NETWORK CODING FOR MIMO SYSTEMS FOR DEVICE-TO-DEVICE COMMUNICATION

BY

YONG JU EE

A REPORT

SUBMITTED TO

Universiti Tunku Abdul Rahman

in partial fulfillment of the requirements

for the degree of

BACHELOR OF INFORMATION TECHNOLOGY (HONS)

COMMUNICATIONS AND NETWORKING

Faculty of Information and Communication Technology

(Kampar Campus)

May 2020

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Date: 11 September 2020

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DECLARATION OF ORIGINALITY

I declare that this report entitled "**NETWORK CODING FOR MIMO SYSTEMS FOR DEVICE-TO-DEVICE COMMUNICATION**" is my own work except as cited in the references. The report has not been accepted for any degree and is not being submitted concurrently in candidature for any degree or other award.

Signature : ______________________

Name : Yong Ju Ee

Date : 11 September 2020

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ABSTRACT

The combination of outdated technology and a rapid increase in the number of a wireless devices and high data demanding applications such as HD video streaming, Internet radio and social demanding creates the challenge of ensuring the speed and reliability of wireless networks. This is why the evolvement of technologies such as LTE and improvements in IEEE 802.11 standards are necessary. Multiple-Input Multiple-Output (MIMO) antenna techniques, network coding and device-to-device (D2D) communications are all necessary in order to help in the enhancement of the capabilities of wireless cellular systems. In this project, we implement all three technologies in the NS-3 simulator and MATLAB in order to model and study the utilization of MIMO, NC and D2D communication together.

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LIST OF ABBREVIATIONS

D2D	Device-to-device communication
GI	Guard Interval
HD	High Definition
IEEE	Institute of Electrical and Electronics Engineers
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MCS	Modulation and Coding Scheme
MIMO	Multiple-Input Multiple-Output
MU-MIMO	Multi-user MIMO
NC	Network Coding
NS-3	Network simulator- 3
NSS	Number of Spatial Streams
OFDM	Orthogonal Frequency Division Multiplexing
ProSe	Proximity-based service
QoS	Quality of Service
SISO	Single-Input Single-Output
UE	User Equipment
WAN	Wide Area Network
WLAN	Wireless Local Area Network

Chapter 1: Introduction

1.1 Problem Motivation and Problem Statement

This project is motivated by problems that are emerging from the following scenario. The world is growing more hyperconnected each day as the use of social networking and other forms of digital content consumption steadily increases. Smart mobile devices and multimedia applications like High Definition (HD) movies, video conferencing and gaming with high visual graphics are steadily becoming more common. There is a prediction that by the year 2020, the number of devices connected with the Internet will reach 70 billion. Thus, the radio frequencies, otherwise known as the spectrum used for wireless communication is becoming congested. Moreover, the limited availability of bandwidth makes ensuring a system that can both provide a higher quality of link availability while maintaining a low cost a challenge.

This increasing reliance on wireless networks as well as growing number of Wi-Fi devices puts an increased pressure on legacy wireless standards and cellular networks. When these communication networks fail to provide the high data rates and throughput required, users then face problems such as slow speeds, unstable connections, delay or even loss of service during periods of high usage. This is in addition to other problems faced by signals transmitted over a wireless communication channel, which include channel interference, path loss effect, fading and so on.

The problems stated above emphasizes the need for wireless data standards and a cellular communication network that can accommodate the demands of the rapidly growing wireless mobile traffic. The only way to accomplish this is by breaking the confinement of behind the times technology and forging ahead with newer technologies such as LTE-A and 5G. MIMO (multiple-input and multiple-output), network coding and using device-to-device communication can help further increment the data rate and data throughput in order to satisfy the demands of modern wireless communication networks. In this project, network coding will be used in conjunction with the MIMO technique for device-to-device (D2D) communication in order to overcome the limitations of older wireless communication technology. A simulation will be produced in order to show the difference in channel performance between the presence and absence of MIMO and network coding in D2D communication.

1.2 Project Scope

This project focuses on exploring and studying network coding for MIMO for device-to-device communication by developing a reliable simulation study. Firstly, the comparison of the performance by a SISO system and a 2x2 MIMO system used by the 802.11n standard for D2D communication is done by using the NS-3 network simulator where the throughput performance is calculated and studied. In another simulation using the MATLAB simulator, a simple packet based network coding is introduced to a butterfly network. Network coding along with MIMO will be applied to the network and the wireless networks will be modelled, simulated. Then, its performance in terms of bit error rate (BER) and throughput over different systems will be analysed and studied. The combined use of NC with MIMO is expected to provide higher throughput and higher reliability. At the end of this project, the advantages brought on by the combined use of network coding and MIMO for device-to-device communication is expected to be seen.

1.3 Objectives

The main aim of this project is to study and explore the application and advantages of implementing MIMO technology with network coding in device-to-device communication in order to achieve better communication system performance through the use of software simulations.

1. To study the potential of network coding in order to improve network throughput and enhance network performance.

2. To validate the use of MIMO technology over traditional SISO technology by proving its advantages.

3. To design and study the integration of MIMO and network coding in a wireless channel environment for device-to-device communication in order to achieve the combined advantages of both for wireless communication. Both techniques should be able to improve throughput, capacity as well as error performance.

1.4 Impact, Significance and Contribution

In this project, a combination of network coding and MIMO technology will be implemented for device-to-device communication in order to study the advantages brought by each technique as a method to enhance cellular communication. Each technology helps improve legacy wireless networks to meet the increasing traffic demands of Internet and cellular network users. The integration of these technologies are significant because they are needed to meet the requirements in wireless standards such as 5G. 5G requires high data rates, reliability, capacity and energy efficiency. This is only possible with certain key technologies which include MIMO, NC and D2D and for them to work interconnectedly. This is because when communicating over wireless channels, there exists unpredictability and error due to issues like fading, mobility, intermitted connectivity and interference. Each technology is able to combat these issues. For example, MIMO uses spatial diversity in order to improve network performance in fading environments. MIMO can be made further reliable though Space Time Block Coding (STBC). Meanwhile, network coding is able to negate interference and enhance throughput while D2D is able to help increase network capacity.

The study is accomplished by running simulations using the the NS-3 network simulator and the MATLAB simulator. This project helps us to understand the effect of MIMO and network coding for device-to-device communication by comparing and analyzing the various output values obtained from simulations for SISO and other MIMO modes in D2D communication.

1.5 Background Information

Wireless data standards can be grouped according to its range. In this study, there is a focus on Wireless Local Area Network (WLAN) which is often known as Wi-Fi and Wide Area Network (WAN) or cellular networks. Although Wi-Fi is synonymous with wireless access in general, it is actually a trademark owned by the Wi-Fi Alliance. Wi-Fi technology provides wireless internet access via the use of radio waves and operate on the set of 802.11 wireless standards set by the IEEE. Meanwhile, cellular network technologies are split into generations. The first four generations of cellular communications networks were designated as 1G, 2G, 3G and 4G. The evolution of cellular networks and IEEE 802.11 standards are because the standards of each generation grew to be outdated. The previous generations were not equipped to meet the growing number of users and increasing demands of modern wireless communication networks which is the reason why there is a motivation to evolve cellular networks even further. Thus, the fifth generation cellular communications network (5G) and newer 802.11 standards were introduced.

The newer 802.11 standards offer faster throughput, increase in network efficiency and work better in dense environments by improving average throughput per user while the introduction and evolution of 5G networks means providing uninterrupted connectivity for any type of devices and applications by having higher data rates, higher reliability, enhanced system capacity and reduction in latency (Ansari et al., 2018). There are many expectations towards 5G, such as users being able to enjoy data rates of 100Mbps, much higher system capacity than 4G and massive connectivity. 5G Networks open up various opportunities in terms of potential applications that range from ultra high definition (4K) video to virtual reality applications (Gandotra et al., 2017). Aside from that, 5G Networks are expected to support wireless services in areas like health care, smart homes and cities and others. As of right now, 5G Network exists and devices which use 5G have proved to be capable of gigabit speeds but it is still uncommon and a work in progress. In order to be able to achieve these expectations set, there must be certain technologies set in place.

