A SIMULATION STUDY OF MEDIUM ACCESS CONTROL PROTOCOLS OF WIRELESS NETWORKS

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In the wireless communication world, wireless local area networks (WLAN) are emerging as an inexpensive and convenient way to get connected from any location. Wireless networks are facing several new challenges like efficiency and speed with the increasing usage and need.

The goal of this thesis is to analyze and compare the performance of the wireless network in a small office under two multiple access control protocols – ALOHA and CSMA/CA. This study also focuses on impacts of the network parameters, like offered load on the performance throughput and delay of the network.

A simulator is designed in C programming language with virtual C++ environment to simulate the desired wireless network under different MAC layer protocols. Also throughput and delay of the network is observed under a range of loads. The data collected from the simulator are processed and plotted to analyze and compare the results.

From the data collected and the graphs plotted, it can be concluded that the designed simulator works reasonably accurate to imitate the real world network. It was also determined that at higher loads, throughput of the network using ALOHA protocol decreases exponentially, while for the network using CSMA/CA protocol it saturates to the stable throughput.

Accepted by: Ahmad Zaqaw, Chair

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CHAPTER I

INTRODUCTION

Wireless technology has shown significant growth in popularity. Unlike Ethernet, data is transported through air in wireless networking. Wireless Local Area Network (WLAN) allows two or more computers to communicate data with each other through radio waves. Mobility is the most significant feature of the WLAN. Wireless networking is emerging as an inexpensive and rapid way to get connected with the internet from virtually anywhere. The research survey by an independent research firm, NOP world technologies has shown that use of wireless LAN has positively impacted their quality of life with increased flexibility, productivity, and time savings.

Amplified Laptop usage and worker mobility within the organization has boosted the demand of wireless networks. Wireless technology is continuously replacing the traditional Ethernet wired communication. Organizations are seemed to be adapting this lightweight, economical, and convenient technology over hazardous and complicated wired medium. Many business problems like mobility, accessibility, communicating, and business transactions are being solved with the help of wireless networks. (Price, 2007)

General area of concern:

The performance of the wireless network depends on certain factors like protocol used, load, and environment. Packet collusion is the general cause of the reduced performance for the wireless networks. The probability of successful transmission is different in various mechanisms for allocation of multiple access. This thesis is concerned with ALOHA and CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) mechanisms and their performance. The network performance is observed from the factors like network throughput, average delay, and network utilization.

Problem Statement:

The purpose of this thesis is to analyze and evaluate the performance of the wireless network in a small office. The study will also consist of designing a simulator to perform an experimental setup of wireless network under two different mechanisms, ALOHA and CSMA/CA. The experiment will examine the wireless network for different network settings to understand the impact of and dependency of each protocol on the network performance like throughput.

Upon completion of the study, following goals are hoped to be achieved:

1. To demonstrate the capability and accuracy of designed simulator
2. To demonstrate and analyze the performance of the network using ALOHA and CSMA/CA protocol
3. To compare the results of both multiple access allocating mechanisms

Significance of the study:

In the world of growing mobility, there is an increasing need for people to have timely access to information regardless of the location of both individual and information. Remote access to important information can change the situation or its outcome, like in medical emergency can save life. The mobile communication poses a huge challenge to meet an efficient, fast, and reliable wireless communication network. WLAN has been proliferated in recent years due to low cost and easily installable Access Points (AP) and PC cards. However utilizing the network to provide better service to each user has always been a huge concern.

This study is significant in determining the network performance under different conditions. It is possible to do experiments under real conditions with actual network implemented, but the cost and time involved in this procedure is too much to conduct these experiments.

In order to avoid the probable losses in practically implementing the network and experiments, virtual environment is created to model original network and observe the network performance under different parameters. Also, re-scalability is one of the advantages of simulating the actual setup. To analyze the network performance, certain assumptions can be changed to obtain the best outcome for the given input parameters.

Research Questions:

In this thesis, following questions are going to be answered regarding wireless network performance:

1. Is the simulator capable and accurate enough to imitate original scenarios?
2. What is the impact of network parameters like offered load on the performance of the network using ALOHA and CSMA/CA protocol?
3. What is the difference in performance of network under ALOHA and CSMA/CA mechanisms?

Definition of terms:

LAN: Local Area Network, a small private network within a single building or campus, connecting PCs or workstations to share resources.

Node: The network consists of N independent stations generating and transmitting frames.

ALOHA: Means 'Hello' in Hawaiian. Pioneering wireless packet switched network developed bye Norman Abramson at University of Hawaii. Two versions are Pure-ALOHA and Slotted ALOHA.

Slotted time: Time is divided into discrete intervals (slots). Frames are transmitted only at the beginning of the time slot.

Carrier Sense: Stations can sense if the channel is in use before using it.

Multiple Access: More than one stations trying to share single channel.

CSMA: Carrier Sense Multiple Access, wireless protocol in which stations listen for carrier and act accordingly. Two types are CSMA/CD (CSMA with Collision Detection) and CSMA/CA (CSMA with Collision Avoidance).

IEEE: Institute of Electrical and Electronics Engineers, an international organization sets the standards for wireless LAN.

Network Throughput(S): Fraction of traffic correctly received by the network analyzer normalized to the overall capacity of the network.

Success Probability (Ps): The degree of reliability achieved by the network for successful transmission.

Average Delay (D): It is the average delay experienced by the data frame from the start of its generation to the end of its reception by analyzer.

Assumptions:

- Single Channel: A single channel is available for all communication. All equivalent stations share same channel
- Discovery and Handoff: All nodes (stations) are known (discovered) to the access point and allowed to share available channel
- Position: Access Point and all nodes are assumed to be stationary

Limitations:

- Immobility: The design lacks in considering any new station entering in the range of AP

- Restricted number of nodes allowed due to delay handling problems
- Delays in real world time are scaled down

Outline of thesis:

Chapter 2 of this thesis discusses basic terminology and concepts involved in wireless networking. The chapter gives detailed information regarding related research, historical background and concepts of wireless technology.

Chapter 3 of this thesis is Methodology. It describes the methods adapted in achieving desired goals.

Chapter 4 of this thesis is Simulation Setup. It explains the simulation considerations like, objective of the simulator, topology considered for the network, brief introduction to the components of the network and the methods employed in this study.

Chapter 5 of this thesis is Results, representing results of the simulation using graphs that visually represents the data collected. Further Performance analysis and comparative study of two MAC layer protocols in terms of throughput are discussed in this chapter.

Chapter 6 of this thesis is Conclusion, demonstrating the achievement of the goal, listed in problem statement. This chapter also presents solutions and suggestions for improving the performance of the small office wireless networks.

Chapter 7 of this thesis is References.

CHAPTER II

REVIEW OF LITERATURE

This chapter discusses basic terminology and concepts involved in wireless networking. The chapter gives detailed information regarding related research, historical background and concepts of wireless technology.

Historical background:

Wireless technology has grown as an invaluable tool in networking. The term "Wireless" came in use referring radio transceiver. This term also refers to the operation which is implemented without use of wires. Electromagnetic waves are induced in signaling for the first time by David E. Hughes in 1878. Hughes transmitted Morse code with the help of induction apparatus utilizing a "Clockwork Transmitter" (Fahie, 1971). Later in 1885 vibrator magnet is used for induction transmission by T. A. Edison. Edison continued his research by deploying Lehigh Valley Railroad signaling system, he attained the wireless patent for his work (U.S. patent 465,971). Meanwhile Heinrich Rudolf Hertz proposed an important theory of electromagnetic waves in 1888. Hertz demonstrated the possible successful transmission and reception of electromagnetic waves traveling through the space in straight line. All this work was done on the channel with only one user. With growing wireless technology and number of users raised the issue of channel allocation problem.

The worlds first wireless packet switched network came in the existence by late 1970 at University of Hawaii. Norman Abramson, a professor at University of Hawaii and his colleagues devised a new method to solve the channel allocation problem. Many researchers have been extended this work since then (Tanenbaum, 2003). Abramson's work is called ALOHA system also called as Pure ALOHA later. He used ground based radio broadcasting for transmission of the data through the air. Due to its simple nature ALOHA had very small network throughput which raised a problem of slower connection. To solve this problem Roberts came up with a technique to double the capacity of ALOHA. He proposed to divide the continuous time of ALOHA into discrete intervals called slots. Roberts' approach is then called as Slotted ALOHA because of its discrete nature. The general idea in slotted ALOHA was to permit the transmission only at the start of new time interval. This increased the channel capacity but with increasing number of users and progressing wireless technology was not good enough to keep up. This problem fetched researchers to develop a mechanism to either reduce the collusions or at least detect if collusion has occurred. In 1975 Kleinrock and Tobagi analyze several protocols in which stations can listen to the carrier or medium and act accordingly (Tanenbaum, 2003). These protocols are called as Carrier Sense Multiple Access Protocols (CSMA). Several researches are done on CSMA protocols developing 1-persistent CSMA, non-persistent CSMA and p-persistent CSMA. All these protocols were improvement of ALOHA protocol. Next step was development of Carrier Sense Multiple Access with Collision Detection. This development has increased channel capacity with large extent and lead to the

thrust of developing Collision Free Protocols which plunged the concepts like Bit-Map protocol, Binary countdown protocol, and Adaptive tree walk protocol. Later in 1990 Karn developed Multiple Access with Collision Avoidance protocol (MACA) for wireless LANs (Tanenbaum, 2003). The basic idea was to send a request and clear signals before communication which lets other non transmitting stations to stay silent through the time of communication. This approach is known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).

In 1992 Humblet discussed a completely different approach to the channel allocation is to divide the channel in several frequency bands unlike the approaches mentioned above in which time is divided among the users (Tanenbaum, 2003). This mechanism is called as Wavelength Division Multiple Access (WDMA). The spectrum is divided in to several channels i.e. wavelength bands to allow transmission at the same time. The techniques of the wavelength division are developing with each new standard set by IEEE.

