Improving the Performance of Vehicular Communication in NOMA Systems using Cooperative Transmission

Melat Abdissa Yadeta

A Thesis Submitted to the Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Communication Engineering

Office of Graduate Studies

Adama Science and Technology University

September, 2023

Adama, Ethiopia

Improving the Performance of vehicular Communication in NOMA Systems using Cooperative Transmission

Melat Abdissa Yadeta

Major advisor: Dr. Demissie Jobir Gelmecha

Co-Advisor: Dr. Rajaveerappa Devadas (Ph.D.)

A Thesis Submitted to the Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Communication Engineering

Office of Graduate Studies

Adama Science and Technology University

September, 2023

Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis entitled *"Improving Performance of Vehicular Communication in NOMA System using Cooperative Transmission"* is my original work. That is, it is not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Name of Student	Signature	Date

RECOMMENDATION OF ADVISORS

We, the advisors of this, hereby certify that we have read the revised version of the thesis entitled *"Improving Performance of Vehicular Communication in NOMA System using Cooperative Transmission"* prepared under our guidance by Melat Abdissa Yadeta submitted in partial fulfillment of the requirement for the degree of Masters of Science in Communication Engineering. Therefore, we recommend the submission of revised version of the thesis is to the department following the applicable procedures.

Major Advisor	Signature	Date
Co-advisor	Signature	Date

APPROVAL PAGE OF M.Sc. THESIS

We, the advisors of the thesis entitled *“Improving Performance of Vehicular Communication in NOMA System using Cooperative Transmission”* and developed by Melat Abdissa Yadeta, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

______________________	________________	______________________
Major Advisor	Signature	Date
______________________	________________	______________________
Co-advisor	Signature	Date

APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiner of the thesis by Melat Abdissa Yadeta have read and evaluated the thesis entitled *"Improving Performance of Vehicular Communication in NOMA System using Cooperative Transmission"* and examined the candidate during open defense. That is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Communication Engineering.

Chair Person	Signature	Date
External Examiner	Signature	Date
Internal Examiner	Signature	Date

Finally approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Post Graduate Studies, Dean	Signature	Date

ACKNOWLEDGEMENT

My highest acknowledgement and praise is for the one who watches over me day and night providing all my needs, God. I would like to thank my thesis adviser Dr. Demissie who has put an effort in accomplishing this work. I would also like to acknowledge my whole family whose support is without condition.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

5G	Fifth Generations
CSMA	Carrier Senses Multiple Access
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport Systems
LOS	Line of Sight
MM Wave	Millimeter Wave
MRC	Maximum Ratio Combining
NLOS	Non-line of Sight
NOMA	Non-Orthogonal Multiple Access
OMA	Orthogonal Multiple Access
PPP	Poisson Point Process
SIR	Signal Interference Ratio
VANET	Vehicular Ad Hoc Network
VC	Vehicular Communication
WLAN	Wireless Local Area Networks

ABSTRACT

The vehicular network is one of the most promising technologies for intelligent transportation system (ITS). And intelligent transportation system has been attracting much attention because of the various applications for vehicles, passengers, and pedestrians. The key technologies in ITS, vehicle-to-infrastructure (V2I) or vehicle to vehicle (V2V) communications, involves the networking of vehicles and other communication devices like the RSU (Roadside Unit) and OBU (On Board Unit). So, a secure and efficient Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure communications are the key to support road safety and traffic efficiency applications in ITS. The services and applications in vehicular communication can mainly be classified into two types. Safety services are the first which require an extremely low latency, such as the vehicle collision warning, obstacle detection and driving assistances. The other is the infotainment services which prefer link reliability to the latency, such as file transmissions, social entertainments, and online services. Vehicular communications offer several applications regarding accident prevention, such as sending safety messages that alert vehicles about accidents happening in their surroundings. However these applications require high bandwidth and high spectral efficiency to insure high reliability and low latency communications. Due to this reason different researchers have been proposed conventional OMA, non-cooperative NOMA and cooperative NOMA multiple access schemes to optimize resource utilization and reduce interference. In this thesis, cooperative NOMA is proposed to improve the performance of vehicular communication. The performances of Conventional OMA, Non-cooperative NOMA and Proposed Cooperative NOMA are analyzed using the performance metrics namely: Bit Error Rate, Outage Probability, and Average Achievable Rate for different M-QAM modulation order namely: 4-QAM, 16-QAM, 64-QAM, 128-QAM, and 256-QAM over Nakagami and Rayleigh fading channel model. Simulation result shows that the performance of proposed Cooperative NOMA systems outperforms over Conventional OMA and Non-cooperative NOMA in Bit Error Rate, Outage Probability, and Average Achievable Rate analysis. The proposed cooperative NOMA system resulted with 96% performance improvement compared to non-cooperative NOMA system as observed from SNR versus outage probability analysis.

Keywords: *Conventional OMA, Non Cooperative NOMA, Cooperative NOMA, Vehicular Communication, Bit Error Rate, Outage Probability, Average Achievable Rate, ITS, V2V, V2I*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

In recent years, the vehicular network is one of the most promising technologies for intelligent transportation system (ITS). And intelligent transportation system has been attracting much attention because of the various applications for vehicles, passengers, and pedestrians. The key technologies in ITS, vehicle-to-infrastructure (V2I) or vehicle to vehicle (V2V) communications, involves the networking of vehicles and other communication devices like the RSU (Roadside Unit) and OBU (On Board Unit). So, a secure and efficient Vehicle to-Vehicle (V2V) and Vehicle to Infrastructure communications are the key to support road safety and traffic efficiency applications in ITS. The services and applications in vehicular communication can mainly be classified into two types (Cheng et al., 2011). Safety services are the first which require an extremely low latency, such as the vehicle collision warning, obstacle detection and driving assistances. The other is the infotainment services which prefer link reliability to the latency, such as file transmissions, social entertainments, and online services.

At the same time, with the emerging of fifth generation (5G) mobile communication system, millimeter wave communications have been an effective technology in V2X communications providing gigabit-per second data rates. Millimeter wave channels suffer from considerable degradation in the channel quality when the signal is Non-Light of Sight between source and destination due to blockage losses by high buildings, vehicles, or pedestrians (J. Choi et al., 2016). Multi hop relaying is thus expected to improve the communication between a source and destination (Abuzainab & Touati, 2015) by transmitting the signal to a sequence of intermediate terminals in which a Line-of-Sight signal exits between two nodes. The Multi-hop transmission helps to achieve broader coverage and reduce channel impairments (Hasna et al., 2003). Millimeter wave links are adopted for wireless multi-hop communications among vehicles. Therefore, different information can be transmitted and shared among vehicles, which enabled different kinds of services and applications in vehicular networks. And high reliability and low latency communications are required in safety-based vehicular communications. To increase the spectral efficiency and data rate (Ding et al., 2017) in the fifth generation (5G) of communication systems, NOMA is an appropriate candidate as a multiple access scheme.

Vehicular communications offer several applications for road safety and traffic management at road intersection and highways. Around 50% of road accidents occur at road intersections including fatal crashes, injury crashes, and property damage crashes. The fact that there are at least two crossing roads is one of the causes of intersection accidents. Because most roads have at least two lanes, most crossroads have four lanes. At a junction, vehicles can turn right, left, or stay on the straight line. As a result, three sorts of moves must be considered by each driver. As a result, junctions become more common. So, each driver needs to consider three types of maneuvers. As a result, crossroads are crucial sites for pedestrians and bicycles as well as automobiles. Therefore, we will concentrate our research on intersection regions, which are more prone to accidents.

Interference is one that affects the vehicular communication. In vehicular network, the employment of multi-hop transmission and the presence of mutual interference will have significant impact on the system performance. So, analyzing the channel for a better vehicle communication at intersections is important. There are different performance metrics such as outage probability, transmission capacity, network connectivity, transport capacity and transmission delay (Vibin et al., 2018). Outage probability is defined as the probability that the signal-to- interference ratio (SIR) at the receiver is below a given threshold. Since the outage probability plays an important role in planning, designing, and evaluating VANETs and other ad hoc networks, here in this paper outage probability will be analyzed.

1.2. Statement of the Problem

Vehicular communications offer several applications regarding accident prevention, such as sending safety messages that alert vehicles about accidents happening in their surroundings. One of the major drawbacks that affect vehicular communications is interference. Hence, investigating the performance of Vehicular Communications in the presence of interference is crucial to design safety applications at urban and suburban intersections. Hence, these applications require high bandwidth and high spectral efficiency to insure high reliability and low latency communications. In this context, non-orthogonal multiple access (NOMA) will be shown to increase the data rate and spectral efficiency. Unlike orthogonal multiple access, NOMA allows multiple users to share the same resource with different power allocation levels. On the other hand, the needs of vehicular communications for the fifth generation (5G) in terms of resources require a larger bandwidth. Since the spectral efficiency of sub-6 GHz bands has already reached the theoretical limits, millimeter wave frequency bands (20-100 GHz and beyond) offer a large bandwidth. Therefore, this thesis work is dedicated to plan for further exploring the performance of vehicular communications at intersections in the presence of interference to design safety applications at urban and suburban intersections.

1.3. Objectives

1.3.1. General Objective

The general objective of the thesis is studying the performance of vehicular communications at intersections in the presence of interference.

1.3.2. Specific Objectives

Specific objectives of the study are:

1. Drive the outage probability over Nakagami-m and Rayleigh fading channels when destination is inside road or outside road.
2. Compare performance of direct transmission with cooperative transmission
3. Identify effect of interference is high when vehicles are near the intersection.
4. Analyze the outage probability and average achievable rate when a source sends a message to destinations.
5. Design the vehicular communication system to optimize the performance in order to minimize the outage probability.

1.4. Significance of the Study

When it comes to planning, constructing, and analyzing VANETs and other ad hoc networks, outage probability is crucial. The novel analytically determined theoretical outage probability constraints quantify the effects of node density and mobility on the competing effects of path loss and interference in VANET. This differs from earlier research, which relied on interference-free assumptions. Second, by considering a wide variety of real system variables, such as node mobility, cluster size, transmission probability, and path loss exponent, the novel analytical conclusions enable the optimum designs of vehicular communication. In the presence of random co-channel interference and dynamization, the optimum designs theoretically find the optimum cluster size that can minimize the outage probability.

1.5. Scope of the Study

Outage probability is one of the key performance measures used to assess the performance of wireless systems under real-world conditions such as fading, path loss, and interference. As a result, the outage probability analysis can be considered the thesis's overarching study goal. Traditionally, outage probability analysis has focused to improve communication quality.

1.6. Limitation of the Study

This thesis limited to simulation of the system which is done using application software called MATLAB and simulation is for vehicle to vehicle communication scenarios. The implementation of the real system is difficult because of the availability of the component.

1.7. Thesis Outline

This thesis organized into five Chapters. Those chapters describe briefly different topics. The first chapter briefly described about the background and introduction of the thesis work. The second chapter focuses on literature reviews of the vehicular network, and types of channel models, transmission schemes and the frequency bands used in vehicular network. The third chapter describes the overall system model like the scenario model, blockage model, transmission model, channel model, channel and interference model and other parts of the system model. The fourth chapter describes the simulation result and discussion of the study. Finally, the fifth chapter describes the summary of contribution, conclusion, and future work in this research area.

CHAPTER TWO

2. LITRATURE REVIEW

2.1. Chapter Overview

This chapter mainly focuses on vehicular communication, wireless networks stochastic geometric model, cooperative transmission, multipath fading models, frequency bands, general performance metrics, and related works.

2.2. Vehicular Communication

VANETs are prospective technologies for intelligent transportation systems (ITS) that have the technological potential to reduce the alarming number of accidents by creating a network on the road with vehicles equipped with wireless communication devices. VANET aims at providing safety and comfort applications through dedicated short range communication (DSRC) that includes different types of communication.

The general form of vehicular communication is referred to as vehicle-to-everything (V2X) communication. There are four types of V2X communication as shown in figure below. Vehicle-to-Vehicle (V2V) communication is a latest and emerging technology that helps nearby moving vehicles to communicate to each other (Vibin et al., 2018). In a V2V environment the vehicles can talk to each other in real time which will help in sharing the information that is useful in enabling safer mobility of automobiles. This paves way for Intelligent Transportation System (ITS), a type of advanced system achieved with the help of V2V communication (Rajiwade, 2012). Second, V2I communication is an attractive solution for many connected vehicles problems. As such, V2I technology has been a focal point for extensive Intelligent Transportation Systems (ITS) research and deployment efforts in the recent few years (Rajab, 2019). Another one is V2P communication Similar to V2V applications instead of a vehicle, in V2P communication information is exchanged between pedestrian UEs and vehicle.

V2P services can be used to warn pedestrians using the information from vehicles in the vicinity or a vulnerable road user UE can give a warning to the nearby vehicles. Different from V2V, a pedestrian UE supporting V2P needs to be low power devices. Therefore, radio sensitivity will be lower than a vehicle's UE and pedestrian UE supporting V2P applications cannot transmit frequently like most IOT devices. The last one is V2N communication In V2N communication vehicle will communicate directly with a network node. Directly sharing information with the network for high priority services using evolved packet switching (EPS) is an example for V2N communication. There are two types of scenarios in which vehicular communications can be used.

