8-23-2012 12:00 AM

Performance Analysis of Channel-Aware Media Access Control Schemes

Abdulfattah Noorwali
The University of Western Ontario

Supervisor
Dr. Abdallah Shami
The University of Western Ontario Joint Supervisor
Dr. Xianbin Wang
The University of Western Ontario

Graduate Program in Electrical and Computer Engineering
A thesis submitted in partial fulfillment of the requirements for the degree in Master of Engineering Science

Performance Analysis of Channel-Aware Media Access Control Schemes

(Spine title: Design of MAC Schemes for Wireless Systems)

(Thesis format: Monograph)

by

Abdulfattah Mohammadtaher Noorwali

Graduate Program
in
Engineering Science
Electrical and Computer Engineering

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Engineering Science

The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

THE UNIVERSITY OF WESTERN ONTARIO
THE SCHOOL OF GRADUATE AND POSTDOCTRAL STUDIES

Certificate of Examination

Supervisor:	Examination Board:
______________________	______________________
Dr. Abdallah Shami	Dr. Raveendra Rao
	______________________
Co- Supervisor:	Dr. Abdelkader Ouda
______________________	______________________
Dr. Xianbin Wang	Dr. Hanan Lutfiyya

The thesis by

Abdulfattah M. Noorwali

entitled:

Performance Analysis of Channel-Aware Media Access Control Schemes

is accepted in partial fulfillment of the

requirements for the degree of

Masters of Engineering Science

Date: ______________________ ______________________

Chief of Examination Board

Abstract

This thesis proposes a new Channel-Aware MAC (CA-MAC) protocol that allows more than two simultaneous transmissions to take place within a single wireless collision domain. In this proposed work, Multiple-Input Multiple-Output (MIMO) system is used to achieve higher spectral efficiency. The MIMO-based PHY layer has been adopted to help in controlling the transmission and to avoid any collisions by using weights gains technique on the antenna transmission, and by recovering any possible collisions using ZigZag decoding. In order to develop CA-MAC algorithm, to exploit the full potential of MIMO system, the library of 802.11x standard has been modified. NS-2 based simulations were conducted to study the performance of the proposed system. Detailed analysis and comparisons with current protocols schemes are presented.

Acknowledgements

I would never have been able to finish my dissertation without the guidance of ALLAH, my supervisors Dr. Abdullah Shami and Dr. Xianbin Wang, help from lab friends, and support from my parents and wife.

I would like to express my deepest thankfulness to my advisor, Dr. Abdallah Shami, for his invaluable insights, excellent guidance, caring, patience, and keep encouraging me with a great atmosphere for doing research. I would like to thank also, Dr. Xianbin Wang, who helped me to develop my background in wireless field and let me experience grateful steps of research. I would also like to thank my supportive brother Ajmal Khan. Thank you Ajmal for our frequent discussions, it was beneficial and interesting. A great thank to Dr. Ahmed Alrefaey and Dr. T. Daniel Wallace for his grateful support. Thank you everyone in ECE office staff and faculty for helping to make this a great experience.

I would like also to thank my parents. My father Dr. Mohammad Tahir has always-supportive saying with a grateful comments. Thank you my mother Sabah who is taking care of me and keeps supporting me. They were always supporting me and encouraging me with their best wishes. Special thanks to my sister Seereen for her understanding when I needed to work in quite area. Thank you Seereen for being with me in this graduate experience, I wish you all the best in your life. I would like to thank the love of my life Esraa. Your comments were supporting me and inspired. I'm happy you are a part of my family.

At last but not least, I would like to acknowledge my inspired father King Abdallah bin Abdulaziz for giving his sons the opportunity of completing their studies overseas. Thank you Saudi government for the financial support I received through Saudi Bureau.

And lastly, thank you to all my friends who have been great throughout my studies by wishing me the best.

Table of Contents

List of Table

List of Figures

Acronyms

ACK	Acknowledgment
AP	Access Point
CP	Contention Period
CTS	Clear-To-Send
DCF	Distributed Coordination Function
DIFS	Distributed Inter-frame Spacing
EDCF	Enhanced Distributed Coordination Function
GHz	Gigahertz
Hz	Hertz
IEEE	Institute of Electrical and Electronic Engineers
IFQ	Interface Queue
kB	Kilobytes
kbps	Kilobits Per Second
MAC	Medium Access Control
Mbps	Megabits Per Second
MIMO	Multiple Input Multiple Output
NAV	Network Allocation Vector
PCF	Point Coordination Function
PDF	Probability Density Function
PHY	Physical
PLCP	Physical Layer Convergence Procedure
PSDU	Physical Layer Service Data Unit

QoS	Quality of Service
RTS	Request-To-Send
SIFS	Short Inter-frame Spacing
SINR	Signal-to-Interference Noise Ratio
SISO	Single Input Single Output
SNR	Signal-to-Noise Ratio
TCP	Transport Control Protocol
WLAN	Wireless Local Area Network

Chapter 1

Introduction

Over the last few decades, life has become busier, and the demands on the wireless communication market have increased markedly. To meet these demands, many electronic devices have been adapted to improve the performance of existing wireless technologies. These devices include such advances as Bluetooth and Wi-Fi, which have been installed in mobile devices, and cameras and/or printers, which have been connected to computers using Wireless Local Area Network (WLAN) connections. The Bluetooth standard was designed for devices operating lower-speeds,While the Wi-Fi was designed to replace existing wire connections to network devices.

The communication world has continued to expand rapidly. Part of the reason for this growth is the introduction of new solutions, which have the ability to simultaneously transfer and receive multimedia data. For example, users of computer technology now have almost unlimited ability to make phone calls, surf the Internet, share in conferences, and to play a wide variety of virtual games. All of these applications must achieve a high level of efficiency in order to provide the high Quality of Service (QoS) which is proposed by V. Srivastava [1] required by the users.

In the early 1980s, a new protocol was proposed to enable multimedia computers to communicate with each other. This protocol, which was called the International Organization for Standardization (ISO), was specially designed for that purpose. Subsequently, the ISO came to include the Open Systems Interconnection (OSI) network stack as described by B.W. Meister [3]. Similarly, the Cross-Layer Design (CLD) is a technique that was developed for use in wireless communications using the existing infrastructure of the switched packet circuit according to J.L. Burbank [2]. This circuit is considered to be a world model for all kinds of communication networks.

The vast increase in the use of wireless technology has lead the Federal Communications Commission (FCC) to limit the transmission bandwidth for different users in order to maximize the benefits to be gained from this magnificent tool. However, the huge demand for sending data at a high transmission rate coupled with wireless communication links with transmission rates nearing 1 Gigabit/second and the setting up of high speed links that offer a high Quality of Service (QoS) has driven researchers to produce new inventions.

The current Wireless Local Area Networks (WLANs) devices utilize complex mechanisms, which allow a large number of users to share networks. Hence, devices should have the inherent ability to access and share a wireless medium. And the existing technologies require the use of advanced control channel access mechanisms in order to successfully complete transmissions.

More recently, however, in order to enable the successful utilization of these communication systems, experts have met these requirements using additional antennas on both sides. Subsequently Wittneben was inspired in 1991 to invent a new technique, which was called the Multiple-input multiple-output (MIMO)[3]. The advantage of the MIMO system is that it helps to maximize antenna capacity. This advantage can be achieved by making significant modifications to the MAC protocol. Consequently, numerous researchers are concentrating on designing new MAC systems to use many advantages offered by MIMO systems for industry purposes.

In this thesis, the MIMO systems are examined as being a possible method of improving WLAN functioning through the use of spatial multiplexing with beamforming and space-time code (STCs) modulation, which are scheduled to increase the spectral efficiency through the application of special measures in the MAC protocol. In this thesis, the new intelligent distributed Channel aware MAC protocol (CA-MAC) is introduced, which leads to the use of MIMO antenna technology to improve the throughput. This proposed algorithm utilizes a weighted nulling technique, which is using for tuning in and tuning out of a station. The ZigZag-decoding model is used to recover the data if any collisions occur during the transmission.

The analysis of these results is conducted by using an NS-2 simulator, which provides the details of the performance, and by using MATLAB, which makes the necessary analysis. The CA-MAC scheme allows for the transmitting of multiple packets at a higher data transmission rate under different overlapping wireless channel scenarios. This proposed scheme allows for numerous performance improvements in aggregate network throughput as compared to existing MAC schemes.

1.1 Thesis Outline

The reminder of this thesis is organized as follows. Chapter 2 provides the background on the role of medium access control schemes as well as a detailed background on MIMO technology and on the Quality of Service in MAC schemes. In Chapter 3, there is a literature review on the latest proposals for MAC schemes, which contains study details and results. The issues related to those particular schemes are also addressed in this chapter. In Chapter 4, the Channel-Aware MAC protocol (CA-MAC) is proposed along with a discussion of the study results. This chapter also includes a detailed analysis and a comparison with a specific MAC scheme. Chapter 5 concludes this thesis and offers suggestions for future research directions.

Chapter 2

Background

B.W Meister [3] states that individuals have tried to communicate without wires since the beginning of the 19^{th} Century for many reasons, e.g., Marconi in 1897. The first one-way wireless communication was set up in 1921 in the Detroit police department. It had a low frequency of 2MHz and was used to control the department's vehicular mobile service. Since that time, services of this type have developed rapidly. By 1933, it was possible for people to communicate two ways. However, this service was limited to gasoline stations, which were located far from urban centres.

Subsequently, the Federal Communications Commission (FCC) was established in 1940 and new frequency allocations of between 30 and 40 MHz were made. These allocations led to having two new modulations. In 1920, they were identified as Frequency Modulation (FM) and Amplitude Modulation (AM) by Daniel E. Noble of the University of Connecticut and the engineers at the Fred M. Line Company.

Between 1970 and 1977, the FCC approved the underlying concepts of wireless cellular phone service and allocated 666 duplex (two-way) channels in the 800 - 900 MHz range for this purpose. In 1978, the Advanced Mobile Phone Service (AMPS) trials begin (850 MHz) in Chicago and the American Radio Telephone Service (ARTS) was set up in Washington DC according to B.W Meister [3]. After the World Administrative Radio Conference, a research group identified a common international standard, which ultimately led to the establishment of the Group Special Mobile (GSM) service in 1982.

The vast increase in the use of wireless technology led the FCC to limit the transmission bandwidth so that more users could benefit from this magnificent tool; however, due to the increased demand for the fast transmission of data, wireless communications links with transmission rates nearing 1 Gigabit/second, which offered a high Quality of Service (QoS), has encouraged researchers to work new solutions.

In this chapter, a brief explanation of the seven OSI layers and how they are related to each other is provided. Then, information about the PHY, the physical layer of the Open Systems Interconnection (OSI) Model (OSI), is given; MIMO systems for the Medium Access Control (MAC), its definition, the related concepts and the major challenges in this area are also described. Finally, the ns-2 platform is presented along with some details of its functionalities.

2.1 Layers Interactions' Concepts

OSI is used to organize data into layers, which the OSI has divided into seven layers. Each layer focuses on a particular kind of data and at the same time provides information about the layers above and below it as it described in B.W. Meister [3].

Figure (2.1) shows the seven layer divisions of the Cross Layer Design (CLD). The important point here is allowing users to allocate available space in any of the networks; by ignoring the QoS, the CLD has successfully minimized the amount of congestion in the network according to Yin Min [7].

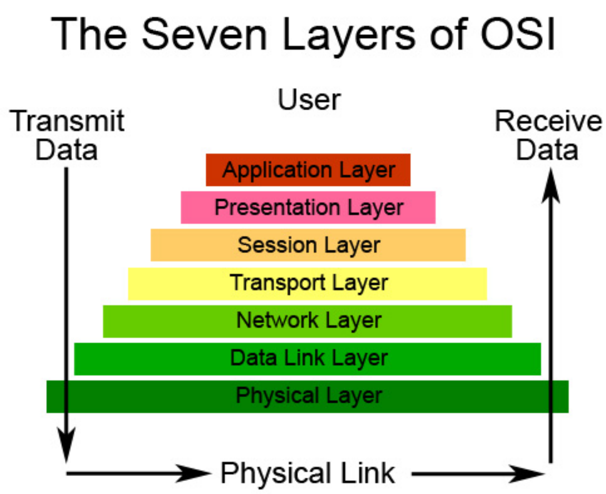

Figure (2.1): The 7 Layers of OSI

S. Mascolo [5] defined how the Transfer Control Protocol/Internet Protocol (TCP/IP) was the base model in the series of OSI layers. Each layer works with two other layers, the one above and the one below it. There is no intervention between them. Consequently, this model led to a new version, which is named the TCP/IP version 4 (TCP/IPv4) .

In the paper of J.L Burbank [2], the authors state that while this model does not fit all types of information; it is considered to be standard protocol for point-to-point communications.

Since each group has its own function, researchers focus on problems that are specific to each group of layers; thus, the relationship between the layers depends on the problem that scientists/ engineers need to address.

Each layer, or group of layers, must do its job correctly, regardless of what is going on in the other groups according to J.L Burbank [2]. There is three overlaping communities: Signal Processing, Wireless Networking, and Information Theory. Hence, according to Yin Min [7] paper, researchers are working on the problems in these areas, which may be combined to produce highly QoS-efficient and highly adaptive systems when different processes or modules are contributing information.

Therefore, in the perspective on CLD paper which is authored by V. Kawadia [6], the CLD can be defined as a technology that attempts to meet the demands of the physical medium and of the QoS from the various applications; thus, information sharing between all of layers to reach the highest level of adaptivity is required to achieve the goal of the CLD. Nevertheless, the Physical Layer (PHY) is the layer that meets the various applications' requirements as it can adapt its rate, power and coding as is described according to B.W Meister [3].

The PHY is located in the first layer of the seven-layer OSI model and serves as the physical transmission medium of the network; therefore, it is considered to be the fundamental and most complex layer in the OSI. The PHY is the medium where the signal is prepared for transmitting over the network since the data is usually converted to raw bits; thus, each bit stream, which is assembled as code words or symbols, is converted to a physical signal to make it suitable for the transmission medium.

In general, according to Yin Min [7], when the Data Link Layer asks the PHY for a translation, the PHY then converts the bit steam into an electrical, mechanical, or practical interface that can be transmitted beyond the medium to reach either the transmitters or the receivers. Each layer contains a group of similar signals that serves the upper layer while using the services have given by the layer below it as it shown in the paper of M.E. Aberson [8]. Each layer from the seven-layer stack asks the layer below to provide services, and at the same time, this layer provides services to the one above; for instance, if one layer needs a path to complete a communication through a network, the lower layer will send and receive data in packets for that path. In short, each layer is connected horizontally to the one below and to the one above. This set up is described as consisting of Protocol Data Units (PDU); consequently, this term leads to define a Service Data Unit (SDU). A SDU is a unit of data that will pass to the layer below it to allow it to be encapsulated within its PDU. In this way, the reached layer will add either a header or footer, or both, to SDU, which makes it easy to represent data at its destination.

Taking these steps between the layers improves the Information Security Components (ISC). These are: Confidentiality, Integrity, and the Availability (CIA) of the data that must be transmitted within the layers. Indeed, it is necessary to choose the appropriate network design and network management protocols to protect the system from a Denial-of-Service attack (DoS attack), which prevents secondary users from using the source services.

In Webopedia [9], the layers of the OSI model are actually divided into two sections: host layers, and media layers. The host layers carry two divisions of information: the segment and the data. On the other hand, the media layers hold three units of information: the packet, the frame, and the bit. Because of their functions, the first three lower layers belong to the media layers but the rest belong to another section. Brief details on each layer including its function are provided below.

The application layer is located at the 7th level of the OSI model layers, and it is closest to the users, which provides them with a network for supporting their applications as is authored by Liu Wai-Xi in [10]. Back to Webopedia [9], many processes take place in this layer. These include: identifying all of the partners in a communication, determining the quality of the communication service, and data checking. Hence, this layer addresses privacy and user identification issues.

The application layer also does the transferring, the online messaging, and the recognizing of any type of software, which is requesting to use the network according to M.E, Aberson [8]. While this layer carries out the users' orders, it also cooperates with the demands of the specific software being used to complete and implement the path of the communicating component.

Therefore, after the users send their requests, the application layer will identify all of the collaborators in the communication who have prepared data to be transmitted. It will also indicate the availability of resource to respond to this command, which means that the layer will decide if a particular operation could be completed or if such a communication as this even existed.

Ultimately, Liu Wai-Xi in [10] states, it will synchronize the communication to send the data. For example, the application that is responsible for the management protocols is called the File Transfer and Access Management Protocol (FTAM), for mails (X.400), and the application for managing the information is called the Communication Management Information Protocol (CMIP). It has four applications that should be carried out on the TCP/IP, which has four abstraction layers each of which has its own protocol: the Hypertext Transfer Protocol (HTTP), the File Transfer Protocol (FTP), the Simple

Mail Transfer Protocol (SMTP), and the Simple Network Management Protocol (SNMP) [9].

The translation of the data, the encryption, will data take place in the presentation layer. This step consists of transforming the application into a format that the network can use; because the data coming from the application layer is now acceptable to the network, this layer is called the syntax. For instance, after the path between the application layer and this layer has been established, the presentation layer will encapsulate the data units into a session layer protocol, and will prepare the data to be passed down as it mentioned by L.L. Hollis [11]. Based on Abstract Syntax Notation One (ASN.1) rules, which the presentation layer uses, an Extended Binary Coded Decimal Interchange Code (EBCDIC-coded) text file would be converted into an American Standard Code for Information Interchange (ASCII-coded) file.

D.M. Swany [12] says, the session layer is a coordination section in which most of the operations taking place between the applications must be done. This layer prepares for the operations, participates if necessary, closes the connections between the applications, and checks the current legality of the session. It provides for full-duplex, half-duplex, or simple works. The most important role of this layer is to terminate, and close the session. The OSI model has used this layer for the remote procedure calls.

In completing the transfer between users, Yide Zhang [13] states that the transport layer presents a transparent transfer of data to the upper layers; this layer may also ensure the reliability of error recovery and flow control. In short, this layer may checks and tracks the data, and retransmits it if the connections fail, and indicates to the users that the data has been transmitted. The OSI designed this layer with five classifications of connections, but the transport layer is not discussed here in detail.

The 3rd layer, which is the network layer, is considered to be a switching or routing technology. Network layer protocols may perform 7 functions: routing, resending, tackling, working on the Internet, finding errors, controlling any congestion, and maintaining the quality of the sequencing of the packet according to T. Suganuma [14]. T. Suganuma [14] claims that the network layer is divided into three sub layers. The first is the Sub Network Access layer, which deals with protocols for the cross point between the networks, e.g., the X.25; the Sub Network Dependent Convergence, which connects the transit network to the other networks; and the Sub Network Independent Convergence, in which the data is transmitted through multiple networks.

The encoding and decoding of the data into bits will be done in the data link layer. J.W. Conard [15] states that the protocols of this layer may perform many functions with respect to the physical layers such as providing the transmission protocol, controlling the transmission, detecting and correcting errors, and synchronizing the frames. This layer has been divided into two sub layers: the Medium Access Control (MAC) layer and the Logical Link Control (LLC) layer. These classifications describe the unique functions of the data link layer, each of which has its own function; thus, the MAC layer is the layer that controls the accessing and authorizing of the transmission of data between devices on the network. In contrast, the function of the LLC layer is limited to synchronizing and controlling the frames, controlling the flow and detecting errors as mentioned by Wu Chun by [16].

The Ethernet and the 802.11 are examples of MAC protocols, which are responsible for providing network access. Consequently, the MAC layer ensures that the transmissions take place without collision by delivering a single-hop of the IP datagram.

Referring to Osi Model [17], the physical layer is the first layer in the OSI model system, and is considered to be the last that is responsible for providing the bit stream, light, or radio signal that travels through the networks. Specifically, it converts data into a form that is suitable for sending, and receiving while providing the hardware carrier that consists of cables, and cards.

In the OSI Model Concepts paper authored by D. Petri [18], the physical layer is defined as the component that is used to introduce the relationship between a device and a transmission medium. It produces electrical and physical conditions for devices. For example, the layouts with which the physical layer deal are the: pins, voltages, cable, hubs, repeaters, network adapters, and host bus adapters (HBA).

To illustrate, InetDaemon in [19], state that the physical layer function can be described as that layer, which interacts with a single device through a particular medium; for instance, the RS-232 is a standard physical layer, which is used to access a medium.

Moreover, the PHY layer is connected to the Data link Layer in order to receive data from it. This layer then transmits the data to the medium channel; hence, it achieves the purpose of modulation, i.e., the encoding and decoding of the data. For instance, if two devices are seeking to communicate, they must be connected in a serial-to-serial mode such as the 802.3 Ethernet to the 802.11 Ethernet according to D. Petri in [18].

Hence, while the PHY layer has numerous functions, the most critical functions are limited to three. First of all, the PHY is the layer that is responsible for establishing and terminating the connection between different devices and the communication medium. Secondly, the PHY layer contributes to the process of communication between users by ensuring conflict resolution and data flow control. The third function of the PHY layer is modulation. Modulation is how the PHY layer converts the digital data from the user device into a suitable form of signal for transmitting over a particular form of communication channel such as copper wire, optical fiber, or radio.

The responsibilities of the PHY layer are to make contact with the data link layer, which is the above layer, and to disintegrate the incoming data into frames stated in Osi Model in [17]. Then, in InetDaemon [19], says that these frames will be reassembled into data link Protocol Data Units (PDU). Finally, this layer is responsible for transmitting and receiving the data.

Like any technique, the PHY layer faces some challenges in the implementation of its design. Actually, many researchers have addressed these challenges, and some of them have found solutions.

In this thesis, based on the IEEE 802.11n standard, which is widely used in the hardware market, the PHY and the MAC layers have been modified. These modifications make the algorithm more capable of sending/receiving more than two simultaneous data streams through a single collision channel. Also, recovering the information if the collisions occurred has been employed in this algorithm.

Hence, we are using PHY technology by adapting the Multiple-Input-Multiple-Out (MIMO) antenna system, to provide a higher level of efficiency. Therefore, the MAC layer should be further improved to achieve a more efficient utilization of data and to provide a higher level of response efficiency.

2.2 Multiple-Input Multiple-Output Antenna Systems

Multiple-input multiple-output (MIMO) is a system that has been developed to increase the diversity of both the transmitters and the receivers. When MIMO is used, the data stream is de-multiplexed into sub-streams before being encoded into channel symbols; this process ultimately leads to equalizing the data transmission rate in all of the transmitters.

The receivers will receive the signals in the same numbers of antenna according to B. Holter [21]. Furthermore, due to the high demand for high Quality of Service (QoS), MIMO has led to improvements in the spectral efficiency due to the rich scattering environment. The signals, which are filtered by the MIMO system, appear to be uncorrelated at the receivers' antennas; this problem leads to different spatial signatures, which can be used to simultaneously derive the separated signals from the different transmission antennas. To avoid the confusion caused by noise in the output, which is caused by the different input sequences, the system must choose a clear subset of the input sequences with a high probability of transmitting. Each input sequence results in a specific output, which ultimately leads to rebuilding the correct input sequences. The capacity of the MIMO system has been investigated by many researchers to improve its performance.

D. Shen in [22] stats that a simulation of the wireless communication system design has been implemented in different type(s) of wireless fading channels. In this section, the channel capacity of the Rayleigh-Lognormal fading channel is received, and its portable density function (PDF) is considered. The Rayleigh, Ricain and Nakagami fading channel progressions have been considered in building this simulation.