Multiple Access Protocols:

The purpose of this thesis is to simulate the distribution of single channel among several users in an office such that they all have better access to the network efficiently. There are two solutions addressing this channel allocation problem, Static and Dynamic schemes.

Static Channel Allocation uses Frequency Division Modulation (FDM) technique in which channel is divided in several portions and each user is assigned one to use for

communication. This scheme works fine with limited number of users, as each one of the user has its private frequency to transmit and receive. In case of large number of users many of them will be denied permission due to lack of available bandwidth.

Other approach is Dynamic Channel Allocation technique. This technique suggests use of single channel for every user by blocking others' working while some station is transmitting or receiving. Like token ring topology, to pass a special token for using the shared channel. This do not holds true in case of wireless communication because users are mobile which can create conflicts between users for possession of token.

Many algorithms are developed to allocate a multiple access to single channel with contention and collision models.

ALOHA:

A professor at University of Hawaii, Norman Abramson developed this protocol in 1970. ALOHA method was a pioneering computer networking system. ALOHA works fine in any wireless system, but as the communication gets heavier collision problem becomes worse. There are two versions of ALOHA: Pure and Slotted

Pure ALOHA:

This is the basic idea of the ALOHA, it allows any user to transmit whenever the data is ready to send. There will be collision if more than one station has transmitted at the same time, and frame or data sent gets grabbled. The user listens to the channel

for any collisions, if there is any collision then transmitter station waits for random interval of time and resends the frame.

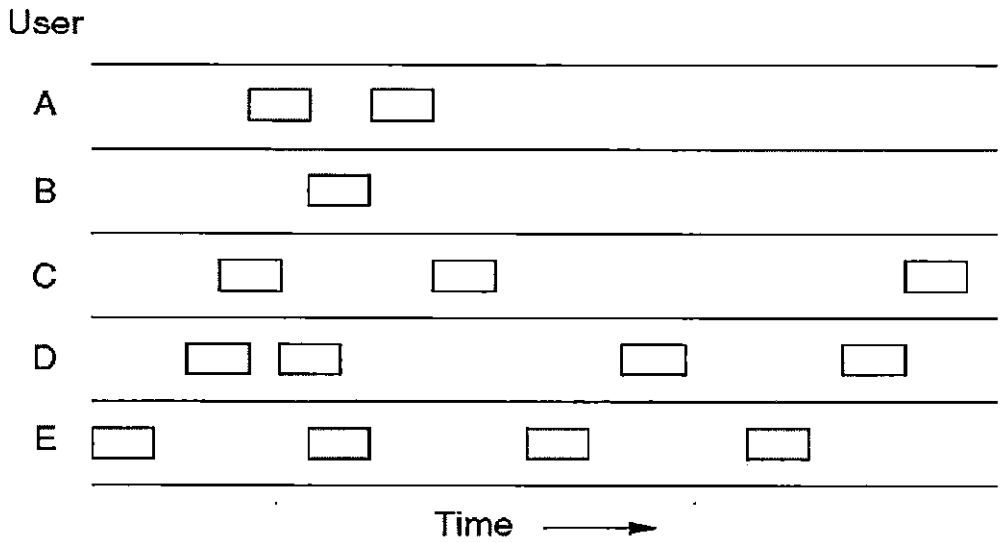


Figure 2.1

The figure 2.1 demonstrates the frame transmitted by each station with time. Whenever two frames tries to occupy the channel at the same time there will be collision.

If the population is generating frames according to a Poisson distribution with mean 'N' and 'G' is the probability of 'k' transmission attempts per time frame, then throughput of the network can be given by.

$$S = G e^{-2G}$$

Slotted ALOHA:

Roberts published a method of increasing the performance of Pure ALHOA in 1972. He proposed to divide the continuous time in Pure ALOHA in small discrete intervals and so it is called as Slotted ALOHA. This scheme practically doubled the throughput performance of the ALOHA. User is not permitted to send frames whenever ready but the user has to till next time slot starts.

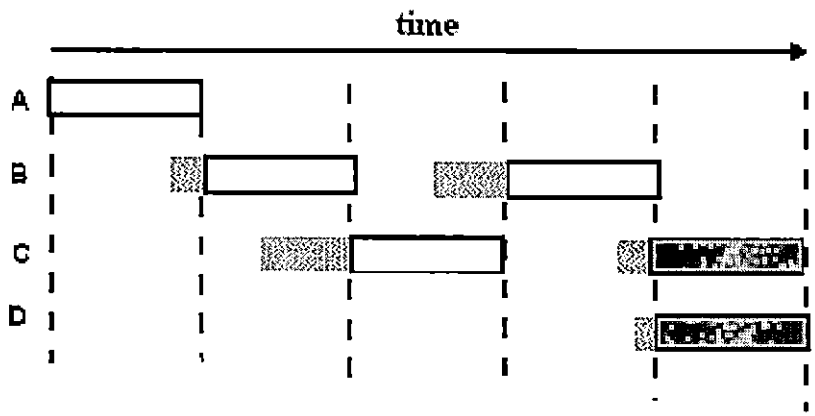


Figure 2.2

As shown in figure 2.2, this approach helped in aligning the frames in a time interval preventing a frame from destroying more than one frame reducing vulnerable period to half of the Pure ALOHA.

The network throughput is:

$$S = G e^{-G}$$

Following figure 2.3 shows the comparison of network throughput versus Traffic offered for Pure and Slotted ALOHA.

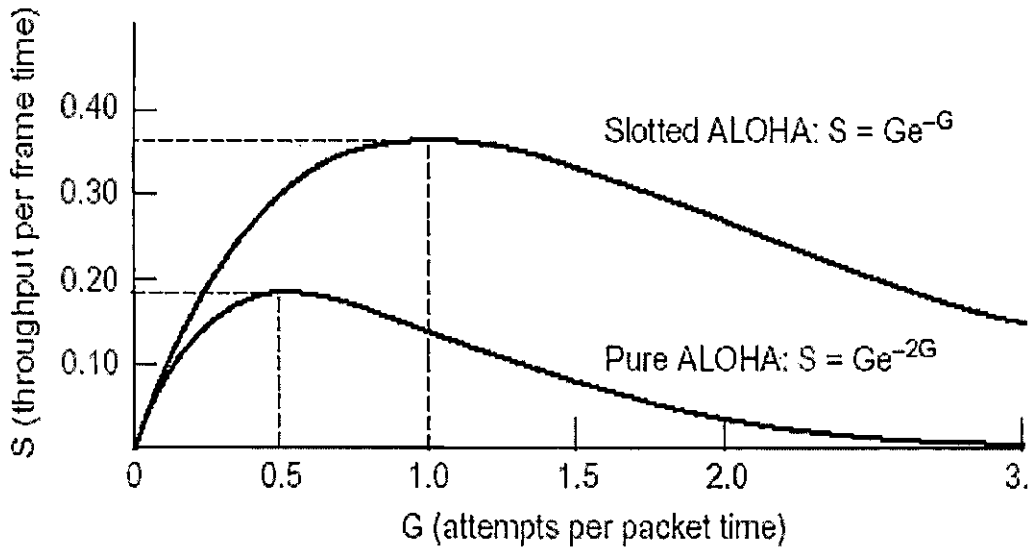


Figure 2.3

Carrier Sense Multiple Access Protocols (CSMA):

Slotted ALOHA has increased network performance with an extent, but as stations keeps on sending frames more frames have to suffer collisions. Solution to this problem is to sense the channel before sending frame and act accordingly.

Persistent and non-persistent CSMA: There are several different protocols which sense the carrier before transmitting frames. 1-persistent CSMA, whenever user has data to send it first senses medium. If the carrier is idle then it transmits the frame

otherwise waits for random interval of time (Tanenbaum, 2003). Station transmits data with probability of 1 whenever it finds channel idle so called as 1-persistent CSMA.

P-persistent CSMA: In this scheme whenever the station finds channel idle it transmits the frame with probability 'P' or differs transmission by probability 'q', where $q = 1 - p$ (Tanenbaum, 2003). This process is repeated until successful transmission or some-other station starts transmitting.

Non-persistent CSMA: Working in this protocol is same as 1-persistent protocol, but it does not keep on sensing the channel continuously instead it waits for random interval of time and repeats the algorithm (Tanenbaum, 2003).

CSMA with Collision Detection (CSMA-CD):

CSMA-CD is widely used in Local Area Networks (LAN) i.e. Ethernet. In this scheme if a station senses the channel to idle it starts transmitting, but they stops transmitting the frame if the detect any collision almost immediately. Then it waits for random interval of time and senses the channel again and repeats the algorithm (Tanenbaum, 2003). This quick termination of transmission saves time and bandwidth of the overall network. This protocol is inherently a half-duplex system cause each station continuously scans the channel for collisions which keeps the receiving logic busy for whole entire time of transmission preventing from receiving frames at the same time of transmitting.

Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA):

In 1990, Karn developed this algorithm for wireless LANs, called Multiple Access with Collision Avoidance (MACA) (Tanenbaum, 2003). The basic concept behind this protocol is the sender sends the frame whenever it finds the channel idle. IEEE 802.11 supports two modes of operation DCF and PCF.

DCF (Distributed Coordination Function) does not use any kind of central control. In this protocol two types of channel sensing are used physical channel sensing and virtual channel sensing. Physical channel sensing, when stations wants to transmit it senses channel. If it is idle then it just starts transmitting and it does not senses the channel while transmitting. If it finds the channel busy then differs its transmission until channels becomes idle and then transmits. If a collision occurs the colliding stations wait for a random time before further transmission using binary exponential back-off algorithm. (Tanenbaum, 2003)

The other mode is virtual channel sensing, the basic concept behind this protocol is sender sends a small frame requesting permission to send whenever it finds channel idle. This small frame stimulates the receiver to transmit a small frame acknowledging the sender that it is ready to receive. These small frames are detected by other stations and they avoid transmission for the duration of upcoming data frame.