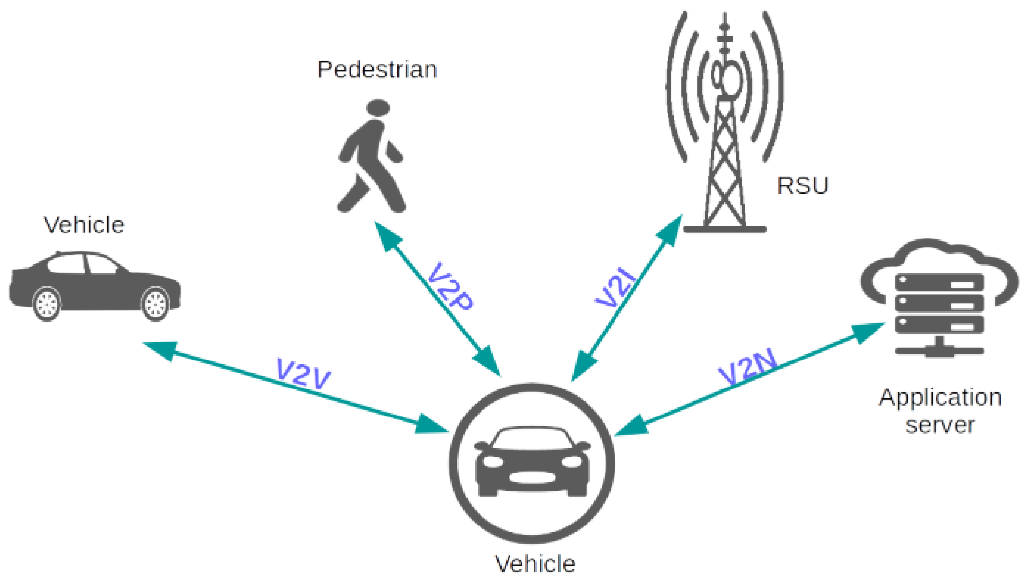


Figure 2. 1 Types of vehicle to everything communication

2.2.1. Highway scenarios

A lot of works has investigated the effect of interference in highway scenarios (Błaszczyszyn & Mühlethaler, 2013; Farooq et al., 2016). The writers in (Farooq et al., 2016) computed the expressions of packet success probability in multi-lane highways using carrier sense multiple access (CSMA) protocols. As far as V2V and V2I communications are concerned, several works have investigated the effect of interference in highway scenarios. In (Ikki et al., 2013), the authors study the performance of Aloha and CSMA multiple access control (MAC) protocols under different attenuation and fading conditions.

In (Kimura & Saito, 2018), the authors derive the expressions for the intensity of concurrent transmitters and packet success probability in multi-lane highways with CSMA MAC protocol.

The outage probability is derived in (Jiang et al., 2016) for Nakagami-m fading and Rayleigh fading, and the authors verify their results with real-world dataset containing locations of Beijing taxis. The authors also propose a reputation-based road traffic information structure to ensure a fair and accurate sharing of information between vehicles.

2.2.2. Intersection scenarios

In terms of VC performance at intersections, various studies have looked into the influence of interference in vehicular communications at intersections. The author Steinmetz et al. derivate the success probability when the receiving node and the interferer nodes are aligned on the road (Steinmetz et al., 2015). He also investigated the success provability considering both Aloha and CSMA MAC protocols and Erlang fading channels in (Steinmetz et al., 2021). (Jeyaraj & Haenggi, 2018) also studied V2V communications at intersections and showed that the performance of the Aloha protocol can be considered as a lower bound of performance of CSMA protocols. (Cebe & Akkaya, 2017) derived the outage probability of V2V communications at the intersection in the presence of interference with a power control strategy. Recently, researchers started to model the vehicle locations as a Poisson line process (PLP). In (C. Choi, 2018), the authors analyze and derive the coverage probability of V2V, V2I, infrastructure-to-vehicle (I2V), and infrastructure-to-infrastructure (I2I).

2.3. Stochastic Geometry Models for Wireless Networks

Stochastic geometry is a branch of applied probability that deals with the study of random spatial patterns. Recently, the idea of using tools from stochastic geometry for the system-level performance analysis of wireless networks has garnered wide acceptance in the wireless community. The basic principle is to model the random locations of wireless nodes by a random set of points, often referred to as a point process, in the 2D space and then analyze the performance of the network using the properties of the point process.

Assessing the performance of wireless network can be mathematically difficult (Approach et al., 2015). The theory of point processes, a branch of stochastic geometry, is a useful mathematical tool that allows for mathematical tractability and aids in the analysis of wireless networks with users are randomly distributed. A point process is similar to a random variable, except that the result of a realization is a set of points rather than a real integer. The Poisson point process (PPP) is the most widely used method for modeling user locations, and its intensity which is defined as the average number of users per unit area of the region studied in (Renzo et al., 2016). (Characterization et al., 2009) discussed well enough about stochastic geometry and Poisson point process.

2.4. Cooperative Transmission

Cooperative communications in wireless networks (Laneman et al., 2004) have been shown to improve the system performance by means of relay stations that cover areas suffering harsh channel conditions or by means of mobile users that can act as relays (Toulouse, 2008). Cooperative transmissions can involve a single relay, or multiple relays. These relays act as distributed antennas to improve the reliability of the links (Renzo et al., 2010). Since wireless transmissions are not isolated from each other, it is realistic to consider the interference originated from other transmitting users in the network.

2.5. Multipath Fading Models

These models describe a feature of wireless propagation in which the received signal's amplitude/envelope fluctuates significantly over a short time or distance. The signal variations occurs because the transmitted signal passes through many multi-paths before these several copies of the same transmitted signal combine constructively or destructively at the receiver. Because these different received copies of the transmitted signal arrive at the receiver at different times, they introduce a time delay spread, which is caused by the time difference between the first and last received copy of the transmitted signal.

2.5.1. Rayleigh Fading

A Rayleigh fading channel is a wireless communication channel in which the amplitude and phase of the signal fluctuate randomly due to multiple reflections and scattering from objects in the propagation environment. This can be modeled mathematically as a complex Gaussian random variable with zero mean and variance that depends on the distance between the transmitter and receiver. Rayleigh fading distribution is one of the most used distributions to represent the rapid amplitude fluctuations when there is no direct line of sight (LOS) between transmitter and receiver.

2.5.2. Nakagami Fading

Nakagami-m distribution is considered as the most general form of Fading. There are two kinds of fading channels based on severity fading parameter "m" and Nakagami distribution has the ability to describe both Rayleigh and Rician distributions (Prabhu et al., 2002). They are listed below.

- When m=1, the Fading is referred to as Rayleigh Fading.

• When m>1, the Fading is referred to as Rican Fading.

But when compared to all the above Fading, Nakagami-m Fading is considered as the most intensive Fading (Yue et al., 2017). It gives a better performance and better results such as outage probability and system throughput in using Nakagami-m Fading channels. Using the Nakagami-m Fading channels we can find out the outage probability and system performance (Yue et al., 2017). In the Nakagami-m Fading the severity fading parameter "m" is equal to 0.5. Since the fading severity parameter "m" is less than 1.

2.6. Frequency Band

In 5G technology, frequency bands are classified in to two. The sub 6 GHz frequency band and the millimeter wave (mm Wave).

2.6.1. Sub 6 GHz frequency band

A sub-6 band 5G technology will be able to cover a larger geographical area for 5G coverage but will not be able to provide higher speed downlink. Sub-6 GHz bands are frequency bands where the frequency transmitted from cell phone towers are less than 6GHz frequency. China is ongoing at 2.5-2.6 GHz, 3.4-3.6 GHz, and 4.8- 4.9 GHz frequency bands (Ikki et al., 2013), while Korea is planning at 3.4-3.7 GHz. The United States schemes the frequency bands of 3.1-3.55 GHz and 3.7-4.2 GHz. Overall, the frequency from 2.5 GHz to 5.9 GHz is the main sub-6 GHz frequency band for V2X communications (Zeng et al., 2020).

2.6.2. Millimeter wave

An mm Wave 5G technology will be able to provide class leading downlink speeds, but at the cost of less geographical area coverage. The higher speeds that really set 5G apart from any of the 4G LTE flavors require mm Wave (millimeter wave, above 24GHz) high-frequency bands. These high frequencies have large bandwidths, so they are ideal for keeping everyone connected in busy environments like stadiums (Zeng et al., 2020).

Figure2. 2 Millimeter wave vehicular network

The extremely high 5G frequency bands at mm Wave, such as 24.25- 27.5 GHz schemed in Europe, 24.25-27.5 GHz and 37- 43.5 GHz schemed in China, 27.5-28.35 GHz and 37- 40 GHz schemed in the United States, will allow the deployment of hotspots providing extremely high throughput thanks to the large available bandwidth for operators (J. Choi et al., 2016).

2.7. Performance Metrics

Performance metrics are critical for determining the system's overall integrity. Some of the analytical tools that can be used to evaluate the performance of a wireless system in diverse situations are discussed.

2.7.1. Average SNR

The signal-to-noise ratio (SNR) is one of the most well-known and widely used performance measurements for determining a system's overall fidelity. The average signal-to-noise ratio (SNR) is the ratio of average received power to noise power. Normally, noise power in average SNR is the power of the ubiquitous thermal noise experienced at the receiver; however, when the received signal experiences fading, it is appropriate to statistically average SNR to account for the randomness introduced. In the presence of fading, the received instantaneous SNR (γ) at a given receiver is a random variable (RV).

2.7.2. Outage Probability

Outage probability is another extensively used performance metric for measuring wireless system performance in fading channels. The probability that the output instantaneous SNR falls below a certain threshold is known as outage probability. Outage probability refers to the probability that the signal power at the receiver falls below a certain threshold. In vehicular communication, the threshold is typically set to a value that ensures reliable communication between vehicles. Nakagami fading and Rayleigh fading are two common models used to describe the random fluctuations in the signal strength experienced in wireless communication channels. When the destination is inside the road, it is referred to as line of sight (LOS) communication. When the destination is outside the road, it is referred to as non-line of sight (NLOS) communication.

2.8. Related Works

The (Steinmetz et al., 2015) paper characterizes the probability that the receiver successfully receives a packet sent by the transmitter accounting for the clustering effect with decreased distance d to the intersection. It considers vehicle to infrastructure and vehicle to vehicle communication at intersections in the presence of interference following the direct transmission scheme. The receiver is on road X and the transmitter can be in any location and it broadcasts its state information with a fixed transmission power p. The propagation model comprises Rayleigh multipath fading with exponential power fading and shadowing effect is neglected. Their limitations are that there is no work in case the receiver does not belong to either road X or road Y, incase Transmitter belongs to the transmitting vehicles that contributes to the aggregate interference and the speed distribution on both roads and the clustering induced by the reduced speed and the vicinity of the intersection.

Vehicular communication in the presence of interference at intersection is studied by computing the outage probability for the three transmission schemes, direct transmission, Relay transmission and Hybrid transmission over Nakagami-m fading channels. Unlike most works related to intersection scenarios, the receivers are assumed to be on the roads or outside the roads. It shows that direct transmission outperforms Relay transmission. Relay transmission is useful in conditions when direct transmission is not possible. This work is limited not considering the effect of Doppler shift and time varying effect of V2V and V2I channel (Eddine, Belmekki, Hamza, et al., 2019).

Mm vehicular network using a NOMA transmission between a source **S**, and two destinations $\mathbf{D_1}$ and $\mathbf{D_2}$ is considered with an intersection scenario of two perpendicular roads, a horizontal road, and a vertical road (Eddine, Belmekki, Hamza, et al., 2019).

In this paper a cooperative vehicular communication NOMA using relay transmission schemes at intersection is analyzed. It considers slotted ALOHA protocol with parameter p so that every node can access the medium with a probability p. Decode and forward (DF) decoding strategy is used since it follows a relay transmission, and a half duplex transmission is used in which a transmission occurs during two phases where each phase lasts one timeslot. What it makes it different from other works is that it considers using Maximum Ratio combining at destination node to offer a significant improvement over the relay transmission(Eddine, Belmekki, & Hamza, 2019).

In existing literature information credibility issue has not been done. In a mechanism in which vehicles share genuine road traffic information is designed considering general scenario and a specific highway scenario. A group of vehicles which are independent of each other and randomly distributed following the PPP are considered in a cooperative vehicular network. The proposed credit based RTI sharing mechanism can ensure that all vehicles aspire to a good reputation. It is seen that the outage performance is related to density of vehicles in which a higher density shows having a small distance among the vehicles and this improves the communication performance (Jiang et al., 2016).

Interference due to congestion of vehicles at intersection that degrade inter-vehicular communication is analyzed. A theoretical interference model of vehicle-to-vehicle communication at intersection using simple power control method is analyzed where the transmission power of each vehicle is determined by the location of the vehicle which might be in queuing (stopped) or running. After analyzing a mathematical interference model with a simple power control method for intersection it is seen that the power control method reduces the outage probability of a vehicle running closer to the intersection by roughly 10% which will help in efficient system design and control in future intelligent transportation system (Kimura & Saito, 2018).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Chapter Overview

This chapter mainly focuses on materials and methods used to accomplish the research work, NOMA system model, transmission and decoding model, OMA system, NOMA system and Cooperative NOMA systems and performance metrics.

3.2. Materials

Software materials used in this thesis are MATLAB R2021a, Microsoft word and Concept Draw Office. Concept Draw Office is used to draw block diagrams, figures. MATLAB R2021a, which is computing software that consists of Editor, which is used to write a code for entire system. Microsoft Word is an integrated writing environment. It is writing tool which is user friendly to write.

3.3. Methods

First different literatures are reviewed and the research gap is identified. Then the data that are directly related to the research problem is collected. The collected data are studied and analyzed. Then by understanding the concept the MATLAB code is written on MATLAB R2021a. From simulation result the best solution for particular and specified case according to scientific research method is recommended.

3.4. NOMA System Model

According to Figure 3. 1 a transmission between a source, S and a destination D_1 and D2 with the help of a relay denoted R in a vehicular network is considered. An intersection scenario with two perpendicular roads, horizontal roads denoted X, and a vertical road denoted Y is taken. In this thesis only Vehicle to Vehicle (V2V) communications is considered, so any node of the set {S, R, D_1, and D_2} will be on the road meaning line of sight. The distance between D_1 and the intersection is denoted as d. The intersection is the point where the X road and the Y road intersect.

M denoted as the receiving node, and m denoted as the distance between the node M and the intersection, where $M \in \{R, D_1, D2\}$ and $m \in \{r, d_1, d2\}$. The angle θ_M is the angle between the node M and the X road. The set {S, R, D_1, and D2} is subject to interference that is originated from vehicles located on the roads.

