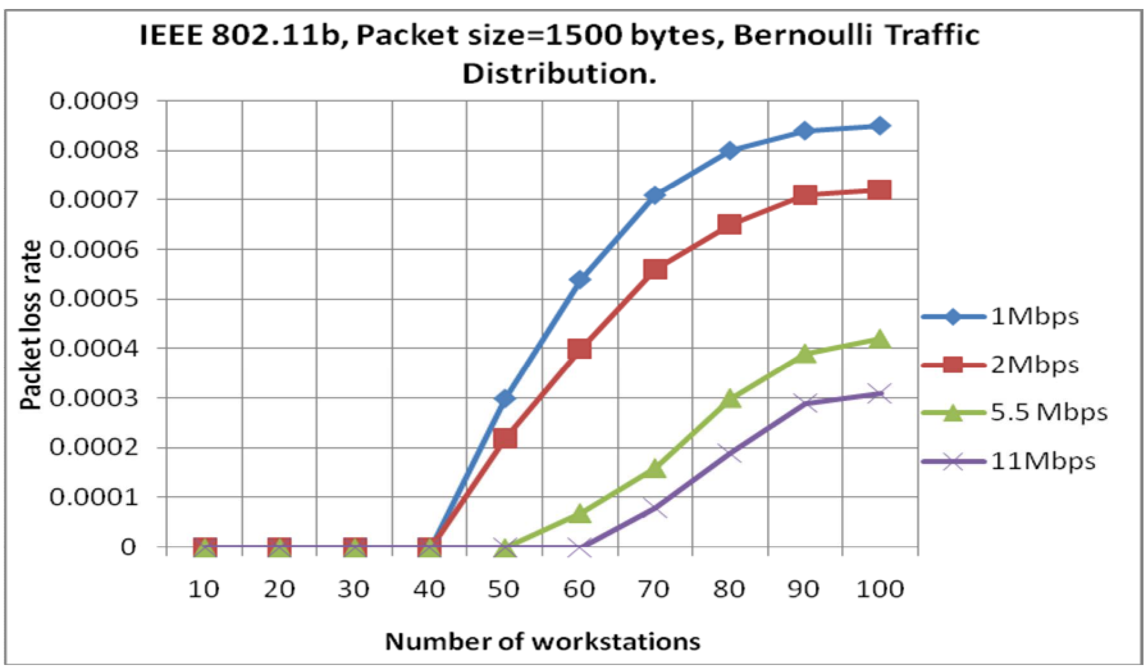


Figure 4.8.2. Effect of increasing number of workstations on packet loss rate performance of IEEE 802.11b network and at four different network data rate using Bernoulli traffic distribution