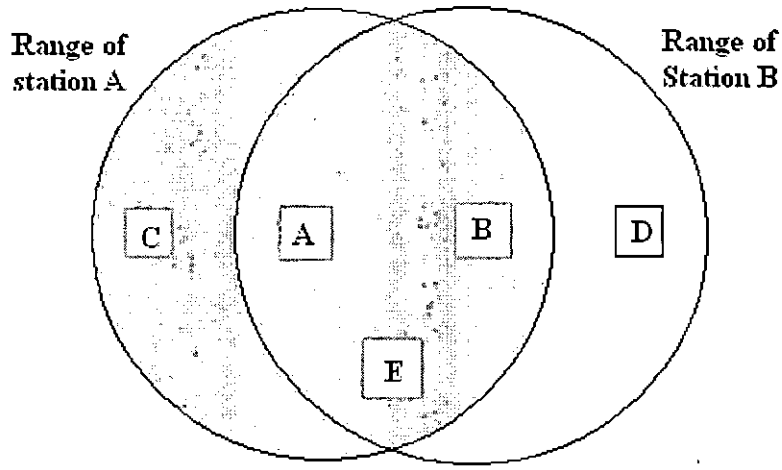


Figure 2.4

Figure 2.4 shows a simple wireless network with five stations. Working of this network is discussed considering these stations use CSMA/CA protocol for communication.

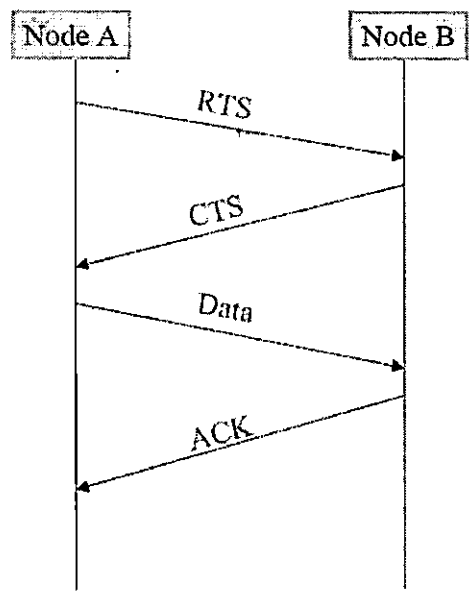


Figure 2.5

As shown in figure 2.5, station **A** has some data to transmit to station **B.** Station **A** senses the channel, if it is busy then it waits for random interval of time and repeats the algorithm. If station **A** finds channel idle then it sends RTS (Request To Send) frame to **B**. Then station **B** sends CTS (Clear To Send) frame to station **A** acknowledging that it is ready to receive. Station **C** will postpone its operation until random interval of time after listening RTS from station **A** immediately, cause it is close to station **A**. Same is the case for Station **D** which listens CTS from station **B** and abort all its actions for random interval of time, cause it is close to station **B** which is about receive a frame. In case of station **E**, it hears both RTS and CTS and aborts its actions. As there is no interruption to the communication from nearby stations the communication gets successfully completed without any collisions.

Despite all these precautions collisions still occurs. In case if station **B** and **A** both send RTS to station **C**, then both the RTS will be grabbled. In case collision occurred the transmitter backs off and waits for random interval of time and tries again. This random interval of time is generated with the algorithm called 'Binary Exponential Backoff Algorithm'. When first collision occurs, each station waits either 0 or 1 slot time. After second collision, each station picks either of 0, 1, 2, or 3 at random and waits until number of slots. In general after 'i' collisions, a random number between 0 and $2^i - 1$ is chosen and that number of slots are skipped (Tanenbaum, 2003). The slot length is equal to a round – trip propagation time of the network.

PCF (Point Coordination Function), it uses the base station to control all activity in its cell. Since transmission from each node is completely polled, no collision ever

occurs. The basic mechanism is the base station broadcasts a beacon frame periodically. Is contains the parameters like number of nodes and their status, and clock synchronization.

DCF and PCF can coexist in one network. All implementation must support DCF while PCF is optional.

Theoretical throughput performance of a node of the CSMA/CA network can be given by,

$$x_i = \frac{p_i q_i T_{TX}}{(1 - p_{TX})T_{SL} + p_{TX} T_{TX}},$$ (Chang, 2006)

Where,

P_{TX} is the probability that the node will transmit

T_{SL} is slot time

T_{TX} is transmission time

Network throughput can be calculated by adding individual node throughput.

Wireless Standards – IEEE 802.11:

Institute of Electrical and Electronics Engineers (IEEE) is international organization for advancement of electrical and electronic technology. IEEE has sets 802.11 standards for wireless Local Area Network developed by IEEE LAN/MAN standards committee. IEEE has published several sets of standards so far.

IEEE 802.11 – 1997 (802.11 legacy): This is the first standard released by IEEE in 1997 and later revised in 1999. This standard has specified very low data rates of 1

and 2 megabits per second (Mbit/s or Mbps). Frequency band for the transmission is Industrial Scientific Medical Frequency band (ISM band) at 2.4 GHz. (Price, 2007)

IEEE 802.11a: This was the first high-speed wireless LAN, was released in 1999 using same core protocol as the original standard 802.11. Transmission allowed in 5 GHz band with increased data rate of 54 Mbit/s. Effective overall range was reduced with 5 GHz frequency. 802.11a uses Orthogonal Frequency Division Multiplexing (OFDM) technique to deliver such a high data rate. 52 different frequencies are used for transmission 48 for data and 4 for synchronization. (Price, 2007)

IEEE 802.11b: This standard was released in 1999 but the products appeared in early 2000 in market. Using same media access method as the original standard it provides maximum data rate of about 11 Mbit/s over the frequency band of 2.4 GHz using CCK modulation technique (Stallings, 2004). It has a larger range than 802.11a. it uses High Rate – Direct Sequence Spread Spectrum (HR-DSSS) as a technique of wavelength division. (Price, 2007)

IEEE 802.11g: This is the enhanced version of 802.11b and third standard developed by IEEE in 2003; it works in 2.4 GHz band with data rate of 54 Mbit/s. This standard is most rapidly accepted and adapted by the consumers. It uses OFDM modulation technique on 12 different channels (Stallings, 2004).

IEEE 802.11n: This is estimated to be proposed in 2009; with dramatic increase in data rate and range. It will use frequency band 2.4 GHz and/or 5 GHz with 300 Mbit/s of data rate and range over 70 m. This will come up with amendment for most of the problems in wireless networking. (Price, 2007)

Related Research:

Wireless technology is growing immensely, so the research to develop existing protocols and development of newer protocols is increasing worldwide. Research on increasing network performance is one of the hottest subjects to work on. Several researchers have simulated wireless networks for analyzing their performance.

Pant Pavan and Castelli Thomas from University of Boston, wrote a research paper "Simulation of Wireless Network using the 802.11 MAC protocol" (Pant, 2005). Their study was to simulate and analyze the network performance of a wireless network using a self designed simulator in MATLAB. The study has discussed the 802.11 MAC protocol and analysis of simulation results.

Koubaa Anis, Alves Mario, and Tovar Eduardo of Polytechnic Institute of Porto Rua Dr. Antonio Bernardino de Almeida, Portugal performed a study to analyze the performance limits of the Slotted CSMA/CA mechanism in their paper " A Comprehensive Simulation Study of Slotted CSMA/CA of IEEE 802.15.4 Wireless Sensors Networks" (Koubaa, 2006). This study is based on accurate simulation of Slotted CSMA/CA under IEEE 802.15.4 standards with the help of network simulator OPNET. The study fairly evaluated the performance of the desired protocol in terms of throughput, average delay, and probability of success.

Friesen Christopher from Stetson University, Florida wrote a research paper on "Simulation of Handoff in WiFi Wireless Networks" (Friesen, 1999). Friesen's study used a self designed simulator in C++ programming to simulate the scanning process

while handoff between two access points. The document provides understanding of handoff process in wireless communication using CSMA/CA protocol.

Henriksson Dan, Cervin Anton, and Arzen Karl-Erik from Lund Institute of Technology published a research paper "TRUE TIME: Real-time Control System Simulation with MATLAB/Simulink" (Henriksson, 2002). The study has developed and described TRUETIME, which is a simulation facility in MATLAB toolbox, providing thorough understanding of simulation and synchronization concepts.

Saiedian Hossein from University of Nebraska, Nebraska published a research paper "Object-Oriented Simulation of CSMA Protocols" (Saiedian, 1997). His study deals with the designing models of different layers of network and object-oriented approach to simulation of CSMA using programming language Ada. Saiedian extended his study to modify the network protocols to examine various network parameters. Ada provides powerful mechanism to develop software to deal with complex problems.

Focus of this thesis is analyzing the throughput performance of the network under two different MAC layer protocols. The wireless LAN simulator based on 802.11 standards is developed to acquire network parameters and calculate the network performance under specified conditions. Analysis of network throughput and success probability undergoes the simulation of same network under two different MAC layer protocols, i.e. ALOHA and CSMA/CA. This thesis pursues the simulation of a wireless network with 'N' number of nodes accessing single Access Point (AP) over single channel.

CHAPTER III

METHODOLOGY

This chapter discusses methods and procedures used in conducting the thesis. As mentioned in problem statement, the purpose of this thesis is to analyze and evaluate the performance of the wireless network in a small office under two different mechanisms, ALOHA and CSMA/CA (Carrier Sense Multiple Access Collusion Avoidance). The experiment will examine the wireless network for different network settings to understand the impact of and dependency of each protocol on the network performance like throughput, average delay, and success probability.

Various methods can be used to acquire the data required to analyze and evaluate the network performance. Three main aspects to collect the results are theoretical approach, experimental setup, and simulation.

Theoretical approach is a collection of theories, concepts, ideas, and assumptions. In this method definition of terms and conceptual knowledge are applied to develop and explain certain phenomena.