The transmission is subject to interference originated from vehicles located on the roads. The set of interfering vehicles located on the X road that are in a LOS with {S, R, D_1, and D_2}, denoted by Φ_X^{LOS} (resp. on axis Y, denoted by Φ_Y^{LOS}) are modeled as a One-Dimensional Homogeneous Poisson Point Process (1D-HPPP), that is, $\Phi_X^{LOS} \sim$ 1D-HPPP (λ_X^{LOS}, x) (resp. $\Phi_Y^{LOS} \sim$ 1D-HPPP (λ_Y^{LOS} , y), where x and λ_X^{LOS} (resp. y and λ_Y^{LOS}) are the position of the LOS interferer vehicles and their intensity on the X road (resp. Y road).

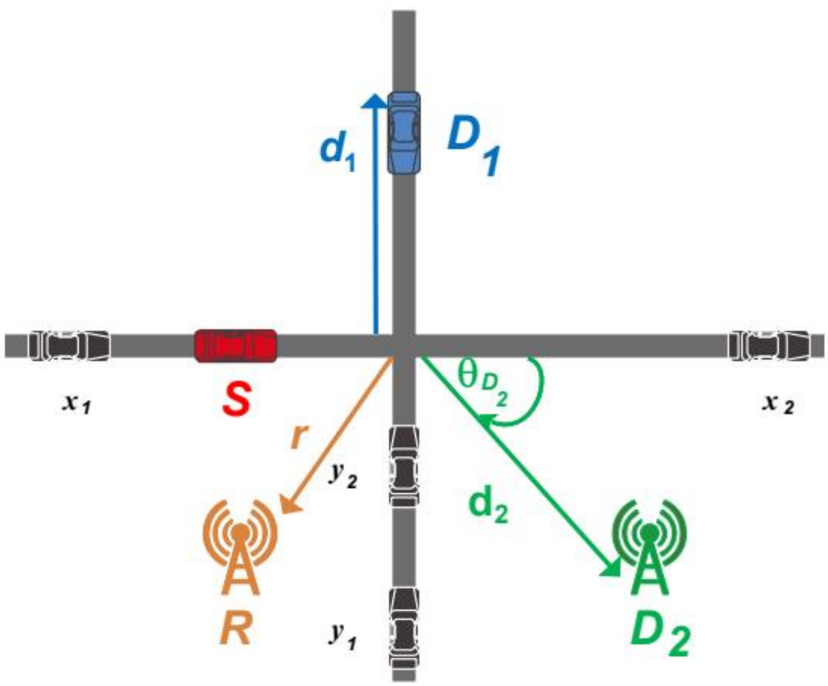


Figure3. 1 NOMA system Model for Vehicular Communication with Relay

Similarly, the set of interfering vehicles located on the X road that are in a NLOS with {S, R, D1}, denoted by Φ_X^{NLOS} (resp. on axis Y, denoted by Φ_Y^{NLOS}) are modeled as a One-Dimensional Homogeneous Poisson Point Process (1D-HPPP), that is, $\Phi_X^{NLOS} \sim$ 1D-HPPP (λ_X^{NLOS} , x) (resp. $\Phi_Y^{LOS} \sim$ 1D-HPPP (λ_Y^{NLOS} , y), where x and λ_X^{LOS} (resp. y and λ_Y^{NLOS}) are the position of the NLOS interferer vehicles and their intensity on the X road (resp. Y road). The notation x and y denotes both the interferer vehicles and their locations.

In figure 3.2, we consider a millimeter wave vehicular network using a cooperative NOMA transmission between a source, denoted *S*, and two destinations denoted D_1 and D_2 with the help of a relay denoted *R*. The set {S, R, D_1, and D_2} denotes the nodes and their locations.

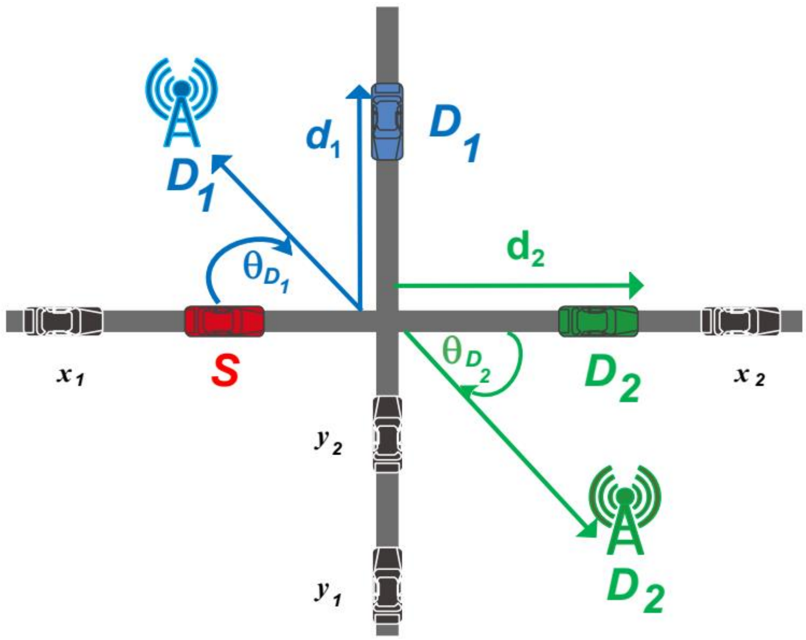


Figure 3. 2 NOMA System Model for Vehicular Communication without Relay

3.5. Intersection Scenario

The intersection scenario consists of two perpendicular roads, horizontal roads denoted X, and a vertical road denoted Y. We consider both V2V and V2I communications,1 hence, the triplet S, D and R can be either on the road (e.g., vehicle) or outside the road (e.g., base station).

3.6. Transmission and Decoding Model

The transmission is subject to a path loss, denoted by $r_{\mathrm{ab}}^{-\alpha}$ between the nodes a and b, where r_{ab} = ||a – b||, and α is the path loss exponent. The path exponent $\alpha \in \{ \alpha_{\mathrm{LOS}},\alpha_{\mathrm{NLOS}}\}$, where $\alpha = \alpha_{LOS}$, when the transmission is in LOS, whereas $\alpha = \alpha_{\mathrm{NLOS}}$, when transmission is in NLOS. We consider slotted ALOHA protocol with parameter p, i.e., every node accesses the medium with a probability p. We use a Decode and Forward (DF) decoding strategy, i.e., R decodes the message, re-encodes it, and then forwards it to D_1 or D_2. We also use a half-duplex transmission in which a transmission occurs during two phases. Each phase lasts one time slot. During the first phase, S broadcasts the message to R (S → R). During the second phase, R broadcasts the message to D_1 (R → D_1) & (R → D_2).

The signal transmitted by S, denoted Xs, is a mixture of the message intended to D_1 and D_2. This can be expressed as

$$Xs = \sqrt{a_1} X_{D1} + \sqrt{a_2} X_{D2}, \tag{1}$$

where a_i is the power coefficients allocated to D_i , and X_{Di} is the message intended to D_i. Since D1 has a higher power allocation than D_2, that is, $a_1 \geq a_2$, then D_1 comes first in the decoding order. Note that, $a_1 + a_2 = 1$.

The signal received at D_i is then expressed as

$$y_{Di} = h_{SDi}\sqrt{\lambda_{SDi}} X_s + \sum_{x \in \Phi_{Y_{D_i}}} h_{D_i x}\sqrt{\lambda_{D_i x}} X_x + \sum_{y \in \Phi_{Y_{D_i}}} h_{D_i y}\sqrt{\lambda_{D_i y}} X_y \tag{2}$$

where y_{Di} is the signal received by D_i. The messages transmitted by the interfering node x and y, are denoted respectively by X_x and X_y, h_{ab} denotes the fading coefficient between node a and b, and it is modeled as CN (0, 1) (Rayleigh channel model). The power fading coefficient between the node a and b, denoted $|h_{ab}|^2$, follows an exponential distribution with unit mean.

The coefficient h_{SD_i} denotes the fading of the link $S - D_i$. The fading coefficient h_{SD_i} is distributed according to a Nakagami-m distribution with parameter m (Belbase et al., 2018), that is

$$f_{h_{SD_i}}(x) = 2\left(\frac{m}{\mu}\right)^m \frac{x^{2m-1}}{\Gamma(m)} e^{-\frac{m}{\mu}x^2},$$

where the parameter $m \in \{m_{LOS}, m_{NLOS}\}$. Note that $m = m_{LOS}$ when $S - D_i$ is in a LOS, whereas $m = m_{NLOS}$, when $S - D_i$ is in a NLOS. The parameter μ is the average received power. Hence, the power fading coefficient $|h_{SD_i}|^2$ is distributed according to a gamma distribution, that is,

$$f_{|h_{SD_i}|^2}(x) = 2\left(\frac{m}{\mu}\right)^m \frac{x^{2m-1}}{\Gamma(m)} e^{-\frac{m}{\mu}x^2},$$

The fading coefficients $h_{D_i x}$ and $h_{D_i y}$ denote the fading of the link D_i − x, and D_i − y. The fading coefficients are modeled as Rayleigh fading (Deng & Haenggi, 2017). Thus, the power fading coefficients $|h_{D_i x}|^2$ and $|h_{D_i y}|^2$, are distributed according to an exponential distribution with unit mean.

The aggregate interference is defined as

$$I_{X_{D_i}} = \sum_{x \in \Phi_{Y_{D_i}}} \left| h_{D_i x} \right|^2 l_{D_i x} \tag{3}$$

$$I_{Y_{D_i}} = \sum_{y \in \Phi_{Y_{D_i}}} \left| h_{D_i y} \right|^2 l_{D_i y} \tag{4}$$

where I_{XDi} denotes the aggregate interference from the X road at D_i , I_{YDi} denotes the aggregate interference from the Y road at D_i, Φ_{XDi} denotes the set of the interferers from the X road at D_i , and Φ_{YDi} denotes the set of the interferers from the Y road at D_i.

According to successive interference cancellation (SIC) (Hasna et al., 2003), D_1 will be decoded first since it has the higher power allocation, and D_2 message will be considered as interference. The SIR at D_1 to decode its desired message, denoted SIR_{D1-1}, is expressed as (Belmekki et al., 2020a)

$$SIR_{D_{1-1}} = \frac{\left| h_{SD_1} \right|^2 l_{SD_1} a_1}{\left| h_{SD_1} \right|^2 l_{SD_1} a_2 + I_{X_{D1}} + I_{Y_{D1}}} \tag{5}$$

Similarly, The SIR at D_1 to decode D_2 message, denoted SIR_{D1-2}, is expressed as (Belmekki et al., 2020a)

$$SIR_{D_{1-2}} = \frac{\left| h_{SD_1} \right|^2 l_{SD_1} a_2}{I_{X_{D1}} + I_{Y_{D1}}} \tag{6}$$

Since D_2 has the lower power allocation, it decodes D_1 message first, then decodes its intended message. The SIR at D_2 to decode D_1 message, denoted SIR_{D2-1}, is expressed as (Belmekki et al., 2020b)

$$SIR_{D_{2-1}} = \frac{\left| h_{SD_2} \right|^2 l_{SD_2} a_1}{\left| h_{SD_2} \right|^2 l_{SD_2} a_2 + I_{X_{D2}} + I_{Y_{D2}}} \tag{7}$$

The SIR at D_2 to decode its desired message, denoted SIR_{D2-2}, is expressed as (Belmekki et al., 2020b)

$$SIR_{D_{2-2}} = \frac{\left|h_{SD_2}\right|^2 l_{SD_2} a_2}{I_{X_{D2}} + I_{Y_{D2}}} \tag{8}$$

When using the cooperative transmission, the node that acts as a relay uses OMA instead of NOMA, since the transmission involves only one receiving node. Hence, the SIR at the receiver is then expressed as (Belmekki et al., 2020b)

$$SIR_{D_k D_l}^{(OMA)} = \frac{\left|h_{D_k D_l}\right|^2 l_{D_k D_l}}{I_{X_{D_l}} + I_{Y_{D_l}}} \tag{9}$$

where $\{k, l\} \in \{1, 2\}$.

The outage probability can be defined as the probability that the SIR at the receiving node is below a certain threshold. We first define the SIR at the receiving node, then we define the outage events and the outage probability related to them, considering direct transmission and cooperative transmission.

3.7. Conventional OMA System

The OMA (Orthogonal Multiple Access) system is a method of assigning radio frequency channels for wireless communication. It is designed to improve the capacity and efficiency of wireless communication networks. In the context of vehicular communication, the OMA system can be used to allocate communication resources for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication.

The OMA system divides the available bandwidth into orthogonal subcarriers, which are assigned to users in a way that minimizes interference between them. The OMA system operates using a time-frequency resource allocation approach, where each user is assigned a unique combination of time-frequency resources. Allocation of these resources is done using algorithms that optimize specific performance criteria such as throughput, capacity, and fairness. Depending on the specific application and use case, different optimization criteria can be chosen. In vehicular communication scenarios, OMA can be used to allocate resources for tasks such as transmission of vehicle position and speed information to other nearby vehicles or infrastructure nodes. This information can then be used to provide traffic updates, collision warnings, and other safety-related communication services.

One possible implementation of the OMA system in vehicular communications is the use of OFDMA (Orthogonal Frequency Division Multiple Access). OFDMA is a multi-user version of OFDM (Orthogonal Frequency Division Multiplexing), a widely used modulation technique in wireless communication systems. OFDMA assigns orthogonal subcarrier frequencies to multiple users, thereby reducing interference between them and improving system capacity.

3.8. NOMA System

The NOMA system is a promising technology for improving the efficiency and capacity of wireless communication systems. Unlike OMA, which uses orthogonal subcarriers to assign radio frequency channels to users, NOMA uses non-orthogonal subcarriers to enable multiple users to share the same channel simultaneously. This is achieved by allowing a more flexible allocation of power and resources among users.