One such technology is the evolution of the current MIMO system. MIMO stands for multiple input and multiple output. Wireless devices in the past used Single-Input Single-Output (SISO) technology that can only send and receive one data stream at a time. The MIMO system however, is a type of wireless technology that utilizes a combination of multiple transmitters and receivers of an antenna along with complex algorithms to allow transmission of more than one data streams from different paths at a time, as seen in Fig.2. This is called multipath propagation.

Signals from the transmitting antenna that travel through different paths are combined at the receiving antenna, which leads to a higher chance of receiving the signals without error and improving the quality of communication. Moreover, the more obstacles the signals encounter and the more interference there is, the more MIMO can take advantage of the multiple paths that exist. Thus, MIMO technology is able to improve the connectivity performance by improving the average Signal-to-Noise power Ration (SNR) and capacity of wireless systems as well as the channel throughput and link range without using additional bandwidth or transmitting power. This is the reason why it has become an essential element of wireless communication standards such as IEEE 802.11n (Wi-Fi) and Long Term Evolution (4G LTE).

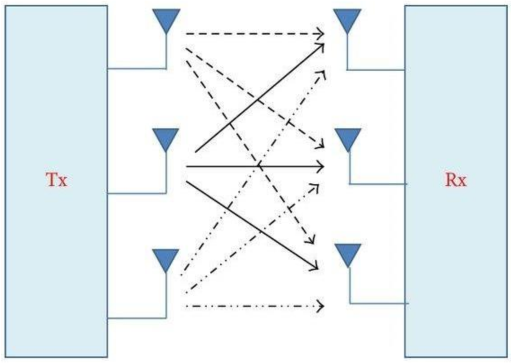

Fig. 1.1: Basic Structure of MIMO System (Meerasri et al., 2014)

Another feature that has vast potential to provide better system performance is device-to-device (D2D) communication. D2D communication was introduced for Long Term Evolution-Advanced (LTE-A) and beyond networks. In a typical cellular network system like the first four generations of cellular networks, devices usually communicate through base stations (BS) and not directly with each other even if they are near enough for D2D communication. This is suitable for low data rate mobile services like voice call and text messages but not for the high data rate services that users use today such as location-aware applications, multimedia sharing and gaming. D2D communication in cellular networks, however, is when mobile devices are communicating directly with one another without first having to traverse all the way through the base station or other fixed core network infrastructure (Kar and Sanyal, 2018) as seen in Fig.3 below. The large focus on device-to-device (D2D) communications in the past few years is due to the various advantages it brings.

According to Ahlswede et al. (2000), they believed that “Introducing D2D communication in cellular networks will dramatically improve spectrum efficiency, network throughput, and energy efficiency, while facilitating new peer-to-peer and location-based social networking applications and services at the same time”. This is due to D2D using shorter signal traversal paths which make up a much stronger channel and enhances channel capacity between devices compared to from the base station to device (Dogra, 2019). Therefore, D2D underlay communication networks have higher spectrum and energy efficiency.

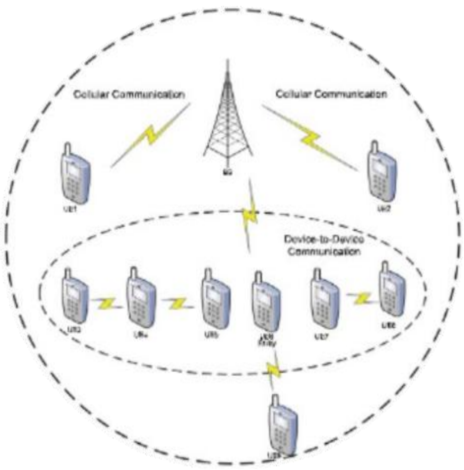

Fig. 1.2: Cellular and D2D Communication (Dogra, 2019)

Last but not least, network coding (NC) which was introduced in 2000 by Ahslwede et al. (2000). While the traditional routing approach allows intermediate network nodes (routers) to store and forward packets, network coding allows these nodes to be able to create brand new packets by computing incoming data packets and performing algebraic algorithms on them using a linear coding scheme, before forwarding those packets in a single transmission as shown in Fig.4. NC encodes these packets in order to remove redundant data packets and adapt the transmission policy to the current network state, thus improving the data throughput and increasing the overall performance of the wireless communication system.

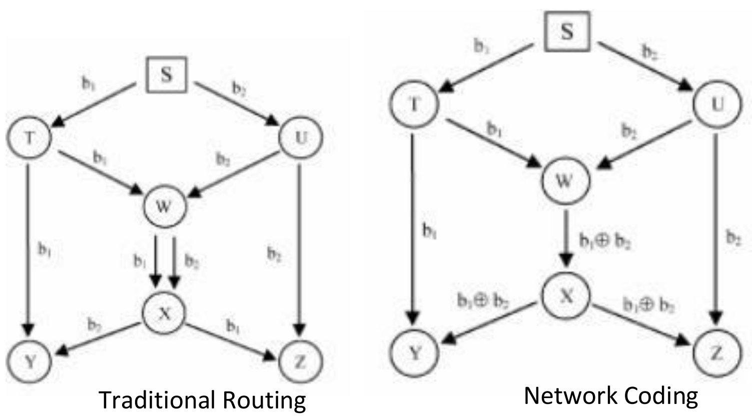

Fig. 1.3: Traditional Routing and Network Coding (Yang T., 2015)

Fig.4 above shows an example of a simple butterfly network that uses traditional routing and one that employs network coding. We work under the assumption that a communication network can be regarded as a directed graph G = (V, E) where V and E represent the sets of vertices and edges. The vertices are the nodes while the edges symbolise the link between those nodes.

Source node S wants to send packets to destination nodes Y and Z. S multicasts to destination node Y with b_1 travelling along the path {TY} and b_2 along the path {UW, WX, XY} while node Z receives b_1 through the path {TW, WX, XZ} and b_2 through {UZ} in each time slot. Thus, every channel has unit capacity. The traditional routing method dictates that nodes follow the store-and-forward method. If the destination nodes want to receive their packets the same time, this creates a bottleneck at edge {WX} as they can only forward either b_1 or b_2 at one time.

With network coding, Node W acts as a coding and relay node that encodes the incoming packets from nodes T and U by linearly combining them (XOR) into an entirely new packet that is regarded as $b_1 \oplus b_2$. The symbol $\oplus$ represents the logical operation XOR. The node then transmits that one encoded packet to all destination nodes. The number of transmissions needed to relay the packets is reduced with the use of network coding which means an improvement in network throughput.

Network coding can be generally defined as “coding at a node in a network”, as stated by Ahlswede et al. (2000) and has been proven to enhance the performance of both wired and wireless networks. Network coding was not deployed in the first four cellular network generations, due to the fact that those network generations only dealt with direct base station to cell-phone communication. In terms of the advantages it brings, network coding can not only improve data throughput, it can also improve robustness, complexity, reliability and security.

The traditional approach used in communications network needs to be replaced to be able to achieve high level of network throughput and network capacity while using less energy consumption. In order to achieve these expectations of 5G, network coding, MIMO and D2D communication is needed.

1.6 Report Organization

The contents of the report will be organized into 5 separate chapters. Chapter one introduces the project and the key topics of the project which are MIMO, network coding and device-to-device communications. It also briefly discusses the current realm of wireless communication. Chapter two will discuss the existing studies done based on the relevant technologies. A more detailed explanation and the advantages of MIMO technology, network coding and D2D communication is discussed further in this chapter. Next is chapter 3 which is about the system design. In this chapter, we have the overview of the system and a complete description of the network and system model. In chapter 5 will be the discussion and analysis of the simulation results. Last but not least, chapter 6 covers the conclusion, summarizes the contributions of this project and suggestions on what can be improved on for future research.