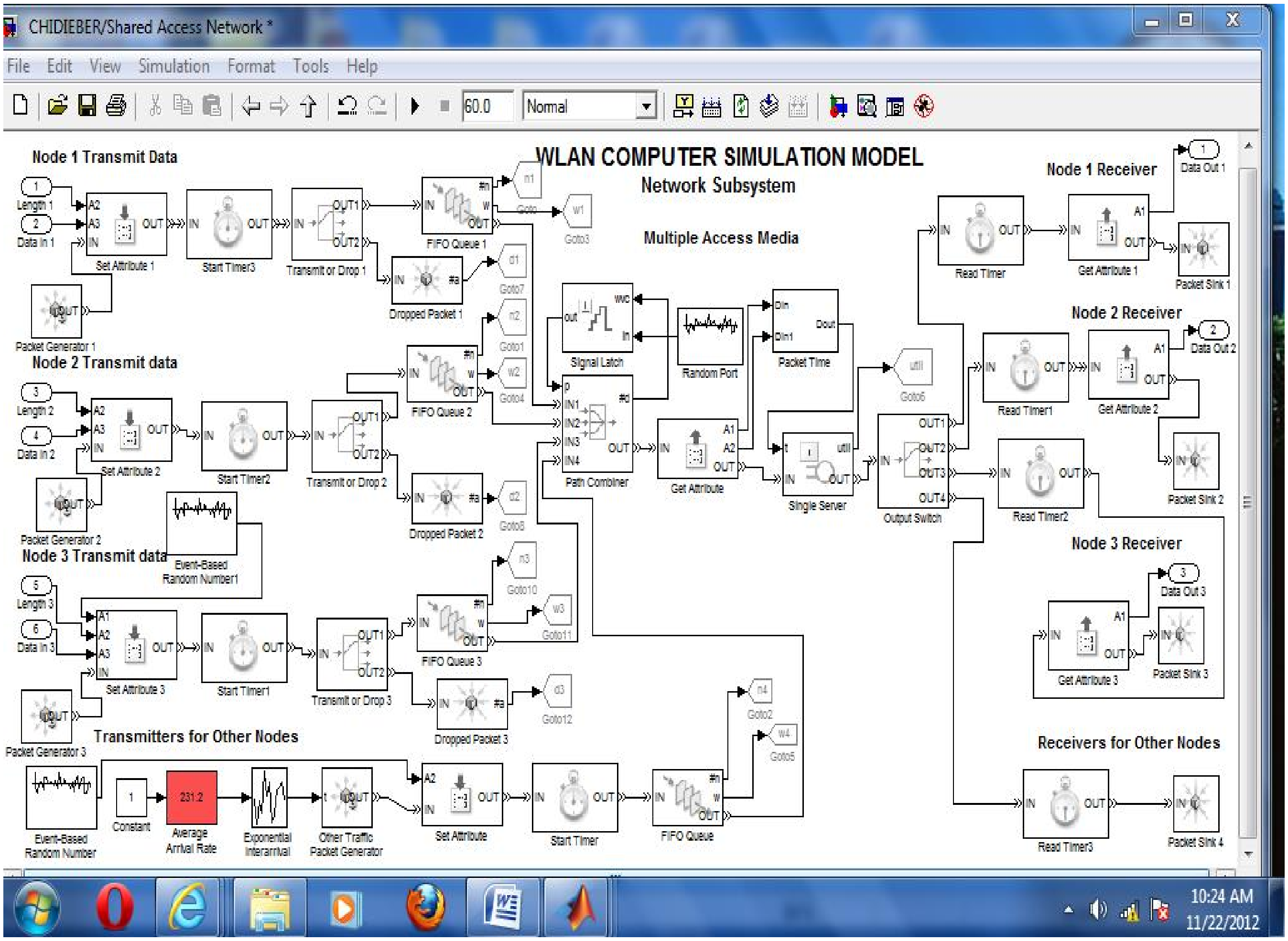


Figure 4.9: WLAN Computer Simulation Model.