NOMA uses power domain multiplexing to simultaneously transmit different signals over the same radio frequency channel. In vehicular communication scenarios, NOMA can be used to improve the capacity and efficiency of V2V and V2I communication by allowing multiple users to share the same channel at the same time. This enables faster and more efficient communication between vehicles and infrastructure nodes, which can help improve traffic management, reduce congestion, and enhance overall driving safety.

One implementation of NOMA in vehicular communication is the use of Multi-User Shared Access (MUSA). MUSA is a technique that employs power-domain multiplexing to enable multiple users to share a single communication resource. MUSA assigns different power levels to different users based on their quality-of-service (QoS) requirements. This allows each user to receive a different level of service while sharing the same channel resource. Another advantage of NOMA in vehicular communication is its ability to handle high-mobility scenarios with fast-changing communication channels. Since each user's power allocation is dependent on their instantaneous channel state, NOMA can dynamically adapt to changes in the communication channel.

3.9. Proposed Cooperative NOMA System

Cooperative Non-Orthogonal Multiple Access (NOMA) is a wireless communication technique that is designed to improve the efficiency of communication in vehicular networks. The cooperative NOMA system allows multiple users to share the same wireless resource simultaneously, while also enabling them to coordinate with each other to achieve better performance. The main idea behind cooperative NOMA in vehicular communication is to create a cooperative communication network where each vehicle shares its resources with other vehicles. This can be achieved by allowing vehicles to relay the messages they receive from other vehicles, thus creating a multi-hop communication network. In this way, cooperative NOMA can significantly improve the reliability and performance of the vehicular communication.

Mathematically, cooperative NOMA can be represented using signal-to-interference-plus-noise ratio (SINR) and a power allocation equation. The SINR is used to quantify the quality of the received signals and to calculate the achievable data rates for each user in the system. The power allocation equation is used to distribute the available power among the users, thereby enabling them to share the wireless resource efficiently.

Let us consider a scenario where there are two vehicles A and B, and both of them want to communicate with a base station located at a distance. We assume that vehicle A is closer to the base station than vehicle B. In this scenario, the cooperative NOMA system works as follows:

1. Vehicle A acts as a relay node and forwards the message it receives from vehicle B to the base station.
2. Vehicle A allocates its power resources according to the power allocation equation, which distributes the available power proportionally among the users.
3. The SINR is used to determine the achievable data rates for both vehicle A and vehicle B.
4. Finally, the base station sends an acknowledgement signal back to both vehicles indicating whether or not their message has been successfully transmitted.

The users with better channel gains receive more power than users with poor channel gains. This enables higher data rates and better performance for those users with strong signals.

3.10. Outage Probability Derivation

Outage probability refers to the probability that the signal power at the receiver falls below a certain threshold. In vehicular communication, the threshold is typically set to a value that ensures reliable communication between vehicles. Nakagami fading and Rayleigh fading are two common models used to describe the random fluctuations in the signal strength experienced in wireless communication channels. When the destination is inside the road, it is referred to as line of sight (LOS) communication. When the destination is outside the road, it is referred to as non-line of sight (NLOS) communication.

3.10.1. Derivation of Outage Probability over a Nakagami-m Fading Channel when the Destination is Inside the Road (Line of Sight)

In this scenario, the received signal power at the receiver is affected by both the desired signal and the interference from other nodes, which follow a Nakagami-m distribution with mean power $\overline{P}_s$ and $\overline{P}_i$, respectively. The instantaneous received signal power is given by:

$$\mathrm{P_r} = \frac{P_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} d^2} + \sum_{i=1}^{N} \frac{P_{ti} G_{ti} G_{ir} G_{rd}}{d_{ti}^{\alpha} d_{ir}^{\alpha} d_{rd}^{\alpha} d^2}$$

Where N is the number of interfering nodes, P_{ti} is the transmit power of the *i-th* interfering node, G_{ti}, G_{ir}, and G_{rd} are the fading gains of the links between the transmitter of the *i-th* interfering node, the *i-th* interfering node and the receiver, and the relay and the destination, respectively; d_{ti}, d_{ir}, and d_{rd} are the distances between the transmitter of the *i-th* interfering node and the relay, the *i-th* interfering node and the receiver, and the relay and the destination, respectively; σ^2 is the noise power, and α is the path loss exponent.

The interference power is modeled as a sum of i.i.d. Nakagami-m fading variables with mean power $\overline{P}_i$, i.e.,

$$I = \sum_{i=1}^{N} I_i$$

where I_i is the interference power from the *i-th* interfering node and follows a Nakagami-m distribution with mean power $\overline{P}_i$. The instantaneous SNR at the receiver is given by:

$$\gamma = \frac{\overline{P}_s}{d^2} \frac{P_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} d^2} + \frac{\overline{P}_i}{d^2} \sum_{i=1}^{N} \frac{P_{ti} G_{ti} G_{ir} G_{rd}}{d_{ti}^{\alpha} d_{ir}^{\alpha} d_{rd}^{\alpha} d^2}$$

where $\overline{P}_s$ is the mean power of the desired signal, which is given by:

$$\overline{P}_s = \frac{P_t}{d_{tr}^{\alpha} d_{rd}^{\alpha}}$$

where $\overline{P}_i$ is the mean power of the interference, which is given by:

$$\bar{P}_i = \frac{P_{ti}}{d_{ti}^{a} d_{ir}^{a}}$$

The outage probability is defined as the probability that the instantaneous SNR falls below a certain threshold γ_{th}, i.e.,

$$P_{out} = P(g < g_{th})$$

Using the PDF of the sum of i.i.d. Nakagami-m fading variables, the outage probability can be expressed as:

$$P_{out} = E_I \left[P\left(\frac{\bar{P}_s}{\bar{P}_i I + d^2} < g_{th} \right) \right]$$

where E_I is the expectation over the interference power I.

Solving the inequality inside the probability, we get:

$$\frac{\bar{P}_s}{g_{th}} - d^2 < \bar{P}_i I'$$

where I' is a Gamma distributed variable with shape parameter m and scale parameter $\frac{\bar{P}_i}{m}$, i.e.,

$$f_{I'}(x) = \frac{m^m}{G(m)\left(\frac{\bar{P}_i}{m}\right)^m} x^{m-1} e^{-\frac{mx}{\bar{P}_i}}$$

Taking the expectation over both sides of the inequality, we get:

$$\frac{\bar{P}_s}{g_{th}} - d^2 < \bar{P}_i E[I'] = \bar{P}_i \frac{m}{\frac{\bar{P}_i}{m}} = m\bar{P}_i$$

Using the CDF of the Gamma distribution, the expected interference power can be expressed as:

$$E[I'] = \frac{\bar{P}_i}{m} \int_0^{\infty} x^{m-1} e^{-\frac{mx}{\bar{P}_i}} dx = \frac{\bar{P}_i}{m} G(m)$$

where $\Gamma(m)$ is the Gamma function.

Substituting the expression for $E[I']$ in the inequality, we get:

$$\frac{\bar{P}_s}{g_{th}} - d^2 < m\bar{P}_i$$

Simplifying, we get:

$$\overline{P}_i > \frac{\overline{P}_s}{m\gamma_{th}} - \frac{\delta^2}{m}$$

The outage probability can then be expressed as:

$$P_{out} = E_I\left[P\left(\frac{\overline{P}_s}{\overline{P}_i I + \delta^2} < \gamma_{th}\right)\right] = P\left(\overline{P}_i > \frac{\overline{P}_s}{m\gamma_{th}} - \frac{\delta^2}{m}\right)$$

Using the CDF of the Gamma distribution, we get:

$$P_{out} = 1 - F_I\left(\frac{\overline{P}_s}{m\gamma_{th}} - \frac{\delta^2}{m}\right)$$

where $F_I(x)$ is the CDF of a Gamma distribution with shape parameter m and scale parameter $\frac{\overline{P}_i}{m}$. Therefore, the outage probability over a Nakagami-m fading channel when the destination is inside the road (line of sight) is given by the expression:

$$P_{out} = 1 - F_I\left(\frac{\overline{P}_s}{m\gamma_{th}} - \frac{\delta^2}{m}\right)$$

3.10.2. Derivation of Outage Probability over a Rayleigh Fading Channel when the Destination is Inside the Road (Line of Sight)

In this scenario, the received signal power at the receiver follows a Rayleigh distribution with mean power $\bar{P}$. The instantaneous received signal power is given by:

$$\mathrm{P_r} = \frac{P_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} d^2}$$

where P_t is the transmit power, G_{tr} and G_{rd} are the fading gains of the links between the transmitter and the relay, and the relay and the destination, respectively; d_{tr} and d_{rd} are the distances between the transmitter and the relay, and the relay and the destination, respectively; σ^2 is the noise power, and α is the path loss exponent.

The instantaneous SNR at the receiver is given by:

$$\gamma = \frac{\bar{P}}{d^2} \frac{P_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} d^2}$$

The outage probability is defined as the probability that the instantaneous SNR falls below a certain threshold γ_{th}, i.e.,

$$P_{out} = P(\gamma < \gamma_{th})$$

Using the PDF of the Rayleigh distribution, the outage probability can be expressed as:

$$P_{out} = 1 - e^{-\frac{\gamma_{th}}{\bar{P}}}$$

3.10.3. Derivation of Outage Probability over a Nakagami-m Fading Channel when the Destination is Outside the Road (Non Line of Sight)

In this scenario, the received signal power at the receiver is affected by both the desired signal and the interference from other nodes, which follow a Nakagami-m distribution with mean power $\bar{P}_s$ and $\bar{P}_i$, respectively. The instantaneous received signal power is given by:

$$\mathrm{P_r} = \frac{P_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} d^2} + \sum_{i=1}^{N} \frac{P_{ti} G_{ti} G_{ir} G_{rd}}{d_{ti}^{\alpha} d_{ir}^{\alpha} d_{rd}^{\alpha} d^2}$$

Where N is the number of interfering nodes, P_{ti} is the transmit power of the *i-th* interfering node, G_{ti}, G_{ir}, and G_{rd} are the fading gains of the links between the transmitter of the *i-th* interfering node, the *i-th* interfering node and the receiver, and the relay and the destination, respectively; d_{ti}, d_{ir}, and d_{rd} are the distances between the transmitter of the *i-th* interfering node and the relay, the *i-th* interfering node and the receiver, and the relay and the destination, respectively; σ^2 is the noise power, and α is the path loss exponent.

The interference power is modeled as a sum of i.i.d. Nakagami-m fading variables with mean power $\bar{P}_i$, i.e.,

$$I = \sum_{i=1}^{N} I_i$$

where I_i is the interference power from the *i-th* interfering node and follows a Nakagami-m distribution with mean power $\bar{P}_i$. The instantaneous SNR at the receiver is given by:

$$\gamma = \frac{\bar{P}_s}{d^2} \frac{P_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} d^2} + \frac{\bar{P}_i}{d^2} \sum_{i=1}^{N} \frac{P_{ti} G_{ti} G_{ir} G_{rd}}{d_{ti}^{\alpha} d_{ir}^{\alpha} d_{rd}^{\alpha} d^2}$$

where $\bar{P}_s$ is the mean power of the desired signal, which is given by:

$$\bar{P}_s = \frac{m}{m+1} \left(\frac{P_t}{d_{tr}^{\alpha}} \right) \left(\frac{1}{d_{rd}^{\alpha}} \right)$$

where $\bar{P}_i$ is the mean power of the interference, which is given by:

$$\bar{P}_i = \frac{m}{m+1} \left(\frac{P_{ti}}{d_{ti}^{\alpha}} \right) \left(\frac{1}{d_{ir}^{\alpha}} \right)$$

The outage probability is defined as the probability that the instantaneous SNR falls below a certain threshold γ_{th}, i.e.,

$$P_{out} = P(\gamma < \gamma_{th})$$

Using the PDF of the sum of i.i.d. Nakagami-m fading variables, the outage probability can be expressed as:

$$P_{out} = E_I \left[P\left(\frac{\bar{P}_s}{\bar{P}_i I + d^2} < \gamma_{th} \right) \right]$$

where E_I is the expectation over the interference power I.