The main point here is the capacity of the MIMO Rayleigh-Lognormal channel, which depends on the capacity of the MIMO Raleigh fading channel.

Recently, experts have achieved high spectral efficiency by using multi-antennas on both the receiving and the transmitting sides. This practice inspired *Wittneben* in 1991 to develop a new technique, which is called the Multiple-input multiple-output (MIMO) delay diversity system according to E. Lindsokg [23]. See Figure (2.2), which illustrates the principles of using the MIMO technique.

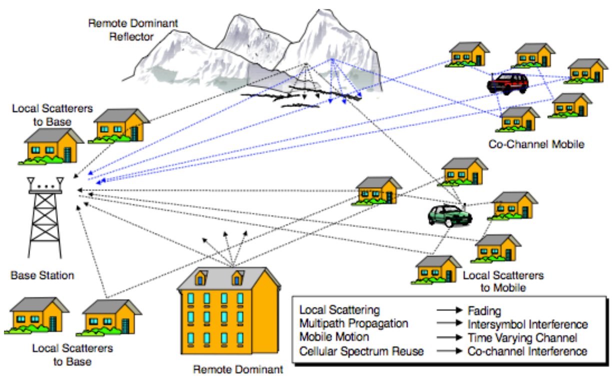

Figure (2.2): Complexity of Connections Using Wireless Communications[23]

MIMO is a system that is used to increase the efficiency of space utilization with respect to both transmitters and receivers. In the MIMO system, A.M. Sayeed [24] states, the data on the transmitter side is de-multiplexed into a specific number of sub streams. These numbers match the number of transmitting antennas. The high spectral efficiencies attained by a MIMO system are enabled by the fact that, in a rich scattering environment the signals from each individual transmitter appear to be highly uncorrelated with respect to the receiving antennas. When the signals are conveyed through uncorrelated channels between the transmitter and receiver, the signals corresponding to each of the individual transmitting antennas attain different spatial signatures.

In completing the transmission, S. Loyka [25] mentioned that the data should be divided into symbols that are mapped into sequence. When passing through the channel, these data will be affected by the random noise of the channel, which may cause confusing differences in the input data. The researcher focused on how the receiver side could accurately detect and reconstruct all of the input data. In other words, to measure the quantity of information that is being passed through the channel in the case of a negligible probability of error, the channel capacity technique is used. The maximum information transmission rate that can be used without causing a negligible probability of errors at the output is called the capacity of the channel. In transmitting information at rate R, the channel is used every Tc seconds. The channel capacity is then measured in bits per channel use.

In 1948, Claude E. Shannon, V. Kawadia [6] defined the notion of channel capacity and provided a mathematical model by which it could be computed. The simple equation used to determine channel capacity can be described as follows:

$$C = log_2(1+SNR) \text{ bits/s/Hz} \quad (2.1)$$

To demonstrate this measurement of channel potential, we assume that a channel encoder receives a source symbol every Ts second. With an optimal source code, the average code length of all the source symbols is equal to the entropy rate of the source. If S represents the set of all source symbols and the entropy rate of the source is written as $H(S)$, then the channel encoder will receive on average $H(S)$ in- Ts formation bits per second as is discussed by K.C. Zangi in [26]. The maximum information rate that can be used without causing a negligible probability of errors at the output is called the capacity of the channel. When transmitting information at the rate R, the channel is used every Tc seconds. The channel capacity is then measured in bits per channel use. Assuming that the channel has a bandwidth of W, the input and output can be represented by samples taken Ts= 1 seconds apart. Hence, the capacity is measured in information bits transmitted per second. It is common to represent the channel capacity within a unit band of the channel. The channel capacity is then measured in bits/s/Hz.

Mai Vu in [27], states another issue that affects the wireless channel, which is fading, is addressed. A fading channel is a communication channel that is subject to fading. In wireless systems, fading may either be due to multipath propagation, which is referred to as multipath induced fading, or to shadowing (sometimes referred to as shadow fading), which results from obstacles affecting the wave propagation**.**

Thus, the capacity of multipath propagation has long been regarded as an "impairment" because it causes signal fading; nevertheless, to mitigate this problem, diverse techniques have been developed.

The rest of this section is organized as follows: Section 2.2.1 reviews various MIMO Independent and Identically Distributed (I.I.D) models, and this section is followed by the development of a MIMO channel capacity model selection algorithm. In Section A, the optimal capacity of the system is presented, which analyzes the parameters of the algorithm and provides estimates for the mathematical equation.

In Section B, which is headed the "Rayleigh – Lognormal Channel Model", the probability density function property is used to estimate the values of the parameters of combining these two different models together, and of its equations.

In Section 2.2.2, the diversity technique is discussed with respect to preparing to implement the simulation design. In Section 2.2.3, the MATLAB – based implementation deals with the MIMO system when using fading.

2.2.1 Capacity Improvements in MIMO channels

An Independent and Identically Distributed (I.I.D) is a common MIMO model that can be described as a flat fading channel. The consistency bandwidth of the channel in flat fading, is larger than the bandwidth of the signal. Therefore, S. Sandhu [28] mentioned that all of the frequency components of the signal will experience the same magnitude of fading.

Several researchers are concerned with the capacity of the MIMO Rician and the Nakagami fading channel. P.J. Smith [29] described the capacity distribution of the dual-branch MIMO Rician channel. The capacity boundaries were evaluated by A. Goldsmith [30] when the transmitter detected the state of the channel information (CSI). M. Mckay [31] described the close upper and lower boundsaries of the ergodic capacity for the spatially correlated Rician (MIMO) channels. The ergodic capacity of the Nakagami-m fading channels was investigated using majorization theory according to P.J. Smith [29]. On the basis of Rayleigh and single-side Gaussian distribution, a new simulation model to simulate a MIMO Nakagami channel was proposed by V. Srivastava [1]. See Figure (2.3).

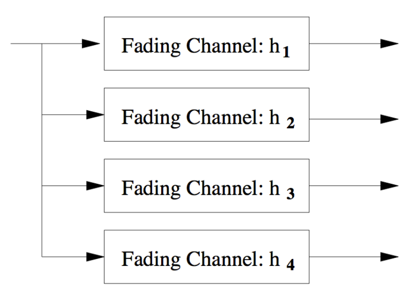

Figure (2.3): How Fading Is Converted within the Channel [1]

For the MIMO I.I.D complex Gaussian fading channel with t transmit and r receive antennas, the received signal matrix, y, is as follows:

$$y = Hx + n \qquad (2.2)$$

x is the (nT × 1) transmit vector, y is the (nR × 1) receive vector, H is the (nR × nT) channel matrix, and n is the (nR × 1) additive white Gaussian noise (AWGN) vector at a given point in time. Here, n is a complex Gaussian noise vector with independent real and imaginary pars and zero man and equal variance and $E[nn''] = \sigma^2 I_r$.

Based on the information theory, which is used to achieve the ultimate data transmission rate based on the channel capacity, the mutual information can be written as:

$$I(x; y) = H(y) - H(y|x) = H(y) - H(n) \qquad (2.3)$$

Where:

$$H(y) = E[-\log p(y)]$$

$$H(y|x) = E[-\log p(y|x)]$$

$H(y|x)$: represents the conditional entropy between the random variables X and Y

A. Maximize the Channel Capacity

It is desirable to design transmission schemes that take full advantage of the channel capacity. When representing the input and output of a memoryless wireless channel with the random variables X and Y, respectively, the channel capacity is defined by B. Holter [21].

$$C = max\ I(x; y) \qquad (2.4)$$

where $I(x; y)$represents the mutual information shared between *X* and *Y*. Equation (2.3) states that the mutual information is maximized with respect to all possible transmitter statistical distributions $P(x)$.

Mutual information is a measure of the amount of information that one random variable contains with respect to another variable which is described by Y. Liang [31]. The entropy of a random variable can be described as a measure of the amount of information required on average to describe the random variable. It can also be described as a measure of the uncertainty of the random variable. Based on eq. (2.3), mutual information can be described as the reduction in the uncertainty of one random variable due to the knowledge of the other. Note that the mutual information between *X* and *Y* depends on the properties of the channel (through a channel matrix *H*) and the properties of *X* (through the probability distribution of *X*).

Throughout this section, it is assumed that the channel matrix is random and that the receiver has perfect channel knowledge. It is also assumed that the channel is memoryless, i.e., for each use of the channel an independent realization of *H* is drawn.

This means that the capacity of the channel can be computed as being the maximum of the mutual information as defined by D. Shen [22]. The results are also valid when *H* is generated by an ergodic process because as long as the receiver observes the *H* process, only the first order statistics are needed to determine the channel capacity as described by W.C. Brown [23].

A general entry of the channel matrix is denoted by channel coefficients $\{hij\}$. This represents the complex gain of the channel between the j^{th} transmitter and the

i^{th} receiver. With a MIMO system consisting of nT transmit antennas and nR receive antennas, the channel matrix is written as:

$$\mathbf{H} = \begin{bmatrix} h_{11} & \cdots & h_{1n_T} \\ h_{21} & \cdots & h_{2n_T} \\ \vdots & \ddots & \vdots \\ h_{n_R1} & \cdots & h_{n_Rn_T} \end{bmatrix} \quad (2.4)$$

Where:

$$h_{ij} = \alpha + j\beta$$
$$= |h_{ij}|.e^{j\varphi_{ij}}$$

Figure (2.4) provides a more detailed explanation of how the MIMO channel works in the system.

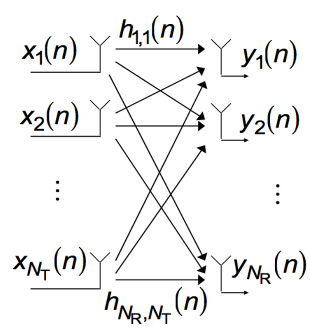

Figure (2.4): MIMO Channel Surrounded by the Transmitter and Receiver Sides

Note that: h_{ij} is estimated as a Rayleigh distribution at the start of implementing the system model and then it is converted to the Rayleigh – Lognormal Channel Model as the next section display as mentioned T.L. Martzetta in [34].

$$C = \max[I(x;y)] = \log\det\left(I + \frac{1}{\sigma^2} HQH^H\right) \tag{2.5}$$

Where:

$$E[x] = 0$$

$$E[xx^H] = Q \leq P$$

$$H^H H$$

$$H^H H = U^H \wedge U$$

Therefore:

$$C = \log\det\left(I + \frac{1}{\sigma^2} \wedge^{\frac{1}{2}} UQU^H \wedge^{\frac{1}{2}}\right) \leq \log\prod_i \left(I + \frac{1}{\sigma^2} Q\,\gamma\right) \tag{2.6}$$

Where: $Q = \left(\mu - \frac{\sigma_1^2}{\gamma_1}\right)^+$

Based on B. Holter [21] and D. Shen [22], researchers have developed a channel capacity equation to represent this specific situation, which can simply be described as follows:

$$\max(C) = \sum(\log(\mu\gamma_t)^+) \tag{2.7}$$

B. Rayleigh – Lognormal Channel Model and Its Capacity

Rayleigh-lognormal distribution is a popular channel-fading model, in which both the multipath effects and the shadowing effects are considered. It is used to model the urban environment and involves two types of fading models, the Rayleigh fading and the

Lognormal fading.

This section focuses on the channel capacity of the MIMO Rayleigh-Lognormal fading channel. The probability density function (PDF) of the eigenvalue and the channel capacity expressed as an integral form of the MIMO Rayleigh-Lognormal fading channel are derived using random matrix theory by S.A. Jafar [35].

This fading has been described by T.L. Marzetta [34]. Therefore, the received signal contains *r(t)*. This parameter can be derived from the product of two independent random processes, one of which is short-term multipath fading and the other is long term shadowing fading, which is a lognormal distribution process (See below).

$$r(t) = R(t) \times S(t) \tag{2.8}$$

R(t) is a Rayleigh process, but *S(t)* is a lognormal process.

In order to find this product, the following steps have been developed in the PDF of the received signal.

$$P_{logn}(S) = P_{logn}(r|R) \times \frac{1}{R} = \frac{1}{\sigma_2 R\sqrt{2\pi}} \exp \frac{\left(-\ln\frac{r}{R} - \mu\right)^2}{2\sigma_2^2} \tag{2.9}$$

Where:

μ is the variance of the lognormal distribution.

σ_2^2 is the mean of the lognormal distribution.

But for the Rayleigh process it is:

$$P_{ray}(R) = \frac{R}{\sigma_3^2}\exp\left(-\frac{R^2}{2\sigma_3^2}\right) \quad (2.10)$$

Therefore, after combining them, the PDF of *r(t)* will be derived from the following equation:

$$P(r) = \int_0^{+\infty} P_{logn}(r|R) \times P_{ray}(R)dR \quad (2.11)$$

Thus,

$$P(r) = \int_0^{+\infty} \frac{R}{\sigma_3^2\sigma_2 R\sqrt{2\pi}}\exp(-\frac{R^2}{2\sigma_3^2} - \frac{(\ln\frac{r}{R}-\mu)^2}{2\sigma_2^2}dR \quad (2.12)$$

Where:

σ_3^2 is the variance of Rayleigh process

P.J. Smith [21] has derived the equation for finding the channel capacity of MIMO when the fading is Rayleigh, which is shown in the following formula:

$$< C >_{T,R} = log_2(e) \times \sum_{k=0}^{m-1}\sum_{l=0}^{k}\sum_{i=0}^{2l}\left\{\frac{(-1)^i(2l)!}{2^{2k-i}l!i!(n-m+l)!}\binom{2k-2l}{k-l}\binom{2n-2m+2l}{2l-i}\right\} \times \int_0^{\infty}\ln\left(1+\frac{\rho\gamma}{T}\right)\gamma^{n-m+i}e^{-\gamma}d\gamma \quad (2.13)$$

Based on the theory of the conditional probability density function, the lognormal probability density function is:

$$P_{logn}(S) = P_{logn}(r|R) \times \frac{1}{R} = \frac{1}{\sigma_2 R\sqrt{2\pi}} \exp \frac{\left(-\ln\frac{r}{R} - \mu\right)^2}{2\sigma_2^2} \tag{2.14}$$

The channel capacity of the Rayleigh – Lognormal fading can be written as follows:

$$< C >_{T,R} = \frac{10}{\ln 10\sqrt{2\pi}\sigma_S} log_2(e) \times \sum_{k=0}^{m-1} \sum_{l=0}^{k} \sum_{i=0}^{2l} \left\{ \frac{(-1)^i (2l)!}{2^{2k-i} l! i! (n-m+l)!} \binom{2k-2l}{k-l} \binom{2n-2m+2l}{2l-i} \right\} \times$$

$$\int_0^\infty \ln\left(1 + \frac{\rho\gamma}{N_T} S\right) \gamma^{n-m+i} e^{-\gamma} d\gamma \int_0^\infty - \exp\left(-\frac{(\ln S - U_S)^2}{2\sigma^2}\right) ds \tag{2.15}$$

2.2.2 Diversity of MIMO System Technique

In the paper that written by S.A. Jafar [35], the capacity has developed for the MIMO system where the fading channel is a Rayleigh-Lognormal Fading channel. This capacity is going to be identified in both the receiver and the transmitter; and leads to the use of a waterfilling solution. Capacity Multipath propagation has long been regarded as an “impairment” because it causes signal fading; therefore, in order to mitigate this problem, diverse techniques were developed. Antenna diversity, for example, is a widespread form of such diversity. To illustrate the solution to maximizing the capacity of a MIMO system, multiple revivers and transmitters antennas should be used.

Throughout this thesis, Tarokh’s scheme has been considered; as developed in S.M. Alamouti [36]; in implementation. In Figure (2.5), shows how the multiple antennas are setup.

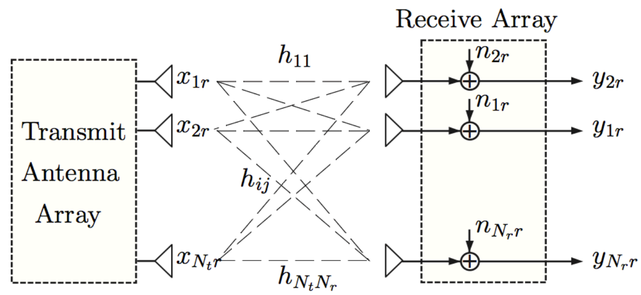

Figure (2.5): Multiple-Antenna Transmit/Receive Setup

Each transmitting antenna should be expressed with this equation:

$$\sum_{i=1}^{N_t} \frac{\sqrt{E_s}}{N_t} h_{ij} x_i(t) + n_i(t) \tag{2.16}$$

And the channel gain, which has been developed in section 2.2.1, is based on Rayleigh – Lognormal distribution.

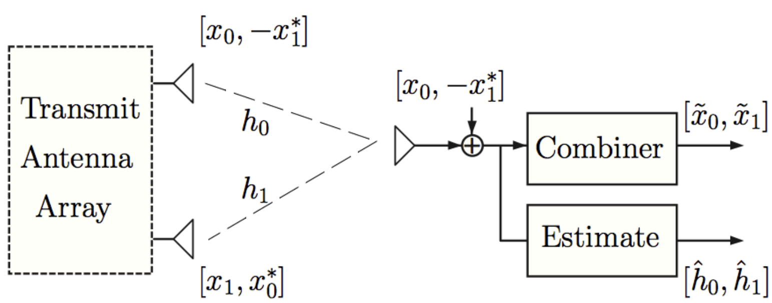

Figure (2.6): Simple STC Block Diagram in the Transmitter Side

The transmission sequence remains the same. However, the number of transmit channels will increase since the number of receive antennas is increased. Nevertheless, the issue of multiple receive antennas (receive diversity) will not be addressed in this thesis. The thesis focuses instead on transmission diversity.

In a departure from the previous discussions, this step will involve coding across both space and time dimensions as is mentioned by S.A. Jafar [35]. See Figure (2.6), to view how the information source has been de-multiplexed into several bit streams, which are equal to the number of antennas.

A.F. Molish [29] states that Tarokh *et al*. has developed the theory for orthogonal space-time block coding (OSTBC) for an arbitrary number of elements, using extremely simple decoding with almost no increase in complexity. The development of OSTBC is based on the theory of orthogonal designs for real symbols, which was developed by Tarokh and his co-authors.

Consider again a communication system with *N* transmitters and *M* receivers. The data is encoded over *L* time slots. At the *l-th* time instant, the transmitter transmits data to vector *cl*.

Over the L time instants, the ML decoder finds the solution to:

$$\underline{\tilde{c}} = \min_{\underline{c}} \sum_{l=1}^{L} \sum_{m=1}^{M} \left| y_l^m - \sum_{n=1}^{N} h_{mn} c_l^n \right|^2 \qquad (2.17)$$

In a $N \times N$ orthogonal design, the N data symbols {*cn*,} are transmitted over N time instants using the *N* elements. The *ML* decoder is equivalent to:

$$\underline{\tilde{c}} = \min_{\{c_n\}} \sum_{n=1}^{N} e_n \qquad (2.18)$$

Where *en* is some measure of error.

The key is that *en* depends on *cn* only, i.e., each symbol can be decoded individually` as described by A.M. Sayeed [24]. Note that an orthogonal code has full rank in its corresponding error matrix.

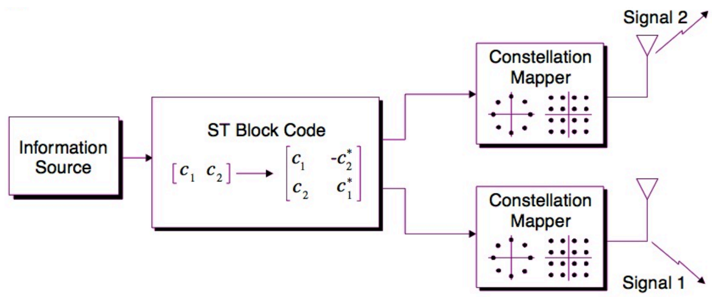

Figure (2.7): The Transmitter Side of STC

Note: The derivation of the transmitter diversity side has been investigated in many papers, so no need to re-describe it here. This work will merely use it to test the performance of my system with Rayleigh - Lognormal channel fading.

2.2.3 MIMO Improving MAC

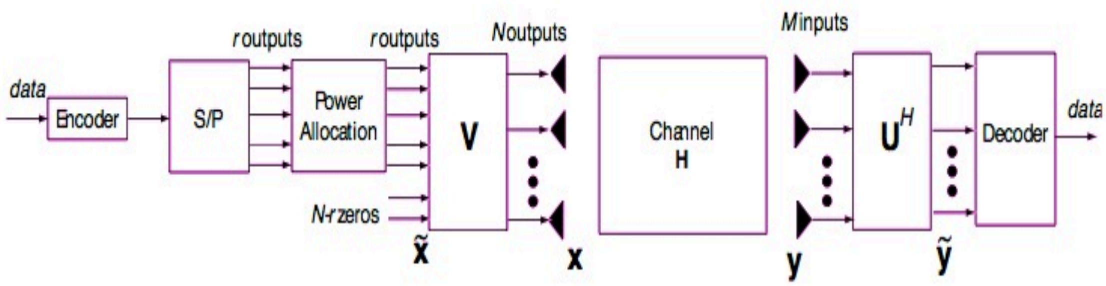

Figure (2.8): Structure of a Specified MIMO System [33]

As we can see in Figure (2.8); the MIMO system, which is included on both the transmitter and the receiver sides, has been used to test the behavior of the channel.

Before applying the new algorithm for determining the channel capacity that has been calculated in Section 2.2.1.B, the diversity of the system on the transmitter and receiver sides checks to see if the system works perfectly or not.

First of all, the users will choose the number of antennas that will be used in the transmitter and the receiver, respectively. Note: the Rayleigh channel distribution had been used as a fading in the channel. Secondly, the Alamouti scheme had been used to test the system. Finally, this process is compared with the Maximum-Ratio combining 1×2 as shown in Figure (2.9).

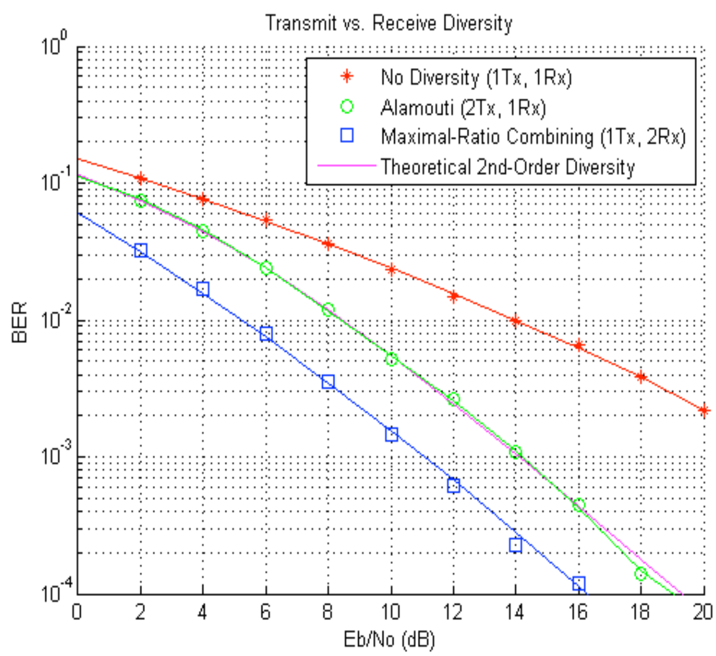

Figure (2.9): SNR Comparison between Alamouti vs Maximal Ratio Combining

Figure (2.9) shows the relationship between the Bit Error Rate (BER) and the Signal to Noise Ratio (SNR); consequently, it shows that increasing the number of antennas will improve the BER. To illustrate, a single input with a single output causes a very low BER as compared to Alamouti or Maximal Ratio Combining. Thus, the effect of increasing in the number of recievers is more efficient than Almouti, which was the case when the number of sender antennas was increased.