Chapter 2: Literature Review

2.1 Device-to-Device Communication

One of the key technologies that is seen as a paradigm that can meet increasing network performance demands is cellular network technology assisted by device-to-device communication (D2D). The idea of D2D communications underlaying cellular networks is not new but D2D technology has only just started to be standardized in industries (Fodor et al., 2016). Initial research on D2D communication by Vieira and Vieira (2017) proposed that it could be used to enable multihop relays in cellular networks. Future works in academia researched on D2D to be used in improving spectral efficiency of cellular networks (Kaufman and Aazhang, 2008) (Doppler et al., 2009) as well as in multicasting (T.Peng et al., 2009), machine-to-machine communication (M2M), cellular offloading and so forth as can be seen in Fig.1. Aside from its use in the various fields such as network traffic offloading, public safety, social services and applications, it is also considered as one of the paradigms of 5G.

The potential of network-controlled D2D communications is expected to evolve as many research activities are taking place. For example, how cellular network assisted D2D technology could be applied in situations like vehicle-to-vehicle and vehicle-to-infrastructure communication has been studied by Du et al. (2012). Early work on D2D communications such as research by F. H. P. Fitzek (2009), Boccardi et al (2014) and Aziz, et al (2015) involved proximity gain, reuse of the cellular spectrum and hop gain while recently, research has extended to more areas like massive MIMO systems. D2D discovery and D2D communication are already used to support 4G LTE-Advanced. The 3GPP Rel. 12 of the LTE-Advanced standard specified a general concept of proximity-based services (ProSe) that allows physically close LTE based devices can discover and communicate directly with one another (Lien S.-Y., 2016). D2D supports ProSe. It is otherwise known as LTE Direct.

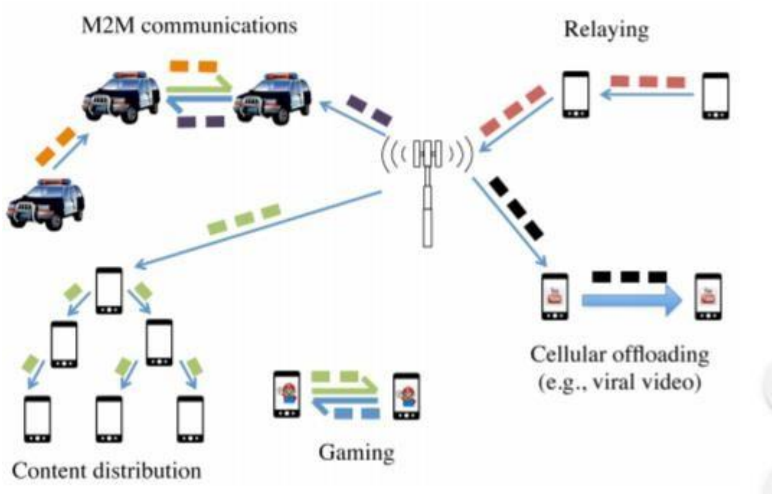

Fig. 2.1: Use cases of D2D Communication (Monserrat et al., 2015)

2.2 Multiple-Input Multiple-Output (MIMO)

On the other hand, network multiple-input multiple-output (MIMO) has been given attention since the late 1990s, given the advantages it brings. In order to meet the increasing demand for faster and more reliable Internet, more complex methods of transmission are necessary. MIMO is used to improve data transmission robustness as well as data rates. It does so by exploiting multipath propagation to send and receive more than one data signal simultaneously over the same radio channel. It uses a massive number of transmit and receive antennas at the Base Station will focus the energy into a narrow beam towards the receiver which helps achieve a higher data rate as well as improve performance in fading environments. The results from the numerical study by Morattab, et al. (2015) that compares the performance of two different approaches, MIMO and SISO (Single-Input-Single-Output) shows that the MIMO based approach provided significantly higher network throughput than that of the SISO based approach for the same D2D transmission range. A MIMO system typically consists of M transmit antennas (Tx) and N receive antennas (Tx) and are described as as MxN MIMO.

There are different MIMO modes of transmission. The existence of multiple antennas in a system creates the existence of different propagation paths, which is used to improve the reliability and data rate of a system. Although multiple paths usually mean interference, the additional paths is used by MIMO to provide additional link robustness and reliability through spatial diversity as well as improve link capacity and data rate through spatial multiplexing.

Diversity or spatial diversity refers to sending the same data stream is sent across different propagation paths. Two receiver antennas that are spatially separate from each other will each receive a slightly different version of the same signal sent by the transmitter which will the be mathematically combined to form a better estimate of the transmitted signal than if there were only one receiver antenna. This method addresses the issue of fading as the probability of properly receiving the transmitted signal increases when multiple versions of the same signal is sent across different fading channels. Even when one link fails in delivering the signal, the exists other links. Hence, increasing the reliability of a system and improvement in performance. This is measured as diversity gain (Mathuranathan, 2014). The following figure depicts a 2x2 MIMO system which means there are 4 diversity paths.

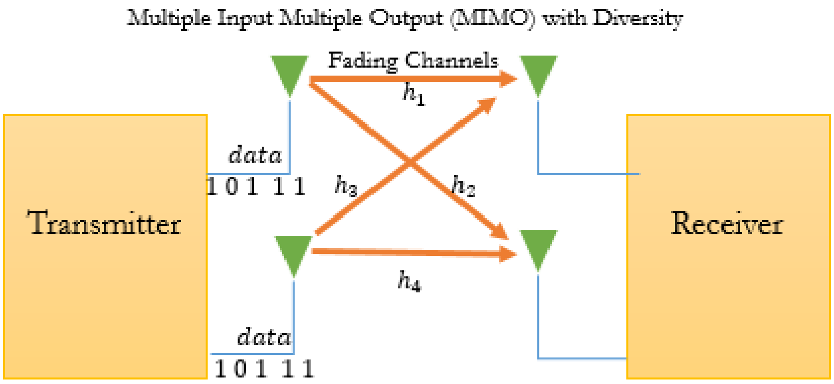

Fig. 2.2: MIMO with Diversity (Mathuranathan, 2014)

Spatial multiplexing effectively utilizes link capacity and spectral efficiency. This is by having each spatial channel carry independent information, thus increasing the data rate of a system. The high rate source data stream is split into two or more independent lower rate data streams that are transmitted over different transmit antennas in the same frequency channel. These data streams are referred to as spatial streams. A common configuration of MIMO is the 2x2 MIMO system that was mentioned previously. In this case, the throughput is theoretically doubled compared to single antenna configuration. According to Muhammad Sana Ullah (2011), this is a powerful technique for increasing channel capacity at higher signal-to-noise ratios

(SNR). The maximum number of spatial streams is limited to the number of antennas at either end.

The different forms of MIMO include multi-antenna types and multi-user types. Multi-antenna MIMO or single user MIMO is implemented in some standards such as 802.11n. Multi-user MIMO or MU-MIMO is relatively new. This includes massive MIMO which is a larger scaled MIMO system. Since massive MIMO offers spatial interference suppression (Rusek et al., 2013) it can used along with D2D communication in the uplink resources of cellular networks. There is also other research on massive MIMO and D2D communication (Fodor et al., 2016) where the precoding and power allocation are joined together and optimized for D2D underlaying massive MIMO multicasting networks, precording and power allocation. D2D based relays with MIMO-enabled devices can enhance system capacities significantly as well as improve data rates.