Solving the inequality inside the probability, we get:

$$\frac{\bar{P}_s}{\gamma_{th}} - \delta^2 < \bar{P}_i I$$

Taking the expectation over both sides of the inequality, we get:

$$\frac{\bar{P}_s}{\gamma_{th}} - \delta^2 < \bar{P}_i E[I]$$

Using the moment generating function (MGF) of the sum of i.i.d. Nakagami fading variables, the expected interference power can be expressed as:

$$\frac{\bar{P}_s}{\gamma_{th}} - \delta^2 < \frac{\mu}{\mu\gamma_{th}}\left(\frac{\pi\lambda_u(d_u + d_r)^2}{\mu}\right)^{\mu} e^{-\frac{\pi\lambda_u(d_u+d_r)^2}{\mu\gamma_{th}}}$$

where λ_u is the density of interfering nodes, du and d_r are the distances between the interfering nodes and the receiver, respectively. Substituting the expression for *E[I]* in the inequality, we get:

$$E[I] = \frac{\mu}{\mu\gamma_{th}}\left(\frac{\pi\lambda_u(d_u + d_r)^2}{\mu}\right)^{\mu} e^{-\frac{\pi\lambda_u(d_u+d_r)^2}{\mu\gamma_{th}}} \frac{\mu}{\mu+1}\left(\frac{P_{ti}}{d_{ti}^{\alpha}}\right)\left(\frac{1}{d_{ir}^{\alpha}}\right)$$

Simplifying the inequality, we get:

$$\gamma_{th} > \frac{\bar{P}_s}{\frac{\mu}{\mu+1}\left(\frac{P_{ti}}{d_{ti}^{\alpha}}\right)\left(\frac{1}{d_{ir}^{\alpha}}\right)E[I] + \delta^2}$$

Substituting the expression for *E[I]* in the inequality, we get:

$$\gamma_{th} > \frac{\bar{P}_s}{\frac{\mu}{\mu+1}\left(\frac{P_{ti}}{d_{ti}^{\alpha}}\right)\left(\frac{1}{d_{ir}^{\alpha}}\right)\frac{\mu}{\mu\gamma_{th}}\left(\frac{\pi\lambda_u(d_u + d_r)^2}{\mu}\right)^{\mu} e^{-\frac{\pi\lambda_u(d_u+d_r)^2}{\mu\gamma_{th}}} \frac{\mu}{\mu+1}\left(\frac{P_{ti}}{d_{ti}^{\alpha}}\right)\left(\frac{1}{d_{ir}^{\alpha}}\right) + \delta^2}$$

Solving for γ_{th}, we get:

$$\gamma_{th} < \frac{\bar{P}_s}{\frac{\mu}{\mu+1}\left(\frac{P_{ti}}{d_{ti}^{\alpha}}\right)\left(\frac{1}{d_{ir}^{\alpha}}\right)\frac{\mu}{\mu}\left(\frac{\pi\lambda_u(d_u + d_r)^2}{\gamma_{th}\mu}\right)^{\mu} e^{-\frac{\pi\lambda_u(d_u+d_r)^2}{\mu\gamma_{th}}} \frac{\mu}{\mu+1}\left(\frac{P_{ti}}{d_{ti}^{\alpha}}\right)\left(\frac{1}{d_{ir}^{\alpha}}\right) + \delta^2}$$

Taking the complement of the inequality, we get the outage probability:

$$P_{out} = P(\gamma > \gamma_{th}) = 1 - E_I\left[P\left(\frac{\bar{P}_s}{\bar{P}_i I + d^2} > \gamma_{th}\right)\right]$$

which can be expressed as:

$$P_{out} = 1 - \frac{m}{m\gamma_{th}}\left(\frac{p\lambda_u (d_u + d_r)^2}{m}\right)^m e^{-\frac{p\lambda_u (d_u + d_r)^2}{m\gamma_{th}}} \sum_{n=0}^{m-1} \frac{\left(\frac{\bar{P}_s}{\gamma_{th}}\right)^n}{n!}\left(\frac{\bar{P}_i}{d^2}\right)^{m-n} \exp\left(-\frac{\bar{P}_s}{\gamma_{th}}\right)$$

where the summation over *n* accounts for the interference from *n* interfering nodes and the desired signal from the remaining $m - n$ interfering nodes. This is the final expression for the outage probability over a Nakagami fading channel when the destination is outside the road (Non-Line of Sight).

3.10.4. Derivation of Outage Probability over a Rayleigh Fading Channel when the Destination is Outside the Road (Non Line of Sight)

In this scenario, the received signal power at the receiver is affected by both the desired signal and the interference from other nodes, which follow a Rayleigh distribution with mean power $\bar{P}_s$ and $\bar{P}_i$, respectively. The instantaneous received signal power is given by:

$$\mathrm{P_r} = \frac{P_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} d^2} + \sum_{i=1}^{N} \frac{P_{ti} G_{ti} G_{ir} G_{rd}}{d_{ti}^{\alpha} d_{ir}^{\alpha} d_{rd}^{\alpha} d^2}$$

Where N is the number of interfering nodes, P_{ti} is the transmit power of the *i-th* interfering node, G_{ti}, G_{ir}, and G_{rd} are the fading gains of the links between the transmitter of the *i-th* interfering node, the *i-th* interfering node and the receiver, and the relay and the destination, respectively; d_{ti}, d_{ir}, and d_{rd} are the distances between the transmitter of the *i-th* interfering node and the relay, the *i-th* interfering node and the receiver, and the relay and the destination, respectively; σ^2 is the noise power, and α is the path loss exponent.

The interference power is modeled as a sum of i.i.d. Rayleigh fading variables with mean power $\bar{P}_i$, i.e.,

$$I = \sum_{i=1}^{N} I_i$$

where I_i is the interference power from the *i-th* interfering node and follows a Rayleigh distribution with mean power $\bar{P}_i$. The instantaneous SNR at the receiver is given by:

$$\gamma = \frac{\bar{P}_s}{d^2}\frac{P_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} d^2} + \frac{\bar{P}_i}{d^2}\sum_{i=1}^{N}\frac{P_{ti} G_{ti} G_{ir} G_{rd}}{d_{ti}^{\alpha} d_{ir}^{\alpha} d_{rd}^{\alpha} d^2}$$

where $\bar{P}_s$ is the mean power of the desired signal, which is given by:

$$\bar{P}_s = \frac{P_t}{d_{tr}^{\alpha} d_{rd}^{\alpha}}$$

where $\bar{P}_i$ is the mean power of the interference, which is given by:

$$\bar{P}_i = \frac{P_{ti}}{d_{ti}^{\alpha} d_{ir}^{\alpha}}$$

The outage probability is defined as the probability that the instantaneous SNR falls below a certain threshold γ_{th}, i.e.,

$$P_{out} = P(\gamma < \gamma_{th})$$

Using the PDF of the sum of i.i.d. Nakagami-m fading variables, the outage probability can be expressed as:

$$P_{out} = E_I\left[P\left(\frac{\bar{P}_s}{\bar{P}_i I + d^2} < \gamma_{th}\right)\right]$$

where E_I is the expectation over the interference power I.

Solving the inequality inside the probability, we get:

$$\frac{\bar{P}_s}{\gamma_{th}} - d^2 < \bar{P}_i I$$

Taking the expectation over both sides of the inequality, we get:

$$\frac{\bar{P}_s}{\gamma_{th}} - d^2 < \bar{P}_i E[I]$$

Using the PDF of the Rayleigh distribution, the expected interference power can be expressed as:

$$E[I] = \bar{P}_i \int_0^{\infty} e^{-\frac{x}{\bar{P}_i}} f_I(x)dx = \bar{P}_i \sum_{n=0}^{\infty} \frac{(-1)^n}{n!}\left(\frac{\gamma_{th}}{\bar{P}_i}\right)^n e^{-\frac{\gamma_{th}}{\bar{P}_i}}$$

where $f_I(x)$ is the PDF of the Rayleigh distribution. Substituting the expression for $E[I]$ in the inequality, we get:

$$\frac{\bar{P}_s}{\gamma_{th}} - \delta^2 < \bar{P}_i \sum_{n=0}^{\infty} \frac{(-1)^n}{n!} \left(\frac{\gamma_{th}}{\bar{P}_i}\right)^n e^{-\frac{\gamma_{th}}{\bar{P}_i}}$$

Simplifying the inequality, we get:

$$\gamma_{th} > \frac{\bar{P}_s}{\bar{P}_i \sum_{n=0}^{\infty} \frac{(-1)^n}{n!} \left(\frac{\bar{P}_i}{\delta^2}\right)^n e^{\frac{\gamma_{th}}{\bar{P}_i}}}$$

This expression gives us the threshold SNR for a given outage probability Pout. To find the outage probability, we can use the complementary cumulative distribution function (CCDF) of the instantaneous SNR, which is given by:

$$\bar{F}_\gamma(\gamma_{th}) = P(\gamma > \gamma_{th}) = E_I\left[P\left(\frac{\bar{P}_s}{\bar{P}_i I + \delta^2} > \gamma_{th}\right)\right]$$

Substituting the expression for $\bar{P}_s$ and $\bar{P}_i$ we get:

$$\bar{F}_\gamma(\gamma_{th}) = EI\left[P\left(\frac{\bar{P}_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} \delta^2 + \bar{P}_i I} > \gamma_{th}\right)\right]$$

Using the CDF of the Rayleigh distribution, we can express this as:

$$\bar{F}_\gamma(\gamma_{th}) = EI\left[1 - F_I\left(\frac{\bar{P}_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} \delta^2 \gamma_{th} + \bar{P}_i}\right)\right]$$

where $F_I(x)$ is the CDF of the interference power, which is given by:

$$F_I(x) = 1 - e^{-\frac{x}{\bar{P}_i}}$$

Substituting this expression in the CCDF, we get:

$$\bar{F}_\gamma(\gamma_{th}) = EI\left[e^{-\frac{\bar{P}_t G_{tr} G_{rd}}{d_{tr}^{\alpha} d_{rd}^{\alpha} \delta^2 \gamma_{th}}}\right] \sum_{n=0}^{\infty} \frac{1}{n!} \left(\frac{\bar{P}_i}{\delta^2 \gamma_{th}}\right)^n$$

Taylor series expansion of the exponential function is used in the above equation. The first term in the expression represents the average fading, which is an exponential random variable with mean:

$$\frac{d_{tr}^{a} d_{rd}^{a} d^{2}}{\bar{P}_{t}} g_{th}$$

Therefore, the outage probability can be expressed as:

$$P_{out} = \bar{F}_{g}(g_{th}) = EI\left[e^{-\frac{d_{tr}^{a} d_{rd}^{a} d^{2}}{\bar{P}_{t}} g_{th}} \right] \sum_{n=0}^{\infty} \frac{1}{n!} \left(\frac{\bar{P}_{i}}{d^{2} g_{th}} \right)^{n}$$

This expression gives us the outage probability for a given threshold SNR γ_{th}. Note that the first term represents the average fading, which decreases with increasing distance between the transmitter and the receiver. The second term represents the interference, which increases with the number of interfering nodes and their transmit powers.

To summarize, the outage probability over a Rayleigh fading channel when the destination is outside the road (Non Line of Sight) can be derived by modeling the received signal power as a sum of the desired signal and interference from other nodes, which follow a Rayleigh distribution. The outage probability is defined as the probability that the instantaneous SNR falls below a certain threshold.

CHAPTER FOUR

4. RESULT AND DESCUSSION

4.1. Overview

In this chapter the detailed analysis of the result is discussed. The result is simulated under acceptable parameters. The Signal to Noise Ratio versus Bit Error Rate, Signal to Noise Ratio versus Outage Probability, Average Achievable Rate analysis is used to check the improvement of the system.

Table 4. 1 Parameters for simulation

Parameters	**Numerical Value**	**Remark**
Number of Symbols (M)	64/256	$M=2^K$ where k= Integer
Number of Bits	10^6	Can Vary
Number of Users	2	Can Vary
Distance between Transmitters in meter	5	Can Vary
Transmit power in watts	0.01	Can Vary
Carrier Frequency in Hertz	2.4x10^(9)	ITU Standard
Bandwidth	1x10^(6)	Can Vary
Number of Tx Antenna	4	Can Vary
Power Splitting Ratio (rho)	0.1-0.9	Can Vary
Time Fraction for EH	0.1-0.9	Can Vary
Path-loss Exponent	3	Can Vary
Energy Conversion Coefficient	0.7	Can Vary
EbNo	0:2:50	Can Vary
M-QAM	4/16/64/128/256	Can Vary
Communication Channel Model	Rayleigh Fading/ Nakagami-m	ITU Standard

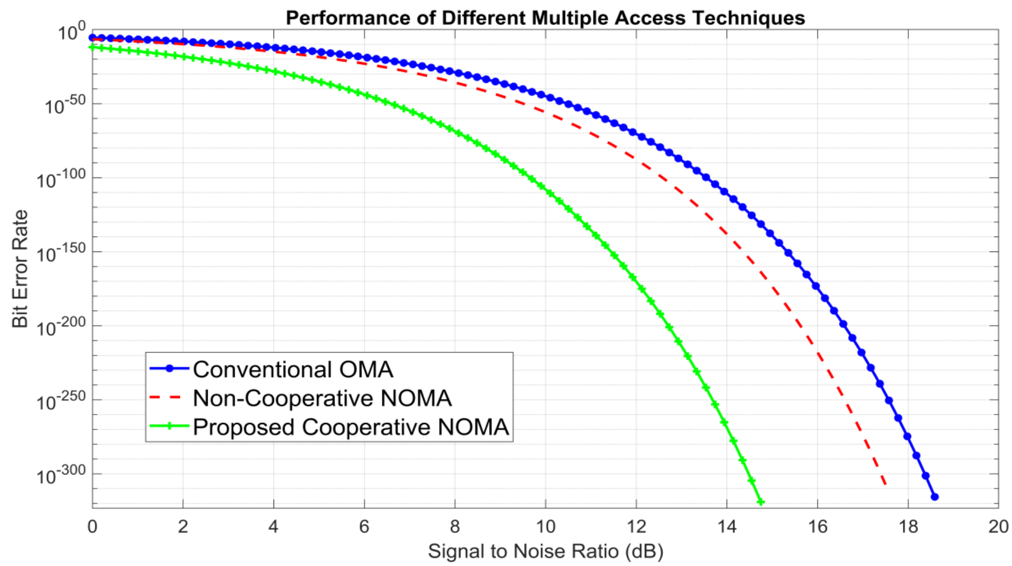
4.2. BER versus SNR Analysis

Bit error rate (BER) versus signal-to-noise ratio (SNR) analysis is the one commonly used technique in wireless communication systems to evaluate the performance of a communication link. The BER is the ratio of the number of received bits that are in error to the total number of transmitted bits. The SNR is the ratio of the received signal power to the noise power.

In this analysis, the BER is plotted against the SNR to evaluate the performance of a communication system at different SNR levels. The analysis involves generating a set of random bits, modulating them onto a carrier signal, and transmitting the modulated signal through the wireless channel. The receiver then demodulates the received signal and compares it with the original transmitted bits to compute the BER. The analysis is typically done for different modulation schemes, like 64-Quadrature amplitude modulation (64-QAM) and 256-Quadrature amplitude modulation (256-QAM).

The BER versus SNR curves can provide insights into the performance of different modulation and help in selecting the optimal scheme for a given channel condition. The analysis can also help in determining the minimum SNR required to achieve a certain BER target. This information is useful in designing and optimizing wireless communication systems by providing insights into the trade-offs between system parameters such as transmit power, modulation scheme, coding scheme, and channel bandwidth. Overall, BER versus SNR analysis is a useful tool for evaluating the performance of wireless communication systems in terms of data rate and error rate and can help in making informed decisions about system design and optimization.