To explain further, using a typical BPSK system under uncorrelated Rayleigh fading conditions wehave performed a simulation based on MATLAB. It has also been assumed that the receivers have perfect knowledge of the channel condition. It shows that at least a 15 dB performance improvement can be gained when the Bit Error Rate is 10^{-15}.

Figure (2.10) illustrates here, that the BER has been implemented through Binary Phase Shift Keying (BPSK) modulation in Additive White Gaussian Noise (AWGN), and simultaneously with more diversity in the receiver antennas.

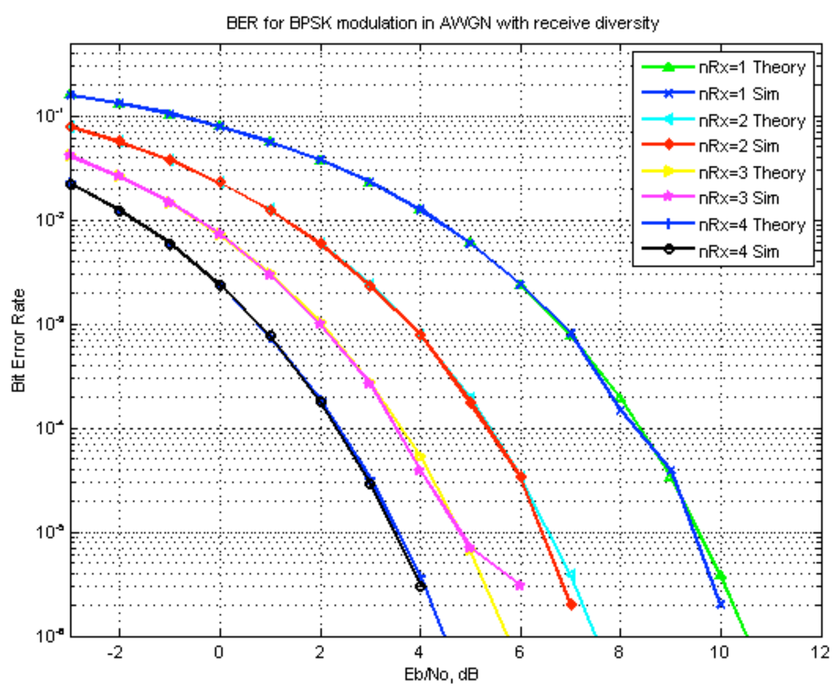

Figure (2.10): BER of Using Multiple Antennas on the Receiver Side

Substituting the equations (2.17) and (2.18) in (2.16), will lead to an increase in the diverstiy input/ouput according to Tarokh's scheme. Moreover, increasing the diversity of the input/output antennas leads to greater channel capacity. The use of uniform Gaussian distribution, is developed in Figure (2.11).

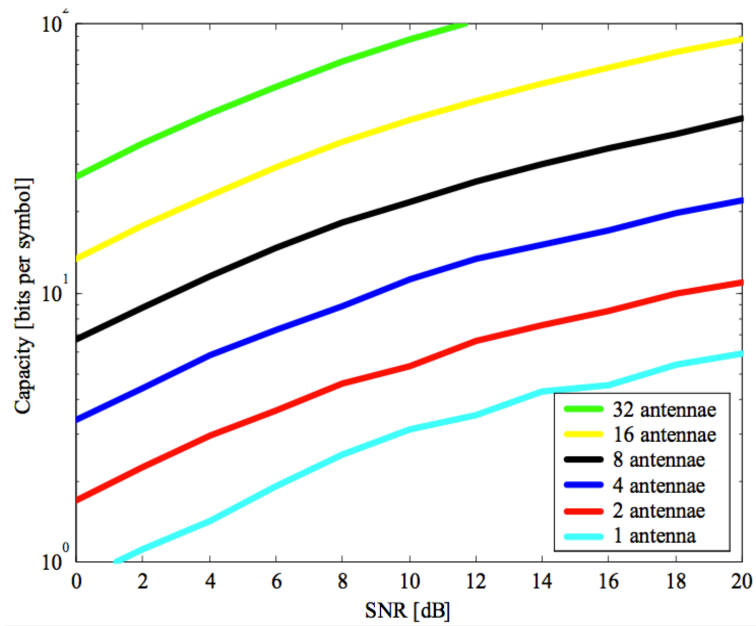

Figure (2.11): Expecting Capacity vs SNR [34]

Figure (2.11) shows that the curves move sharply upwards when the number of antennas is increased. To demonstrate, the capacity of the channel will be improved as compared to the SNR and that allows us to enhance the system with multiple inputs and multiple outputs; however, not all of the channels behave and fade in the same way, so experts should pay attention when implementing a system so that it satisfies the needs of all of the desired channels. Figure (2.12) shows the channel capacity improvement when users choose an appropriate SNR.

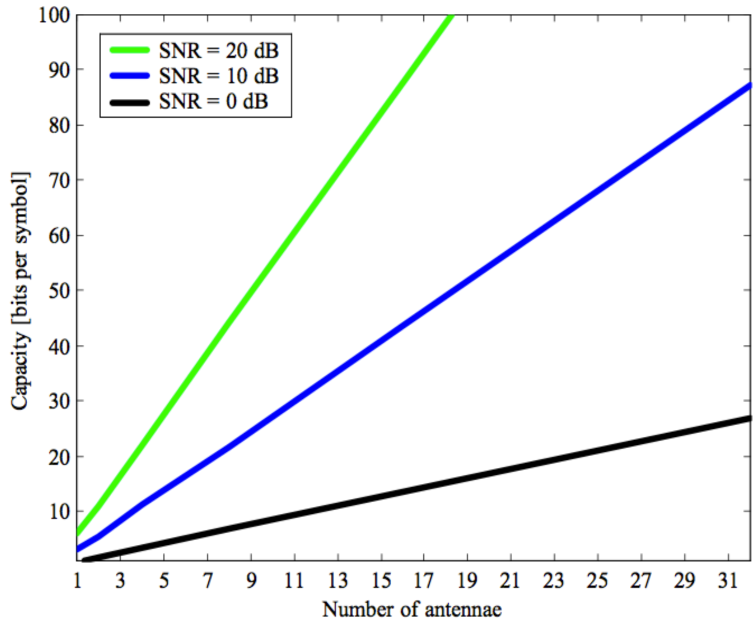

Figure (2.12): MIMO System Behavior when Uniform Gaussian Distribution Is Used [34]

We now refer back to the discussion of channel capacity that developed in Section 2.2.1.B Exchanging the channel fading that has been used in this system for the Rayleigh – Lognormal distribution to test the behaviour of the model system and identifying the diversity will solve these combined fading problems. By substituting (2.15) and (2.16), the new channel-fading algorithm will be combined in the system instead of the Rayleigh Fading being used on its own.

It had been assumed that the receiver side had the full knowledge of the channel and that the transmitter side had no information on the channel. Therefore, Figure (2.13), shows how the capacity of the channel has been improved after using multiple antennas on both sides.

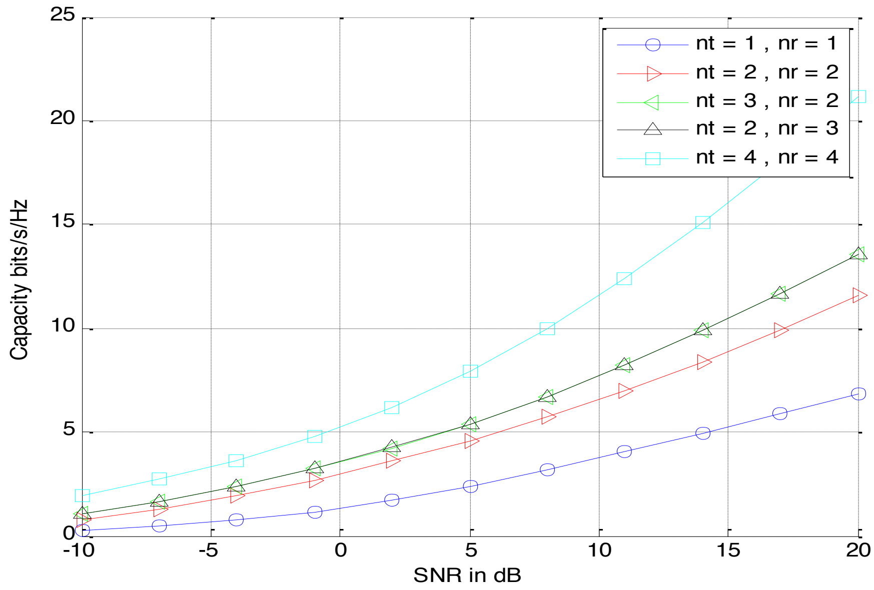

Figure (2.13): Increasing in the Channel Capacity vs the SNR by Using Diverse Antennas

The dark blue curve shows the minimum capacity rate in a different SNR, which means that a single input/output channel is not suitable for future technology and that with a limited bandwidth the data rate needs to be higher than this. Moreover, increasing the diversity on both side leads to enhancing the capacity performance of the channel and we can see the significant change in the red curve because of 2×2.

The question of what happens when we increase only one side of the transmission can be answered by examining the green curve shown in Figure (2.13) by P.Daniel [43]. It seems that regardless of the diversity and which channel is increased, changes in any of the antennas will affect the performance of the system whether it is enhanced or not.

Finally, as can be seen in the light blue curve, the capability of the channel has increased markedly. And we can easily see that the channel capacity has jumped at least by 15 bits/s/Hz with respect to the SNR which is 20. Actually, the problem of the fading that was prevalent in the MIMO system has been solved by the diversity of the antennas. Therefore, the problem of fading in a wireless communication system is going to become much less significant because of antenna diversity.

Throughout this work, it is assumed that the channel matrix is random and that the receiver has perfect channel knowledge. It is also assumed that the channel is memoryless, i.e., for each use of the channel an independent realization of H is drawn. This means that the capacity can be computed as being the maximum of the mutual information being shared as defined by D. Shen [22]. The results are also valid when H is generated by an ergodic process because as long as the receiver observes the H process, only the first order statistics are needed to determine the channel capacity.

The AWGN MIMO channels are an extension of parallel Gaussian channels. Another example of parallel channels is the use of channels on different frequencies. Moreover, introducing both multiple transmitting and receiving antennas is equivalent to increasing the bandwidth. Thus, the linear capacity increase becomes natural.

This shows that by increasing the number of anttenas will improve the BER. To illustrate, a single input with a single output will cause a very low BER when compared to Alamouti or Maximal Ratio Combining. Thus, the effect of increasing the number of recievers is better than the Almouti approach, which was to increase the number of sender antennas.

Changes in any number of antennas will have an effect on the performance of the system whether it is enhanced or not. Finally, the capability of the channel was greatly increased, and we can easily see that the capacity has jumped at least to 15 bits/s/Hz in a fixed amount of SNR, which is 20.

Hence, the bottom line is that the problem of fading using the MIMO system has been solved by increasing the diversity of the antennas. Therefore, the importance of the fading problem in a wireless communication system is going to decrease because it can be solved by antenna diversity.

2.3 Summary

In few words, the MAC layer is the layer that controls the accessing and authorizing of the transmission of data between devices on the network. MIMO is a system that is used to increase the efficiency of space utilization with respect to both transmitters and receivers. In completing the transmission, the data should be divided into symbols that are mapped into sequence. By increasing the diversity of the antennas, fading problem, which may cause confusing differences in the input data, will be decreased.

Chapter 3

Literature Review

3.1 Existing MIMO MAC Protocols

Several researchers have had the goal of increasing the spectral efficiency of wireless transmissions through the MAC layer when there are multiple users. Hence, the methodology for achieving the throughput to allow simultaneous transmission has been considerably improved. As discussed in Chapter 2, using the MIMO system is one way to achieve these improvements in assembled network throughput. The MIMO layer allows the antennas to transmit multiple streams of data by using spatial multiplexing or spatial diversity to achieve combined transmissions.

3.1.1 Medium Access Control Based on 802.11 Review

Generally, the encoding and decoding of the data into bits will be done in the data link layer. J.W. Conard [15] states that the protocols of this layer may perform many functions with respect to the physical layers such as providing the transmission protocol, controlling the transmission, detecting and correcting errors, and synchronizing the frames. This layer has been divided into two sub layers: the Medium Access Control (MAC) layer and the Logical Link Control (LLC) layer. These classifications describe the unique functions of the data link layer, each of which has its own function; thus, the MAC layer is the layer that controls the accessing and authorizing of the transmission of data between devices on the network. In contrast, the function of the LLC layer is limited to synchronizing and controlling the frames, controlling the flow and detecting errors as mentioned by Wu Chun by [16].

The Ethernet and the 802.11 are examples of MAC protocols, which are responsible for providing network access. Consequently, the MAC layer ensures that the transmissions take place without collision by delivering a single-hop of the IP datagram. Nevertheless, the 802.11 MAC protocol requires major modifications to make it capable of accepting changes in the multiple transmitting.

Based on the term of coordination functions, stations are allowed to send it allowed. Distributed Coordination Function (DCF) synchronous data to be transferred through the channel. It based on Carrier Sensing Multiple Access with Collision Avoidance (CSMA-CA) protocol. CSMA/CA is responsible to monitor the channel if it is idle or not while there is no possible to detect collision if it occurred. In order to allow this protocol to work perfectly, Short Interframe Space (SIFS), which is a required period for giving the priority to other stations, use different type of frames such as Acknlogment (ACK) frame, CTS frame, and any frame exchanges. For completing one transmission, handshaking frames, which are Request to Send (RTS) and Clear To Send (CTS), require to operate with CSMA/CA. If the data arrived without any error, the receiver will reply back with ACK packet. The length of RTS frame is 20 bytes, which is much shorter than data frame, while the length of Data frame is 2300 bytes long. Moreover, CTS has only 14 bytes length.

For avoiding collision, CSMA/CA must sense the channel in order to perform a transmission while the backoff counter is random. The duration that required to complete one successful transmission is imported in duration field that is suppose to be adjusted in Network Allocation Vector (NAV). The Slot Time used in 802.11 it to define Interframe Space period (IFS), which is responsible to determine the backoff time in range 0 to 7. When the backoff counter becomes zero, CSMA/CA will sense the channel in the way of doing the transmission.

3.1.2 Adapting MIMO with MAC

In adapting the MIMO system to the MAC protocol, adjustments must be made. Because applying spatial measures in the MAC layer is not straightforward when adapting it with MIMO, it is necessary to make special changes in the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) protocol. Hence, Wireless Local Area Networks (WLANs), for example, are required to achieve signal distribution in a wireless network.

Consequently, in order to control MIMO's antennas so that they are capable of identifying two-way signal traffic (both the sending and the receiving of data), the MAC protocols, such as the CSMA/CA, must be modified.

The role of the CSMA/CA is to identify the channel before any data transmission occurs over it in order to avoid any possible collisions. Therefore, such tools as the Request To Send (RTS), the Clear To Send (CTS), and the Acknowledgment (ACK) have been added to MIMO's antennas information. The MIMO functionalities also require changes to achieve smooth interacting between the modifications to the CSMA/CA and the various other features.

3.1.3 Organizing Sections

The rest of this Chapter is organized as follows. In Section 3.2, making multiple transmissions within an aware system is discussed according to A. Thapi [40]. Based on the nature of the physical layer (PHY), A. Thapi has derived a new expression using MATLAB to achieve a higher level of throughput performance for multiple transmissions in multiplexing scenarios.

In Section 3.3, a particular data reception technique that can be used to receive multiple packets of data especially in saturation situations is described based on the PHY and the MAC layer. Based on MATLAB, S. Baghi [41] has further enhanced the aware system while simple modifications have been made to the MAC features to permit a larger number of interactions between layers.

In Section 3.4, the NS-2 platform has been used to make major modifications to all of the Distributed Coordination Function (DCF) frames. In this section, simultaneous transmissions are discussed based on beamforming, and weighted nulling in the PHY layer. D.J. Dechene [42] has also developed a new extended exchange function, which is called a special packet. Implementing scenarios, which are based on a NS-2 simulator network, are discussed in Section 3.5. In Section 3.6, the thesis analysis is proven and suggestions are made as to how to make further improvements in this area after making tradeoffs between the current systems.

3.2 Single User /Multiple User -MIMO

In an 802.11 MAC protocol, the node required to transmit a packet through a channel must first monitor the packet's activity. When the proper node has been identified, and the Distributed Inter Frame Space (DIFS) is less than the duration of the sending interval, the channel is then ready to receive a new transmission order (is in idle status). Therefore, the node will start making its transmission.

Otherwise, the node should wait until the channel becomes idle; meanwhile, the back off time will continue to decrease until it reaches zero. If the back off of two or more nodes reaches zero at the same time, a collision will occur.

The sending mechanism is based on a handshake process, which is called the Request to Send (RTS) and the Clear to Send (CTS). Thus, in order to complete the transmitting step, the idle interval time should be greater than the DIFS. The RTS and the CTS will complete their exchange after a Short Inter Frame Space (SIFS), and all nodes will then update their Network Allocation Vector (NAV).

3.2.1 MIMO AWARE CSMA/CA

Authors in A.Thapi [40] paper, have introduced a new scheme that is called the MIMO AWARE CSMA/CA, which is an extended version of the current MAC protocol handshaking RTS, CTS, and Acknowledge (ACK) approach. These modifications have been applied to the internal frames of this handshaking approach to make it more sensitive to the transmission environment to avoid any collisions.

A. Single User Transmission Scenario

In A. Thapi [40] paper, the authors have imported a new system that will carry the antenna information, which is to be involved in the transmission. Figure (3.1) shows a simple view of how a single user communicates in a MIMO-MAC scheme scenario, which is explained in this section. This interaction uses extended frames that are built for a single user. Please see Tables (3.1), (3.2), and (3.3) for the implementation of this scheme.

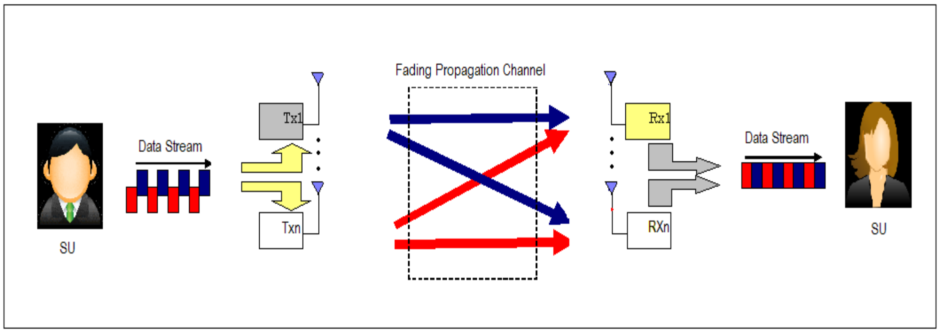

Figure (3.1): SU-MIMO Connecting the Network

Table (3.1) Extended RTS Frame for Single User

Frame Control	Duration	Receiver Address	Transmitter Address	Proposed Antenna	Frame Check
2 byte	2 byte	6 byte	6 byte	1 byte	4 byte

Table (3.2) Extended CTS Frame for Single User

Frame Control	Duration	Receiver Address	Accepted Address	Frame Check
2 byte	2 byte	6 byte	1 byte	4 byte

Table (3.3) Extended ACK Frame for Single User

Frame Control	Duration	Receiver Address	Accepted Address	Frame Check
2 byte	2 byte	6 byte	1 byte	4 byte

In the scheme proposed by A. Thapi [40], two scenarios have been analyzed; the first is the Single User-MIMO, which is used to test for changes for a single user (antenna to antenna). Here, the single user will send an application request for a transmission through a particular channel using the new modified M-DCFs. Indeed, each new function has an extended blank to be used for the receiver address information.

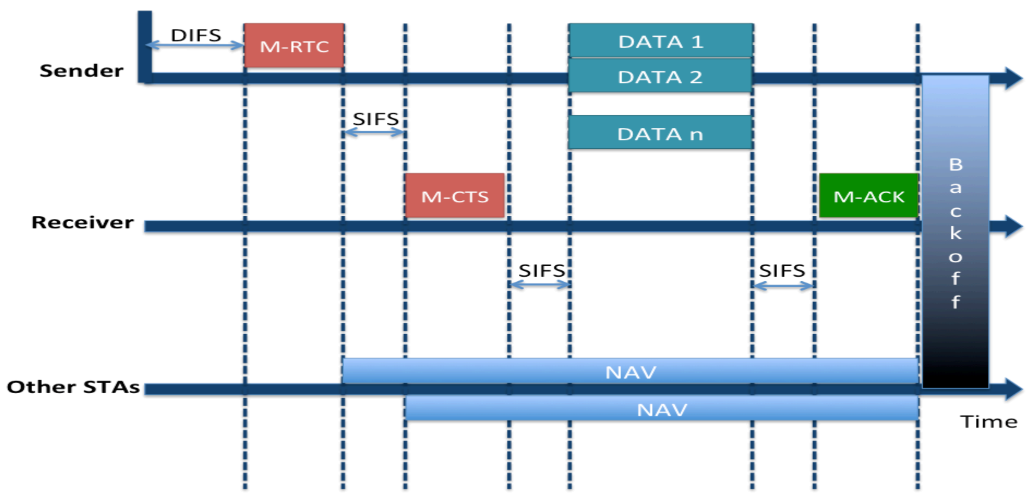

Figure (3.2): The Mechanism of Accessing the Channel for SU

Using a single user spatial multiplexing MIMO (SU-MIMO), the data streams from the X transmitting antennas will be transmitted to the X receiving antennas. Figure (3.2) shows how the station makes the extended transmission request when the node, which carries the information about the antennas, finds the channel idle for the DIFS interval.

After the SIFS time interval, a specified reviver will reply with an M-CTS frame. As a MAC protocol is required, all of the stations will update their NAV. In addition, data streams will be sent in parallel to the target receivers.

B. Multiple User Transmission Scenario

Nevertheless, Tables (3.4), (3.5), (3.6), and Figure (3.4) are considered to be the extended and the accessing mechanisms for the multiple users (Multi User - MIMO) are identified by applying equations (3.2) & (3.3) to maximize the throughput, and to minimize the delay time. Figure (3.3) gives an overview of how this particular system would access the channel.