Nowadays, MIMO is used in many next generation and current technologies. This includes multiple 802.11 standards, beginning from 802.11n as well as LTE as per 3GPP standard. The networking performance of 802.11n is studied using both SISO and MIMO techniques in a study by Moghe et al., (2009). A single Orthogonal Frequency Division Multiplexing (OFDM) symbol SISO and MIMO system were simulated using Simulink and then tested by Matlab's built in bit-error-rate (BER) tool. The outcome of the paper showed that the performance of 802.11n is enhanced whereby the system capacity, system reliability, throughput and coverage range is increased and widened with the use of MIMO. It is also important to note that while 802.11a/g can have multiple antennas too, their radios are not MIMO as it does not have multiple radio chains.

In LTE-A, D2D enhances the spectrum utilization, increases cellular capacity and improves user throughput. D2D enabled User Equipments (UEs) should be able to operate in multiple modes in order to maximize throughput. As LTE-A UEs, D2D transceivers are able to use multiple antennas and MIMO to increase data throughut and link coverage without increasing transmitting power or bandwidth. Morattab., (2015) addressed the issue of selecting the most optimal MIMO mode for D2D transmission in cellular networks so that overall network throughput is maximized and the QoS requirements are satisfied by using a precoding strategy for four antennas. In the same study, the performance of the MIMO based approach with that of the SISO based were compared which resulted in the MIMO based mode selection method producing significantly higher throughput for the same D2D transmission range.

2.3 Network Coding

Network coding (NC) has proven to be capable of many other things such as improving system throughput performance (Fig.6) and enhancing data secrecy compared to data without NC which is why applying NC to wireless communications has received a lot of attention (Huang et al., 2017). In Fig.2, it can be seen that less transmissions are needed to exchange packets with network coding. Matsuda et al. (2011) conducted a survey that summarizes the state-of-the-art research on NC, particularly on the applications of NC to computer networking such as throughput enhancement techniques and techniques to solve the broadcast storm problem. Up-to-date research on NC can be found in numerous journals and international conferences such as The International Symposium on Network Coding (NETCOD) and Wireless Network Coding Conference (WinC) which are forums for research developments of NC that is held every year.

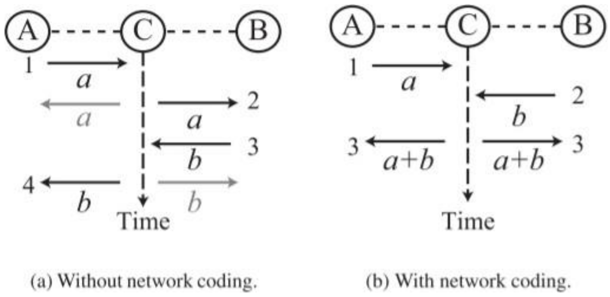

Fig. 2.3: Throughput enhancement with network coding (Ansari et al., 2018)

The advantages of applying network coding with D2D communications has been explored thoroughly in (Ansari et al., 2018). A diagram of D2D communication assisted by network coding can be seen below (Fig.7). Using the NC coding scheme along with D2D communication can help improve the capacity of cellular networks and cellular spectrum efficiency as well. Uplink messages between cellular users were exchanged over D2D link before they were transmitted to the base station. Following that, users would transmit coded data that contains the original data from the other user to the BS.

However, there was an inefficiency to this method since the users were picked at random and there was a possibility that the combination of users' channel qualities would not be suitable for network coding.

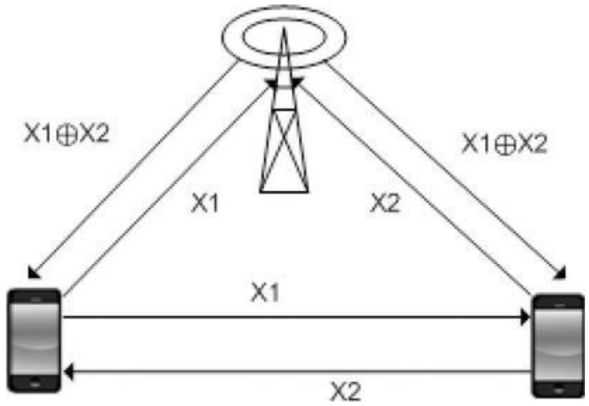

Fig. 2.4: Network coding assisted D2D communication (Ansari et al., 2018)

Further research of network coding involved D2D communications includes a proposal by Huang et al., (2017) where a session mechanism is introduced and used when the cellular users generate interference signals to perform network coding process at the relay node. The transmission efficiency is therefore improved while resources are saved and interference eliminated. This research only focused on relay-assisted D2D communications. Additionally, they address the possible application scenarios of network coding in D2D communications and weighing the advantages as well as disadvantages of all the different network coding approaches by using network coding techniques in dual-hop D2D communication as a case study.

Most work regarding network coding assumes the use of single antenna, but the advantages of NC with MIMO and multiple antennas used in conjunction prove very beneficial. Chen et al. in 2006 showed the application of NC in wireless networks that has either distributed antenna systems or support user cooperation between user terminals. In 2008, Fasolo et al. came up with a proposal for a system that combines NC and MIMO together that is better than traditional network coding in terms of being more robust to fading and packet losses. Although NC and MIMO systems can be easily integrated, NC functionalities still need to be moved towards the physical layer in order for spatial diversity to be exploited. Following this, Ono and Sakaguchi (2008) proposed realizing MIMO network coding, co-channel interference cancellation and efficient bi-directional transmission simultaneously with lower complexity in multi-hop networks.

Lee and Hanzo in 2009 introduced two new types of decoding algorithms for a network coding relaying scheme (NCR) that adopts multiple antennas at the transmitter and receiver as well as studied the possibility of running into decoding errors at the relay station (RS). The research done by Zhang and Liew (2010) introduced a new scheme called MIMO-PNC. The PNC stands for physical network coding. In these scheme, the single-antenna PNC scheme and the linear MIMO detection scheme is jointly combined and used at the relay node which extracts the summation and difference of the two end packets before converting it into a network-coded packet. XU et al. in 2010 used a combination of virtual MIMO and network coding technique in a new two-step communication protocol called MINEC (MImo NEtwork Coding). They analyzed MINEC's theoretical and simulative performances and proved that MINEC outperforms other relay schemes as well as provide more efficient transmission.

The combination of network coding and MIMO is researched in (Zhang and Liew, 2010) where it is assumed that full channel state information (CSI) is available at the two end nodes and is used to pre-code the packet before it is transmitted. To implement this techniques is quite challenging as the pre-coding requires the packets from the two ends nodes to be synchronized when arriving at the relay. The need for synchronization can be removed by applying the maximum likelihood (ML) based detection and encoding schemes in but when the number of data streams transmitted at the same increases, the complexity of its implementation increases exponentially. In 2012, Gupta and Choudhary combined MIMO and network coding, based on a two-step communication protocol called MIMO Network Coding. The channel is assumed to be known or estimated at the receiver which then gives a comparison of the probability of error versus SNR (signal-to-noise ratio) characteristic.

Chapter 3: Proposed Method/Approach

3.1 System Requirement and Design Specifications

A performance study is carried out by using simulation. Firstly, a simple network topology that implements SISO or MIMO for device-to-device communication is modeled and simulated using NS-3 network simulator. The latest version of NS-3 which is NS-3.29 is used. The system is tested with different MIMO modes of transmission for D2D. One of the features of the MIMO system is that it reduces signal interference which addresses the shortcomings of D2D underlay communication. The integration of MIMO with D2D enhances capacity and coverage of cellular networks, hence why the combination of these two technologies make sense.

Fig. 3.1: NS-3

As NS-3 is primary developed on GNU/Linux platforms and supports Linux operating system, Oracle VM VirtualBox is first installed then followed by Ubuntu 18.04 (64 bits) virtual machine. Ubuntu is an open source Linux operating system based on Debian. Next, NS-3 is an open source discrete-event network simulator used for networking research and education. It allows the study of protocols and network performance of large-scale systems in a controlled environment by writing scripts in C++ or Python. The programming language involved in this project is primarily C++. There is no official GUI and everything is executed from the command line. It is not backwards-compatible with ns-2 and ns-2 code is not reused. NS-3 allows the simulation of complete communication systems as it has a multilayered framework, from simplified layer 1 (PHY) modelling to detailed modelling of layer 2 (MAC) to layer 7 (Application). NS-3 is designed as a system of software libraries that can be combined together. The basic components types of a network are nodes, applications, net devices, channels and topology helpers. These are represented by modules in NS-3 which include many different sets of C++ classes along with their functions and properties.