The graph plots the SNR of a communication system on the horizontal axis and corresponding BER on the vertical axis. As mentioned before the BER represents the percentage of bits that are received incorrectly, while the SNR is a measure of the strength of the received signal relative to the background noise. The SNR versus BER graph is useful because it allows engineers to evaluate the trade-off between the quality of the signal and the amount of noise in the channel. As the SNR increases, the BER typically decreases, indicating better performance. Engineers can use this graph to find the optimal operating point for a given system, where the SNR is high enough to achieve an acceptable BER while minimizing power consumption or other system costs.



c

Figure 4. 1 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 64 QAM over Rayleigh fading channel

Figure 4.1 is plotted for number of symbols 64, number of bits 10^6, number of users 2, distance between transmitters 5 meter, carrier frequency 2.4x10^9, noise power in watts 1x10^(-9) and Rayleigh fading channel model. From the figure it is concluded that the proposed Cooperative NOMA has less BER value compared to Non-Cooperative NOMA and conventional OMA. Therefore cooperative NOMA outperforms than other multiple access techniques.

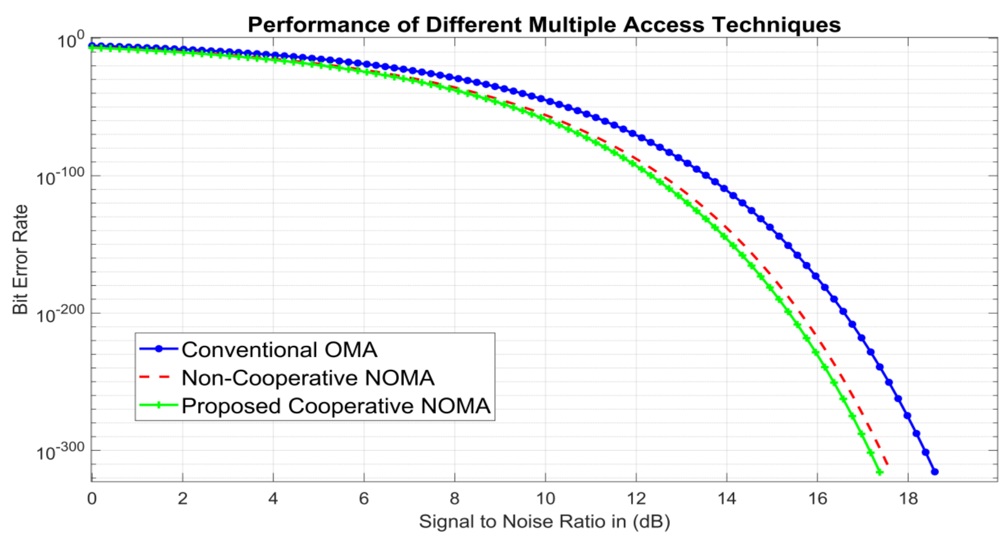


Figure 4. 2 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 256 QAM over Rayleigh fading channel

Figure 4.2 is plotted for the number of symbols 256, the number of bits 10^6, the number of users 2, the distance between transmitters 5 meter, the carrier frequency 2.4x10^9, the noise power in watts 1x10^(-9) and the channel type is Rayleigh fading channel model. From the figure it is concluded that the proposed Cooperative NOMA has less BER value compared to Non-Cooperative NOMA and conventional OMA. Therefore cooperative NOMA outperforms than other multiple access techniques. It is observed that when SNR increases cooperative NOMA system also increase accordingly. This shows cooperative NOMA system is robust while supporting a large number of users.

4.3. SNR versus Outage Probability Analysis

Outage probability versus signal-to-noise ratio (SNR) analysis is a commonly used technique in wireless communication systems to evaluate the performance of a communication link. The outage probability is the probability that the instantaneous signal-to-noise ratio falls below a certain threshold, which is typically set to ensure a certain level of reliability in the communication link. In this analysis, the SNR is the ratio of the received signal power to the noise power, and it is typically expressed in decibels (dB). The higher the SNR value, the better the quality of the received signal. However, in practice, the SNR can fluctuate due to various factors such as fading, interference, and noise. Therefore, the outage probability analysis is used to evaluate the probability of the SNR falling below a certain threshold. The analysis involves modeling the wireless channel and computing the probability of the SNR falling below the threshold for different values of the threshold and different channel conditions. This analysis can help in designing and optimizing wireless communication systems by providing insights into the trade-offs between system parameters such as transmit power, modulation scheme, and channel bandwidth. Overall, outage probability versus SNR analysis is a useful tool for evaluating the performance of wireless communication systems in terms of reliability and can help in making informed decisions about system design and optimization.

4.3.1. Power Splitting Ratio and Time fraction for Energy Harvesting versus Outage Probability Analysis

Figure 4.3 shows a 3D plot that shows the outage probability as a function of the power splitting ratio (rho) and time fraction for energy harvesting (alpha), for three transmission schemes: conventional OMA, non-cooperative NOMA, and cooperative NOMA.

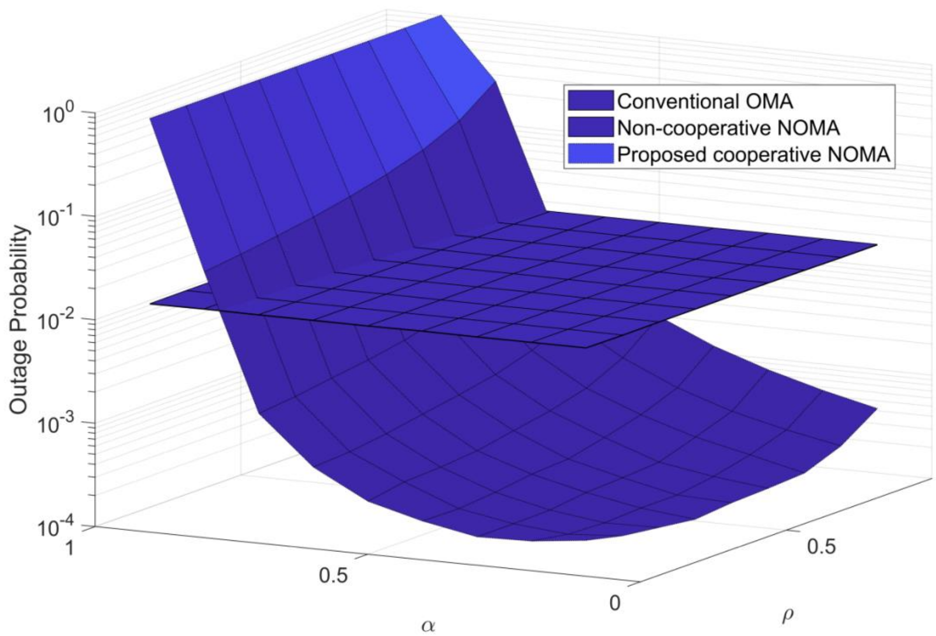


Figure 4. 3 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 256 QAM over Rayleigh fading channel

The x- axis represents the power splitting ratio (rho), the y-axis represents the time fraction for energy harvesting (alpha), and the z-axis represents the outage probability of three different communication schemes: conventional NOMA, non-cooperative NOMA and proposed cooperative NOMA. The power splitting ratio in wireless communication system is a parameter that determines how the received signal power from the transmitter is split between two different paths at the receiver. The power splitting ratio is typically a design parameter that is optimized to achieve a trade-off between energy harvesting and signal decoding performance. For example, if the power splitting ratio is 0.5, half of the received signal power is used for energy harvesting, and the other half is used for signal decoding.

The time fraction for energy harvesting is a parameter that determines the amount of time during which the receiver harvests energy form the received signal. In wireless communication systems, the received signal power can be used to charge a battery or capacitor at the receiver to power it or other devices. However, the receiver needs to allocate some time to harvest energy, which reduces the time available for signal decoding and transmission. For example, if the time fraction for energy harvesting is 0.5, half of the available time is used for energy harvesting and the other half is used for signal decoding and transmission. It is a design parameter that is optimized to achieve a trade-off between energy harvesting and signal decoding/transmission performance.

The surface plot shows that the outage probability decreases as the power splitting ratio (rho) increases, indicating that the increasing the fraction of power allocated for energy harvesting improves the performance of the system. Similarly the outage probability decreases as the time fraction of energy harvesting (alpha) increases, indicating that increasing the time fraction for energy harvesting improves the performance of the system.

Figure 4.1 show that cooperative NOMA outperforms conventional OMA and non-cooperative NOMA in terms of outage probability. This is because cooperative NOMA utilizes the combined power of the users to improve the overall system performance, while conventional OMA and non-cooperative NOMA relay on individual users to transmit their signals. The performance gain of cooperative NOMA is more pronounced when the power splitting ratio (rho) is small and the time fraction of energy harvesting (alpha) is large

4.3.2. Signal to Noise Ratio versus Outage Probability over Rayleigh Fading Channel

A Rayleigh fading channel is a common model used to describe the effects of signal propagation in wireless communication systems. In this model, the transmitted signal encounters multiple reflected paths from the environment, each with a different phase and amplitude. The resulting signal at the receiver is the sum of all these paths, which can interfere constructively or destructively, leading to fluctuations in signal strength.

In a Rayleigh fading channel, the amplitude and phase of the reflected paths are assumed to be independent and identically distributed random variables with a Rayleigh distribution. This distribution is a good approximation for the amplitude of the signal when there are many random reflections, such as in a large opens area or in the presence of many scatters. The Rayleigh fading model is commonly used in the design and analysis of wireless communication systems, as it provides a simple and tractable way to model the effects of multipath propagation and fading on the transmitted signal. By understanding the characteristics of the Rayleigh fading channel, communication system designers can optimize their system parameters to improve performance, such as by using error correction coding, diversity techniques, or adaptive modulation and coding schemes.

The main parameters used to simulate figure 4.4 is the number of QAM order and the channel model. It is simulated using QAM order 4 over Rayleigh fading channel model. QAM, or Quadrature Amplitude Modulation, is a modulation scheme that is used to transmit digital data over a carrier signal. The main function of QAM is to increase the amount of data that can be transmitted over a limited bandwidth, by encoding the digital data as variations in the amplitude and phase of the carrier signal. In QAM, the amplitude and phase of the carrier signal are modulated by two separate digital data streams, which are usually referred to as the in-phase (I) and quadrature (Q) components. By varying the amplitude and phase of the carrier signal, QAM can transmit multiple bits of data per symbol, enabling higher data rates and greater spectral efficiency than other modulation schemes.

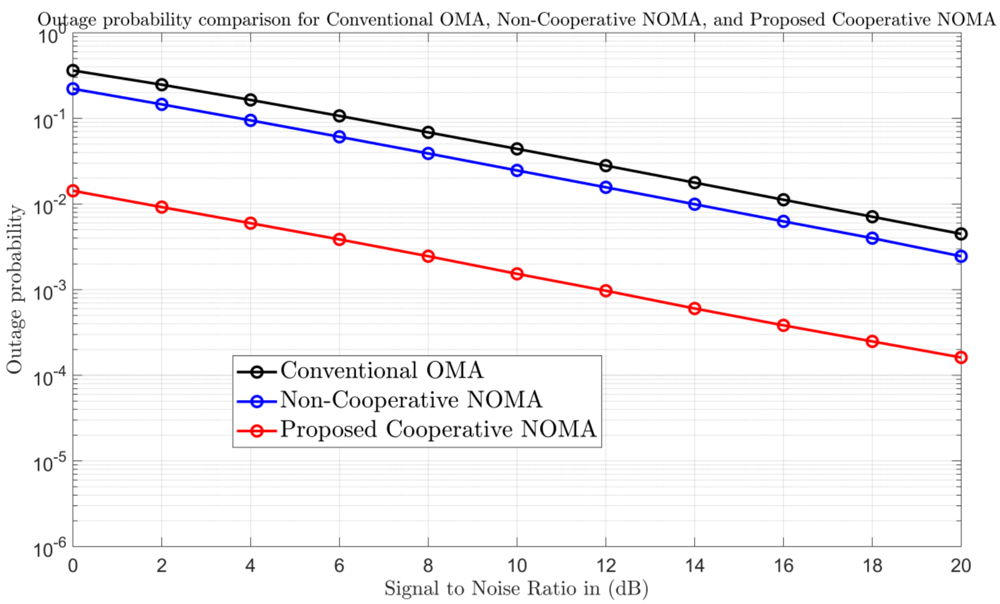


Figure 4. 4 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 4 QAM over Rayleigh fading channel

Figure 4.4 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 4-QAM over Rayleigh fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA is 0.0044768, 0.002454, and 0.0001616 respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 4-QAM over Rayleigh fading channel it has 93.41% improvement.

From the Figure 4.4 it is observed that Cooperative NOMA has the least outage probability value 0.0001616 compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 4-QAM over Rayleigh fading channel decreases.

Based on the Figure 4.4, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

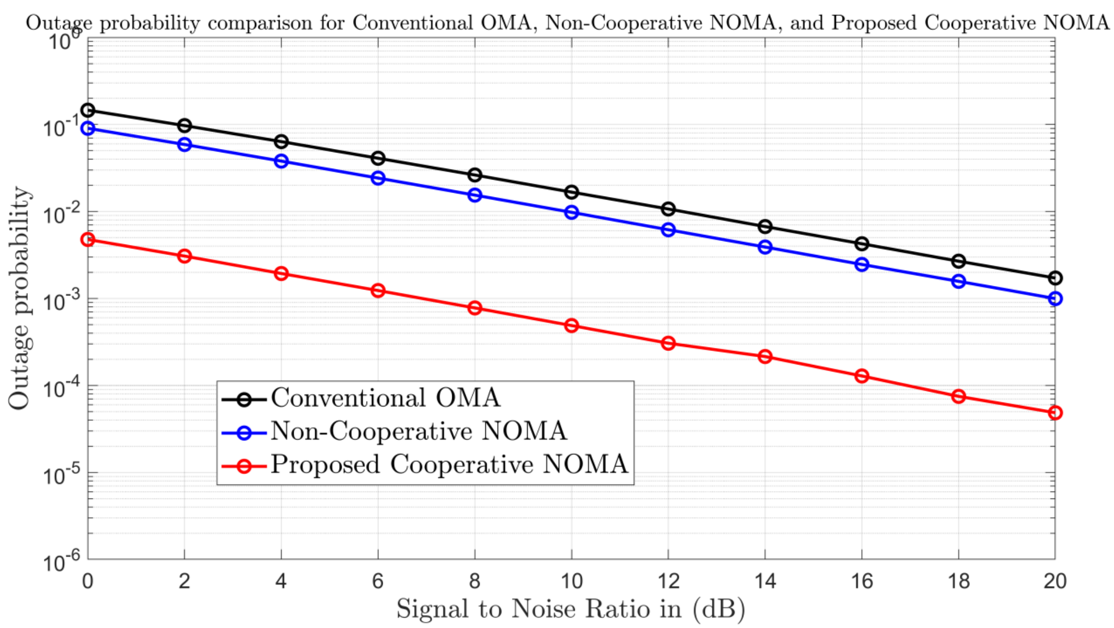


Figure 4. 5 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 16 QAM over Rayleigh fading channel

Figure 4.5 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 16-QAM over Rayleigh fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed

Cooperative NOMA is 0.001717, 0.000997, and 4.8 x 10^{-5} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 16-QAM over Rayleigh fading channel for this specific case it has 95.19% improvement.