Experimental Setup is an approach which involves practically implementing the designed experiment and research on its behavior. It also includes practically manipulating the factors which affects the output to obtain desired or best outcome off the design. This method can not be used for this thesis because it will take lots of time and money to practically implement the network and changing its parameters.

Third method, the method adapted by this thesis is simulation. This method deals with creating a virtual environment and experimental setup using computer program. The program attempts to mimic the working of the original setup. Simulation approach is chosen for this study because it needs a real-time model network to examine the network performance. Also in order to suggest developmental ideas needs to change the network settings several times to investigate the changes in performance output of the network, which will be very complicated practically.

Network Simulators:

Simulators are the highly effective in performing various tests under different scenarios of the same network. Simulator saves time and money needed in practically implementing the network. There are lots of network simulators available in the market, and they can be selected on the basis of type of data to handle, desired output, amount of data, accuracy and acquaintance with the user.

Some of the types of Network Simulators:

- **NS2** – it is a discrete event simulator for networking. Provides support to simulate TCP, routing and multicast protocols over wired and wireless networks.
- **OMNeT++** - OMNeT++ is a public-source, component-based, modular and open-architecture simulation environment with strong GUI support and an embeddable simulation kernel. [7] It supports simulation of IT systems, queuing networks, and hardware architectures.

- **NetSim** – A product of Tetcos. Simple and user friendly functionality. Supports protocols like Ethernet, IP, TCP, ARP, RARP, UDP, and ICMP
- **OPNET Modeler** – It is a modeler provides environment for designing and developing protocols and technologies. Demonstrates realistic scenarios and testing facilities. Supports protocols like VOIP, TCP, OSPFv3, MPLS, IPv6, and more
- **QualNet** - QualNet improves the design, operation, and management of these networks through virtual networking. Virtual networking enables the testing, optimization and integration of network technologies in a lab environment and at a fraction of the cost of deploying physical test beds. [8]

A wireless system can be elaborated as individual components like wireless nodes, frames, channels, and access points interacting with each other. Every component summarizes it behavior as a single unit. The object oriented model of wireless network is well suited for illustrating the behavior of the real world network. This study deals with simulation and analyzing of the network under two different MAC layer protocols under certain assumptions.

Analysis of network throughput and success probability undergoes the simulation of same network under two different MAC layer protocols, i.e. ALOHA and CSMA/CA. This thesis pursues the simulation of a wireless network with 'N' number of nodes accessing single Access Point (AP) over single channel. At each node random data with random number of frames are generated by Poisson distribution with mean less

than 1. In ALOHA the frame generated is instantly transmitted over the medium, irrespective of the channel status but in CSMA/CA it waits until the channel becomes idle. Outcomes are analyzed using graphs and are compared with theoretical results for both ALOHA and CSMA/CA protocols.

CHAPTER IV

SIMULATION SETUP

The simulator is one of the key contributions of this thesis. This chapter describes the software design and implementation of Wireless Local Area Network Simulator. As well this chapter explains objective of the simulator, topology considered for the network, brief introduction to the components of the network and the methods employed in this study.

Objective of the Simulator:

The focus of this thesis is analyzing the throughput performance of the network under two different MAC layer protocols. The wireless LAN simulator based on 802.11 standards is developed to acquire network parameters and calculate the network performance under specified conditions.

WLAN System:

Any network has two distinct components that are elements and medium. The wireless local area network system can also be visualized as two components:

- WLAN components
- Propagation medium

Wireless network consist of nodes and an Access Point (AP). Nodes transmit frames to AP. On the other hand, AP acts as a sink to the frames transmitted by nodes. Two

main functions of the node are MAC layer functionality and channel interface functionality. MAC layer functionality is used to transmit available data with MAC layer protocol standards i.e. 802.11 standards and channel interfacing is used for exchanging frames between node and AP. It also keeps the track of collisions in the channel.

The propagation medium provides a space to exchange the frames between AP and nodes. Medium caused degradation of the signal by introducing attenuation to the transmission. This study assumes the medium to be idle introducing no attenuation and delay to the transmitted signal.

Simulator Design:

A wireless network can be designed as number of individual components interacting with each other. The components like nodes and packets. All the components exhibit different states during the simulation.

WLAN Node:

WLAN node means a workstation or a Laptop with different applications running on it like internet browser. Function of node in the network is to generate frames and transmit over the channel. MAC layer of the node concerns with the transmission of frames. This study concerns with MAC layer protocols ALOHA and CSMA/CA based on Distributed Coordination Function (DCF) with physical scanning mechanism. During the simulation, node undergoes various different states of operation.

- Idle state: The node waits in this state until it needs any frame to be transmitted.
- Defer state: Node reschedule their transmission for random interval to avoid any possible interruption to competing nodes.
- Transmit state: Node tends to start transmitting if the channel is found idle and random delay expires.
- Backoff state: If collision occurs, colliding nodes defers their further transmission for longer time which is derived from Binary exponential Algorithm.

Access Point:

The access point is a special node which performs all the functions of WLAN node and distribution services in addition. The Access Point keeps the track of WLAN node addresses. This simulation assumes the nodes to be stationary and already introduced to the access point, so the access point behaves like a normal WLAN node.

WLAN Packets:

Packet is set of information traveling over the medium. The IEEE standard specifies three types of packet frames- Data, Control, and Management. In this implementation, with already set network, only data frames are used. In this study, for convenience, packet size is assumed to be 1000B.

Collision:

The channel object monitors the channel for any collision and updates each node with information:

- Number of nodes evolved in collision
- The address of each node

Implementation:

The simulator is implemented in C programming language in Virtual C++ environment. The code consists of two parts, header and source. Header files are with (.h) extension and are included to support source code. Source file is with (.cpp) extension and are used to define and call the functions declared in header. The main file is responsible for generating the statistics by calling the functions during the run.

Simulation Execution:

The simulation involves interaction of all individual components of wireless LAN system. The simulation is based on discrete time slot model and runs for specific number of iterations. During simulation following events occur in order:

Simulation Program flow for ALOHA protocol:

1. Input number of nodes in the network
2. Generate random number of data frames to transmit from each node
3. If data available for transmission and backoff delay expires (if any) transmit

4. Count total number of frames Transmitted
5. Scan the channel for Collision
6. If collision occurs, set random interval of delay for each colliding node
7. If collision does not occur, go back to Step 2
8. Show outputs.

Simulation Program flow for CSMA/CA protocol:

1. Input number of nodes in the network
2. Generate random number of data frames to transmit from each node
3. If data available for transmission, scan the channel
4. If channel idle and backoff delay expires, transmit; else wait for longer interval of time, and transmit whenever channel is idle and delay expires
5. Count total number of frames Transmitted
6. Scan the channel for Collision
7. If collision occurs, set Exponential random interval of delay for each colliding node
8. If collision does not occur, go back to Step 2
9. Show outputs.

Figure4.1: Flow-chart for ALOHA Simulation:

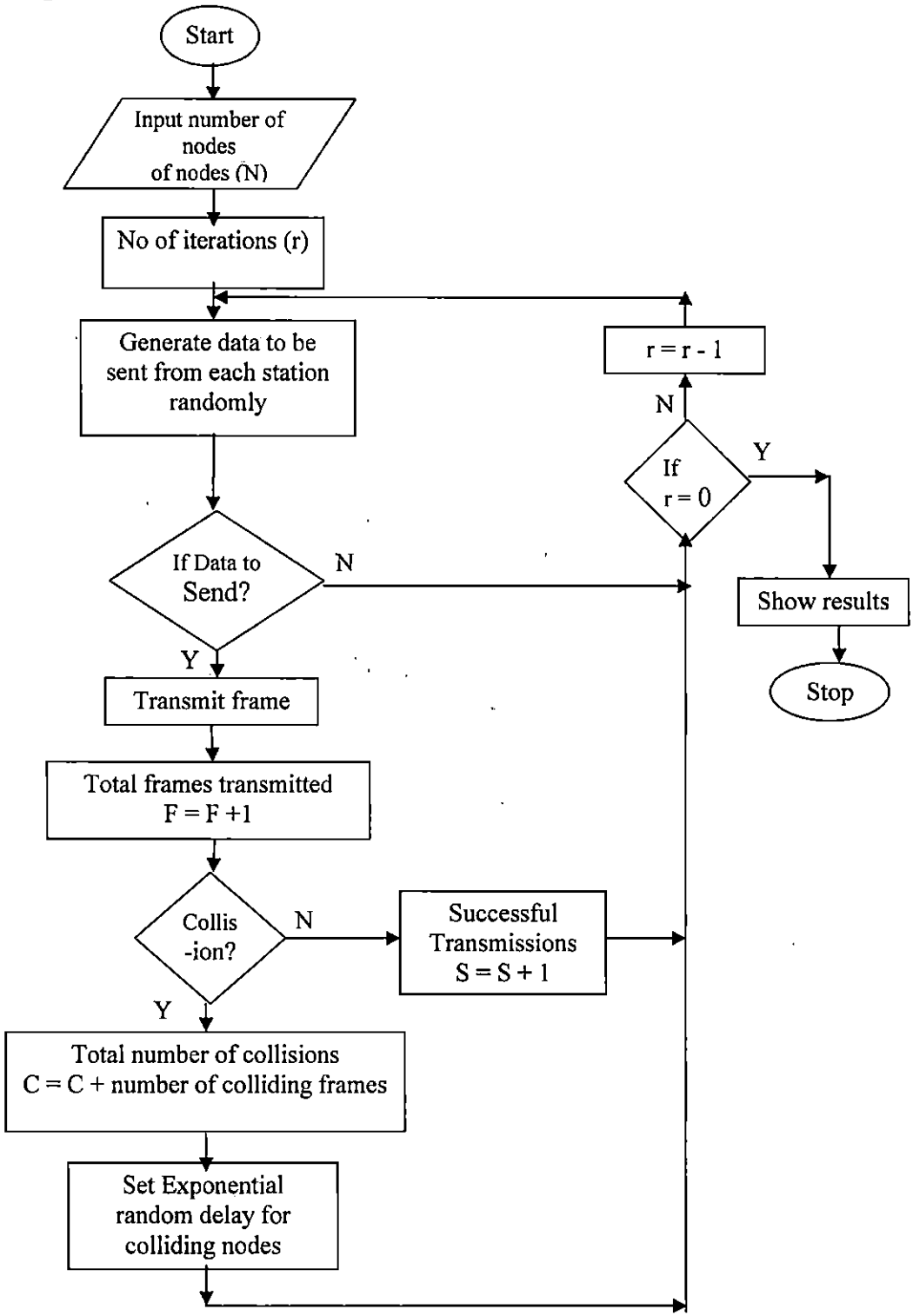


Figure 4.2: Flow Diagram for CSMA/CA Simulation

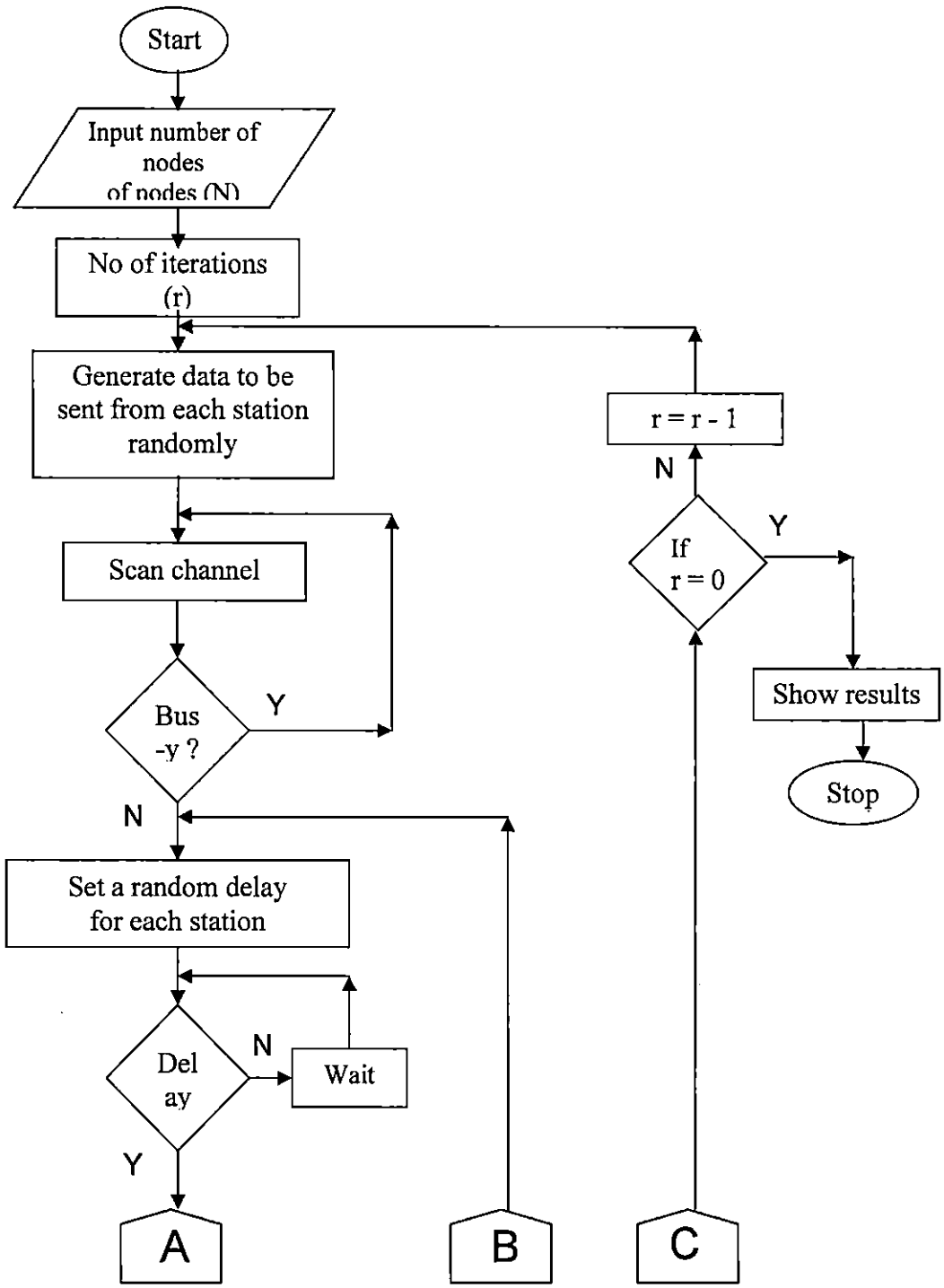
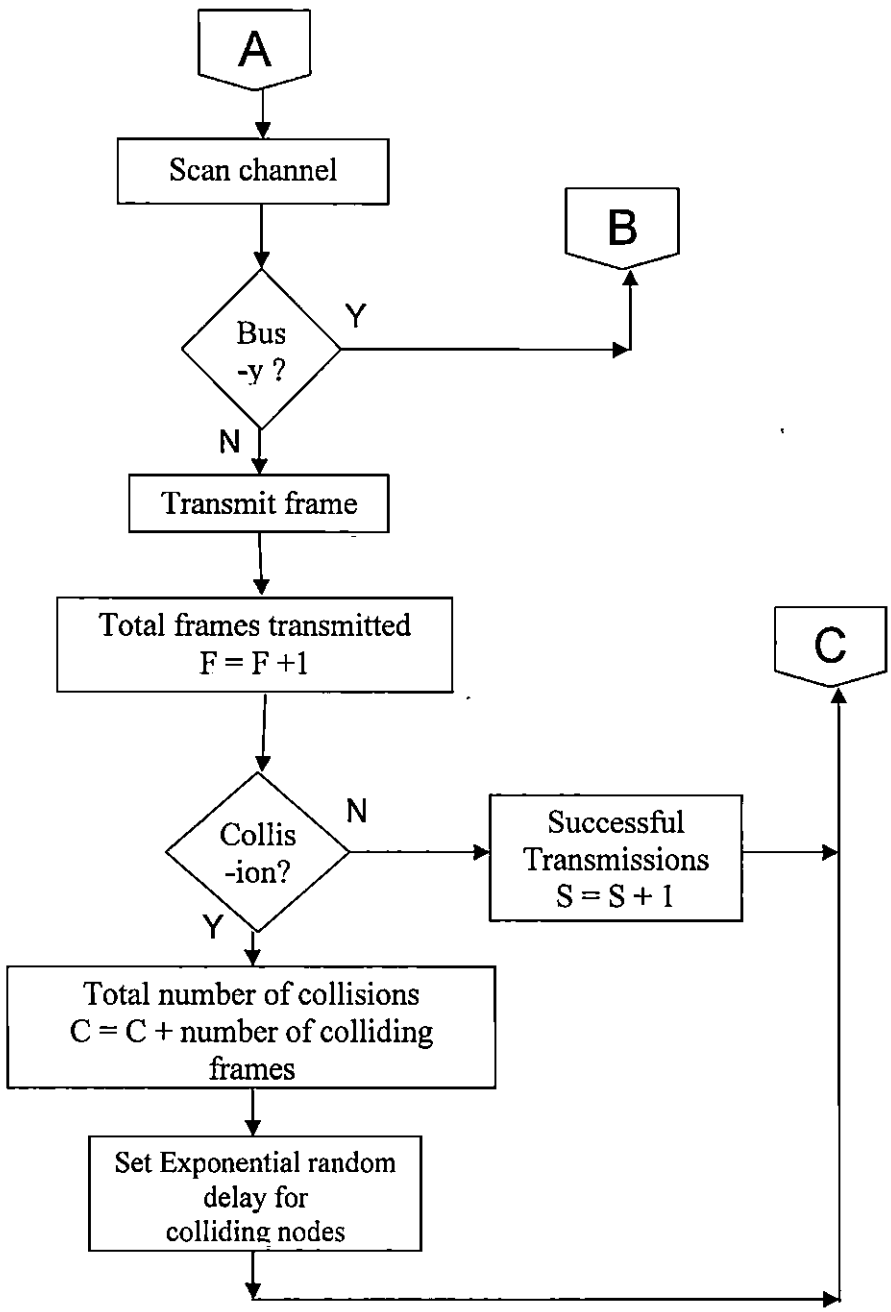


Figure 4.2: Flow Diagram for CSMA/CA Simulation (Contd.)



CHAPTER V

RESULTS

This chapter presents the results obtained through simulation. Results are divided in two sections – performance analysis and comparative study of two MAC layer protocols in terms of throughput. In the performance analysis section, the performance of the simulated network is discussed and compared with observed outcomes. The comparative study compares the performance of the network under two different MAC layer protocols- Slotted ALOHA and CSMA/CA.

Simulator model:

Implementation of the simulator to study the throughput of a wireless LAN is as follows:

- WLAN node which randomly generates and transmits the packets of constant size with Poisson distribution
- Access point, which acts as a sink for the transmitted frame
- Channel, holds packets during propagation time and detects if there is any collision.
- Constant packet size, equal to 100 slot time

Various data like total time of transmission, total number of frames transmitted, and number of collisions are collected to compute the effective data throughput.

Performance analysis using simulator:

Wireless network performance mainly depends on network throughput and average delay. In the network different applications places different functional requirements. Data transfer applications like FTP (File Transfer Protocol) requires much bandwidth as possible and are insensitive to delay, while real time applications like VOIP (Voice Over Internet Protocol) are sensitive to delay produced but works satisfactorily with small bandwidth.