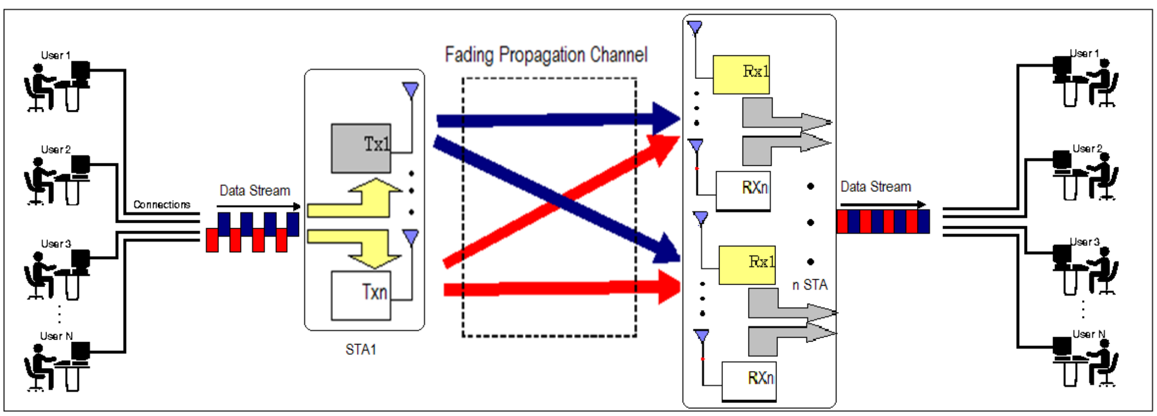

Figure (3.3): Shows How the MUs Access the Channel through MIMO Antennas

Table (3.4): Extended RTS Frame for Multiple Users

Frame Control	**Duration**	**Receiver Address**	**Transmitter Address**	**Proposed Antenna**	**Frame Check**
2 byte	2 byte	N*6 byte	6 byte	1 byte	4 byte

Table (3.5): Extended CTS Frame for Multiple Users

Frame Control	Duration	Receiver Address	Accepted Address	Frame Check
2 byte	2 byte	6 byte	1 byte	4 byte

Table (3.6): Extended ACK Frame for Multiple Users

Frame Control	Duration	Receiver Address	Accepted Address	Frame Check
2 byte	2 byte	6 byte	1 byte	4 byte

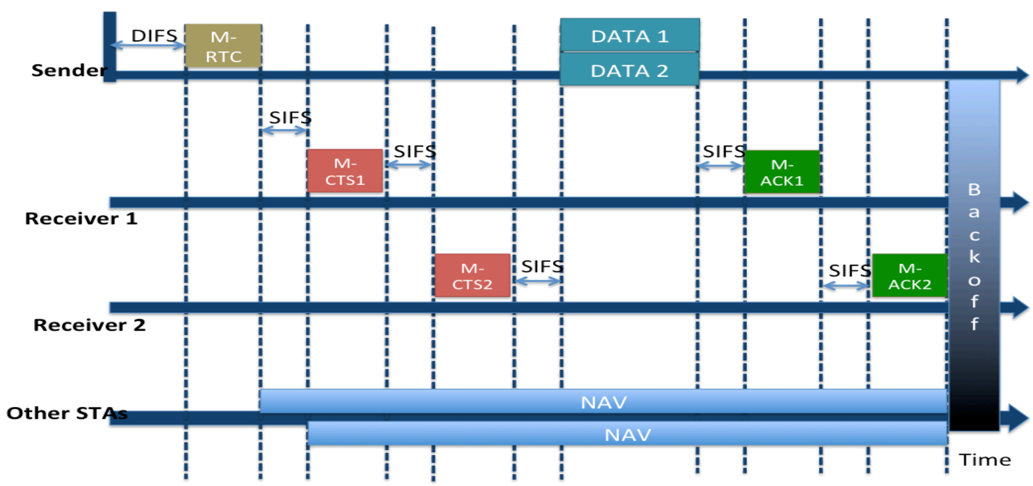

Figure (3.4): Shows the Mechanism for Accessing the channel for MU.

When the base stations on Figure (3.4), which seek to transmit data, send a request (M-RTS), and the extended frame contains all of the required information on the multiple receiver antennas' addresses, each antenna will reply to each of the base stations with the necessary permission.

Thus, data streams will be sent in the channel in parallel in order to avoid collisions. All stations in the system will, therefore, adjust their behaviour to control stop its NAV from starting any transmissions.

C. Theoretical Analysis for Single User/ Multiple User (SU/MU) System

The table below shows the parameters that have been used in building the system. Please see Table (3.6).

Table (3.7): SU/MU Parameter System

Parameters	**Value**
SIFS	$10\mu s$
SlotTime(θ)	$20\mu s$
DIFS	$50\mu s$
MAC header	224 bits
PHY header	192 bits
RTS	160 bits + PHY header
CTS	112 bits + PHY header
ACK	112 bits +PHY header
Available Antenna	1, 2, 4, 8
Channel Data Rate	1, 6, 11, 54 Mbps
Data Rate	2Mbps
Minimum Contention Window (W)	32

To maximize the throughput, the following models have been used:

$$T = \frac{PS}{T_s} \tag{3.1}$$

$$T_{s,su} = \bar{W}\times\sigma + T_{DIFS} + T_{M-RTS} + 3T_{SIFS} + NT_{M-CTS} + T_{HDR}$$
$$+ T_{PS} + NT_{M-ACK} \tag{3.2}$$

$$T_{s,mu} = \bar{W}\times\sigma + T_{DIFS} + T_{M-RTS} + 2KT_{SIFS} + NT_{M-CTS}$$
$$+ T_{HDR} + T_{PS} + NT_{M-ACK} \tag{3.3}$$

Where:

T_s is the time of a successful transmission.

PS is the payload size.

$T_{s,su}$ is the time of maximum throughput for a single user.

$T_{s,mu}$ is the time of maximum throughput for multiple users.

$\bar{W}$ is the average back off value.

σ is the slot time.

HD consists of the headers for the both physical and the MAC.

D. Aware System Achievements

Equations (3.1), (3.2) & (3.3) show how each antenna independently sends parallel data streams to multiple antennas on the other side. Indeed, all of these activities took place after the acceptance of the extended features that carried receiver addresses in the MAC protocol.

Figures (3.5) & (3.6) show the behaviour of the system for achieving maximum throughput when implementing equations (3.1), (3.2), & (3.3) in MATLAB.

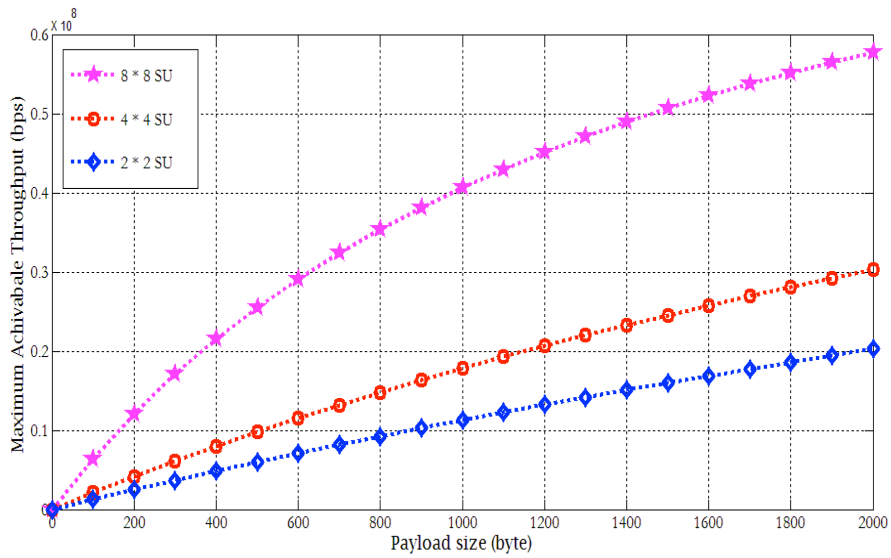

Figure (3.5): Maximum Throughput for a Single User (SU)

Based on the above equations, the system has been evaluated numerically as presented in Figures (3.5) **&** (3.6). Based on the parameters set out in Table (3.7), the maximum throughput for a SU and a MU is shown in Figures (3.5) **&** (3.6), respectively. With respect to how the payload sizes are increasing, it shows that the different number of antenna elements in both the SU and the MU situations is increasing linearly.

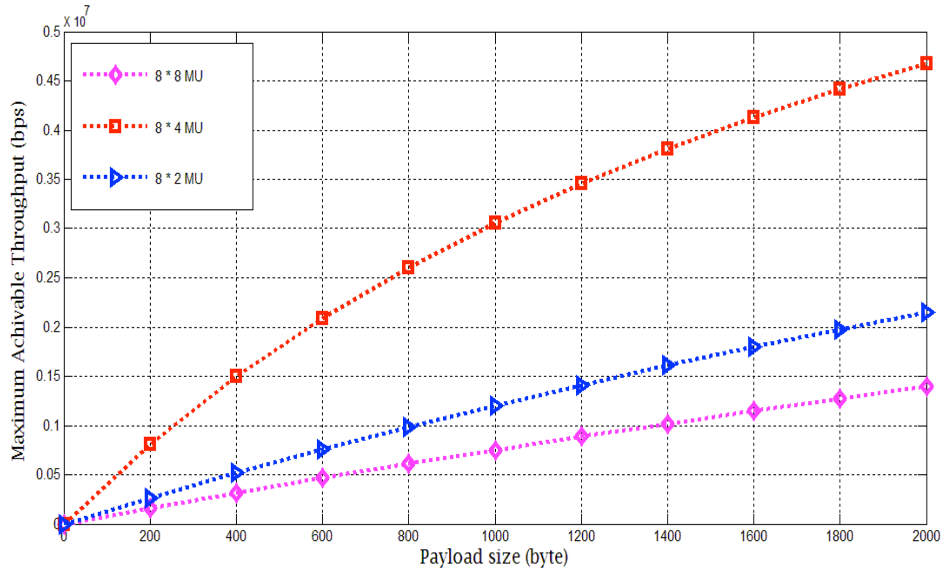

Figure (3.6): Maximum Throughput for Multiple Users (MU)

Figure (3.5) for a SU situation shows a higher achievable throughput than is shown in Figure (3.6) for a MU situation; that is because in the MU case, the higher number of exchange packets, such as the M-CTS and the M-ACK, affects the overall achievable limit.

The overhead associated with each successful data transmission made with the CSMA/CA is a major factor in the throughput.

3.3 Multiple Packet Reception

Multiple-packet reception (MPR) is an enhanced reception technique used to receive multiple packets especially in a saturation situation as is shown in Figure (3.7). The authors of S. Barghi [41] paper has proposed improvements in the design of an aware system where data streams are being simultaneously sent and received. The authors have developed a combination of many algorithms on the PHY layer side, and have extended the features in the IEEE 802.11 as well.

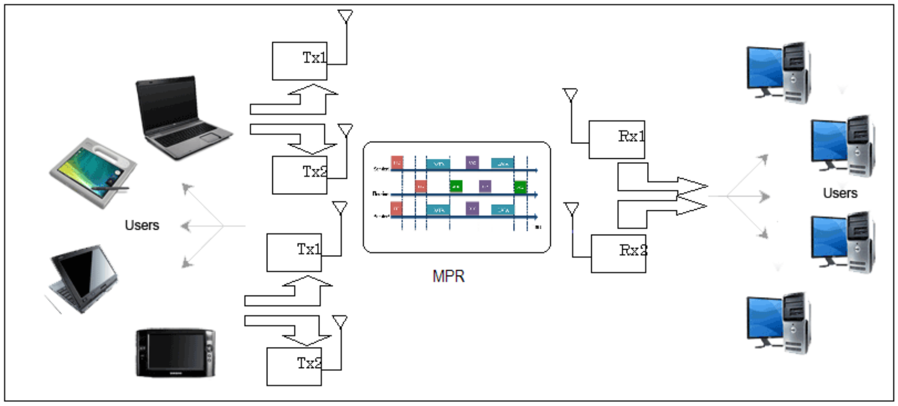

Figure (3.7): Multiple-packet Reception Technique Network Scenario

3.3.1 Interference Cancellation

For an interference cancellation, which is done in PHY, the Code Division Multiple Access (CDMA) technique has been used in many research studies for detecting the identification of the users. This is called the Multi User Detection (MUD) technique. The CDMA technique actually allows several transmitters to send information simultaneously over a single communication medium.

However, a shortcoming of this technique is the negative side effects for the power control. Thus, Space-Time Codes (STCs), which are based on a non interference technique, have been used in this system instead of the CDMA for the purpose of enhancing the link quality and increasing the data transmission rate.

Meanwhile, the PHY is used to detect the number of simultaneous transmissions; therefore, a synchronous method for the MPR should be applied. For that purpose, a shuffle algorithm that is used for the scheduling of transmissions has been designed, which deals with the interference at the Access Points (APs).

3.3.2 Detecting Users on the PHY side

Alamouti's theory which has been done by S.M. Alamouti [36] has been modified to make it suitable for the new blanks, the channel type, and the interference at the access points (APs). The AP technique is used for detecting any requests from the transmitter that have more than one packet; it then replies with permission to send or not. Consequently, it will detect the clock and the frequency asynchrony of the transmissions. Therefore, the CTS/ACK has been modified in the MAC layer so that it can make contact with the APs.

A. Introducing Waiting Time (t_w)

CTS/ACK's frames are be extended in order to accommodate the additional receiver address. Moreover, in the MAC protocol, the new time parameter has been introduced, which is responsible for the time waiting to eliminate collisions. Now the time for the MAC process will be expanded to allow for the completion of all the current procedures.

Under the IEEE 802.11 standard, the timeout for sending a packet is not specified; thus, the value of the timeouts, which are usually used for the sending of the RTSs packets, can be calculated using Formula (3.4) as shown below.

$$EIFS_{802.11} = SIFS + CTS + DIFS \tag{3.4}$$

Consequently, the element of time waiting is introduced **(t_w)** This is the waiting time on the receiver side, which can be demonstrated as being the difference in time between the two RTSs packets. Indeed, any two RTSs packets, which have less than t_w, can be detected while t_w is searching for the other RTS after the first RTS packet has been sent.

$$RTS_{timeout_{MPR}} = EIFS_{802.11} + t_w \tag{3.5}$$

Equation (3.5) allows a protocol to allow these two RTSs to be sent as one packet (single RTS).

B. Interacting between Handshaking in MAC and PHY (AP)

The AP can detect any pair of RTS when they do not exceed the $\boldsymbol{t_w}$ time. The SIFS will also be doubled to ensure that the multiple packets have gone through. These minimal modifications, which are made in the 802.11, help in avoiding collisions and limiting the size of the bandwidth.

C. MPR to MPR Scenario Analysis

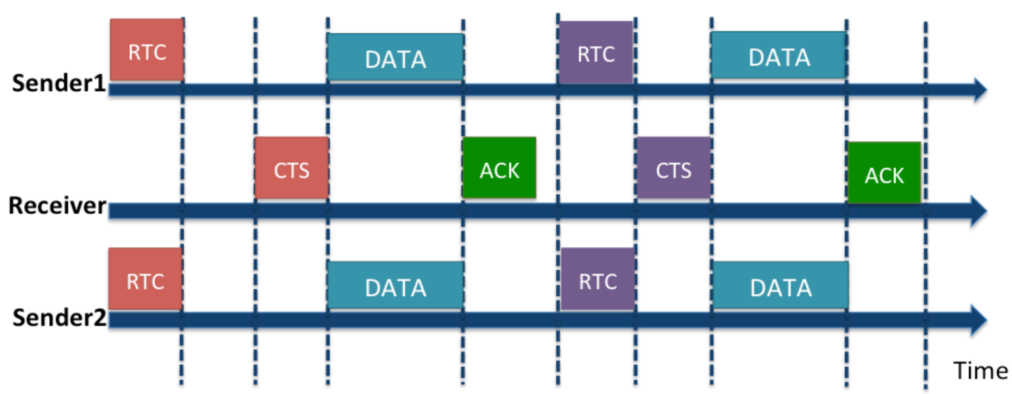

Figure (3.8): Transition from MPR to MPR

In the scenario displayed in Figure (3.8), the transmitter node has two antennas. These two antennas are used for splitting data into two parts in order to minimize its length. Moreover, it also provides an opportunity for others to make data transmissions. Hence, two terminals are transmitting information at the same time.

After each terminal sends a request (RTS) for permission to send data through the channel, the AP will detect this request and will consider both RTSs as a single RTS packet. When the protocol process responds to the RTSs, it will go back to the transmitters using the CTS.

Figure (3.8) shows all the steps in each operation. Finally, the AP is responsible for allowing the ACK to reply to the transmitters after completing the two packet transmissions. The parameter choices made for this research are shown in Table (3.8).

Table (3.8): MPR Parameter System

Parameters	**Value**
SIFS	$10\mu s$
SlotTime(θ)	$20\mu s$
DIFS	SIFS+2SlotTime
MAC header	224 bits
PHY header	192 bits
RTS	160+PHY header
CTS	112 bits +(48)+PHY header
ACK	112 bits +(48)+PHY header
EIFS	SIFS+CTS+DIFS

Data (L)	ϵ {512, 1024}
Data Rate	2Mbps
Basic Rate	1Mbps

D. Scenario Throughput

For the throughput in this scenario, as compared to the contention window, they have proven that by decreasing the number of W_c the new transmission time t_w will be minimized. The (3.9) & (3.10) figures shown below demonstrate this process.

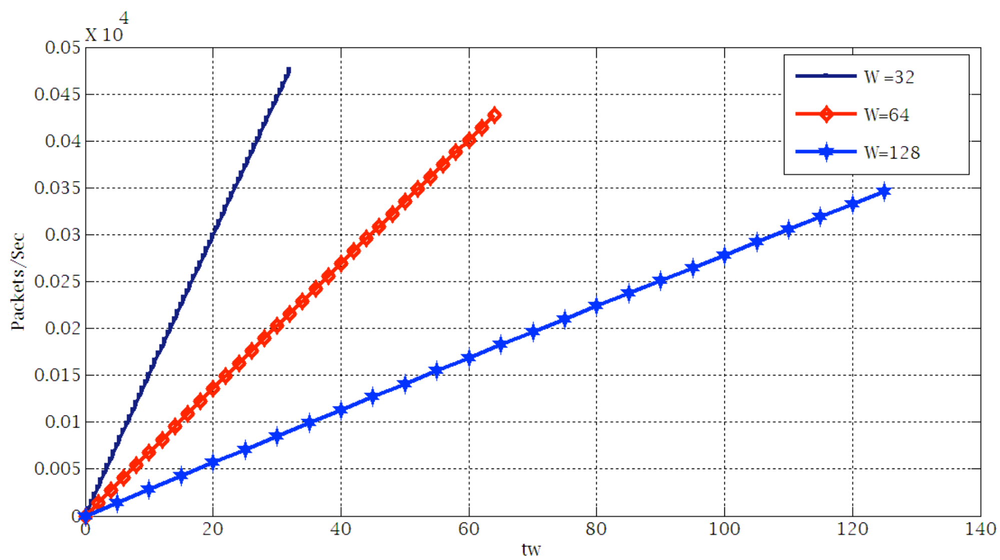

Figure (3.9): Curves Show the Improvement in the Packet Transmission when Minimizing t_w & L=512, which Is Half of the Packet

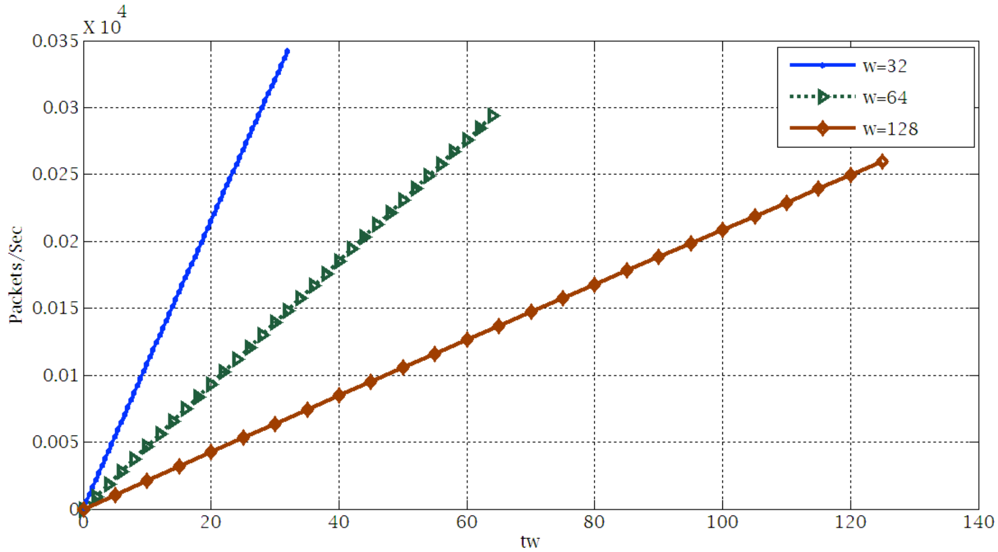

Figure (3.10): Improvement in the Packet Transmission when Minimizing the New Transmission time t_w, when L=1024 (Saturated Transmission)

The advantage of this scheme is that whenever the number of antennas is increased, the waiting time will also increase; consequently, the probability of doubling the transmission time will increase.

Nevertheless, this diversity leads to a lower bit error rate (BER), which decreases the throughput; thus, the probability of retransmitting all of the data is very high.

3.4 MAC Aware (MA)

Making up to two simultaneous transmissions within a single collision domain and making adjustments with respect to the appropriate scheduling decisions have been investigated in [42]. In MA-MAC, the status of the channel will dominate the decisions; thus, the 802.11’s DCF has been adapted to make them compatible with the targets.

Hence, this protocol leads the wireless stations to make contact through the MAC layer in a single collision domain without interfering. And thus all stations will be able to share this channel if necessary.

3.4.1 PHY -Interference Cancellation

Consequently, the numbers of antennas in the PHY layer impose the number of simultaneous transmissions; see Equation (3.4) for calculating the number of simultaneous transmission, which is related to the number of antennas.

$$\frac{m+1}{2} \tag{3.4}$$

where *m* is numbers of the antennas.

3.4.2 Adapting the Environment of 802.11n

The authors of [42] have chosen to use three antennas, so all of the results are related to two simultaneous transmissions only.

[42] has accomplished this modification in the 802.11's DCF by reforming its RTS and CTS packets, adding new packets that have the weight details of the antennas, and reorganizing the timer protocol. Meanwhile, the RTS and the CTS will perform channel estimations by using pilot symbols from the PHY preamble.

A. Adjusting Weighting in PHY

On the PHY side, weight adjustments for both the idle and the busy states have been used to tune in or tune out a particular transmission. The MIMO here plays the role of organizing the transmission; thus, modifying this organizing system according to Alamouti's theory has been accomplished.

$$r(t) = s(t)w_n H_{nm} w_m \tag{3.5}$$

Where:

$r(t)$: is the signal at the input receiver.

w_n: is the weight of the transmitting station.

w_m: is the weight of the receiving station.

$s(t)$: is the data signal to be transmitted.

H_{nm}:is the MIMO channel matrix between transmitting station n and receiving station m.

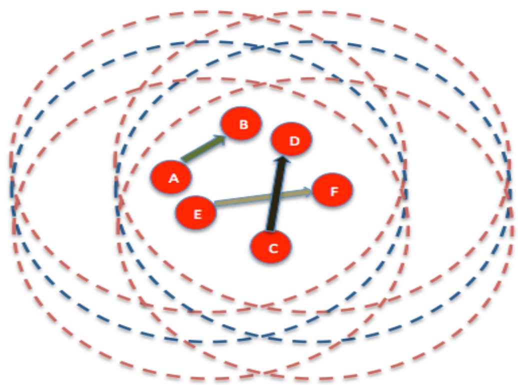

Figure (3.11): Beamforming Network Scenarios

In the idle channel status, the receiver adjusts its antennas' weights in order to maximize the signal to noise ratio (SINR), and to allow the transferring of data to proceed.