From the Figure 4.5 it is observed that Cooperative NOMA has the least outage probability value 4.8 x 10^{-5} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 16-QAM over Rayleigh fading channel decreases.

Based on the Figure 4.5, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

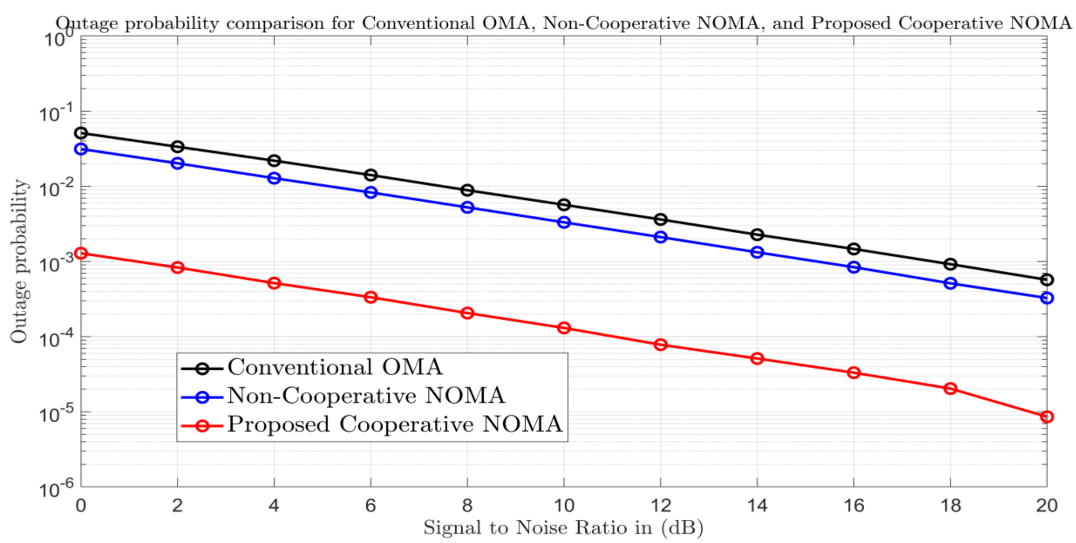


Figure 4. 6 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 64 QAM over Rayleigh fading channel

Figure 4.6 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 64-QAM over Rayleigh fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB.

The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA is 0.000571, 0.0003266, and 8.6 x 10^{-6} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 64-QAM over Rayleigh fading channel for this specific case it has 97.37% improvement.

From the Figure 4.6 it is observed that Cooperative NOMA has the least outage probability value 8.6 x 10^{-6} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 64-QAM over Rayleigh fading channel decreases.

Based on the Figure 4.6, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

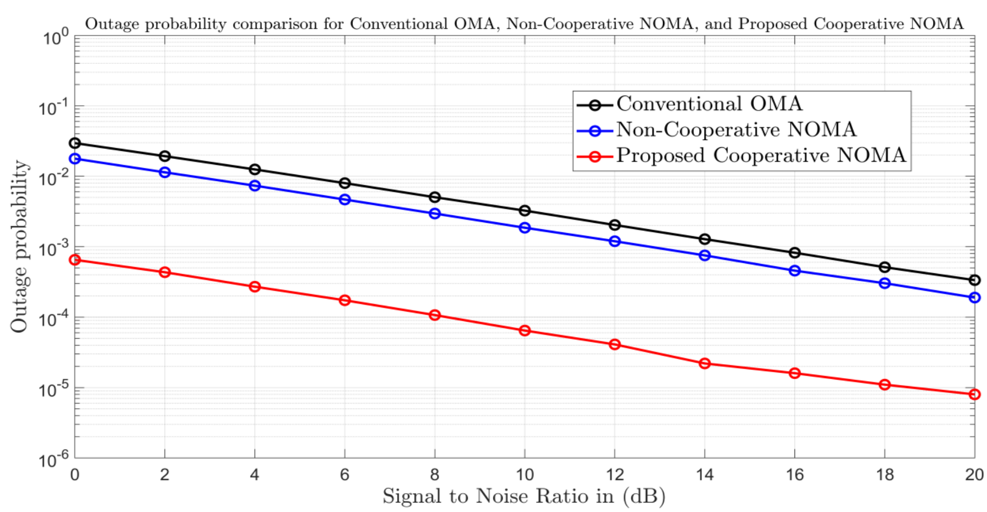


Figure 4. 7 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 128 QAM over Rayleigh fading channel

Figure 4.7 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 128-QAM over Rayleigh fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA is 0.000335, 0.0001895, and 8 x 10^{-6} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 128-QAM over Rayleigh fading channel for this specific case it has 95.78% improvement.

From the Figure 4.7 it is observed that Cooperative NOMA has the least outage probability value 8 x 10^{-6} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 128-QAM over Rayleigh fading channel decreases.

Based on the Figure 4.7, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

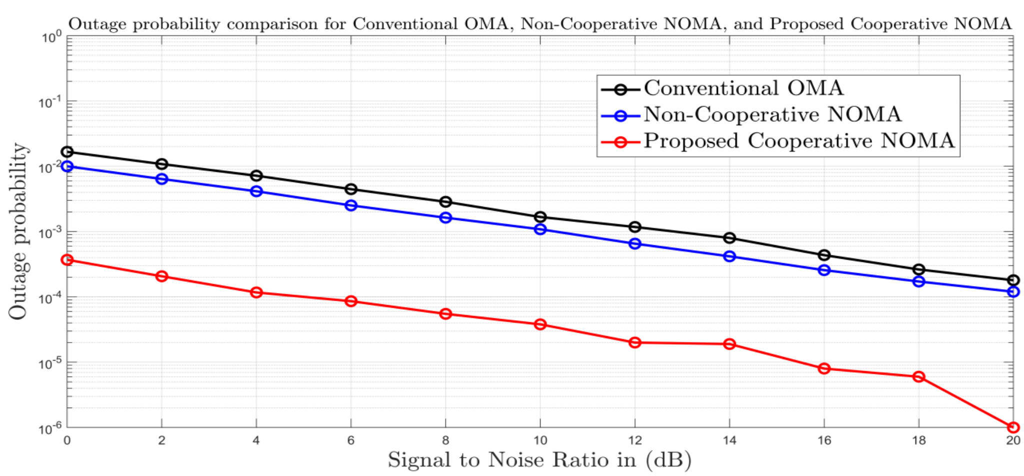


Figure 4. 8 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 256 QAM over Rayleigh fading channel

Figure 4.8 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 256-QAM over Rayleigh fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA is 1.8×10^{-4}, 1.2×10^{-4}, and 1×10^{-6} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 256-QAM over Rayleigh fading channel for this specific case it has 99.17% improvement.

From the Figure 4.8 it is observed that Cooperative NOMA has the least outage probability value 1×10^{-6} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 256-QAM over Rayleigh fading channel decreases.

Table 4. 2 Numerical Analysis of Conventional OMA, Non Cooperative NOMA, and Proposed Cooperative NOMA over Rayleigh fading channel under different M-QAM modulation

Multiple Access Schemes	**M-QAM Modulation**		**SNR=12dB**	**SNR=16dB**	**SNR=20dB**
Conventional OMA	4-QAM	Outage Probability	0.0280688	0.0112156	0.0044768
	16-QAM		0.010678	0.0042542	0.001717
	64-QAM		0.003625	0.0014674	0.000571
	128-QAM		0.0020325	0.0008205	0.000335
	256-QAM		0.001176	4.36×10^{-4}	1.8×10^{-4}
Non -Cooperative NOMA	4-QAM		0.015673	0.0062716	0.002454
	16-QAM		0.006166	0.0024604	0.000997
	64-QAM		0.0021122	0.0008406	0.0003266
	128-QAM		0.001195	0.000457	0.0001895
	256-QAM		6.53×10^{-4}	2.57×10^{-4}	1.2×10^{-4}
Proposed Cooperative NOMA	4-QAM		0.0009716	0.0003832	0.0001616
	16-QAM		0.000306	0.0001286	0.000048
	64-QAM		7.82×10^{-5}	3.32×10^{-5}	8.6×10^{-6}
	128-QAM		4.1×10^{-5}	1.6×10^{-5}	8×10^{-6}
	256-QAM		2×10^{-5}	8×10^{-6}	1×10^{-6}

Based on the Figure 4.8, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

Table 4.2 shows numerical analysis of Conventional OMA, Non Cooperative NOMA, and Proposed Cooperative NOMA over Nakagami-m fading channel under different M-QAM modulation. It shows the outage probability for 4-QAM, 16-QAM, 64-QAM, 128-QAM, and 256-QAM at signal to noise ratio of 12dB, 16dB, and 20dB. The signal to noise ratio values of 12dB, 16dB, and 20dB are chosen randomly to demonstrate the performance of Conventional OMA, Non Cooperative NOMA, and Proposed Cooperative NOMA over Nakagami-m fading channel.

4.3.3. Signal to Noise Ratio versus Outage Probability over Nakagami-m Fading Channel

The Nakagami-m fading channel is another commonly used model for wireless communication systems, similar to the Rayleigh fading model. However, in the Nakagami-m model, the amplitude of the reflected paths is assumed to follow a Nakagami distribution, which is a generalization of the Rayleigh distribution. The Nakagami distribution has two parameters: the shape parameter (m) and the scale parameter (ω). The shape parameter determines the shape of the distribution, with larger values of m indicating less severe fading and a more Gaussian-like distribution. The scale parameter determines the average received signal power. The Nakagami-m model is often used to represent wireless channels that experience a moderate to strong line-of-sight component, such as in indoor environments or in urban areas with tall buildings. In these scenarios, the received signal strength may be less affected by multipath reflections and more influenced by the direct path between the transmitter and receiver.

One advantage of the Nakagami-m model over the Rayleigh fading model is that it can better capture the effects of the line-of-sight component on the received signal. Moreover, the Nakagami-m model provides more flexibility in modeling different channel conditions, as the value of m can be adjusted to match the characteristics of the specific wireless channel being modeled. In practice, communication system designers may use both the Rayleigh and

Nakagami-m models to analyze and optimize the performance of their wireless systems, depending on the specific channel conditions and application requirements.

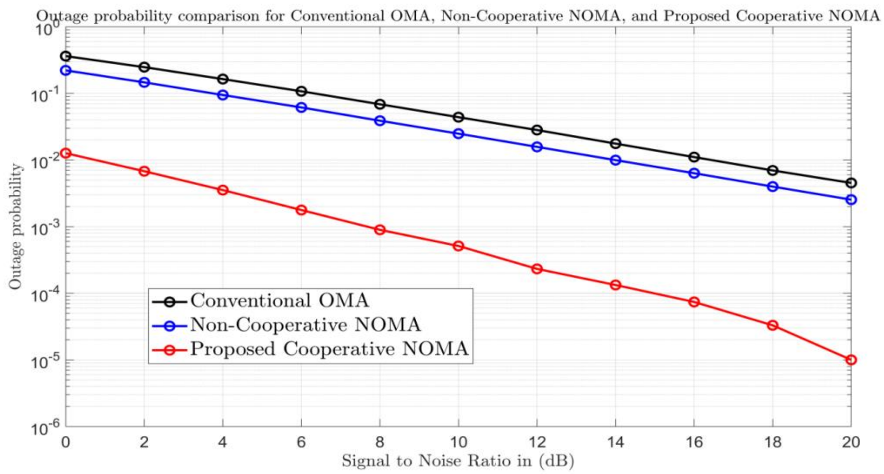


Figure 4. 9 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 4 QAM over Nakagami-m fading channel

Figure 4.9 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 4-QAM over Nakagami-m fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA is 0.004523, 0.002538, and 1 x 10^{-5} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 256-QAM over Nakagami-m fading channel for this specific cases it has 99.6% improvement.

From the Figure 4.9 it is observed that Cooperative NOMA has the least outage probability value 1 x 10^{-5} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 4 QAM over Nakagami-m fading channel decreases.