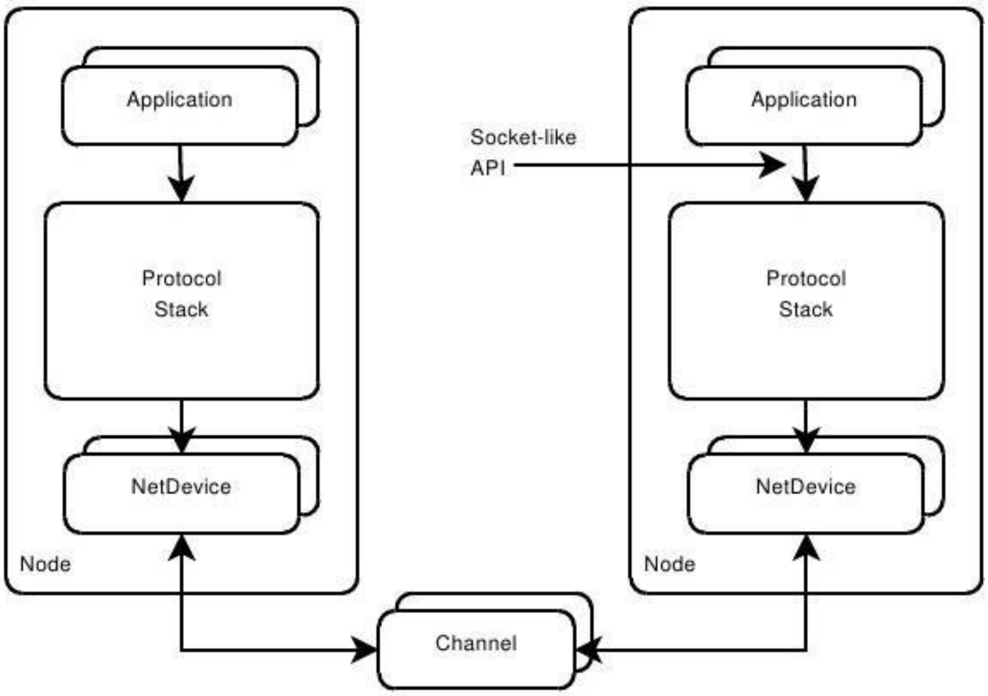

Fig. 3.2: Basic ns-3 wireless network model

In NS-3 simulations, firstly, the nodes of different configurations are created. These nodes represent computing devices such as a router, a wireless access point or a telephone and can be managed using the node module. The nodes are then interconnected by channels to form a network. Channels are able to model wired cables or wireless connections using CsmaChannel and WifiChannel respectively. The WifiChannel represents a Wifi connection and is designed to behave as such. Net devices are then attached to nodes and channels, forming the network interfaces. Subsequently, applications are run in the nodes. Application forms the actual functionality of the nodes which is for the creation, processing and transmission of data. Last but not least, simulations are configured and output such as traces and measurements is generated. NS-3 also provides topology helpers to help with connecting between nodes, net devices and channels.

There are several internal and external animators as well as data analysis tools that can be used in conjunction with NS-3 to help simulation studies. Firstly, NetAnim, which stands for Network Animator, enables us to view an animated version of the network and how the data is transferred from one node to another. Next, N3-3 creates pcap files that contain all information of data packets, including sequence number, IP addresses and so on. The pcap files can be studied using Wireshark. Additionally, NS-3 generate trace files. GnuPlot uses the data from these trace files to plot graphs.

In summary, in order to run simulation studies of SISO vs MIMO, NS-3 is first installed and configured. Coding in NS-3 is studied. Next, tools such as NetAnim and GnuPlot that help with analysis of code and graphical visualization of the network is installed and configured. Core concepts of how MIMO and D2D is implemented in networks need to be understood in order to write programs for every device in the network as well as to compare and analyze the output values obtained from the simulations. Simulation of different MIMO modes and different scenarios will be carried out. The results obtained will be plotted in graphs in order to compare and analyze the data.

MATLAB

Fig. 3.3: Matlab

Next, the programming platform MATLAB is used to simulate the performance of network coding and MIMO together. MATLAB, which stands for MATrix LABoratory, is a programming platform that uses the MATLAB language. The name is due to the fact that the language used is a high performance matrix-based language. It is normally used for technical computing and computational mathematics and is widely used among scientists and engineers. This is due to the fact that it contains powerful built-in editing and debugging tools and supports object-oriented programming (mmcormick). Moreover, its built-in graphics commands are easy to use and can have results visualized immediately which makes it easier to analyze the data. MATLAB operates primarily on arrays and matrices. The Communications System Toolbox in MATLAB provides algorithms for the design, simulation and analysis of communication systems. Modulation, channel modelling and MIMO techniques are all enabled by this toolbox.

3.2 System Model and Design

3.2.1 SISO vs MIMO

The WifiNetDevice module in NS-3 is able to provide an implementation of IEEE 802.11 specifications. It provides about three sublayers of model which include the PHY layer models, the MAC low models and MAC high models. To compare SISO and MIMO performance, a network using IEEE 802.11n is created. 802.11n builds on previous 802.11 standards by adding MIMO, 40 MHz channels to the PHY later and frame aggregation to the MAC layer. The PHY data rate of a WiFi connection is dependent on a few factors. Firstly, MIMO technology improves the data rate of WLANs.

As mentioned in the previous chapter, it spatially multiplexes multiple independent data streams which are transferred within one channel of bandwidth which leads to an increase in bandwidth. The number of data streams (NSS) is dependent on the number of antennas in use. The a x b notation is used. (a) refers to the maximum number of transmit antennas (Tx), (b) refers to the maximum number of receiver antennas (Rx) and (c) represents the maximum number of data spatial streams that can be used. 802.11n runs up to 4 spatial streams when using MIMO technology. NS-3 enables the configurations of these parameters in WiFi modelling but not LTE modelling. Moreover, the LTE module within NS-3 supports until 2x2 MIMO natively. The NS-3 WiFi module is used for the 802.11n simulations.

The Modulation and Coding Scheme (MCS) Index Values can be used to determine the data rate as it is a summary of the NSS, modulation type and coding rate. Modulation refers to how data is communicated through the air whereas the coding rate gives an indication of how much the data stream is actually being used to transmit usable data. Next, Guard Interval (GI) is the short pause between packet transmission for any false information to be ignored. Last but not least, channel width refers to how much of the channel is being used, ranging from 20MHz to 40MHz. These parameters are configured to get the necessary output.

Firstly, two nodes are created in the 802.11n simulation. N1 refers to the station node (STA) while N2 refers to the access point (AP) node. These two nodes are then connected in an WLAN infrastructure. The packet is transmitted with UDP over a point-to-point link.