ALOHA:

The throughput of the network is observed under varying load. Offered load G (attempts per packet time) is varied from 0% to 300% by increasing number of participating nodes at constant packet size and transmission time. The packet traffic is generated randomly with the Poisson distribution with constant mean. Results obtained from the simulation are as follows:

G (%)	Throughput (S)
0	0
50.13	0.3537
98.01	0.3916
150.87	0.3337
203.81	0.2622
244.54	0.2095
301.99	0.1455

Table: 5.1: simulation output (Throughput) in terms of load (G)

The network throughput as a function of offered load G compared with observed network throughput under varying load G is represented in figure 5.1.

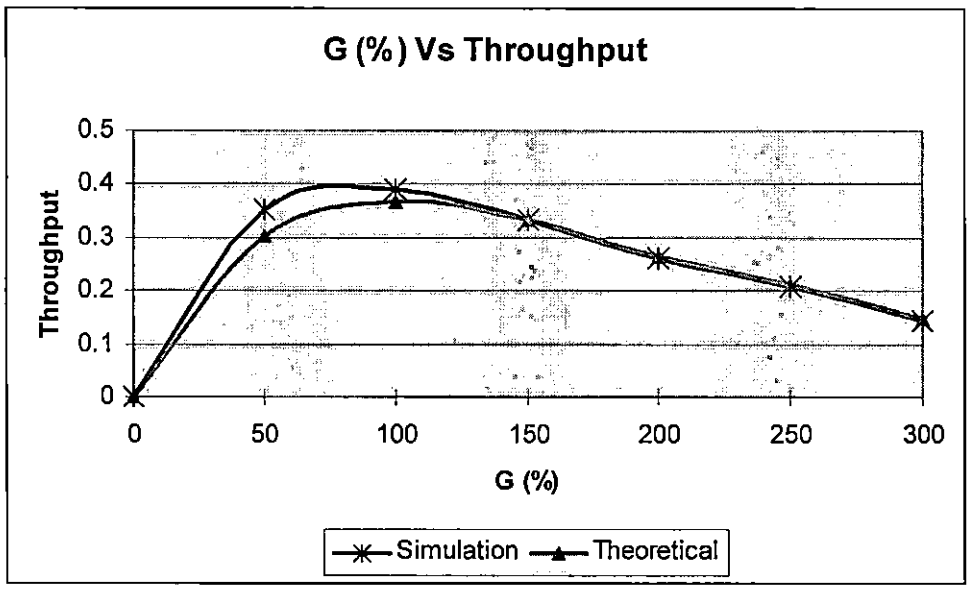


Figure: 5.1: The network throughput as a function of the offered load

Simulation results fairly match with the observed throughput of the network (about 4% percent of error). As expected, at higher values of load network throughput decreases. At higher loads, large number of participating nodes, the cumulative rate at which data is generated exceeds the channel capacity of the system. Hence, throughput of the wireless network decreases because of increase in collisions. Theoretically, for Slotted ALOHA network, the throughput of the network can be given by the expression:

$$\text{Throughput} = \text{load} * \text{Success Probability}$$

Success Probability can be given by,

$$Po = e^{-G}$$

Throughput can be given by,

$$S = G * e^{-G}$$

At 100% offered load, G is equal to 1 so throughput can be expressed as:

$$S = 1/e = 0.368 \approx 0.37$$

The simulator results illustrate that the network throughput reaches its maximum of 39.16% at about 98% of offered load, which fairly satisfies the theoretical maximum of 37% at the load of 100% (1 packet transmission or retransmission attempt per unit time).

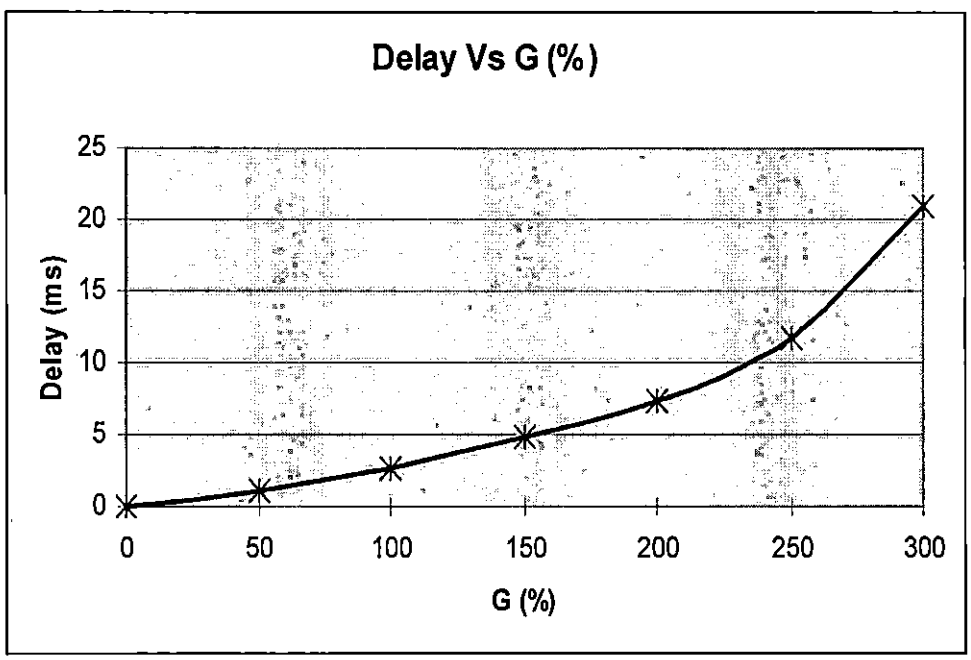


Figure: 5.2: The Delay as a function of the offered load

Figure 5.2 demonstrates the delay offered by the network using ALOHA protocol. As the figure illustrates delay increases with the increasing load. Delay increases because of increase in number of frames generated per slot, increasing the number of collisions which results in retransmitting the same frame until successful transmission.

CSMA/CA:

Same network is simulated with MAC layer protocol CSMA/CA. the throughput of the network is observed for different values from 0% to 300% of the load (G). Load is increased by increasing number of nodes participating in the network, with constant packet size and packet arrival time. Packets are generated randomly with Poisson distribution at constant mean. Results obtained through the simulator are as illustrated below

G (%)	Throughput (S)
0	0
50	0.4215
100.21	0.5316
149.47	0.5799
200.01	0.5992
250	0.5864
301.74	0.5782

Table: 5.2: simulation output (Throughput) in terms of load (G)

The network throughput is drawn as a function of the offered load, figure 5.3 demonstrates the comparison of simulation outcomes with the observed throughput.

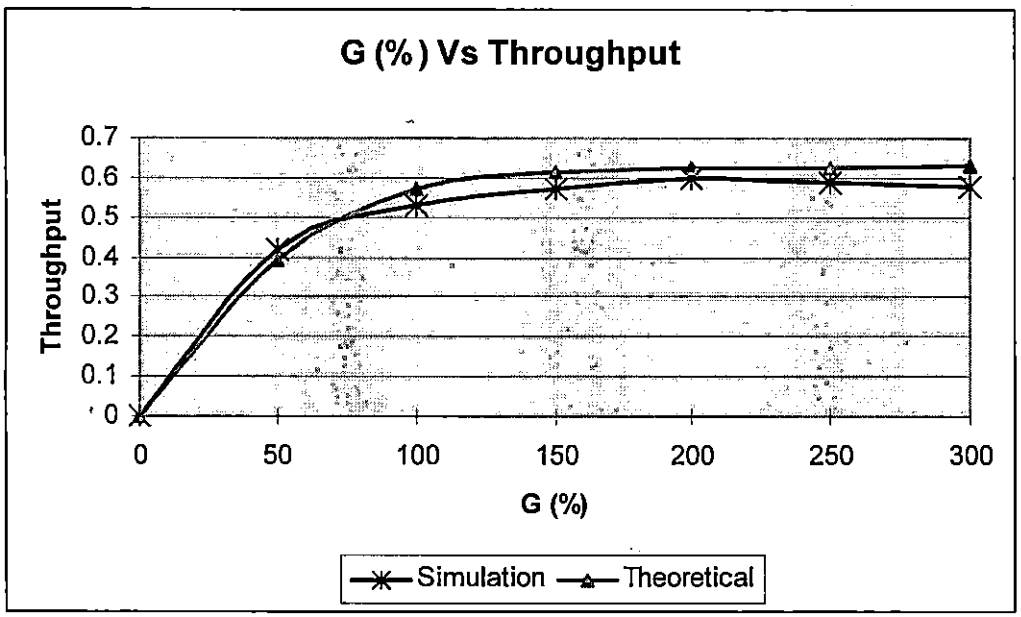


Figure: 5.3: The network throughput as a function of the offered load

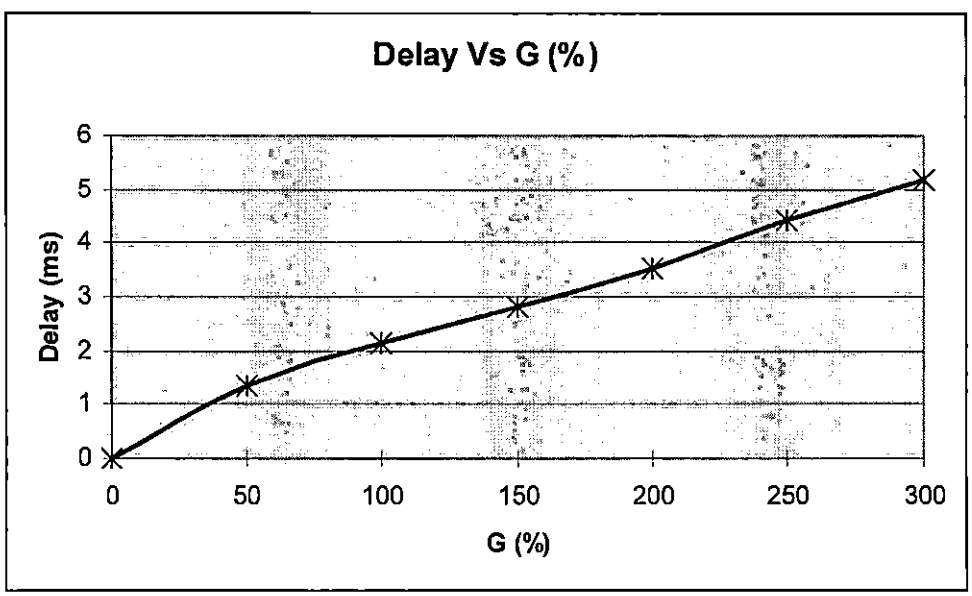


Figure: 5.4: The delay as a function of the offered load

As graphs illustrate, simulation results moderately matches with the theoretical throughput of the network. The throughput of the network increases exponentially till 100% load. For higher loads, the network throughput reaches a stable saturation throughput around 62%. Theoretically, for loads higher than 150% throughput saturates to 65%. This is because, number of packets to be transmitted increases, and which can lead to higher network traffic. To avoid collisions, MAC layer backoff its transmission till it finds channel idle. Leading to lower overall throughput and increase in delay. Since at high network traffic probability of channel being busy is high which increases the delay. The backoff delay does not have a great impact on the throughput at lower loads, because the channel is sensed as idle more often. Offered delay saturates at higher loads.