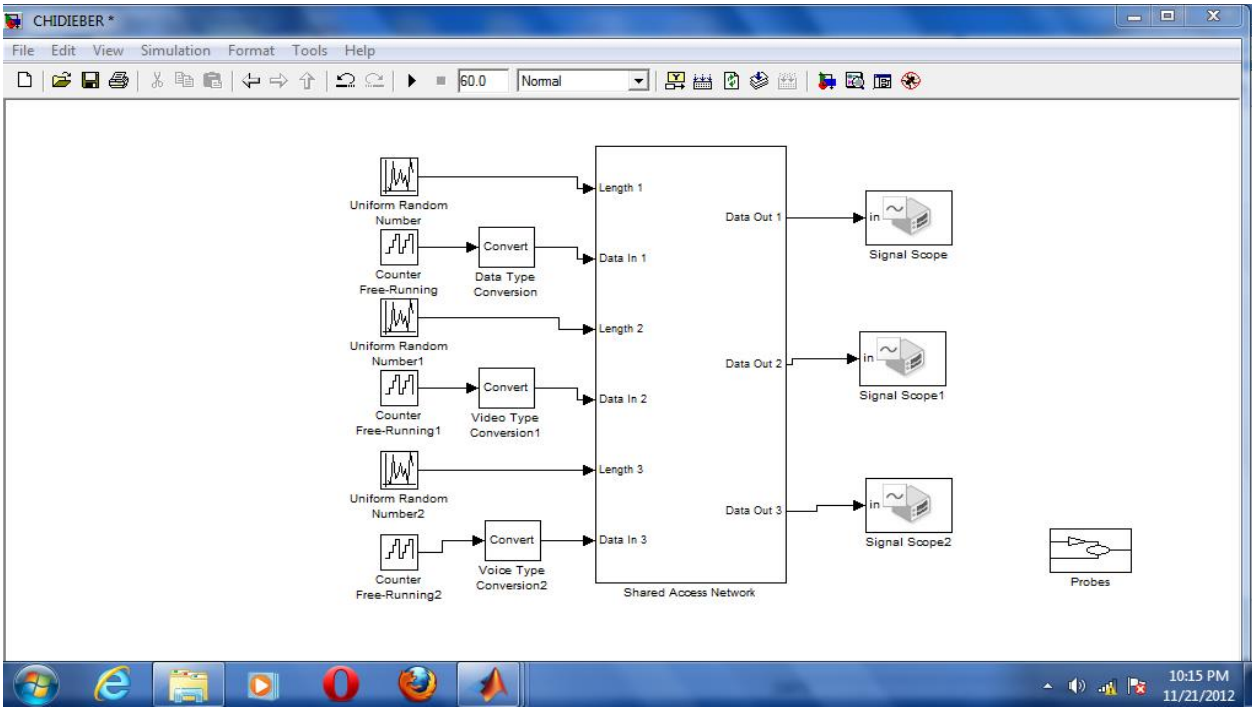


Figure 4.9.1: WLAN Computer Simulation Model (A Shared Access Communication System).