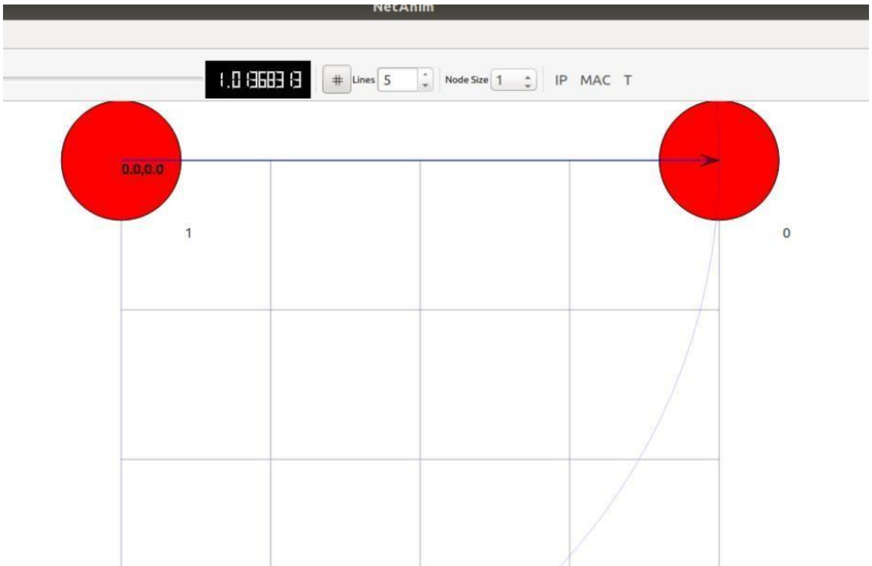

Fig. 3.4: NetAnim

The configuration parameters are listed in the table below.

Parameter	**Value**
MCS	MCS 0 to MCS 15
Distance	20 metres
Simulation Time	5 seconds
Frequency	5.0 GHz
Channel width	20MHz
Guard Interval (GI)	Long
Payload Size	1472 bytes (UDP)
Number of MIMO Streams (NSS)	1 to 2
Mobility Model	ConstantPositionMobilityModel

Table 3.1: 802.11n Simulation Settings

3.2.2 MATLAB

Simulations are conducted for this study of the combination of network coding and MIMO technology. These simulations are performed in an abstract network coding layer between the network (IP) and transport (MAC) layers. The well-known butterfly network is used, which can be seen in the figure below. Node 0 and Node 1 represent the source nodes, Node 2 is the coding and relay node while Node 3 and Node 4 are the receive nodes or the sinks. Node 3 is not directly connected to Node 1, similar to Node 4 which is not directly connected to Node 0. Thus, they are unable to directly communication with one another and must do it through the intermediate Node 2. The nodes send their respective packets to the relay node, which adds the packets together (XOR-ed) and then sends this combined packet to the destination nodes. This takes one less transmission, thus saving the number of transmissions and increasing overall throughput.

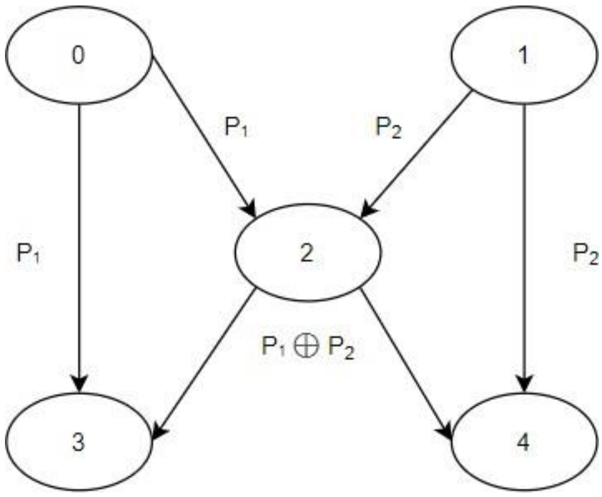

Fig. 3.5: Simple butterfly network

The type of network coding used in this study is random network coding (RNC). RLNC is used due to its simplicity. It is a type of linear network coding where packets are encoded by linearly combining them and then multiplied by coefficients chosen from a finite field known as Galois Field. These coefficients are randomly chosen and is represented by a GF array with 2^m elements where m can be an integer from 1 to 16. This is due to the fact that coded packets can be generated with minimal overhead. This is one of the reasons MATLAB is chosen for this simulation as it is capable of generating and performing calculations with Galois Fields.

As mentioned in the previous chapters, network coding is essentially the combination of routing and coding at intermediate nodes. RLNC consists of two main processes which are encoding at the source and decoding at the sink. The system follows the following steps. First, packets are generated at the source which are then buffered and stored in a First In, First Out (FIFO) queue until the generation number of packets is reached. Generations are groups of packets created and only packets of the same generation are able to be combined. Once that number is reached, the packet payload is then multiplied with the Galois Field coefficients and the result if bitwise XORed to form newly coded packets. These coded packets consist of the protocol header and the coding coefficient used as this knowledge is necessary for the sink node to decode the packet successfully. The packets are then received at the sink. Any repeating or corrupted files are first discarded before the sink starts the decoding process.

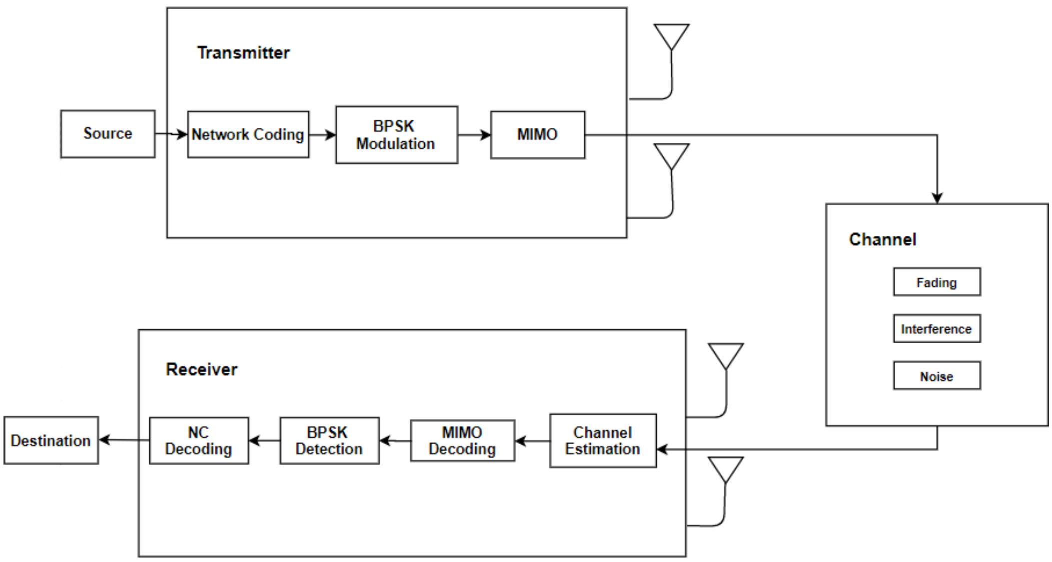

Fig. 3.6: System Model

There are three entities that must first be modelled which is the transmitter, communication channel and the receiver. As seen in the figure above, a system that implements MIMO and network coding is introduced in this simulation. The MIMO system used is a 2x2 system, similar to the last simulation. This system follows the usual wireless communication structure and is divided into a few layers. The physical layer model that includes the modulation process and MIMO coding in the transmitter as well as the channel estimation, MIMO decoding and detection process at the receiver. This model represents how packets are transmitted through each wireless link in the nodes of the network.

The transmitted packets, as a stream of bits, is first encoded by network coding before being modulated using Binary Phase Shift Keying (BPSK) modulation. Next, they move to the MIMO stage before being transmitted over a wireless channel model. Alamouti Space Time Block Coding (STBC) MIMO is used in this system. This is due to the higher capacity and reliability that can be achieved with STBC-MIMO when compared with regular MIMO. At the sink, the packets go through MIMO reception and channel estimation before BPSK demodulation. The packets are then reconstructed and decoded by network coding. Additionally at the receiver, the pilot-aided Minimum-Mean-Square-Error (MMSE) method is used to estimate the channel coefficients. Pilot symbols refer to cell-specific reference signals inserted in both time and frequency. Pilot symbols are the ones that help provide a channel estimate at any given location. MMSE estimator is used due to the fact that it brings better performance when compared to other estimators. The specific parameter settings are listed in the table below.