Comparison of ALOHA and CSMA/CA simulator outcomes:

Results demonstrate that designed simulator functions reasonably accurate to simulate MAC layer protocols- Slotted ALOHA and CSMA/CA. The network with similar settings is simulated with both the MAC layer protocols- Slotted ALOHA and CSMA/CA. network performance is observed in terms of throughput of the network. A network is simulated under load (G) at 0% to 300% using both multiple access protocols. Results obtained are as in Table 5.3. Figure 5.3 demonstrates the comparison between network throughputs of two protocols under different values of offered loads.

Load G (%)	Throughput (S-ALOHA)	Throughput (CSMA/CA)
0	0	0
50	0.3537	0.4215
100	0.3916	0.5316
150	0.337	0.5739
200	0.2622	0.5992
250	0.2095	0.5864
300	0.1455	0.5782

Table: 5.3: simulation output (Throughput) in terms of load (G)

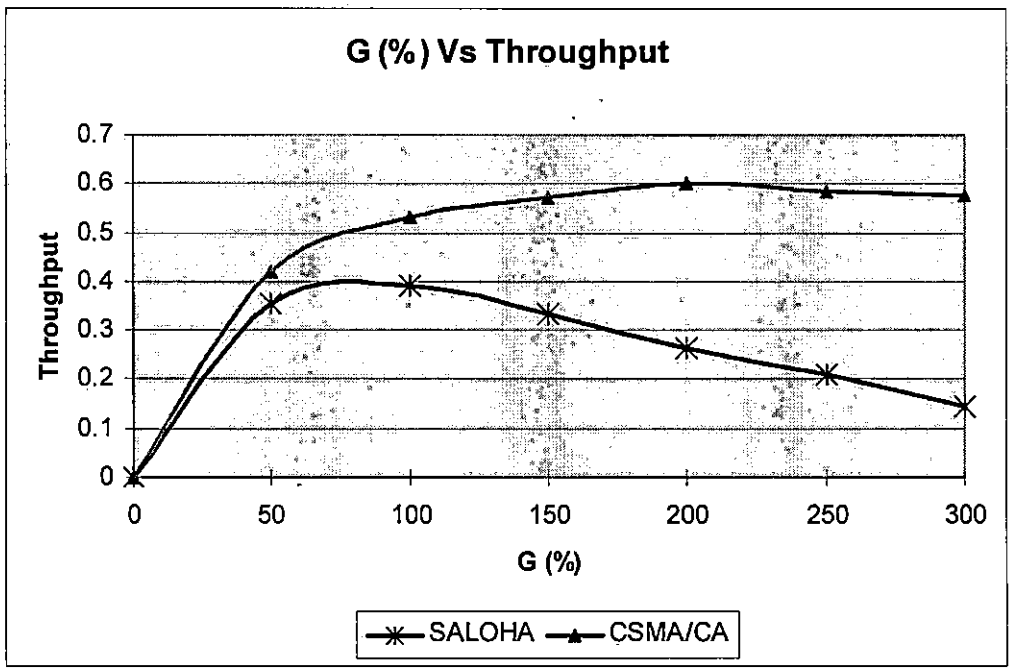


Figure: 5.5: The network throughput as a function of the offered load

As illustrated in the graph, at load of about 50% both the protocols produces moderately similar throughput. At load of 100% throughput of network under ALOHA reaches its maximum of about 39% while same network under CSMA/CA gives performance throughput of about 53%. At higher loads throughput of the network using ALOHA protocol decreases exponentially because of higher number of collisions. On the other hand, throughput performance of the network using CSMA/CA protocol saturates to the throughput of about 58% because of collision avoiding scheme.

G (%)	ALOHA	CSMA/CA
0	0	0
50	1.4173	1.3362
100	2.5029	2.1211
150	4.5211	2.8236
200	7.7730	3.5377
250	11.6725	4.4133
300	20.7553	5.1885

Table: 5.4: Delay offered in terms of load (G)

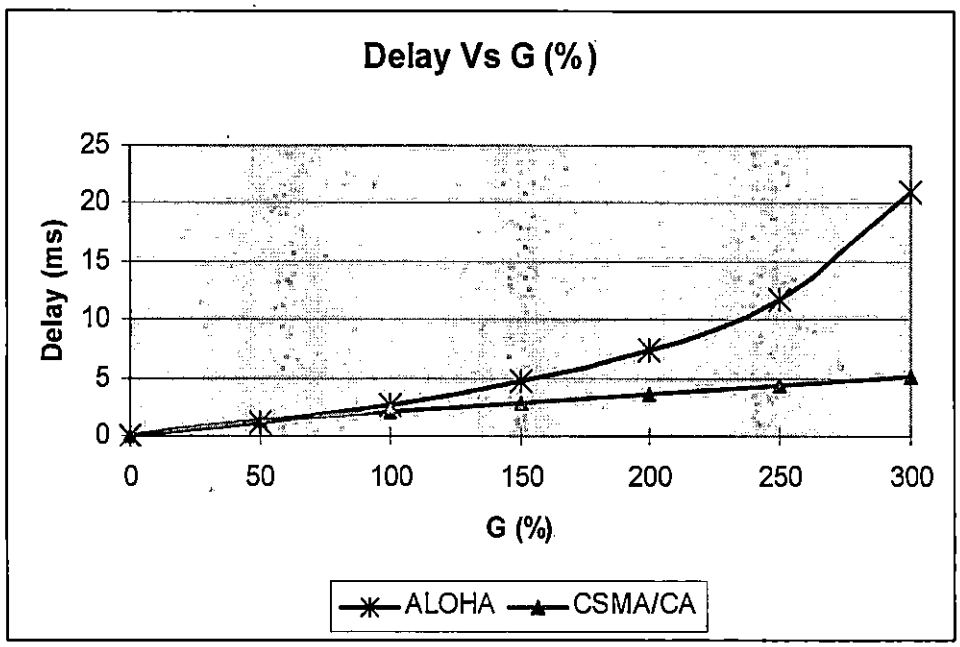


Figure: 5.6: The Average Delay as a function of the offered load

As demonstrated in figure 5.6, the network with CSMA/CA protocol offers more delay the delay offered in ALOHA network at smaller loads at about 50%. At the load of round 100 %, both the networks offer nearly same delay to the offered load. At smaller loads CSMA/CA protocol provides slightly more delay because it spends more time for backoff delays even though channel is sensed idle for most of the times. At higher loads delay in CSMA/CA network grows with the throughput and load and tends to stabilize at very loads. This is because with increasing load, number of frames to be transmitted increases due to the collision avoidance scheme CSMA/CA protocol offers more delay in order to reduce possible collisions. In case of ALOHA delay grows exponentially because of increasing number of frames to be transmitted.

CSMA/CA with Directional Antenna:

In CSMA/CA improved throughput can be obtained by using directional antennas. Directional antennas radiate larger amount of power in one direction. It increases performance of the transmitter and receiver by reducing interference with other transmissions. All nodes out of the range of transmitting antenna senses the channel idle even if one station is transmitting with directional antenna, reducing the backoff delay produced in CSMA/CA cause of busy channel. It also helps to reduce the power usage as it transmits in only one direction. Probability of collision decreases because of small overlap of range of each antenna, increasing overall throughput of the network and reducing total delay.

Following graphs are obtained considering that each station uses four directional antennas for transmission. Load is assumed to be uniformly distributed across each antenna of each station. In this scenario, total load is divided equally among all four antennas of the node, increasing the success probability of each transmission which increases the overall throughput of the network. As total load is divided among four different antennas, waiting time (backoff delay) for each station decreases to find the channel idle. Being a major part of the overall delay, reduced backoff time results in decreasing the overall delay of the network to around ¼ of the total delay with omni-directional antenna network.