In Figure (3.11), which is an example of an idle channel, nodes A and B are connected. Thus, according to (3.6) this formula is used for the connection that has been established between these two nodes for its transmission.

On the other hand, a busy channel leads the other nodes to nullify their transmissions. Equation (3.7) is used to nullify the other nodes.

$$\frac{max}{norm\ (w_R)=1}\ (w_T H_{TR} w_R) \tag{3.6}$$

$$w_n H_{nm} w_m = 0 \tag{3.7}$$

B. Reforming/Introducing Handshaking Frames

Going to the MAC layer, the antenna weight information, which has been collected using the PHY layer, has been imported into the frames of the IEEE 802.11 standard DCF's features.

The RTS, and the CTS handshaking has expanded with the MA-MAC augmentation, which is the increased antenna weights as shown in Figure (3.12) and Figure (3.13).

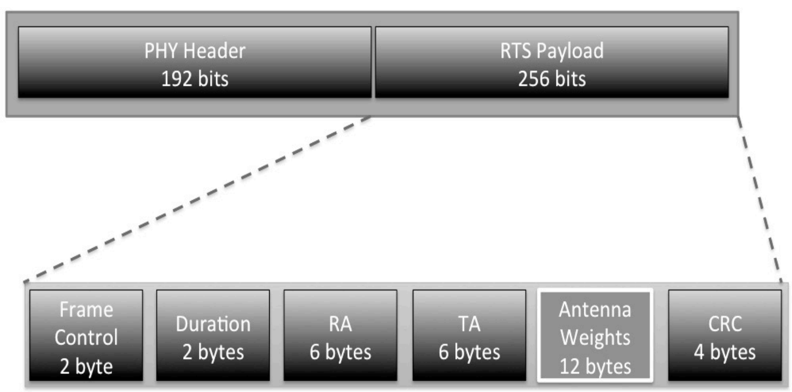

Figure (3.12): Imported Antenna Weights in the RTS Frame (MA- MAC Augmentation)

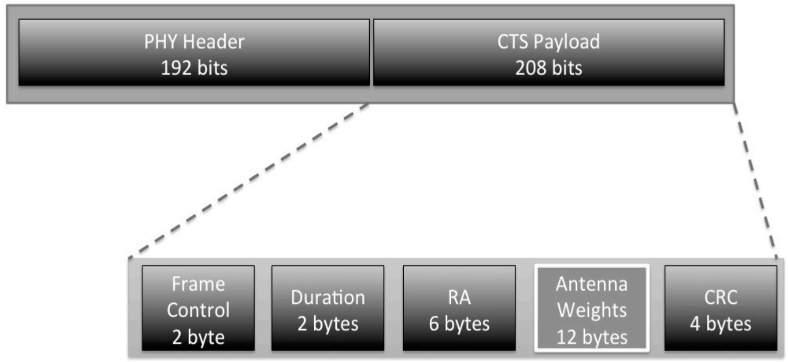

Figure (3.13): Import Antenna weights in the CTS Frame (MA- MAC Augmentation)

In order to achieve the MA-MAC protocol operation, the library of the IEEE 802.11 made some important changes in the timming of the protocol operations to modify the possible scenarios. In section 3.4.3, all of these possible scenarios will be discussed.

Creating new handshaking frames to extend the period of the antenna weights has also modified the two handshaking packet frames; they are described in Figure (3.12) **&** Figure (3.13). They exchange preamble and antenna weights to allow for the continuous transmitting of data when the system needs to split the packet to avoid a collision.

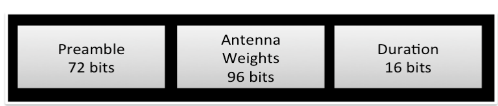

Figure (3.14): Introducing a New Handshaking Packet Called (SP_{src})

Figure (3.15): Introducing a New Handshaking Packet Called (SP_{dst})

3.4.3 MA Simulation Analysis

After setting up the parameters as shown in Table (3.9), and in scenarios (1), (2), (3), and (4), which are shown in Figures (3.16), (3.17), (3.18), and (3.19) have been programmed using NS-2, and the IEEE 802.11 library have also been modified.

Table (3.9): MA Parameter System

Parameters	**Value**
SIFS	$10\mu s$
SlotTime(θ)	$20\mu s$
DIFS	$50\mu s$
Data Frag2 PHY header	72 bits
WSP Partial	$194\mu s$
WSP	$450\mu s$
RTS	56bytes
CTS	50 bytes
SP_{src}	184 bits
SP_{dst}	168 bits
Propagation Delay (δ)	$6\mu s$
Data Rate	1Mbps
Minimum Contention Window (W)	32
Maximum Contention Window (W)	1024

A. Saturated Performance

As is shown in Table (3.1), the analysis has been completed for the MA scheme under a saturated condition. The following scenarios have been created using the stations that send data at the maximum rate (1 Mbps) offered by the PHY.

Saturated stations use the station buffer, which always have packets to send. In these scenarios, the simulation has been created using all of the stations in the MA-system, which are within the range of the transmission.

A.1 Scenario 1

In scenario (1), the time for completing the full transmission in the primary connection is more than that for the secondary transmission. Referring to Figure (3.11) as an example, C will send the RTS to the channel.

However, if the condition is accepted, D will update the weight of the reception weights and will apply it within the CTS. This procedure will help the other nodes to update their NAV. See Figure (3.16).

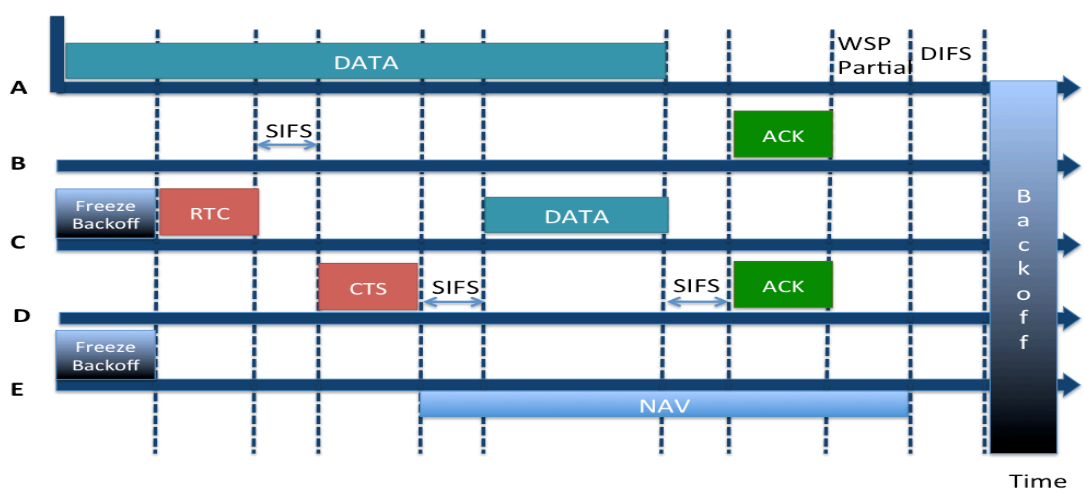

Figure (3.16): Time of Secondary Transmission is Less than Primary

A.2 Scenario 2

Nevertheless, in Figure (3.17), the transmission has started but the secondary connection has realized that the primary station activity will end soon. In this case, new parameters will be introduced. This step is called Partial Weight Sensing ($WSP_{partial}$).

This parameter is used to identify any ongoing transmission; therefore, it will refer to the ACK packet until the transmission is complete, and then it will notify all of the stations to update their NAVs so that their primary connections will be extended along with the new ACK_{defer}time.

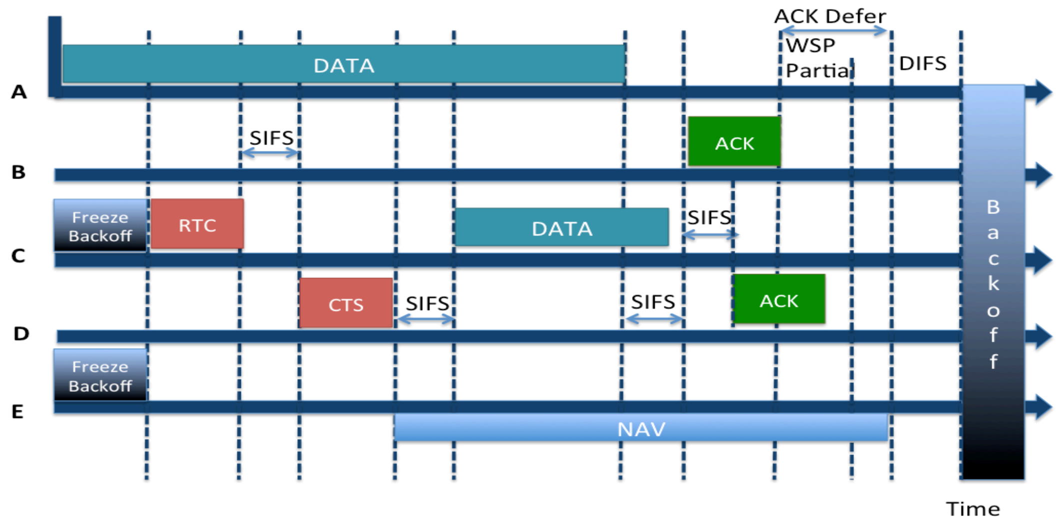

Figure (3.17): Case of Partial Weight Sensing

The splitting of the secondary data packet, and the use of the new hand shaking as shown in Figure (3.18), takes place when the primary transmission has been completed, but it is not aware of the other outgoing transmission since the nodes do not sense the secondary transmission.

A.3 Scenario 3

Using Figure (3.11) as an example, node C holds the data packet transmission information and, after the SIFS, the SP_{src} will be sending it through this node. The SP_{src} contains the antenna weights, the transmission duration, and the pilot symbols for the next channel use estimate.

After calculating the propagation delay, D will respond with the $SP_{\square st}$ it contains the same information as the SP_{src} except that the transmission duration as is shown in Figure (3.18).

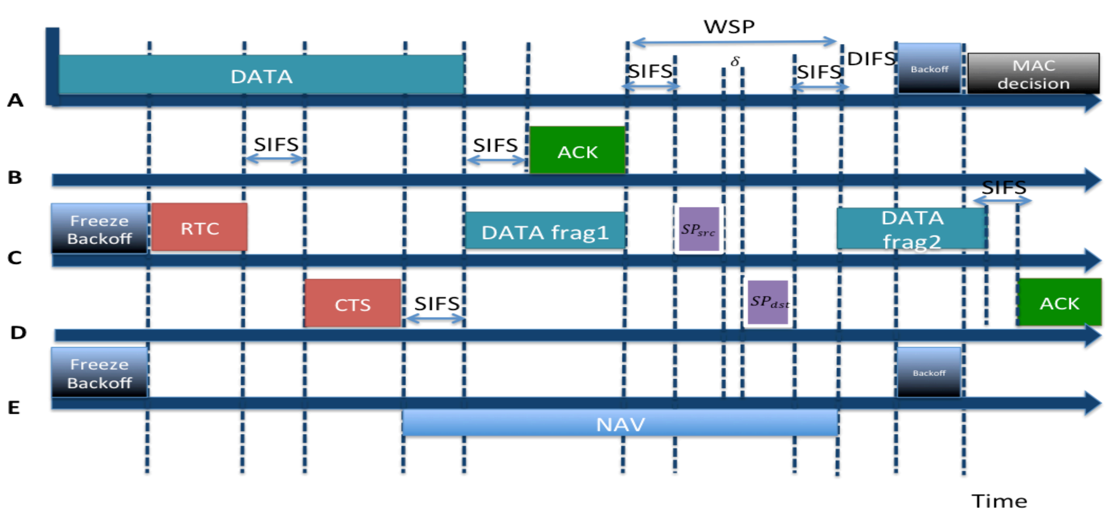

Figure (3.18): Splitting Data through Transmission

After proceeding with the transmission, and the necessary short PHY header has been attached, the secondary transmission will be converted to primary.

A.4 Scenario 4

The worst case scenario is when the handshaking process is insufficient. This happens when the request does not take place until the primary connection is complete. This situation is illustrated in Figure (3.19).

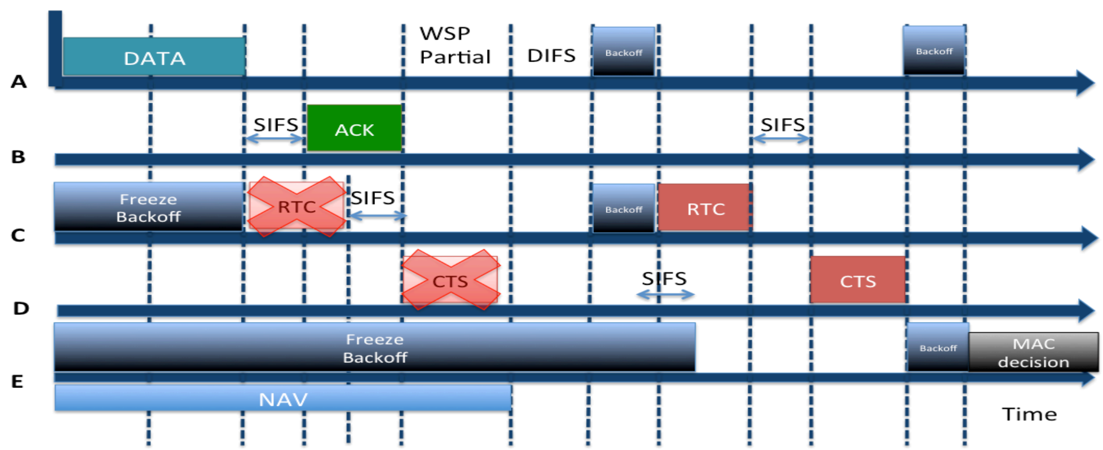

Figure (3.19): Band Reaction Case

3.4.4 NS-2 Network Simulator Implementation

In this section, the results are presented in a saturated condition for a MA-MAC scheme using the NS-2 platform programming. Based on Table (3.9), the stations are sending at the maximum data transmission rate (1 Mbps) offered by the PHY. This saturated status will act as a buffer for the stations that still have packets to send.

A. Saturation Throughput

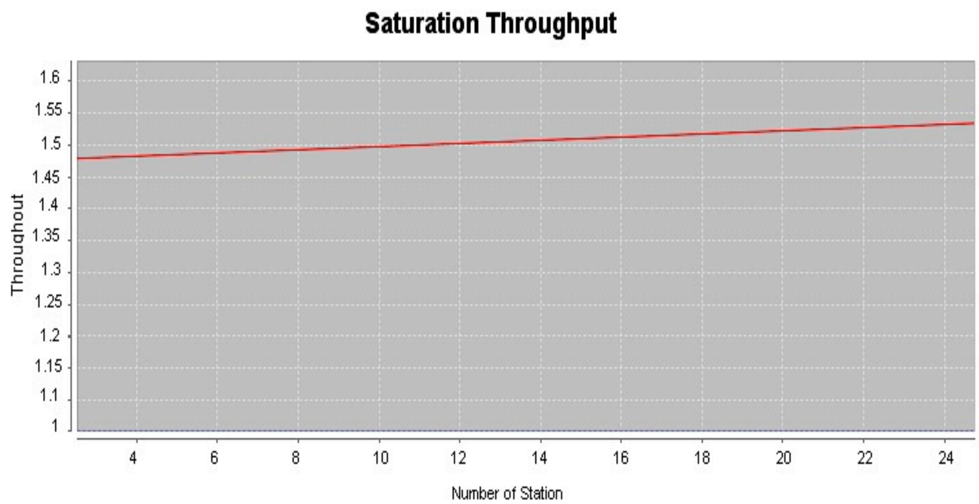

Figure (3.20): Average Saturation Throughput vs Number of Stations in Mbps

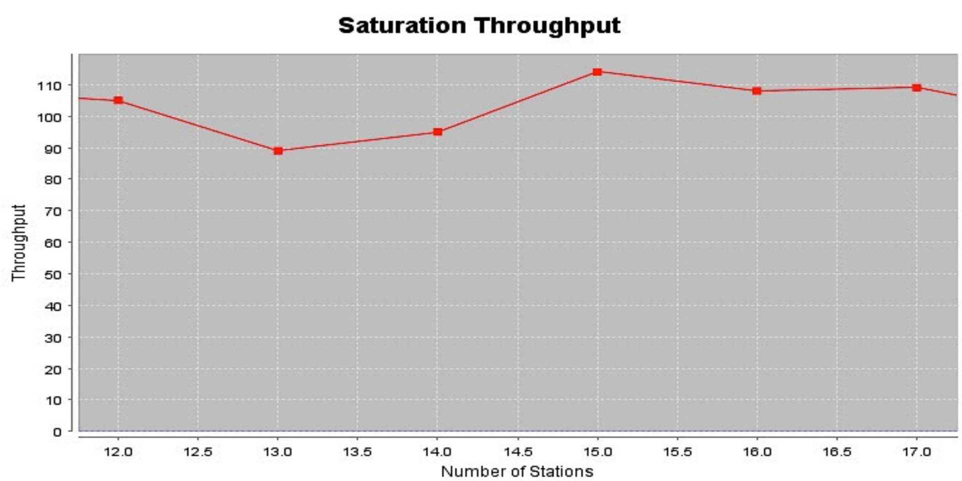

Figure (3.21): Single Scenario Saturation Throughput vs Number of Stations in Kbps

Figure (3.20) & Figure (3.21) illustrate the higher level of performance of the MA-MAC scheme under saturated conditions. It is enhanced to 1.5 Mbps while other systems such as the SPACE-MAC cannot deal with more than 1.3 Mbps according to [42].

B. Average Packet Delay

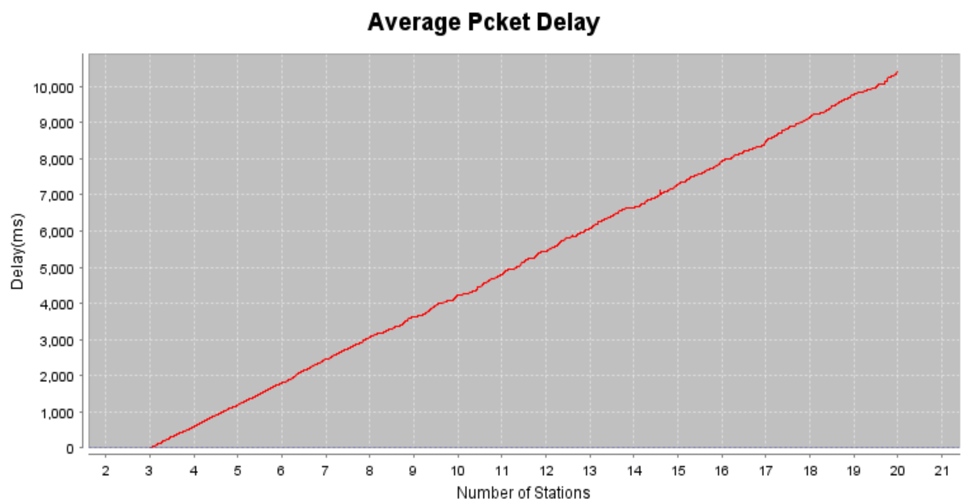

Figure (3.22): Average Packet Delay vs Number of Stations

The overall performance in the delay value has improved somewhat under saturated conditions. Figure (3.22) & Figure (3.23) show that there is a significantly smaller fluctuation in the average delay value in the MA-MAC scheme when transmitting data packets as compared to other systems, which is done by D.J. Dechene [42].

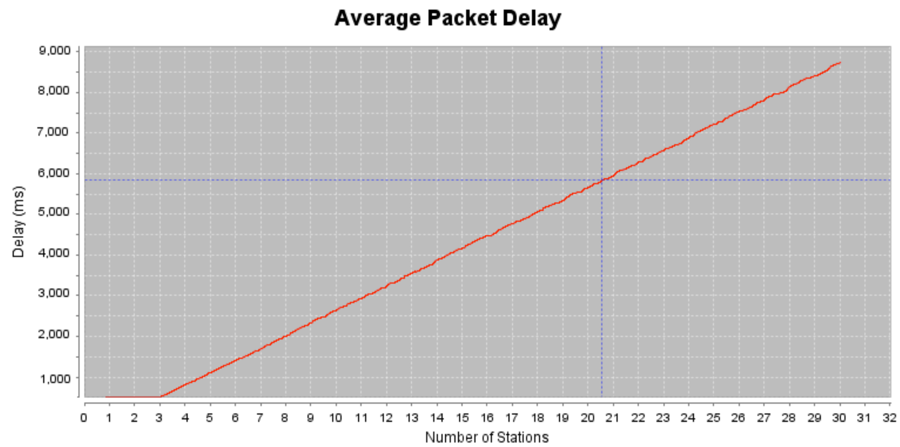

Figure (3.23): Average Packet Delay

C. Packet Sizes Effects

Where there are a variety of packet sizes, the throughput is increased as the packet size is increased. However, because of the collisions that occur, the larger number of packets will affect the throughput and the performance curve will be slightly reduced.

Figure (3.24) shows the breakpoint when the packet size has a value of 1600 bytes. Hence, the overall throughput using the MA-MAC scheme is enhanced as compared to other systems.

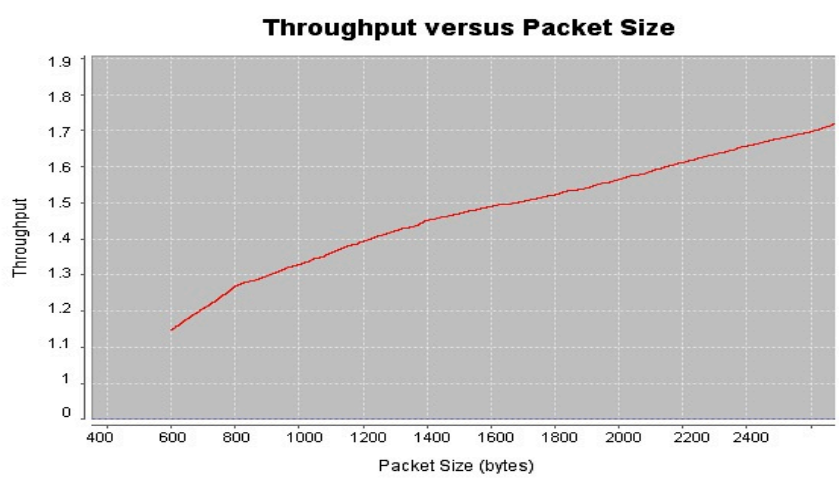

Figure (3.24): Throughput vs Packet Size

D. Minimum Contention Window of MA

Figure (3.25) shows the maximum throughput with all packet sizes, when the packet size is fixed to 1024 bytes and the minimum contention window is varied.