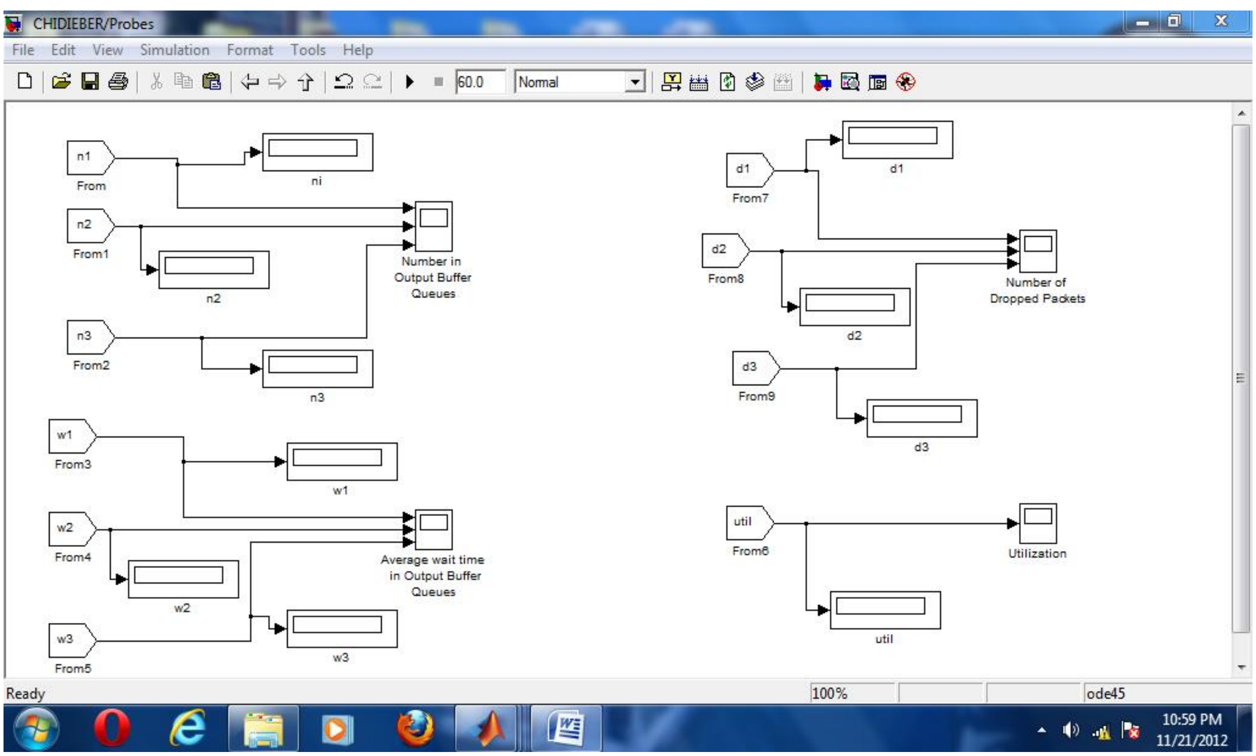


Figure 4.9.2: Probes

CHAPTER FIVE

5.1 Conclusion and Recommendation.

The objective of this research is to carry out a performance analysis of IEEE 802.11b medium access control distributed co-ordination function traffic loading under network saturation. This is achieved by investigating the effect of traffic loading and traffic distribution patterns on the quality of service (QoS) parameter on WLAN at different data rate, in other to establish the sort for optimum WLAN Performance. In order to evaluate the mean packet delay, loss rate and network throughput performance, this research has presented a traffic loading for MAC DCF which supports WLANös QoS Parameters. Using the proposed model, we have evaluated the mean packet delay, loss rate and network throughput performance of IEEE 802.11 DCF for basic access method under network saturation condition using MATLAB. Based on this physical model, a computer simulation model was developed over a MATLAB Simulink Simevent Environment. it is characterized by a MAC DCF protocol that enhances stationös transmission probability and fair access to the channel, which is more realistic, such as non ideal channel conditions. In other words, The basic access mechanism is a key feature of the IEEE 802.11 standard that uses virtual carrier sensing and random back off procedure to avoid the probability of two or more station from accessing the channel at the same time, thus, causing collision. To realize this feature, the WLAN MAC architecture is organized, modeled, and implemented in the Simevent within the MATLAB Simulink framework, in an organized manner following the software engineering best practices.

This thesis considered three different traffic distribution patterns namely Lognormal, Binomial and Bernoulli traffic distribution for analysis. The results showed that lognormal traffic distribution has considerable (better) packet loss rate, throughput, and delay performance at different data rate when compared with the other two traffic distributions whereas Bernoulli has the least performance in terms of high loss rate, high delay and low throughput also at different data rate. This means that lognormal traffic distribution will yield optimum performance at network saturation traffic loading within the data rate limit of IEEE 802.11b. The effect of the traffic distribution patterns on the network slightly vary at low and partly medium traffic loading and also vary at different data rate.

In this thesis, results show that the IEEE 802.11b does not perform well in terms of high throughput, low mean delay and low loss rate at high traffic load conditions. If the number of workstations increases, mean packet delay, loss rate and throughput performance of the IEEE 802.11b protocol degrades significantly. Moreover, as the number of workstations increases, improvement increases. Similarly, it was shown that the mean packet delay of arrived packets decreases as the number of workstations decreases with different network load levels. At saturation, it was also shown that throughput decreases, mean packet delay increases, packet loss rate increases with continuous increase in the number of workstation. The IEEE 802.11b optimum parameters under high traffic loadings, at 11Mbps data rate are 4.6 Mbps throughput, 300 ms delay and 0.00017 loss rate. Clearly, the existing IEEE 802.11b WLANs cannot be used for high bandwidth real - time applications serving large number of users. Therefore, to achieve an optimum network performance, it was observed that the IEEE 802.11b WLAN requires an improvement on its window back-off algorithm and fairness. Although various enhancements to the original IEEE 802.11 protocol have been proposed in the past, the problem of efficient channel utilization, higher throughput and good fairness has not been fully solved yet. Therefore, a planned extension of the present study is recommended, as the joint MAC-physical layer design approach for performance improvement of the IEEE 802.11b.

Lastly, figure 4.3, 4.5, 4.7 and 4.8 showed that WLAN performance reaches its optimum when 40 workstations are used in a wireless LAN hotspot scenario. In order words, it means that a WLAN Performance is best when a total number of workstations equal to 40 are connected to an access point at network saturation, and it represents the maximum load the system can carry in the stable condition. When each workstation generates 1,763 Erlang traffic intensity.

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