G (%)	CSMA/CA with Omni-Directional Antenna	CSMA/CA with Directional Antenna
0	0	0
50	0.4215	0.96075
100	0.5316	0.9115
150	0.5739	0.86225
200	0.5992	0.843
250	0.5864	0.78515
300	0.5782	0.7273

Table: 5.5: Throughput in terms of load (G)

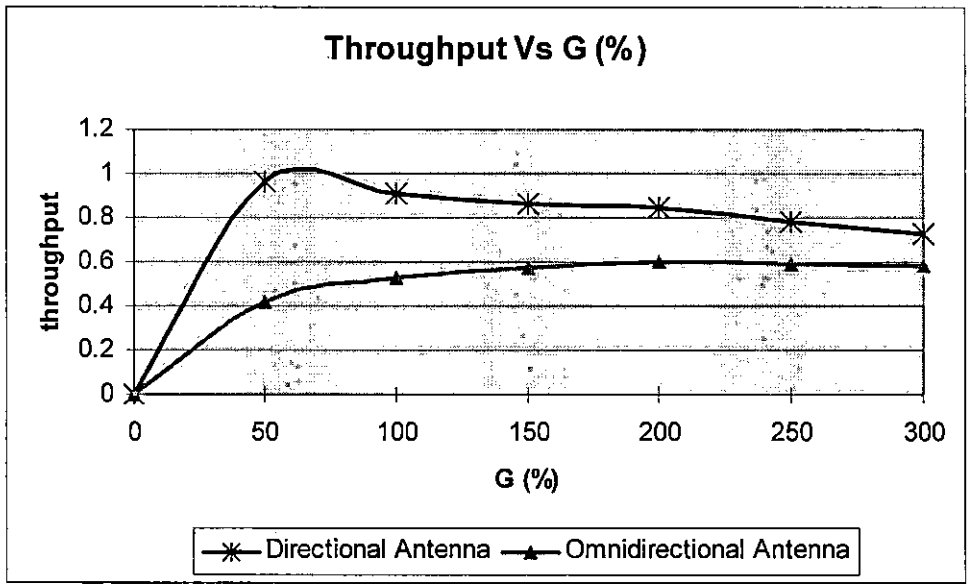


Figure: 5.7: Network throughput as a function of the offered load

As the graph demonstrates, throughput of the network is greater than 80% up-to 200% load. At higher loads throughput decreases and tends to be stable at around 70%

G (%)	CSMA/CA with Omni-Directional Antenna	CSMA/CA with Directional Antenna
0	0	0
50	1.3362	0.1301
100	2.1211	0.2742
150	2.8236	0.4349
200	3.5377	0.5931
250	4.4133	0.7960
300	5.1885	1.0312

Table: 5.6: Delay offered in terms of load (G)

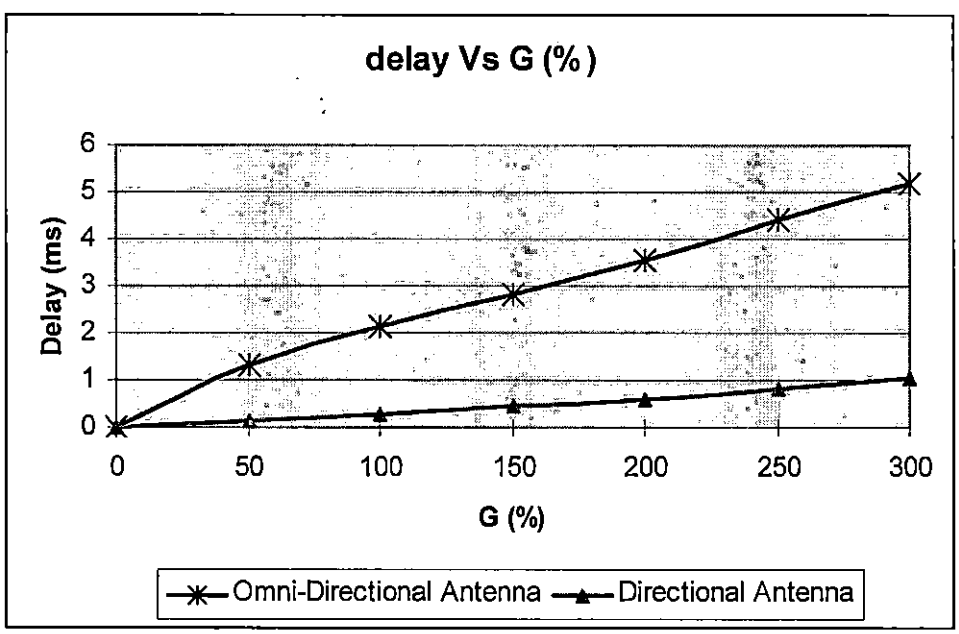


Figure: 5.8: The Average Delay as a function of the offered load

Figure 5.8 illustrates the delay offered by the network is about ¼ times the delay of the network with omni-directional antenna. The delay increases with increasing load

as it increases number of collisions, which results in increased backoff delay. At smaller loads delay is small because of the negligible channel access time as the channel in the range of transmitting antenna is idle for most of the time, about four times more than the network with omni-directional antennas. At higher loads delay tends to saturate with stabilizing throughput.

CHAPTER VI

CONCLUSION

This thesis had three main goals, as follows:

1. To demonstrate the capability and accuracy of designed simulator
2. To demonstrate and analyze the performance of the network using ALOHA and CSMA/CA protocol.
3. To compare the results of both multiple access allocating mechanisms

In order to achieve these goals, simulator is designed to model a wireless local area network. The modeled network was to simulate a small wireless network in small office. The load offered to the network was varying depending work hours, number of employees, and the applications running on each station. In order to model small office network, it was necessary to simulate the network under different load conditions and MAC layer protocols.

The simulator is implemented in C programming language in Virtual C++ environment to collect the outcomes of the network under different loads and MAC layer protocols. As demonstrated in the chapter 5, simulator produces fairly accurate results and is capable to serve the purpose.

The network is simulated for two multiple access protocols- ALOHA and CSMA/CA. the throughput of the network is obtained for various loads and multiple access schemes. Load (G) is varied by increasing number of nodes in the network,

considering variable number of employees in the office at particular time. Packet size and packet arrival rate are kept constant, assuming similar applications are running on each station. The outcome of the network simulation, i.e. Network throughput for both multiple access techniques are demonstrated and discussed in chapter 5. By observing the graphs, it is clear that for ALOHA network as load increases more than 100% the network throughput decreases exponentially, while for CSMA/CA network the throughput performance saturates and remains stable for higher loads.

In order to model a better performing wireless network for an office, the network is simulated with two multiple access protocols. The protocol to be used depends upon the load offered to the network and delay requirements. Hence the outputs of both the protocols were compared against the offered load. From the graphs in chapter 5, it is clear that CSMA/CA protocol provides better network performance (throughput) than the network with ALOHA protocol. Same network is simulated with CSMA/CA protocol and four directional antennas for transmission. As illustrated in graph 5.7, directional antenna produces prominent increases in the throughput of the network with reduced delay.

Solutions:

In order to build a small office wireless network, it is necessary to consider throughput and delay requirements. From the data collected through the simulator and the comparison graphs in chapter 5, if delay requirements are to be considered for the load smaller than 50% ALOHA protocol will be useful. CSMA/CA protocol will

produce unnecessary delay due to collision avoidance scheme at lower loads, where channel is supposed to be idle for almost every other time slot. In case of load like of both data and real time applications more than 50% and the load, CSMA/CA protocol is the best suitable option with fairly constant throughput (about 58%) even at higher loads. To obtain even better throughput with smaller delay, directional antennas can be used. From the graphs in chapter 5, it can be concluded that CSMA/CA protocol with directional antenna can be used to achieve higher throughput performance (about 70%) and smaller delay in heavy network traffic.

Future Work:

The network performance seems to be increased spontaneously with directional antennas, providing greater network throughput with reduced delay. The accurate simulation of the network using CSMA/CA and directional antennas needs accurate positioning of each node. The positioning of nodes can be expressed in Cartesian coordinate system. Position of each node and direction of the transmitting antenna can be determined to precisely mimic the original network. This study can be further extended to accurate simulation of the CSMA/CA protocol with directional antennas which can be very helpful in designing and modeling of original scenario of the network.

CHAPTER VII

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APPENDIX A

Source code of the simulator programs

The source code for simulator using Slotted ALOHA protocol:

```
//-------------------------------------------------------
//                    Source Code for ALOHA
//-------------------------------------------------------


#include<stdlib.h>
#include<stdio.h>
#include<conio.h>
#include<math.h>
void delay_reset(int D[], int i, int N);
void delay_val(int P,int D[],int i, int j, int N, int
zero_delay);
void data_gen(int T[], int D[], int N, int i, int j);
void check(int &frame, int &F,int &C,int &S, int i, int
T[], int N);
void set_delay(int P,int T[],int D[],int i,int j,int N);
void Show_output(int F, int C, int S);

void main()
{
int N, T[100], i, j, iterations=10000, F=0, C=0, S=0,
D[100], frame,P,zero_delay=1;
printf("Enter Number of Nodes = ");
scanf("%d",&N);
P=30;
delay_reset(D,i,N);

do{
data_gen(T,D,N,i,j);
check(frame,F,C,S, i, T, N);
set_delay(P,T,D,i,j,N);
delay_val(P,D,N,i,j,zero_delay);

iterations=iterations-1;

} while(iterations>0);
Show_output(F,C,S);
getch();
}
```

The source code for simulator using CSMA/CA protocol:

```
//-------------------------------------------------------------
//                    Source Code for CSMA/CA
//-------------------------------------------------------------
#include<stdlib.h>
#include<stdio.h>
#include<conio.h>
#include<math.h>
void delay_reset(int D[], int i, int N,int T[]);
void delay_val(int P,int D[],int i, int j, int N, int
zero_delay);
void data_gen(int T[], int D[], int N, int i, int j);
void check(int &frame, int &F,int &C,int &S, int i, int
T[], int N);
void set_delay(int P,int T[],int D[],int i,int j,int N);
void scan_channel(int Sc[],int Tx[], int i, int T[],int
N);
void Show_output(int F, int C, int S);

void main()
{
int N, T[100], i, j, iterations=100000, F=0, C=0, S=0,
D[100], frame,P,zero_delay=1,Sc[100],Tx[100];
printf("Enter Number of Nodes = ");
scanf("%d",&N);
P=N*10;
delay_reset(D,i,N,T);

do{
scan_channel(Sc,Tx,i,T,N);
data_gen(T,D,N,i,j);
check(frame,F,C,S, i, T, N);
set_delay(P,T,D,i,j,N);
delay_val(P,D,N,i,j,zero_delay);
iterations=iterations-1;
} while(iterations>0);

Show_output(F,C,S);

getch();
}
```