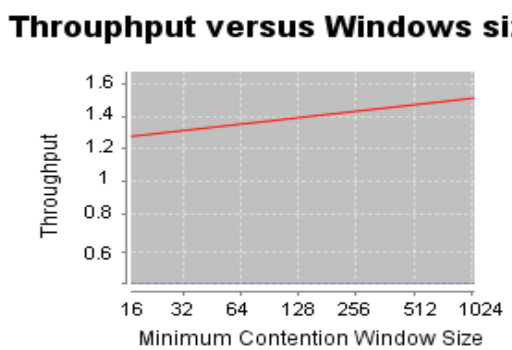

Figure (3.25): Throughput vs Window Size

3.5 Motivation Issues Analysis

The various ways of improving the Aware System are discussed in the following sections. There are many modifications to all of the systems to make them capable of sending and receiving multiple packets within an intelligent environment. Combining all of the results from the previous sections, leads to a differentiation between the layers.

3.5.1 PHY - Layer Modifications Effects

According to P. Daniel, the physical layer is defined as a component that is used to define the relationship between a device and a transmission medium. It produces electrical and physical conditions for the different devices. For example, the layouts that the physical layer deals with, are pins, voltages, cable, hubs, repeaters, network adapters, and host bus adapters (HBA).

To illustrate, the physical layer's function can be described as a layer that interacts between a single device and a medium; for instance, the RS-232 is a standard as described by InetDaemon [44] use physical layer that provides access to the medium.

The PHY has numerous functions; however, the primary functions can be limited to three. First of all, the PHY is the layer that is responsible for establishing and terminating the connections between the various devices and the communication medium. The second function is its contribution to the communication process as a conflict resolution and flow control device.

The third function of the PHY is modulation. Modulation is a way that the PHY layer can convert the digital data being transmitted from the user's device into a suitable signal format for transmission over a communication channel such as copper, optical fiber, or radio. Indeed, the adaptor can perform all of these functions.

In the following sections, the different ways of analyzing the MIMO system has been described with respect to its various improvements. The reasons behind the spatial signatures of the PHY modulation, which have been chosen for implementing these systems, have also been investigated.

A. MIMO System Analysis

The high spectral efficiencies attained by a MIMO system are enabled by the fact that in a rich scattering environment, the signals from each individual transmitter appear to be highly uncorrelated to each of the receiver antennas.

When the signals are conveyed through uncorrelated channels between the transmitter and receiver, A.M. Syeed [45] describes that the signals corresponding with each of the individual transmitting antennas have attained different spatial signatures.

According to B. Holter [46], the receivers will receive the same number of signals as there are antennas. Furthermore, because of the high demand for high Quality of Service (QoS), the spectral efficiency of MIMO has been improved because of the rich scattering environment. The signals, which are filtered by MIMO, appear to be uncorrelated at the receivers antennas, and this situation obviously leads to there being different spatial signatures, which can be used simultaneously to derive the separated signals from different transmitting antennas.

B. Modulations and Interference Cancellation

The PHY is connected to the data link layer so that it can receive data from it, and it then transmits the data to the medium channel; therefore, InetDaemom [44] manages to achieve modulation, the encoding and decoding of the data. For instance, if two devices want to communicate, they must be connected to each other in a serial-to-serial mode such as 802.3 Ethernet to 802.11 Ethernet.

The responsibilities of the PHY as described by Osi Model [47] are to make contact with the data link layer, which is the top layer, and to disintegrate the incoming data into frames. Then, these frames will be reassembled into data link Protocol Data Units (PDU).

The PHY is responsible for transmitting and receiving data. The physical protocol interacting examples include: the Carrier Sensed Multiple Access/ Collision Detect (CSMA/CD), and the Carrier Sense Multiple Access/ Collision Avoid (CSMA/CA).

Examples of PHY modulations stated by S. Mascolo [5] are: Frequency Division Multiple Access (FDMA), Minimum Shift Keying (MSK), Gaussian – Filtered Minimum Shift Keying (GFMSK), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Binary 8 Zero Substitution (B8ZS), 2 Binary 1 Quaternary

(2B1Q), Pulse Code Modulation (PCM), Quadrature Amplitude Modulation (QAM), and Phase Shift Keying (PSK).

The Code Division Multiple Access (CDMA) technique has been used by many researchers for detecting the different users. This step is called the Multi User Detection (MUD) technique. The CDMA actually allows several transmitters to send information simultaneously over a single communication device. Furthermore, the STCs have been used for the purpose of enhancing and increasing the data transmission rate.

C. Channel Capacity

Rayleigh-lognormal distribution is a popular fading channel model in which both multipath effects and shadowing effects are considered. It is used to model the urban environment due to its involving two types of fading models, the Rayleigh fading and the Lognormal fading models.

The channel capacity as described by S.A. Jafar of the MIMO Rayleigh-Lognormal fading channel has been used in these implementations. The probability density function (PDF) of the eigenvalue and the channel capacity are expressed as the integral form of the MIMO Rayleigh-Lognormal fading channel, which are derived using the random matrix theory.

D. Dealing with Handshaking in the MAC-Layer

Many researchers have invented new PHY techniques for interacting with MAC features through PHY. These techniques, however, might cause unexpected collisions during saturation transmissions.

After analyzing many of them, it was found that it was necessary to develop a new handshake technique to achieve coordination between the AP in the PHY and the DCF features in order to complete the transmissions as mentioned by S. Barghi [41]. This situation is caused by inadequacies in the system with a saturated performance. Consequently, in cases of high demand for requests for transmitting multiple packets through the channel, the AP failed to respond. Thus, ending the signals to the DCF will cause more collisions.

Furthermore, using STCs for enhancing and increasing the data transmission rate as it is used by A. Thapi [40], has complicated the analysis. While increasing the data transmission rate for multiple transmission can be achieved by using the multiple antennas in the MIMO system.

Beamforming with weighting adjustments is an enhanced way of reaching the maximum throughput without causing an imbalance or increasing the complexity of the analysis.

3.5.2 MAC – Layer Major Modifications

Encoding and decoding the data into bits will be done in data link layer. This layer performs many functions such as providing the transmission protocol, controlling the transmission, detecting and correcting errors, and synchronizing the frames according to S.A. Jafar [48].

This layer has been divided into two sub layers: The medium Access Control (MAC) layer and the Logical Link Control (LLC) layer. These classifications identify the different functions of data link layer; each of which has its own function within the system.

Thus, based on S.M. Alamouti [49], the MAC layer is the layer that is used to control the computers within the network with respect to accessing and authorizing the transmission of data. In contrast, the LLC layer is limited to synchronizing and controlling the frames, controlling the data flow and detecting errors.

The Ethernet and the 802.11 are examples of protocols, which are responsible for providing network access. Consequently, the MAC layer is used to ensure collision-free transmissions by delivering a single-hop of the IP datagram. Thus, the protocols perform the necessary detections to avoid collisions.

In the following sections, the DCF frames have been reformed. This leads to a discussion about ways of interacting with the PHY. In many system methods, new features should be introduced, which are capable of exchanging data under specific circumstances. Finally, the time for completing transmissions versus the throughputs is discussed in section 3.4.3.

A. DCF Features

The RTS, and the CTS handshaking has been expanded with a MA-MAC augmentation, which consists of antenna weights, receiver addresses, or sender addresses. These extensions are required to increase the number of packet transmissions.

Many researchers have imported antenna details into the DCF's frames to increase the transmission quantity on the PHY side. However, it is necessary to modify it so that it fits all of the unexpected scenarios.

In this work, the 802.11 has been modified so that any scenario may be dealt with. In the research of B. Holter [46], the authors improved the design of the exchange packets while the authors have made major modifications to this protocol for this purpose. Combining these changes and increasing the data transmission rate in the PHY, leads to an increase in efficiency and the ability to avoid collisions.

B. Creating New Exchanging Packets

A new handshaking frame, which can be used to exchange the period of the antenna weights, has been divided into two handshaking packet frames as is shown in [42]. They exchange preamble information and antenna weights for continuously transmitting data when the system needs to split the packet in order to avoid a collision.

3.6 Summary

This chapter discussed making multiple transmissions in multiplexing scenarios within an aware system based on the nature of the physical layer (PHY). Moreover, a particular data reception technique that can be used to receive multiple packets of data especially in saturation situations is described based on the PHY and the MAC layer. Based on NS-2 platform, the major modifications to all of the Distributed Coordination Function (DCF) frames have been made. Simultaneous transmissions are also discussed based on beamforming, and weighted nulling in the PHY layer. Lastly, implementing scenarios, which are based on a NS-2 simulator network, are proposed and analyzed for further improvements in this area.

Chapter 4

Channel – Aware MAC Protocol System

As discussed in Chapter 3, it is possible to make multiple concurrent transmissions over a wireless channel. The various constraints and possibilities of previous works were discussed for several protocols.

In this Chapter, a new Channel-Aware MAC protocol (CA-MAC) is proposed. The CA-MAC algorithm is developed to increase the efficiency of simultaneously transmitting data based on using spatial multiplexing along with beamforming and STCs modulation in the PHY layer. Moreover, the 802.11x MAC layer, which is based on D.J. Dechene [42]'s changes, will be modified to make it compatible with the new system. This chapter also includes a detailed analysis and comparisons with previous protocol schemes. Thus, this chapter is organized as follows.

In Section 4.1, the restrictions imposed by the current systems are discussed to point out how multiple transmissions within channel aware system occur. Comparison between previous works is discussed to analyse the throughput performance for multiple transmissions under different scenarios.

In Section 4.2, different techniques to send/receive multiple packets -- especially when the system is saturated -- based on PHY and MAC are described. The achievable enhancements of channel aware systems are also described. The advantages and disadvantages of these schemes are discussed. Furthermore, modifications to 802.11x Distributed Coordination Function (DCF) frames have been proposed. In this section, simultaneous transmissions are discussed based on spatial multiplexing, beamforming, and weighted nulling. Implementation scenarios are also provided in Section 4.2. Section 4.3 presents the analytical perspective of ZigZag decoding. Section 4.5 concludes the work. The thesis analysis is provided and suggestions for further research to enhance this work are discussed in Section 4.5.

4.1 Motivations:

4.1.1 Evaluation of Previous Works

Based on the characteristics of the physical layer (PHY), the authors of [40] state that users who want to share a particular channel send a request (RTS) for making such a transmission. The DCFs features are then modified (M-DCFs) so that the packets can be transmitted at the same time. Indeed, each new function has an extended blank in its frame for the receiver address information. Base stations send a request (M-RTS) before transmitting information data. This extended frame contains all the required information regarding the addresses of the multiple receivers' antennas. Each antenna will, respectively, reply with the necessary permissions. Thus, data streams can be sent in parallel through the channel and collisions can be avoided. Here, the number of simultaneous transmissions that can be processed through this system is equal to the number antennas on the sender side. Through the implementation of this system, transmissions will be error free in the channel without any interference cancelation. Moreover, each of the senders' antennas will be sending one packet of data to a different receiver. This system allows the receiving stations to receive different packets of data from different senders depending on number of antennas used. However, the main disadvantage of this system is that it is not suitable when the number of antennas increases because of the need for interference cancellation.

In the paper of D.J. Dechene [42], the authors have made significant modifications to 802.11 MAC protocol to make it suitable for sending simultaneous transmissions through the wireless channel. Modifications to the 802.11 DCF's features frames, the exchanging timer, and the weighting gain are proposed. MAC Aware (MA-Aware) protocol allows the wireless stations to be connected through the MAC layer within a single collision domain without interference. This makes it possible for all of the stations to share this channel. However, the technique of interference cancellation is limited to only a three transmissions and to the beamforming. Despite the fact that this scheme necessitates major modifications to the 802.11 MAC layer to make it possible to communicate properly within the system, the main disadvantage of this data exchange arrangement is the limited numbers of packets in the channel transmissions because of the limitation of the antennas.

According to S. Barghi [41], the major modifications are proposed to the PHY layer. Here, the interference cancellations reserve the packets from any collisions; sending of multiple packets through the channel increase the efficiency of the QoS. Space-Time Codes (STCs) based on Zigzag decoding have been used in this system instead of CDMA to enhance the link quality and to increase the data transmission rate. Meanwhile, the PHY functionalities is used to detect the number of simultaneous transmissions; therefore, a synchronous method for the Multiple-Packet Reception (MPR) has been applied. Hence, a Shuffle algorithm for scheduling transmissions has been designed, which is concerned by different interfering called 802.11x Access Points (APs), which responses to individual requests. It relies on the PHY layer and controls all of the operations from there. Because of the separations between them, there will be unexpected collision because the coordination in this arrangement disregards the exact operation of the 802.11x protocol. For example, DCF's features are responsible for the exchange of all of the packets.

4.1.2 Throughput Comparison between Previous Works

The authors of D.J. Dechene paper [42] proposed this scheme using 3X3 antennas to avoid signal interference. In comparing two schemes, the MA-Aware as proposed in [42] and the MIMO-Aware – Multiple User transmission scheme as proposed in [40] together in case of this antenna, the MA-Aware scheme provides a higher level of throughput performance. Figure (4.1) illustrates the difference in the increased throughput in the MA-Aware system, which now has almost a 12% enhancement.

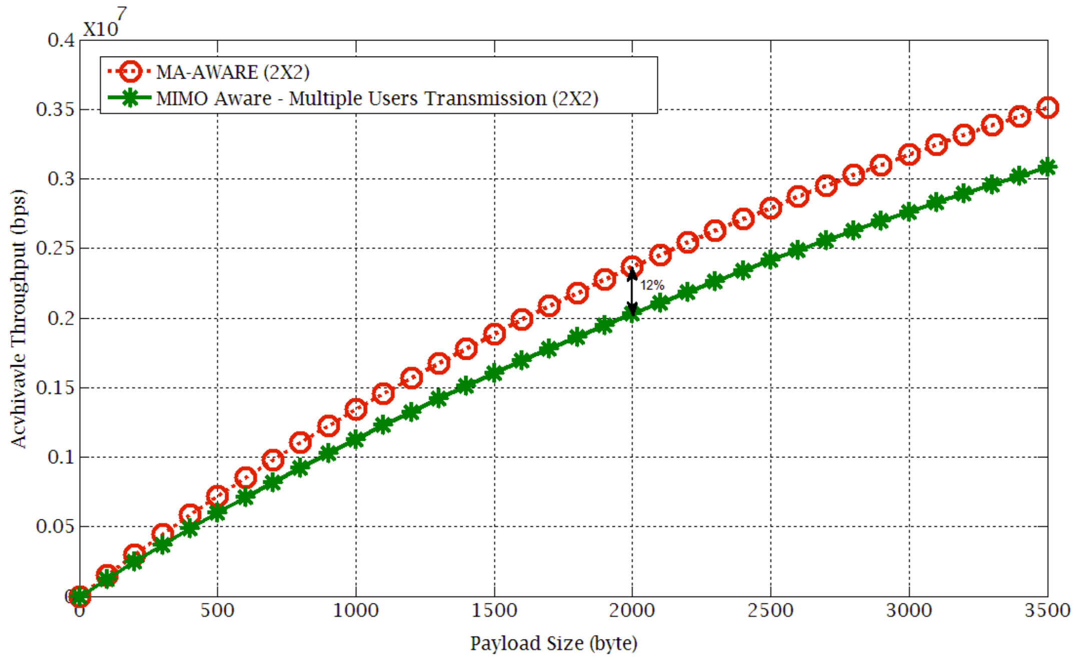

Figure (4.1): Enhancement in Throughput vs Packet Sizes for MA-AWARE scheme

In comparing the MPR scheme that described by S. Barghi [41] to the MIMO-Aware scheme which is described by D.J. Dechene [42] – The timing of the Multiple User Transmission, the MPR has a higher level of performance as compared to the MU. While MPR allows the transmission of multiple packets, it shows really major enhancement. Figure (4.2) shows the 60% higher level of throughput performance achieved when transmitting packets during a sample time simulation case of MPR.

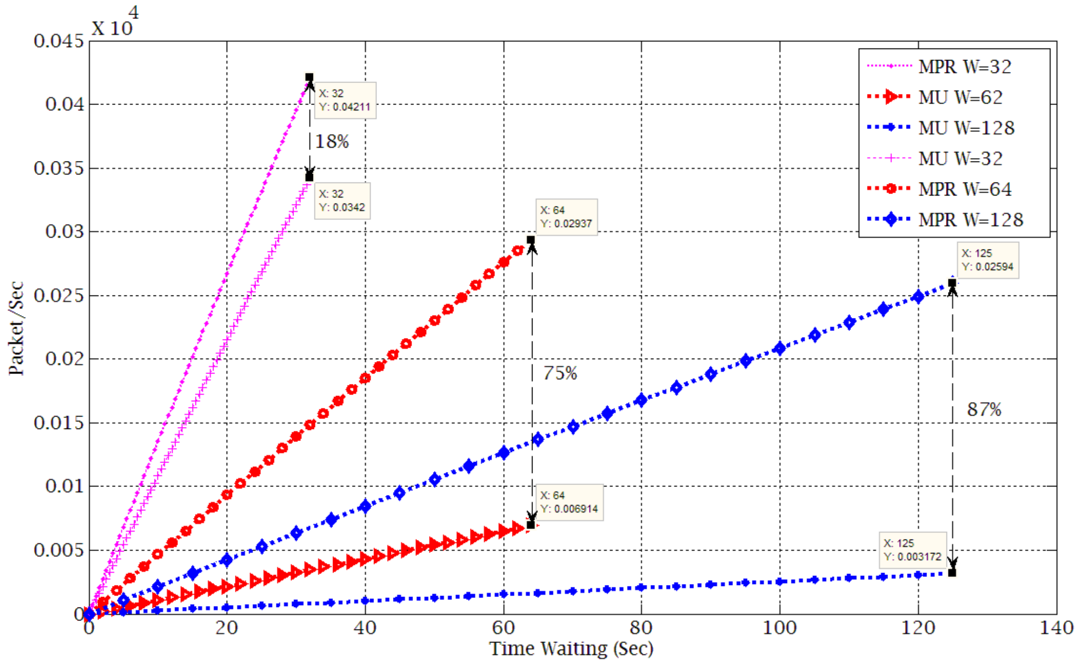

Figure (4.2): Performance of the MPR is Higher by 60% than in the MU scheme.

4.2 Proposed Channel-Aware MAC (CA-MAC) protocols

4.2.1 Proposed MIMO Modifications to CA-MAC

As discussed in the MIMO section in Chapter 2, the major function of a MIMO system is to increase spectral efficiency using spatial multiplexing, spatial diversity, and/or beamforming. The high level of spectral efficiencies attained by a MIMO system due to the fact that, in a rich scattering environment, the signals from each individual transmitter appear to be highly uncorrelated at each of the receiving antennas.

For making transmissions using spatial multiplexing, the data should be divided into symbols that are mapped into a sequence. However, when they are passed through the channel, these data are affected by the random noise of the channel. This form of interference might cause confusing inconsistencies in the input data. Spatial multiplexing, on the other hand, will allow a station to produce multiple data streams simultaneously from different antennas each of which would be considered as a separate channel. The beamforming technique is then used to avoid any other interface in the signal transmission. Thus, the entire signal spectrum can be made fully efficient. The availability of this technique will lead all wireless stations to choose to transfer to particular stations in the receiving side. The range of the transmissions will also be improved because the transmitter point will focus in the target receiver direction. The signal to noise ratio (SNR) will increase.

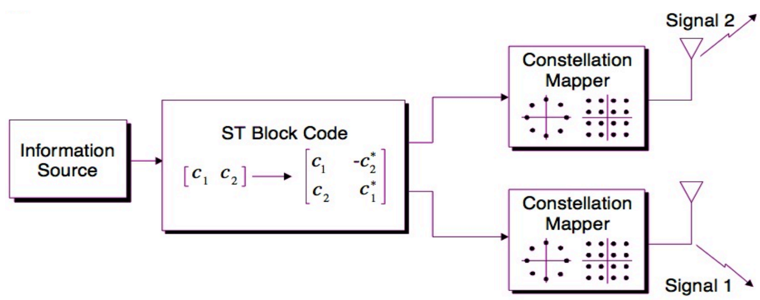

Figure (4.3): STCs Transmitter Side

As can be seen in Figure (4.3), the Space Time Coding (STCs) are combined using the spatial multiplexing technique. Here, the STCs transmitter increases the data transmission rate because of the use of the data constellations.

Moreover, weighting gains controlling technique can control all stations that share a single collision domain. Consequently, using the same adjustment weights of antennas as proposed in [42]. The ability to control the tuning in or tuning out of the channel through different transmission stations will increase.

Weight adjustments for both idle and busy statues have been designed to either tune in or tune out for a particular transmission. MIMO in [42] plays the role of organizing the transmission; thus, by modifying this organizer, Alamouti's theory has been modified.

$$y(t) = x(t)w_n H_{nm} w_m \quad (4.5)$$

where;

$y(t)$: is the signal at the input receiver.

w_n: is the weight of transmitting station.

w_m: is the weight of receiving station.

$x(t)$: is the data signal to be transmitted.

H_{nm}: is the MIMO channel matrix between the transmitting station n and the receiving station m.

4.2.2 Proposed Modifications to DCF Control Frames

In order to achieve a hardware protocol operation, the library of 802.11x has been modified to the timing of the protocol operations that could be expected in any scenario.

Moreover, the RTS, and the CTS control frames have been extended with antenna weights.

Adapting a MIMO system with 802.11x MAC protocol needs some adjustments. Applying the spatial measures on what have been used in a 802.11x MAC layer protocols is not as straightforward as it is with MIMO, because special changes in the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) are required. Consequently, the MIMO's antennas must be adjusted so that they work with the system for both sending and receiving data.

Nevertheless, the mechanism by which data is sent through the 802.11x MAC layer is still based on a handshake process, which is called a Request to Send (RTS) and a Clear to Send (CTS). Thus, where it is necessary to complete the transmitting procedure, the idle interval time should be greater than the Distributed Inter-Frame Space (DIFS). The RTS and the CTS will complete their exchange step after a Short Inter Frame Space (SIFS), and all nodes will update their Network Allocation Vector (NAV).

In order to simulate the practical CA-MAC algorithm, to be able to exploit the full potential of MIMO system, the library of 802.11x standards is modified. Modifications are shown in Table (4.1) and Table (4.2) for the RTS and the CTS packets, and in the timing of the protocol operations to allow for all possible scenarios.

Table (4.1): Extended RTS Frame with Antenna Information

Frame Control	Duration	Receiver Address	Transmitter Address	Antenna Weights	Frame Check
2 byte	2 byte	6 byte	6 byte	12 bytes	4 byte

Table (4.2): Extended CTS Frame for CA-MAC

Frame Control	Duration	Receiver Address	Antenna Weights	Frame Check
2 byte	2 byte	6 byte	12 byte	4 byte

In this work, the transmitted packet is divided into two parts. Each portion is sent independently to the receiver. This technique is similar to the MPR as is shown in [41]; however, in [41] only two senders transmit for one receiver. As noticed in the literature review section, the MPR shows a 60% enhanced transmission performance as compared to the MU according to [40]. Therefore, based on Figure (4.1) and Figure (4.2), the expectation of the CA-MAC performance level compared to MA-AWARE is doubled, which is around 48% of the current performance of MA-WARE. Many scenarios have been studied to avoid any unexpected collisions.

Thus, as to fully exploit the benefits of MIMO systems, newly proposed frames and new imported parameters should be applied. Moreover, the MIMO characteristics has been used to help in controlling the transmission and to avoid any collisions by performing weights gains on the transmitting antenna, and by detecting any possible interfere by using ZigZag decoding. Figure (4.5) shows the proposed protocol operation flow chart.