Parameter	**Value**
Galois Field Size	GF(2^8)
Generation Size	20
Number of packets	3000

Link Loss Probability	0.005
No. of Tx Antennas	2
No. of Rx Antennas	2
Frame Length	100
Eb/No	0 – 20 dB
Channel	AWGN, Rayleigh

Table 3.2: RNC-MIMO Simulation Parameters

3.3 Timeline

Task	**Project Week**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Conduct further study on project title														
Define project problem statement, scope and objectives														
Review of Technology														
Installation of technology														

required														
Define project contributions and background information														
Review and analysis for literature review														
Define system requirement														
Configuration of NS3 and other software														
Develop NS3 C++ script for 802.11n SISO														
Develop NS3 C++ script for 802.11n MIMO 2x2 system														
Documentation														
Presentation of FYP 1														

Table 3.3: Gantt Chart of FYP 1

Task	**Project Week**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Review on FYP 1 feedback														
Conduct further study on project title														

Develop MATLAB script for intended MIMO environment	
Design MATLAB script that combines MIMO and NC	
Review of network simulation scripts	
Testing and analysis of network simulation scripts	
Documentation	
Presentation of FYP 2	

Table 3.4: Gantt Chart of FYP

Chapter 4: Simulation Results and Discussion

The performance of each network is evaluated by BER and throughput. The bit error rate (BER) performance of different systems is evaluated over different channels. BER is simply the rate at which error occurs in a system. The BER is calculated from the following equation:

$$BER = \frac{number\ of\ error\ packets}{total\ number\ of\ transmitted\ packets}$$

E_b/N_o is used to compare the BER performance. E_b represents the average signal energy per bit while N_o is the noise power spectral desntiy ratio (noise power in a 1Hz bandwidth). It is also known as signal-to-noise-ratio (SNR) per bit.

Meanwhile, throughput performance is defined by:

$$Throughput = \frac{number\ of\ correct\ received\ packets}{total\ number\ of\ transmitted\ packets}$$

Firstly, the simulation of SISO vs MIMO in NS3 network simulator is presented here. As per the figure below, the program plots the throughput versus the HT MCS value and from 1 to 2 spatial streams for SISO and MIMO. One spatial stream is used in MCS 0 to MCS 7 while two spatial streams are used in MCS 8 to MCS 15. SISO is 1x1 meaning it only has one antenna and thus, MCS 8 to MCS 15 cannot be used. In the below figure, it can be seen that the throughput of SISO is half of the throughput of 2x2 MIMO for the same MCS index.

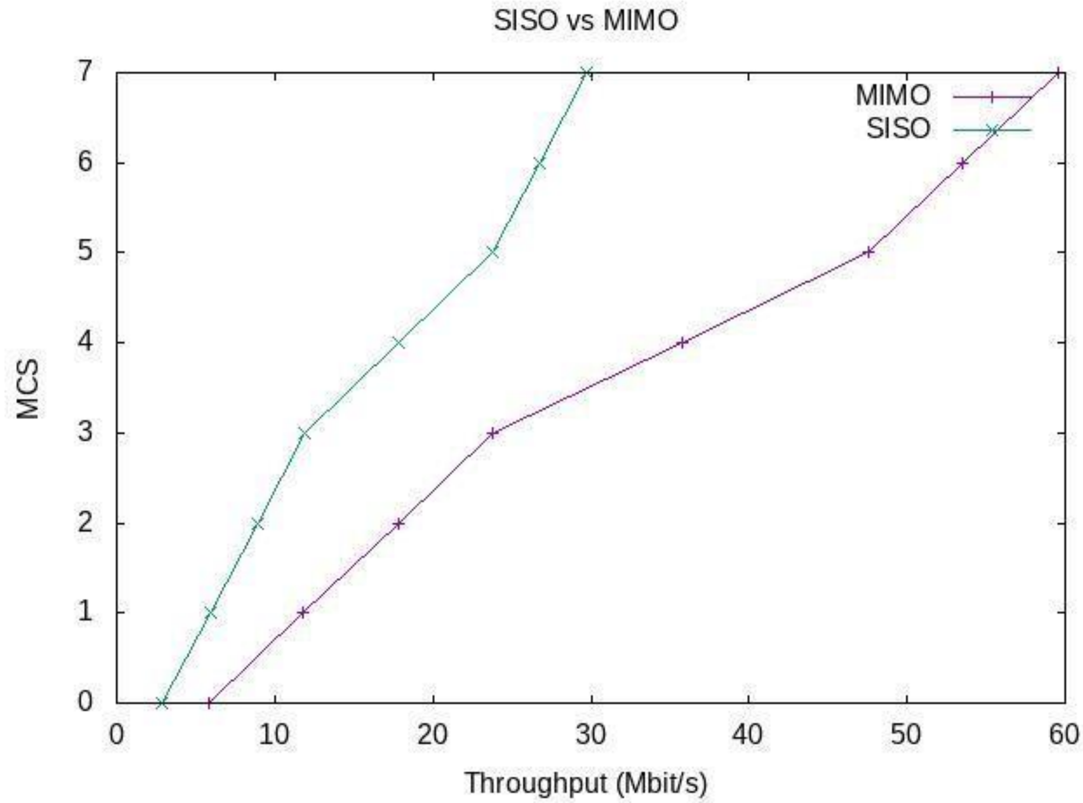

Fig. 4.1: Throughput Performance for SISO vs MIMO

Theoretically, the increase in the number of spatial streams should mean a steady increase in the data rate. However, as seen in the figure below, that is not the case. Although factors such as the guard interval, channel bonding, distance, frequency and protocol used are kept constant, the modulation type and coding rate are not taken into account. Number of spatial streams, modulation type and coding rate need to be considered when it comes to MCS Index Values. Despite there not being a steady increase, there is still a noticeable increase in throughput starting from MCS 12 onwards.

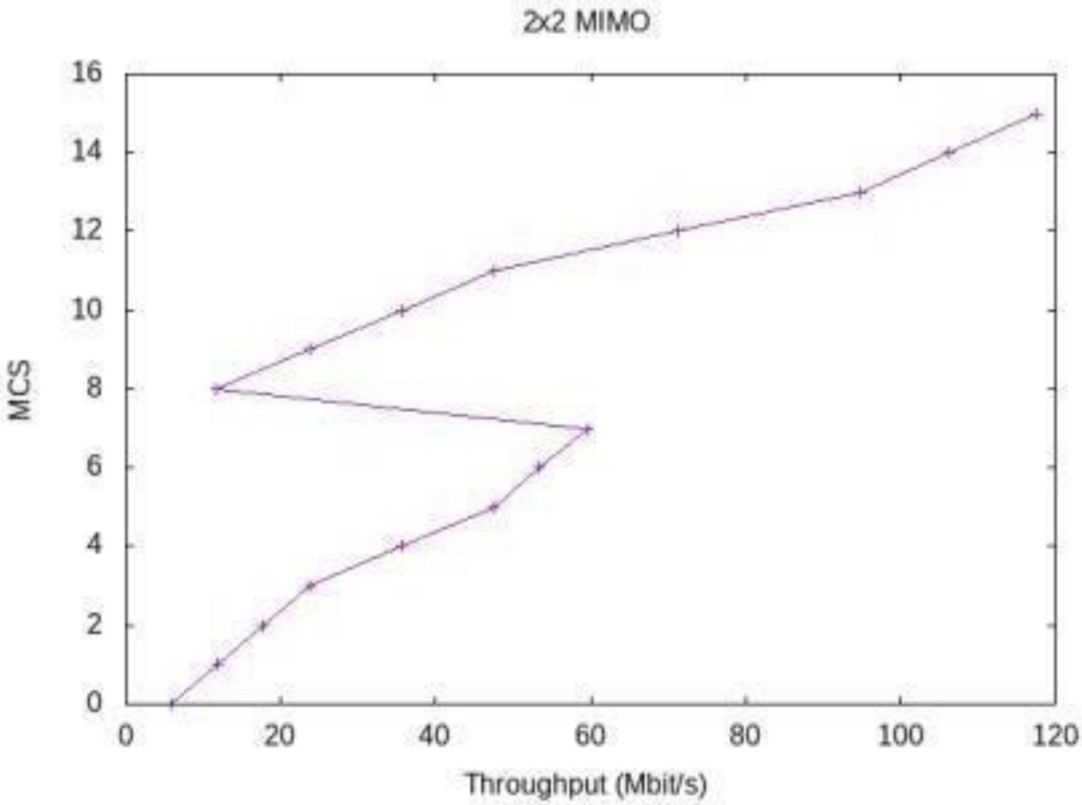

Fig. 4.2: Throughput Performance vs MCS for 2x2 MIMO

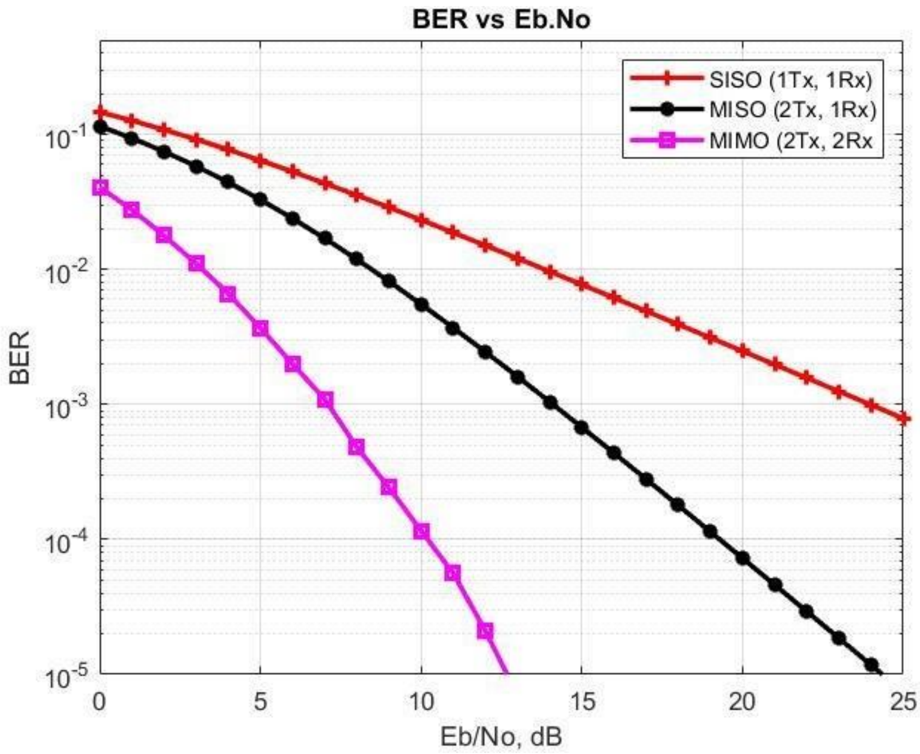

Fig. 4.3: BER Performance without NC over Rayleigh fading channel

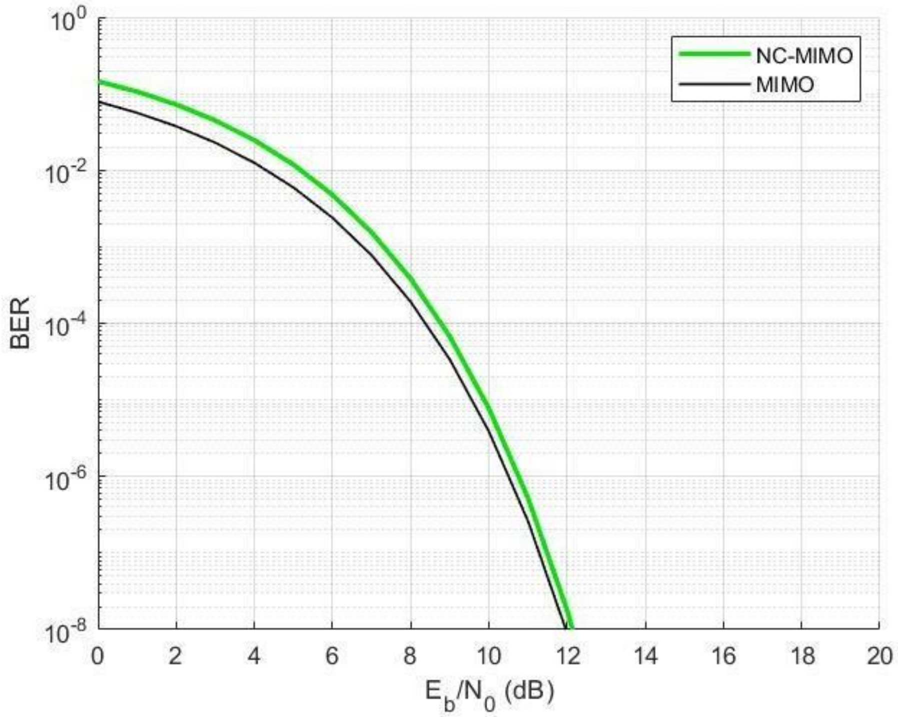

Fig. 4.3: BER Performance with NC over Rayleigh fading channel

The result above shows the BER performance of different MIMO systems without network coding over the Rayleigh fading channel. As we can see in Figure 4.2, it is evident that systems that implement MIMO provide improvement in SNR for more than 10dB for BER values lower than 10^{-3} when compared to SISO. In Figure 4.3, network coding can be seen to only provide a small improvement.

Chapter 5: Conclusion

5.1 Conclusion

In conclusion, the rapid escalation in the number of wireless devices all around the world has led to a strong need for the deployment of wireless technology with significant improvements in terms of speed, reliability and Quality of Service (QoS). This is where the implementation of MIMO and network coding for D2D communication comes in to play. Each of these technologies has been a crucial part in the enhancement of older wireless data standards and cellular communication networks in order to meet demands of steadily growing wireless mobile traffic by producing higher throughput from existing bandwidth as well as meeting higher system reliability and capacity expectations. The signification of these improvements are very important, as user demands for higher throughput to support applications such as Internet radio, online streaming services and virtual reality (VR) continually increases every day. Firstly, MIMO utilizes antenna techniques such as spatial diversity and spatial multiplexing in order to further increment data throughput in comparison to traditional SISO systems by using more antennas and spatial streams. Network coding significantly improves the throughput and robustness of networks as well. Lastly, the direct communication between devices in D2D communication brings us one step closer to providing a faster, more reliable network. All three technologies prove promising and can help bring us one step closer to reliable 5G networks. Thus, there is a need to study the advantages brought upon by the combination of the three technologies.

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Poster


Network Coding for MIMO Systems for D-2-D Communication
PROJECT DEVELOPER
Yong Ju Ee
PROJECT SUPERVISOR
Dr. Robithoh Annur
INTRODUCTION
The world is growing more hyperconnected each day, with the number of wireless devices rapidly increasing as well. This creates a need for wireless technological standards that can accommodate the demands of this rapidly growing wireless mobile traffic.
OBJECTIVE
To study and explore the application and advantages of implementing network coding and MIMO for device-to-device communication in order to bring us closer to better wireless communication systems.
DISCUSSION
All three technologies possess capabilities and advantages that help significantly improve data throughput as well as reliability of networks. Using them together means we can reap the benefits of all three.
METHODS
This project is carried out by performing simulation studies in the NS3 simulator and MATLAB for different network models. The networks are designed, simulated then analyzed..
RESULTS
It is clear from the simulations carried out that network coding and MIMO can help increase network performance for D2D communication.
CONCLUSION
In conclusion, more research should be done into implementing these technologies as the have the capability of bringing us one step closer to 5G connectivity.

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