4.2.3 Algorithm Architecture

Figure (4.4) provides an illustration of the proposed CA-MAC algorithm. Each node has a direction target. Meanwhile, the STCs, which are based on spatial multiplexing, take advantage of the enhancements in the system. Therefore, instead of sending one packet of information per transmission, this system can send multiple packets in each beam direction to the receiver. Similar to [42], weight gains and MAC features are modified so that a transmitter can transmit more than one packet.

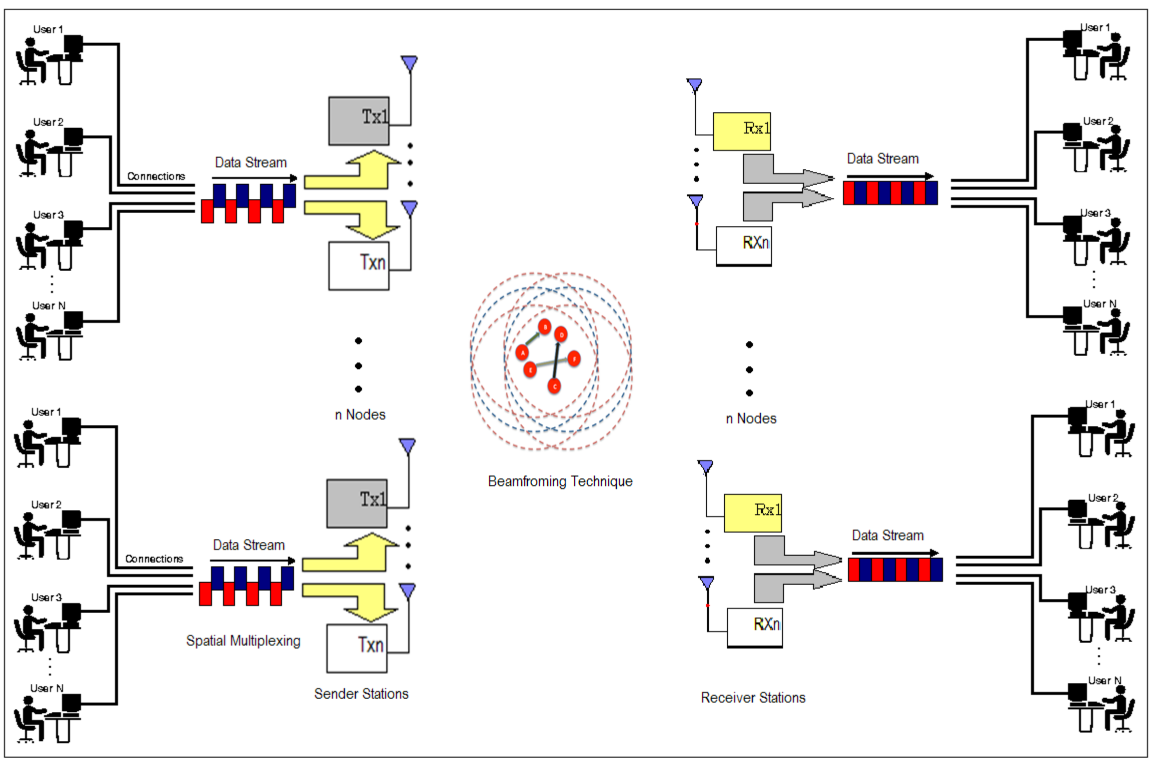

Figure (4.4): Architecture of CA-MAC algorithm for multiple packets transmissions with multiple users

4.2.4 Proposed Interference Cancellation for CA-MAC

To limit the interference in the proposed algorithm, ZigZag decoding, or the limiting of the number of antennas should be used. However, increasing the number of transmissions leads to more data collisions. Depending on the requirements, this system can use a limited number of antennas to work within the space/size limitations such as those found in mobile phones, and laptops. In this work, because the STCs modulation is used, the cancellation features are also considered.

4.2.5 Formal Protocol Operation

As discussed in Chapter 2, system performance can be improved by maximizing the channel capacity, implementing a complete MIMO system with STCs modulation, and creating different scenarios. The inputs and the outputs of the system refer to the number of antennas that have been used on the transmitter and the receiver, respectively. While the MIMO system is used to achieve higher spectral efficiency, STCs modem on the transmitter encodes and modulates the data to be conveyed to the receiver side, and maps the data to be transmitted across space and time. Thus, on the receiver side, the STCs decodes and demodulates the signal. As shown in Figure (4.3), the constellation map shows that each antenna has an individual constellation, and depending on the number of antennas that are required by the system, data will be constellated. Typically, the signal at the receiver end arrives with separated spatial signatures; this can help the receiver to identify the differences in the spatial signatures, which can help to differentiate between the interference and the data. Despite the presence of the interfering signals, ZigZag decoding can be used to reduce their impact.

The proposed CA-MAC protocol is designed to allow more than two simultaneous transmissions to take place within a single collision domain. Figure (4.5) and Figure (4.6) provide the details of the CA-MAC protocol operation.

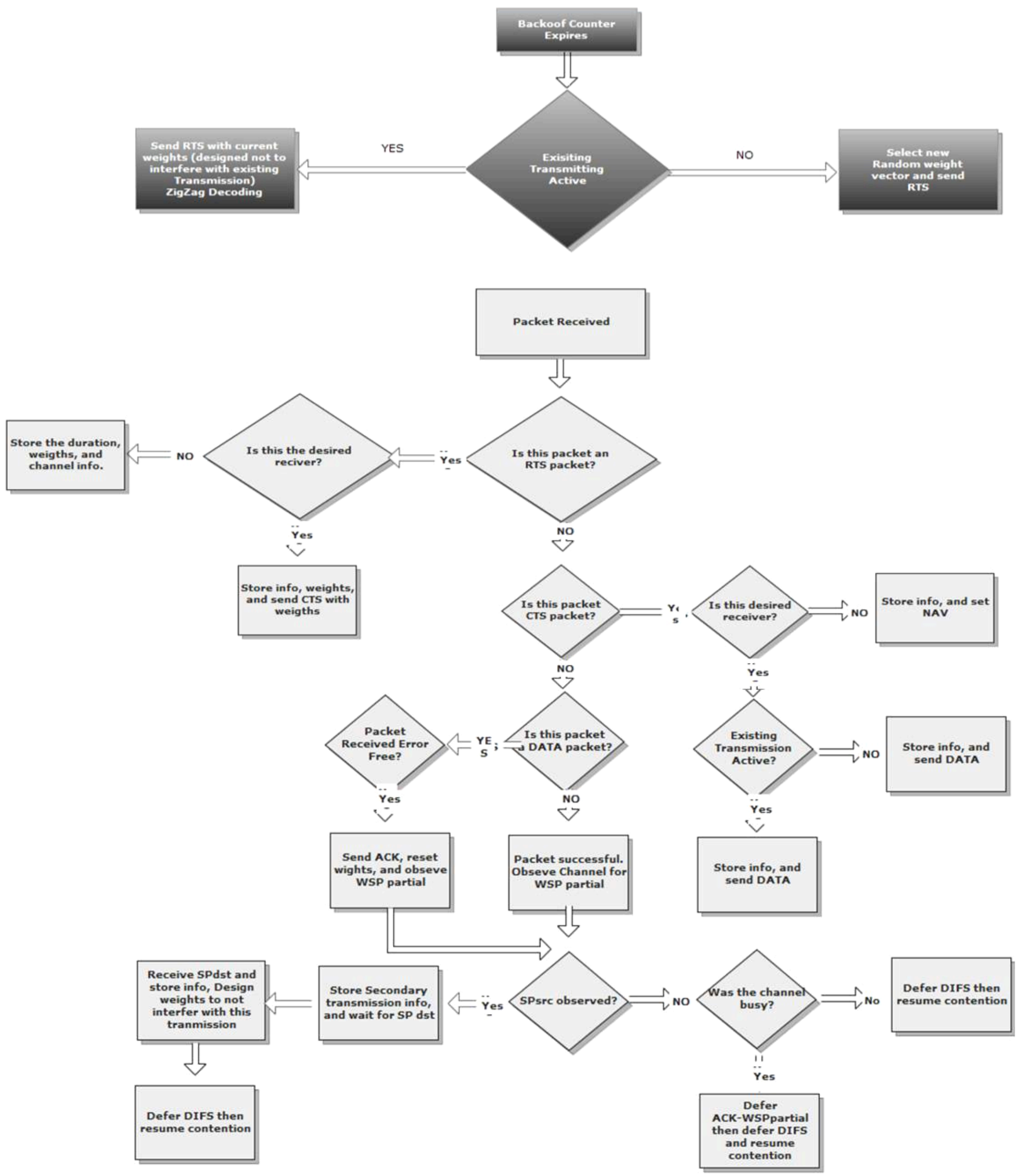

Figure (4.5): Flow Chart of CA-MAC Operation

4.2.6 Pseudo-Code for CA-MAC Operation

RECEIVE_RTS (Beamforming) (*channel*)

//If the aimed station at the receiver side receives RTS request

```
IF channel is idle THEN
    IF station is the destination THEN
        Design Weights for best SNR;
        Send CTS;
    ELSE
        Design Weights to NULL transmission
        Store Transmission Duration in NAV1;
ELSE
    IF station is the destination THEN
        Send CTS (designed with Antennas weights to not interfere);
    ELSE
        Store the Weights of Antennas;
        Store the Durations in NAV2;
        SET the General NAV to min(NAV1, NAV2);
        FREEZE backoff counter;
END if
```

CHANNEL_ ASSERT (*channel*)

//Backoff is reached to zero

17. IF *channel is idle* THEN

18. Send CTS (designed with Antennas weights);

19. ELSE

20. **MAC_DECISION**(*NAV1_expire_time*);

21. END if

MAC_DECISION

// Collision will Occur

22. RTS/CTS exchange: SET NAV to *NAV1*

23. Increment Contention Window ; // [5] for better throughput

24. Send RTS has **(Offset and Phase tracking_Chunk (1))**; //**ZigZag Decoding** is considered.

25. ELSE;

26. Send RTS (designed with Antennas weights to not interfere);

ZigZag Decoding()

//If first transmission line is considered as a primary transmission

27. Listen to *Channel* for WSPpartial time; //after the transmission is done

28. IF *channel* is NOT *idle* THEN

29. IF RTS *received* THEN

30. Listen for and receive **Chunk1**;// Do Correlation and subtractions for

```
recovering
            Store Antenna and channel information;
            Store Transmission Duration in NAV1;
      ELSE
            Break;
      END if
END if
Defer DIFS;
Backoff stage starts decrementing its counter;
```

Figure (4.6): Pseudo-Codes for CA-MAC Operation

4.2.7 ZigZag Decoding Discussion for CA-MAC

The 802.11x networks have known problems with collisions and hidden terminal problems. CSMA/CA is used to limit these problems when the senders sense the transmitting medium and wait until the medium becomes less active. Nevertheless, as shown in [40, 41, 42], modified 802.11x protocols can achieve better performance. For example, as is shown by A.Tahoi [40] and by D.J. Dechene [42], limiting the number of antennas and relying on the CSMA helped to avoid collisions. However, in the paper of A.Thapi [41] reduced the level of interference by using AP; this proposed modification reduced the overall all throughput as discussed in Chapter [3].

4.2.8 CA-MAC Detecting/Recovering Packets

ZigZag decoding for detecting hidden terminals/users in wireless networks is needed. In the paper that authored by S. Rahman [50], discussed many scenarios of collisions and how ZigZag decoding can be operated. ZigZag works when senders are sending simultaneously data through a channel as is shown in Figure (4.7).

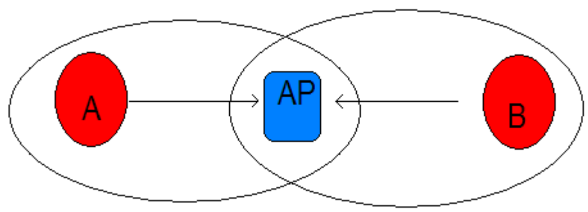

Figure (4.7): Collision Scenario of Transmitting More than One Packet of Data through a Channel

This scenario causes data collisions and will require interference cancellation. ZigZag decodes the packets on the receiver side assuming that there is no data collision. However, after the decoder checks and finds the packets are experiencing collisions. Then it will ask AP to start with the necessary preamble.

As is shown in Figure (4.8), the two packets most likely will have different offsets. When the collision occurs on the receiver side, ZigZag decodes Chunk1 of the first packet so that there is no collision. And then, it will subtract Chuck1 from the collision to decode Chunk2. Meanwhile, for detecting Chunk3, Chunk2 will subtract from the first collision and so on for the rest Chunks.

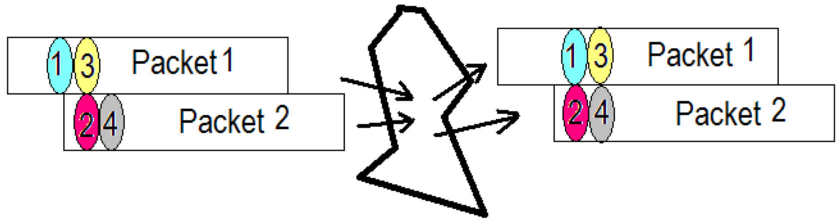

Figure (4.8): Two Transmitted Packets with Collision

Theoretically, the received signal can be expressed as:

$$y[i] = Hx[i] + n[i] \tag{4.1}$$

Where:

$y(t)$ is the signal at the input receiver.

H is the MIMO channel matrix between transmitting station and receiving station

This equation has been analysed and discussed in Chapter 2; however, the particular mathematical issues for the ZigZag decoding as derived in [50] are discussed below.

4.2.9 Offset and Phase tracking

Because it is impossible to have exactly matching transmission packets, there is always an offset or a phase different between them as is shown in the following equation:

$$y[i] = Hx[i]e^{j2\pi ni\delta fT} + n[i] \tag{4.2}$$

Where:

δf: Frequency differences

4.2.10 Correlation Γ between Two Nodes at Phase Δ

$$\Gamma(\Delta) = H_B \sum_{k=1}^{L} |S[k]|^2 e^{j2\pi ni\delta f_B T} \tag{4.3}$$

Where:

L: known preamble samples

B: current user

$S[k]$: the samples

A correlation technique is used to detect collisions of the known preamble on the receiver side. In CA-MAC proposed protocol, AP will compute the correlation of these received samples, and will shift it and re-compute it until it reaches the end of the packet. Thus, to detect the collision, AP will compensate for the current offset of user B and itself. Therefore, AP will maintain the common estimation and relay the other packets, which are correlated with it.

4.3.3 Nyquist Criterion

According to the Nyquist criterion, while these scenarios have a band-limited signal, the chunk re-encoding can be expressed as:

$$y[n+\mu_A] = \sum_{i=-\infty}^{\infty} y_A\,[i] sinc(\pi(n+\mu_A-i)) \qquad (4.4)$$

Where:

$n+\mu_A$: Discrete position

$sinc$: is sinc function

n: neighbourhoods of chunks

Referring to [50], this equation has implemented an approximation of an 8-symbol summation of n. Thus, AP in CA-MAC will have a created an image of Chunk1 and then will have subtracted it from the next collisions as is shown in Figure (4.6).

4.4 Simulation Analysis

Based on Table (4.3), the parameters of this scheme have been chosen for implementing CA-MAC system in term of increasing the data transmission rate. Table (4.3) is shown a higher number in the size of packets such as in RTS, and CTS. And that because to give the users more flexibility to import more address in the receiver side.

Table (4.3): CA-MAC Parameter System

Parameters	**Value**
SIFS	$10\mu s$
SlotTime(θ)	$20\mu s$
DIFS	$n\times$(SIFS+2SlotTime)
Data Frag2 PHY header	72 bits
WSP Partial	$194\mu s$
WSP	$450\mu s$
RTS	$n\times$56bytes
CTS	$n\times$50 bytes
Propagation Delay (δ)	$6\mu s$
Data Rate	2Mbps
Minimum Contention Window (W)	32
Maximum Contention Window (W)	1024
EIFS	SIFS+CTS+DIFS
Data (L)	$\epsilon\ \{512, 1024\}$

NS-2 networking platform has been used to implement the proposed CA-MAC system. The total throughput as compared to the payload size is shown in Equations (4.6 & 4.7)

$$Total\ Throughput = \frac{Packet\ Size}{T_s} \tag{4.6}$$

$$T_s = \overline{W} \times \sigma + T_{DIFS} + T_{RTS} + 2T_{SIFS} + T_{M-CTS} + T_{HDR} + T_{PS} + T_{ACK} \tag{4.7}$$

where,

T_s is the time of a successful transmission.

Packet Size is the payload size.

T_s is the time of maximum throughput.

$\overline{W}$ is the average backoff value.

σ is the slot time.

HDR includes the header of both physical and MAC.

4.4.1 Performance Results

As discussed in Chapter 3, the performance of the previously discussed schemes as proposed in MU, MPR, or MA-AWARE rely heavily on specific side transmitting solutions. For instance, the MU and the MA-AWARE relies on there being a limited number of antennas to limit the number of possible collisions.

Furthermore, the MPR relies on the AP exchanging enhanced to precede the order to network area. In this section, the evaluation is performed in NS-2 to compare it with the previously proposed MA-AWARE protocol done by D.J. Dechene [42], and to calculate the overall throughput of the system. Table (4.3) shows the standard parameters of the CA-MAC that are used in implementing the system.

Here the main objective is to increase the rate of the data transmission; thus, the results of the saturation status are presented in the following section. In this situation, all of the stations, which are sharing the same wireless channel, have always packets to transmit in their buffer.

To reach a saturated condition in order to properly evaluate the performance of CA-MAC scheme, different scenarios have been investigated.

4.4.2 Overall Saturation Improvements

A. Throughput

The stations are set up to be located within each other transmitting range. The maximum number of stations is 50. Figure (4.9) shows the throughput performance under saturated conditions for 50 stations. It can be observed that the lower number of stations is shown wasted idle channel and consequently it is causing a reduction in throughput. To demonstrate, when the transmission made with 3 stations or less as is shown in Figure (4.9), the throughput shows zeros. However, when the number of stations was increased, the throughput shows higher throughput. Indeed, CA-MAC proposed system has a limited number of stations, which is 4 – 30 to be considered.

In this figure, it can be seen that the CA-MAC shows a better enhancement in the throughput as compared to the MA-AWARE; 29% improvement. Approximately more than 2.1 overall achievements in the throughput performance in higher number of stations is shown. On the other hand, the MA-Aware is shown to only achieve around a 1.5 improvement in the throughput performance, compared with CA-MAC.

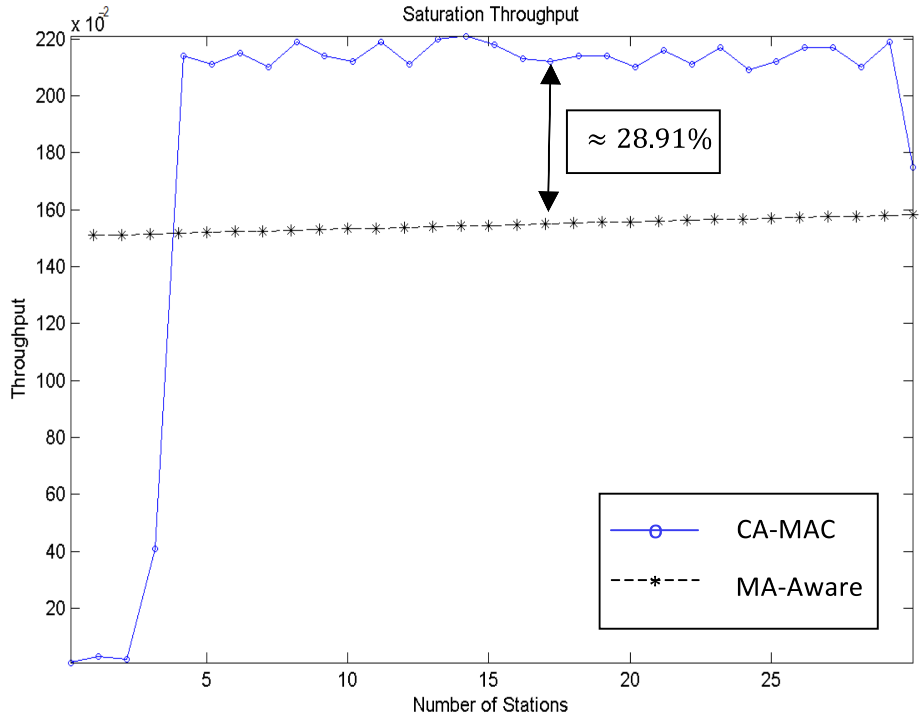

Figure (4.9): Throughput Performance under a Saturated Condition

B. Average Packet Delay

Nevertheless, while the CA-MAC provides a higher level of enhancement as compared to MA-AWARE, it introduces extra delay. This delay is introduced by the reconstruction collision technique, ZigZag decoding. Figure (4.10) shows that CA-MAC introduces an additional 2 ms delay if compared to MA-Aware protocol. .

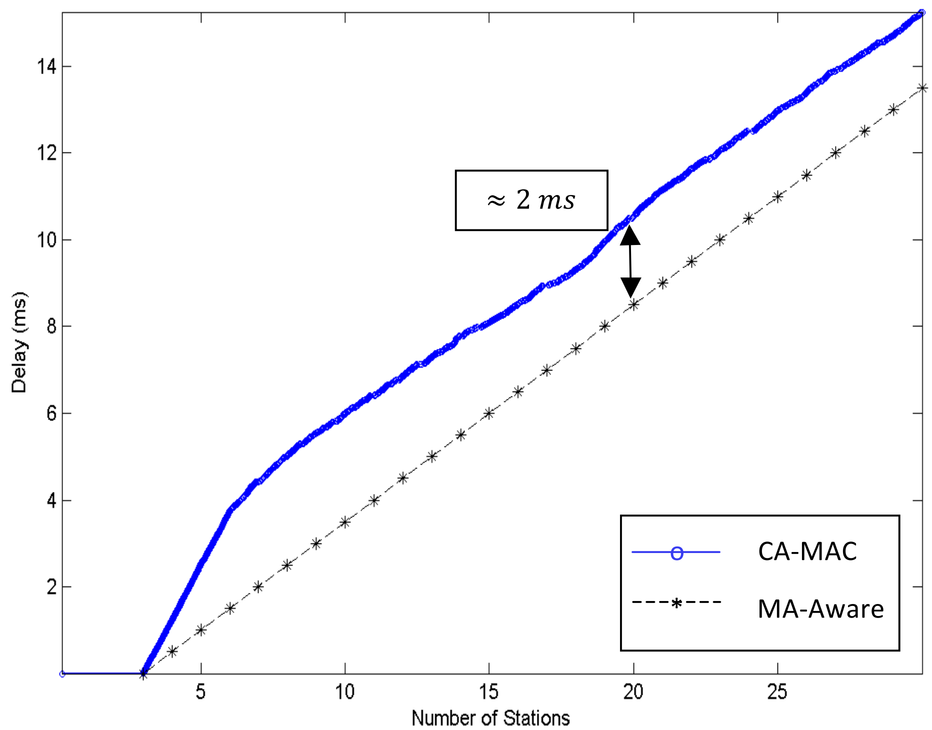

Figure (4.10): Average Packet Delay in Saturation Conditions

In the previous sections, different scenarios are examined under saturated conditions. Below, the system performance under different traffic load conditions has been presented.

For instance, in this section, the number of stations will be reduced to the lowest number to study the contention window effects on the throughput, to measure the increases in the packets sizes, to evaluate the performance of the different schemes, and to study the various sizes of the contention window relay through to the throughput enhancements.

C. Fixed Size of Contention Window

For a better evolution, the simulation was done under unsaturated conditions, contention window was fixed to 64, and with a low number of stations. 10 stations were used in this analysis for both schemes, the CA-MAC and the MA-AWARE. Figure (4.11) shows the throughput performance of both schemes with a varied number of packet sizes.

The graph shows significant increase in the throughput for both schemes (CA-MAC and MA-Aware); however, still CA-MAC shows better performance.

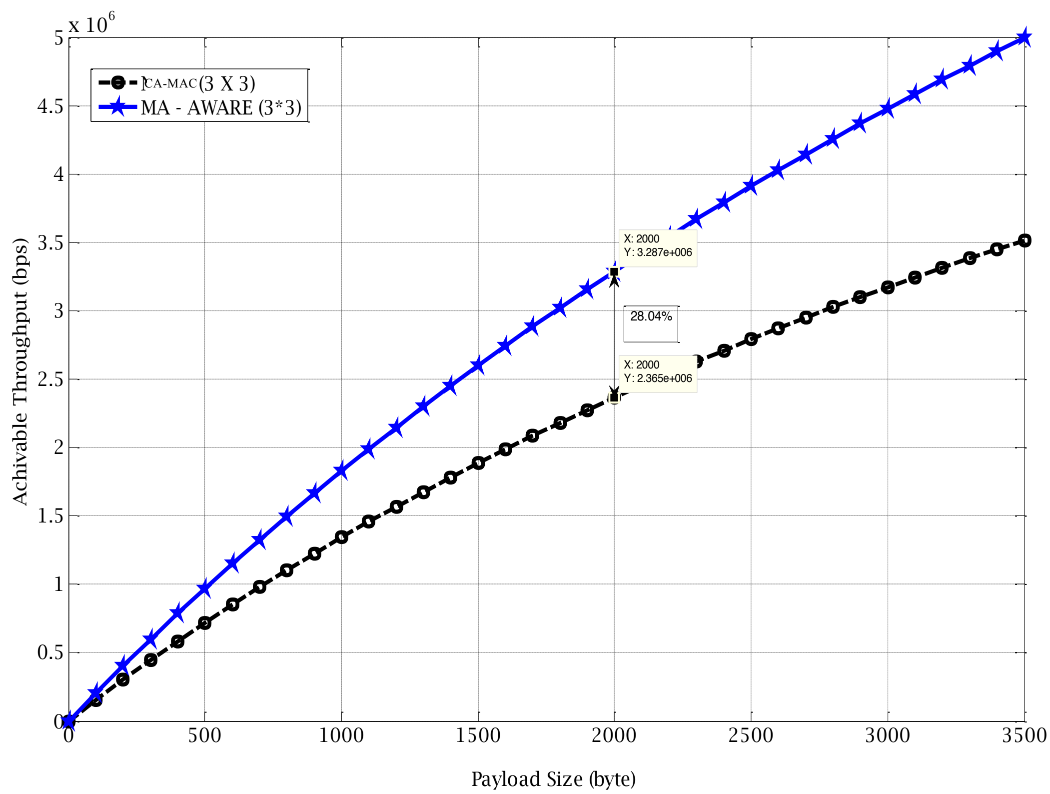

Figure (4.11): Throughput in a Fixed Contention Window Size

D. Varying Size of Contention Window

In this scenario, the packet-size is fixed to 1024 bytes. The size of contention window is varied during the simulation. The backoff stage, which is a counter that return to the exact value of the duration of the collision contention period and the contention window size, is set to 6, which is the maximum number of back offs that can be offered.

Figure (4.12) shows that the highest throughput for CA-MAC is achieved when the window size is set to 64. CA-MAC throughput is slightly better than the throughput offered by MA-AWARE protocol.

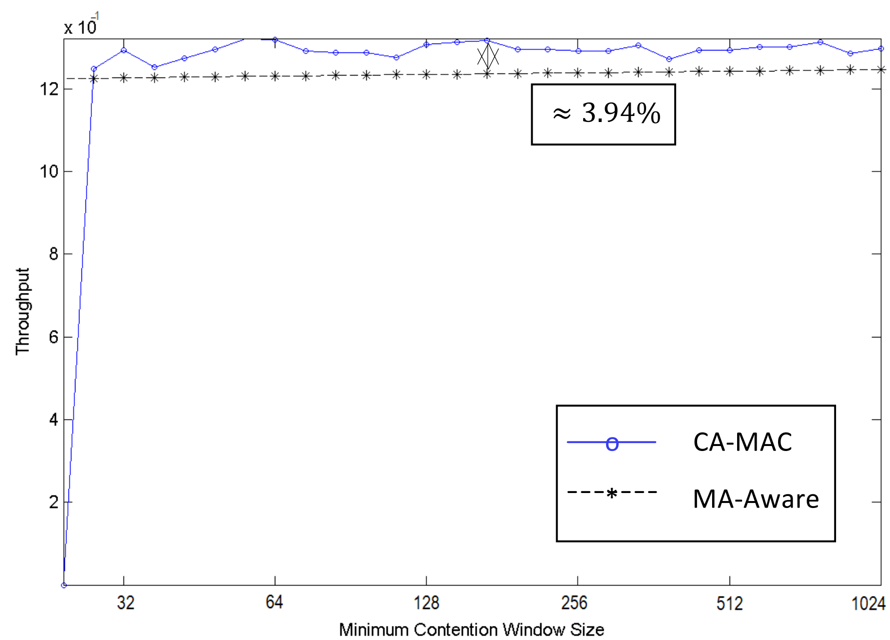

Figure (4.12): Throughput vs Minimum Contention Window Size

E. Throughput vs Time Waiting

In Section 4.1.2, the MPR shows a higher level of enhancement for the different values of the contention window sizes during the simulated scenario time. In this section, three sets of contention window sizes are used with three different sets of back off stages. Figure (4.13) shows the highest throughput, which is approximately 51% higher in CA-MAC, when the contention window is set to 128 and the back off stage is set at 3.

It can be observed both schemes (CA-MAC and MPR) improve the throughput performance. However, due to limitation in the MPR scheme, CA-MAC has shown a higher level of enhancement.

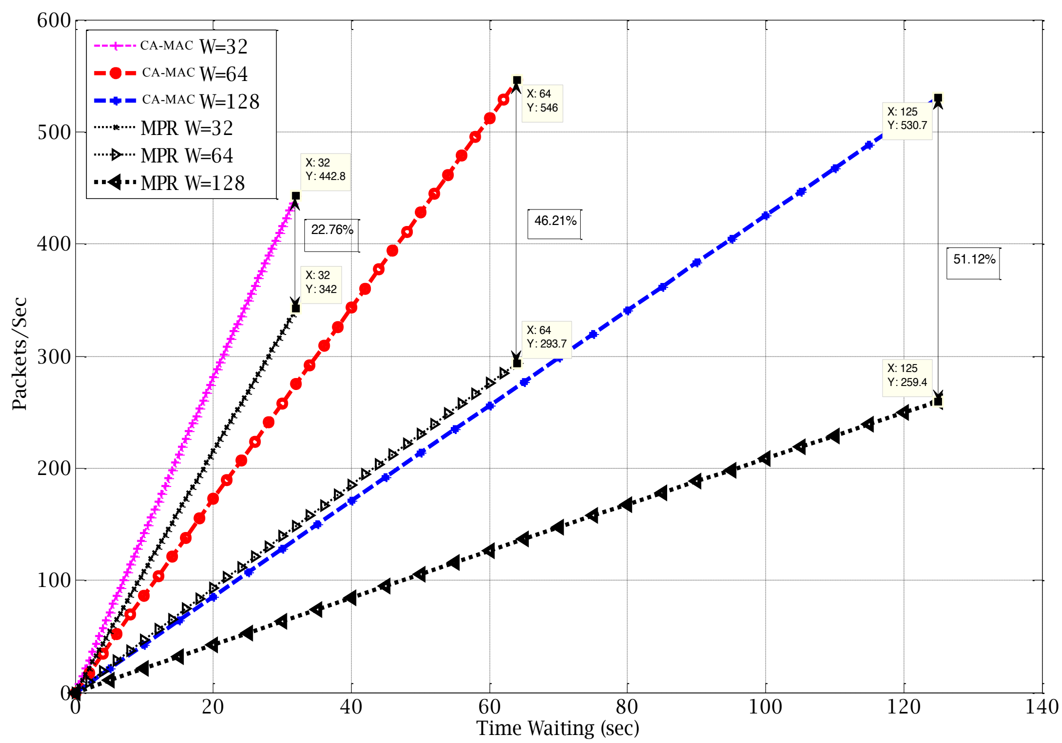

Figure (4.13): Throughput vs. Different Minimum Contention Window Sizes and Different Backoff Stages

4.5 Summary:

CA-MAC protocol is proposed to allow more than two simultaneous transmissions to take place within a single collision domain. While the MIMO system is used to achieve higher spectral efficiency, STCs modem on the transmitter side encodes and modulates the data to be conveyed to the receiver side, and maps the data to be transmitted across space and time. Thus, on the receiver side, the STCs decodes and demodulates the signal. Furthermore, the MIMO on the PHY layer has been adopted to help in controlling the transmission and to avoid any collisions by performing weights gains on the antenna transmission, and by detecting any possible interfere by using ZigZag decoding.

Simulation results show that the CA-MAC achieves better throughput as compared to the MA-AWARE. CA-MAC introduces approximately 29% of throughput improvement. However, CA-MAC introduces an additional 2 ms delay because of the ZigZag decoding reconstruction collision technique used. The most efficient maximum throughput for CA-MAC is achieved when the window size is set to 64.

Finally, the highest throughput for CA-MAC is also achieved when the window size is set to 64.

Chapter 5

Conclusion

This thesis proposes a novel CA-MAC scheme that allows transmission of multiple packets through multiple antennas with higher data rate. In this proposed work, the advantage of MIMO technology has been utilized to improve the throughput performance.

The proposed algorithm utilizes weighting nulling technique as well as ZigZag-decoding model to recover the data lost after a collision.

Based on NS-2 simulations, it can be seen that the CA-MAC shows a better enhancement in the throughput as compared to the MA-AWARE (proposed earlier in [42]). The proposed CA-MAC shows approximately 29% throughput improvement.

Moreover, CA-MAC shows higher throughput performance with approximately 28% when the simulation was done under unsaturated conditions and with a low number of stations. The most efficient throughput for CA-MAC is achieved when the window size is set to 64. Approximately 4% is the enhancement level in CA-MAC compared to MA-Aware when the backoff stage is set to 6. Simulation experiments here were conducted with fixed size of payload packet, 1024 bytes.

However, CA-MAC introduces an additional 2 ms delay as compared to the MA-AWARE. This additional delay is caused by the ZigZag decoding reconstruction collision technique used.

References

[1] Srivastava, V.; Motani, M.; "Cross-layer design: a survey and the road ahead," *Communications Magazine, IEEE* , vol.43, no.12, pp. 112- 119, Dec. 2005 doi: 10.1109/MCOM.2005.1561928

[2] Burbank, J.L.; Kasch, W.T.; "Cross-layer design for military networks," *Military Communications Conference, 2005. MILCOM 2005. IEEE* , vol., no., pp.1912-1918 Vol. 3, 17-20 Oct. 2005. doi: 10.1109/MILCOM.2005.1605952

[3] Meister, B.W.; "A performance study of the ISO transport protocol," *Computers, IEEE Transactions on* , vol.40, no.3, pp.253-262, Mar 1991. doi: 10.1109/12.76402

[4] Kahlouche, H.; Girardot, J.-J.; "Design of the ISO class 0 transport protocol: a stepwise refinement based approach," *Performance, Computing, and Communications Conference, 1997. IPCCC 1997., IEEE International* , vol., no., pp.363-370, 5-7 Feb 1997. doi: 10.1109/PCCC.1997.581539

[5] Mascolo, S.; "Smith's predictor for congestion control in TCP Internet protocol ," *American Control Conference, 1999. Proceedings of the 1999* , vol.6, no., pp.4441-4445 vol.6, 1999. doi: 10.1109/ACC.1999.786418

[6] Kawadia, V.; Kumar, P.R.; , "A cautionary perspective on cross-layer design," *Wireless Communications, IEEE* , vol.12, no.1, pp. 3- 11, Feb. 2005 doi: 10.1109/MWC.2005.1404568

[7] Yin Min; Tang Yao; Yu Quan; , "Cross-layer ideas in wireless network designs," *Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, 2005. MAPE 2005. IEEE International Symposium on* , vol.2, no., pp. 891- 894 Vol. 2, 8-12 Aug. 2005. doi: 10.1109/MAPE.2005.1618063

[8] Aberson, M.E.; "An object-oriented real-time open protocol (EWIT)," *Electrical and Electronics Engineers in Israel, 1996., Nineteenth Convention of* , vol., no., pp.25-28, 5-6 Nov 1996. doi: 10.1109/EEIS.1996.566884

[9] Webopedia. The 7 Layers of the OSI Model. 10 Aug. 2010 . 13 Feb. 2011 <http://www.webopedia.com/quick_ref/osi_layers.asp>.

[10] Liu Wai-Xi; Yu Shun-Zheng; Cai Jun; Tang Dong; "Secure Physical Layer Network Coding: Challenges and Directions," *Internet Technology and Applications, 2010 International Conference on* , vol., no., pp.1-4, 20-22 Aug. 2010. doi: 10.1109/ITAPP.2010.5566630

[11] Hollis, L.L.; "OSI presentation layer activities," *Proceedings of the IEEE* , vol.71, no.12, pp. 1401- 1403, Dec. 1983. doi: 10.1109/PROC.1983.12786

[12] Swany, D.M.; Wolski, R.; "The Logistical Session Layer," *High Performance Distributed Computing, 2001. Proceedings. 10th IEEE International Symposium on* , vol., no., pp.443-444, 2001. doi: 10.1109/HPDC.2001.945218

[13] Yide Zhang; Jianhao Hu; Gang Feng; "Cross-layer transport layer enhancement mechanism in wireless cellular networks," *Broadband Communications, Networks and Systems, 2008. BROADNETS 2008. 5th International Conference on* , vol., no., pp.64-69, 8-11 Sept. 2008. doi: 10.1109/BROADNETS.2008.4769044

[14] Suganuma, T.; Kinoshita, T.; Shiratori, N.; , "Flexible Network Layer in dynamic networking architecture," *Parallel and Distributed Systems: Workshops, Seventh International Conference on, 2000* , vol., no., pp.473-478, Oct 2000. doi: 10.1109/PADSW.2000.884670

[15] Conard, J.W.; , "Services and protocols of the data link layer," *Proceedings of the IEEE* , vol.71, no.12, pp. 1378- 1383, Dec. 1983. doi: 10.1109/PROC.1983.12781

[16] Chun Wu; Fei Shao; Lifeng Wang; , "MAC layer intelligent split-stream scheme for alleviating congestion in Ad hoc networks," *Wireless Information Technology and Systems (ICWITS), 2010 IEEE International Conference on* , vol., no., pp.1-4, Aug. 28 2010-Sept. 3 2010. doi: 10.1109/ICWITS.2010.5611961

[17] Osi Model. Osi Model. . 20 Feb. 2011 <http://www.osimodel.org/>.

[18] Petri, Daniel . OSI Model Concepts. 8 Jan. 2009. 21 Feb. 2011 <http://www.petri.co.il/osi_concepts.htm>.

[19] InetDaemon. Physical Layer . . 22 Feb. 2011. <http://www.inetdaemon.com/tutorials/basic_concepts/network_models/osi_model/physical.shtml>.

[20] Di Renzo, M.; Debbah, M.; "Wireless physical-layer security: The challenges ahead," *Advanced Technologies for Communications, 2009. ATC '09. International Conference on* , vol., no., pp.313-316, 12-14 Oct. 2009 doi: 10.1109/ATC.2009.5349370

[21] Holter, Bengt, "On the Capacity of the MIMO Channel - A tutorial Introduction-." Norwegian University of Scince and Technology Department of Telecommunication. First ed. 2001.

[22] Dongya Shen; Anxian Lu; Yanni Cui; Fuqiang Kuang; Xiupu Zhang; Ke Wu; Jianping Yao; , "On the channel capacity of MIMO Rayleigh-Lognormal fading channel," *Microwave and Millimeter Wave Technology (ICMMT), 2010 International Conference on* , vol., no., pp.156-159, 8-11 May 2010. doi: 10.1109/ICMMT.2010.5525261

[23] Lindskog, E. ; "Time-reversal space-time block coding and transmit delay diversity-separate and combined,", Oct. 29 2000-Nov. 1 2000

[24] Sayeed, A.M.; "Deconstructing multiantenna fading channels," *Signal Processing, IEEE Transactions on* , vol.50, no.10, pp. 2563- 2579, Oct 2002 doi: 10.1109/TSP.2002.803324

[25] Loyka, S.; Kouki, A.; "On MIMO channel capacity, correlations, and keyholes: analysis of degenerate channels," *Communications, IEEE Transactions on* , vol.50, no.12, pp. 1886- 1888, Dec 2002. doi: 10.1109/TCOMM.2002.806543

[26] Zangi, K.C.; Krasny, L.G.; "Capacity-achieving transmitter and receiver pairs for dispersive MISO channels," *Wireless Communications, IEEE Transactions on* , vol.2, no.6, pp. 1204- 1216, Nov. 2003. doi: 10.1109/TWC.2003.819036

[27] Mai Vu; Paulraj, A.; "On the Capacity of MIMO Wireless Channels with Dynamic CSIT," *Selected Areas in Communications, IEEE Journal on* , vol.25, no.7, pp.1269- 1283, September 2007. doi: 10.1109/JSAC.2007.070902

[28] S. Sandhu, R. U. Nabar, D. A. Gore, A. Paulraj, ”Near-optimal selection of transmit antennas for a MIMO channel based on shannon capacity,” Conference Record of the 34th Asilomar Confer- ence on Signals, Systems and Computers, 1:567– 571, 2000.

[29] A. F. Molisch, M. Z. Win, J. H. Winters, A. Paulraj, ”Capacity of MIMO systems with an- tenna selection,” In Proc. IEEE International Conference on Communications (ICC), 2:570– 574, 2001.

[30] Goldsmith, A.; Jafar, S.A.; Jindal, N.; Vishwanath, S.; , "Capacity limits of MIMO channels," *Selected Areas in Communications, IEEE Journal on* , vol.21, no.5, pp. 684- 702, June 2003. doi: 10.1109/JSAC.2003.810294

[31] Yingbin Liang; Veeravalli, V.V.; "Capacity of noncoherent time-selective Rayleigh-fading channels," *Information Theory, IEEE Transactions on* , vol.50, no.12, pp. 3095- 3110, Dec. 2004. doi: 10.1109/TIT.2004.838113

[32] D. Chizhik, G. J. Foschini, R. A. Valenzuela, ”Capacities of multi-element transmit and re- ceive antennas: Correlations and keyholes,” Elec- tronic Letters, 36(13):1099–1100, jun 2000.

[33] Ziri-Castro, K.I.; Scanlon, W.G.; Evans, N.E.; , "Prediction of variation in MIMO channel capacity for the populated indoor environment using a Radar cross-section-based pedestrian model," *Wireless Communications, IEEE Transactions on* , vol.4, no.3, pp. 1186- 1194, May 2005. doi: 10.1109/TWC.2005.846974

[34] T.L. Marzetta and B.M. Hochwald, “Capacity of a mobile multiple-antenna com- munication link in Rayleigh flat fading,” IEEE Trans. Inform. Theory., Vol. 45, No. 1, January 1999

[35] Jafar, S.A.; Goldsmith, A.; , "Multiple-antenna capacity in correlated Rayleigh fading with channel covariance information," *Wireless Communications, IEEE Transactions on* , vol.4, no.3, pp. 990- 997, May 2005
doi: 10.1109/TWC.2005.847029

[36] Alamouti, S.M.; "A simple transmit diversity technique for wireless communications ," *Selected Areas in Communications, IEEE Journal on* , vol.16, no.8, pp.1451-1458, Oct 1998

[37] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, “Spacetime block codes from orthogonal designs,” IEEE Transactions on Information Theory, vol. 45, pp. 1456–1467, July 1999.

[38] I. Telatar, ”Capacity of multi-antenna gaussian channels,” AT&T Technical Memorandum, jun 1995.

[39] EURASIP “Journal on Wireless Communications and Networking” Volume 2011 (2011), Article ID 653506, 9 pages. doi:10.1155/2011/653506

[40] A. Thapa, S. Pudasaini, M. Kang and S. Shin. On achievable performance limits of CSMA/CA adapted MIMO aware MAC for WLANs. Presented at Networked Computing (INC), 2010 6th International Conference on. 2010.

[41] S. Barghi, H. Jafarkhani and H. Yousefi'zadeh.MIMO-assisted MPR-aware MAC design for asynchronous WLANs.*Networking, IEEE/ACM Transactions on 19(6),* pp. 1652-1665. 2011.

[42] D. J. Dechene, K. A. Meerja and A. Shami. Performance evaluation of MIMO-aware media access control protocol. *Physical Communication 2(3),* pp. 204-216. 2009.

[43] Petri, Daniel . OSI Model Concepts. 8 Jan. 2009. 21 Feb. 2011 <http://www.petri.co.il/osi_concepts.htm>.

[44] InetDaemon. Physical Layer . . 22 Feb. 2011 <http://www.inetdaemon.com/tutorials/basic_concepts/network_models/osi_model/physical.shtml>.

[45] Sayeed, A.M.; , "Deconstructing multiantenna fading channels," *Signal Processing, IEEE Transactions on* , vol.50, no.10, pp. 2563- 2579, Oct 2002 doi: 10.1109/TSP.2002.803324

[46] Holter, Bengt, "On the Capacity of the MIMO Channel - A tutorial Introduction-." Norwegian University of Science and Technology Department of Telecommunication. First ed. 2001.

[47] Osi Model. Osi Model. . 20 Feb. 2011 <http://www.osimodel.org/>.

[48] Jafar, S.A.; Goldsmith, A.; , "Multiple-antenna capacity in correlated Rayleigh fading with channel covariance information," *Wireless Communications, IEEE Transactions on* , vol.4, no.3, pp. 990- 997, May 2005 doi: 10.1109/TWC.2005.847029

[49] Alamouti, S.M.; , "A simple transmit diversity technique for wireless communications ," Selected Areas in Communications, IEEE Journal on , vol.16, no.8, pp.1451-1458, Oct 1998

[50] Shahriar Rahman, M.; Yonghui Li; Vucetic, B.; , "An iterative ZigZag decoding for combating collisions in wireless networks," Communications Letters, IEEE , vol.14, no.3, pp.242-244, March 2010. doi: 10.1109/LCOMM.2010.03.092252 URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5426596&isnumber=5426577

Curriculum Vitae

Name:	Abdulfattah Mohammadtaher Noorwali
Place of birth:	Makkah, Kingdom of Saudi Arabia
Year of Birth:	1985
Post – secondary Education and Degree:	2010-2012 M.E.Sc Electrical and Computer Engineering Western University London, Ontario, Canada
	2004-2009 B.Eng. Electrical Engineering Umm Alqura University Makkah, Kingdom of Saudi Arabia
Related Work Experience	Teaching Assistant The University of Western Ontario 2010-2012