Based on the Figure 4.9, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

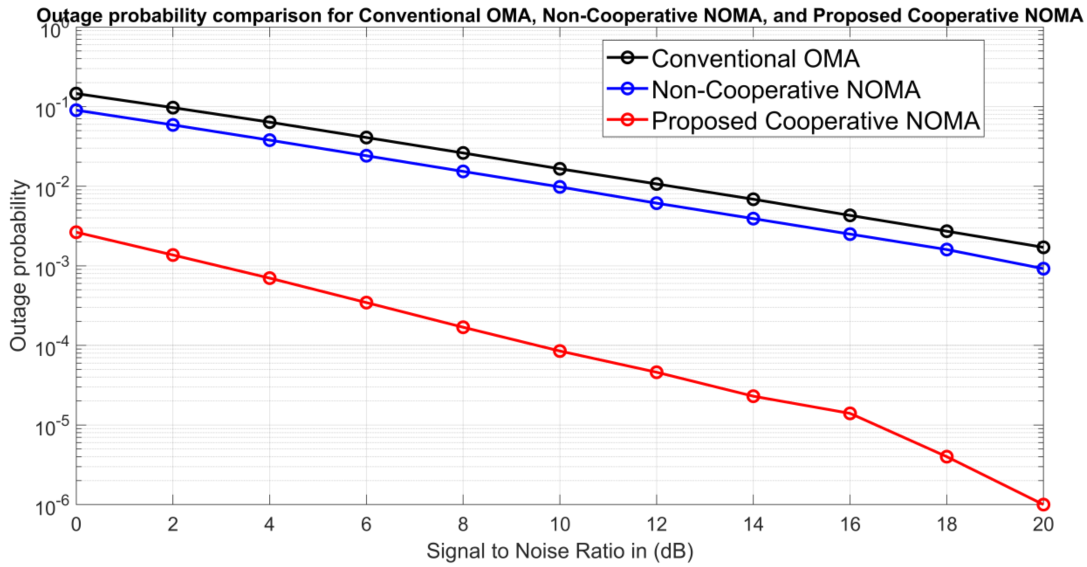


Figure 4. 10 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 16 QAM over Nakagami-m fading channel

Figure 4.10 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 16-QAM over Nakagami-m fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA is 0.001706, 0.00092, and 1×10^{-6} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 16-QAM over Nakagami-m fading channel for this specific cases it has 98.9% improvement.

From the Figure 4.10 it is observed that Cooperative NOMA has the least outage probability value 1×10^{-6} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 16-QAM over Nakagami-m fading channel decreases.

Based on the Figure 4.10, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

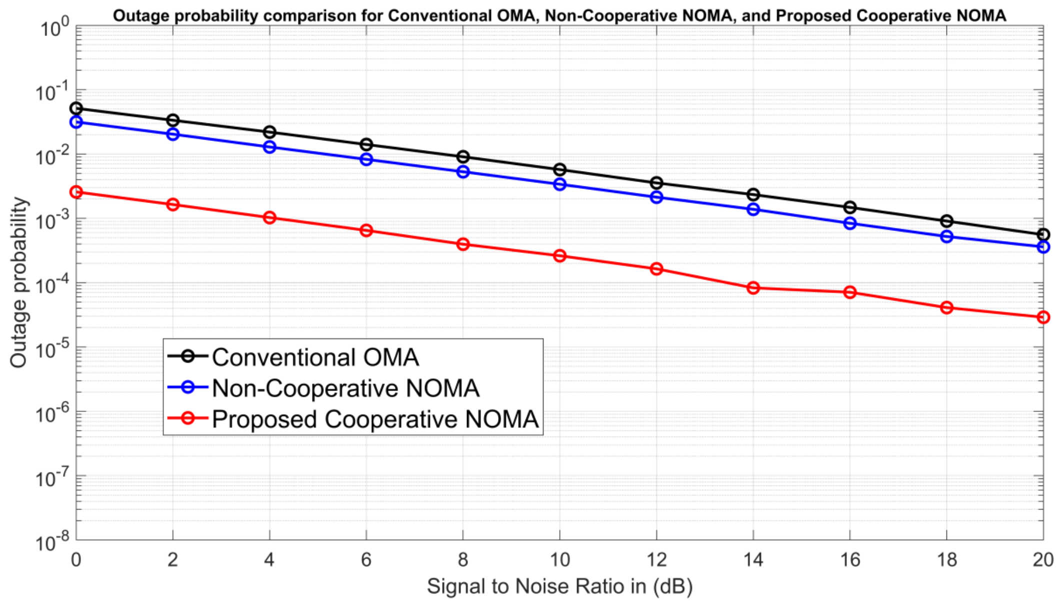


Figure 4. 11 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 64 QAM over Nakagami-m fading channel

Figure 4.11 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 64-QAM over Nakagami-m fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA is 0.000557, 0.00036, and 2.9 x 10^{-5} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 64-QAM over Nakagami-m fading channel for this specific cases it has 91.94% improvement.

From the Figure 4.11 it is observed that Cooperative NOMA has the least outage probability value 2.9 x 10^{-5} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 16-QAM over Nakagami-m fading channel decreases.

Based on the Figure 4.11, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

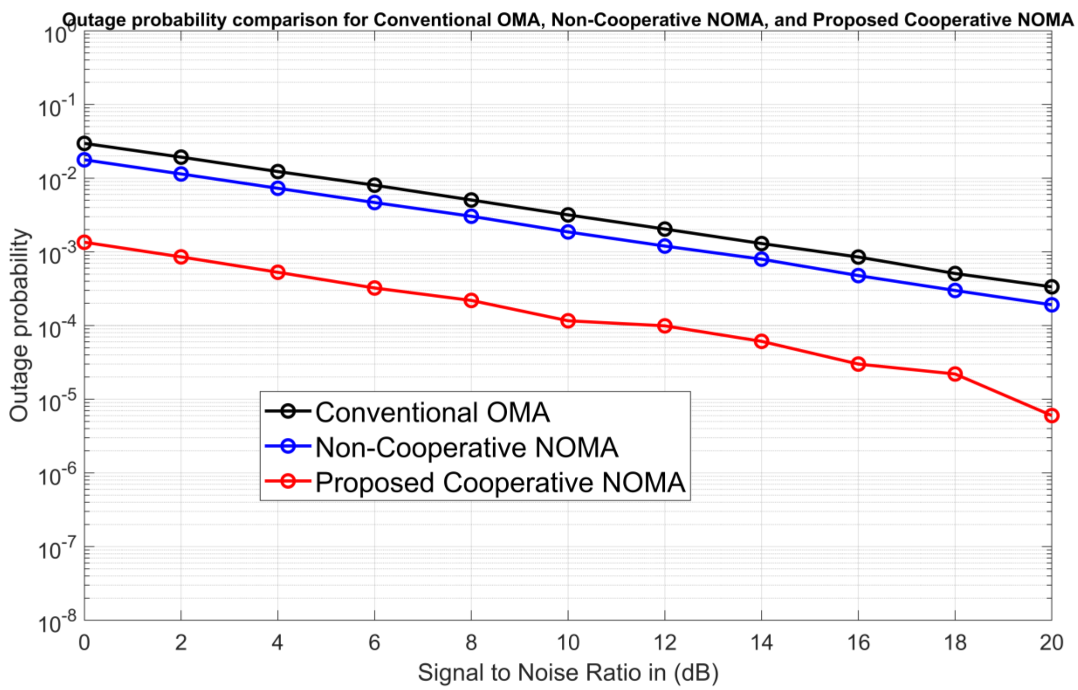


Figure 4. 12 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 128 QAM over Nakagami-m fading channel

Figure 4.12 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 128-QAM over Nakagami-m fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA is 0.000335, 0.000191, and 6 x 10^{-6} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 128-QAM over Nakagami-m fading channel for this specific cases it has 96.85% improvement.

From the Figure 4.12 it is observed that Cooperative NOMA has the least outage probability value 6 x 10^{-6} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 128-QAM over Nakagami-m fading channel decreases.

Based on the Figure 4.12, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

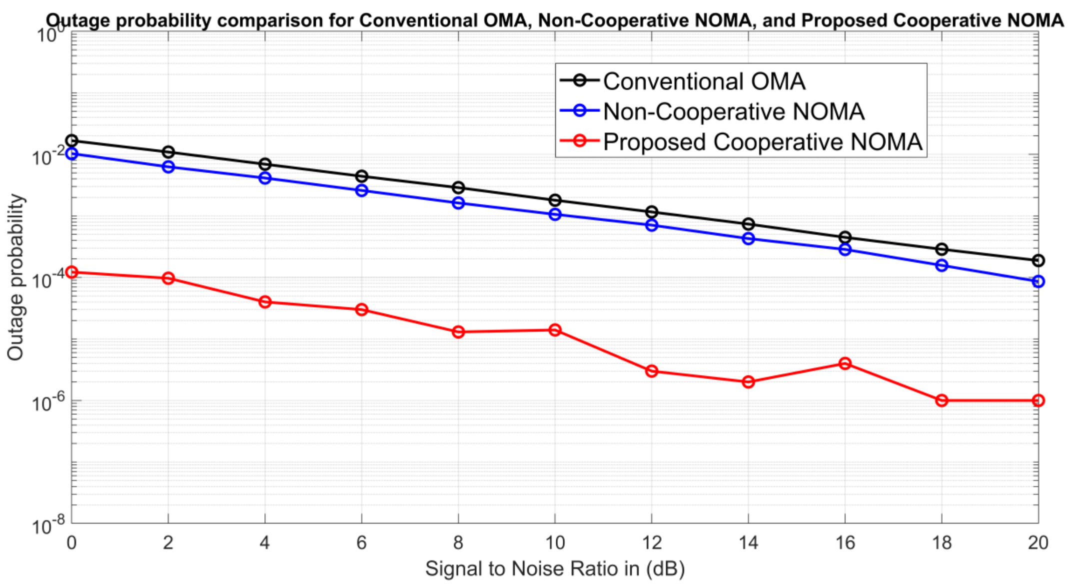


Figure 4. 13 SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 256 QAM over Nakagami-m fading channel

Figure 4.13 shows SNR versus Outage Probability of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA simulated using 256-QAM over Nakagami-m fading channel model. To see the performance of the system, consider the outage probability value for SNR value at 20dB. The outage probability value of Conventional OMA, Non cooperative NOMA and Proposed

Cooperative NOMA is 0.000188, 8.6 x 10^{-5}, and 1 x 10^{-6} respectively. When we compare the outage probability value of Non-Cooperative NOMA with Proposed Cooperative NOMA for 256-QAM over Nakagami-m fading channel for this specific cases it has 98.83% improvement.

From the Figure 4.13 it is observed that Cooperative NOMA has the least outage probability value 1 x 10^{-6} compared to Conventional OMA and Non-Cooperative NOMA. And also, it clearly shows that as the number of signal to noise ratio increases, the outage probability value of conventional OMA, Non cooperative NOMA and Proposed Cooperative NOMA for 256-QAM over Nakagami-m fading channel decreases.

Table 4. 3 Numerical Analysis of Conventional OMA, Non Cooperative NOMA, and Proposed Cooperative NOMA over Nakagami-m fading channel under different M-QAM modulation

Multiple Access Schemes	**M-QAM Modulation**		**SNR=12dB**	**SNR=16dB**	**SNR=20dB**
Conventional OMA	4-QAM	Outage Probability	0.028168	0.011055	0.004523
	16-QAM		0.010673	0.004296	0.001706
	64-QAM		0.003548	0.001479	0.000557
	128-QAM		0.002037	0.00085	0.000335
	256-QAM		0.001159	0.000448	0.000188
Non -Cooperative NOMA	4-QAM		0.015741	0.006334	0.002538
	16-QAM		0.006118	0.002501	0.00092
	64-QAM		0.002132	0.000838	0.00036
	128-QAM		0.001197	0.000476	0.000191
	256-QAM		0.000708	0.000285	8.6 x 10^{-5}
Proposed Cooperative NOMA	4-QAM		0.000232	7.4 x 10^{-5}	1 x 10^{-5}
	16-QAM		4.6 x 10^{-5}	1.4 x 10^{-5}	1 x 10^{-6}
	64-QAM		0.000164	7.1 x 10^{-5}	2.9 x 10^{-5}
	128-QAM		9.9 x 10^{-5}	3 x 10^{-5}	6 x 10^{-6}
	256-QAM		3 x 10^{-6}	4 x 10^{-6}	1 x 10^{-6}

Based on the Figure 4.13, it appears that the proposed cooperative NOMA outperforms Non-Cooperative NOMA and conventional OMA in terms of outage probability. This can be seen from the fact that the red curve (Proposed Cooperative NOMA) is consistently below the blue curve (Non-Cooperative NOMA) and black curve (Conventional OMA) for all values of signal to noise ratio. The proposed Cooperative NOMA achieves better performance by exploiting the cooperation between users to improve the received signal quality. In contrast, Non-Cooperative NOMA treats each user as an independent entity and does not utilize any cooperation between users.

Table 4.3 shows numerical analysis of Conventional OMA, Non Cooperative NOMA, and Proposed Cooperative NOMA over Nakagami-m fading channel under different M-QAM modulation. It shows the outage probability for 4-QAM, 16-QAM, 64-QAM, 128-QAM, and 256-QAM at signal to noise ratio of 12dB, 16dB, and 20dB. The signal to noise ratio values of 12dB, 16dB, and 20dB are chosen randomly to demonstrate the performance of Conventional OMA, Non Cooperative NOMA, and Proposed Cooperative NOMA over Nakagami-m fading channel.

4.4. Average Achievable Rate Analysis

In vehicular communication, the distance between vehicles plays a crucial role in determining the achievable rate of communication. As the distance between two vehicles increases, the signal power decreases, and the noise level increases. This results in a decrease in the signal-to-noise ratio (SNR), which in turn reduces the achievable rate of communication. The relationship between the distance between vehicles and the achievable rate of communication can be analyzed using the average achievable rate analysis. By modeling the communication channel between two vehicles as a noisy channel, the average achievable rate can be calculated as a function of the distance between the vehicles.

In general, as the distance between vehicles increases, the achievable rate of communication decreases. However, this relationship depends on various factors, such as the transmission power, modulation scheme, and coding rate used in the communication system. For example, if a high transmission power is used, the achievable rate may remain relatively high even at larger distances between vehicles. To optimize the performance of vehicular communication systems, engineers can use average achievable rate analysis to determine the optimal transmission power, modulation scheme, and coding rate for a given distance between vehicles. This can help to maximize the achievable rate of communication while ensuring sufficient reliability and error correction capability.

Overall, average achievable rate analysis is a valuable tool for analyzing and optimizing the performance of vehicular communication systems, and the distance between vehicles is a critical factor that must be taken into account.

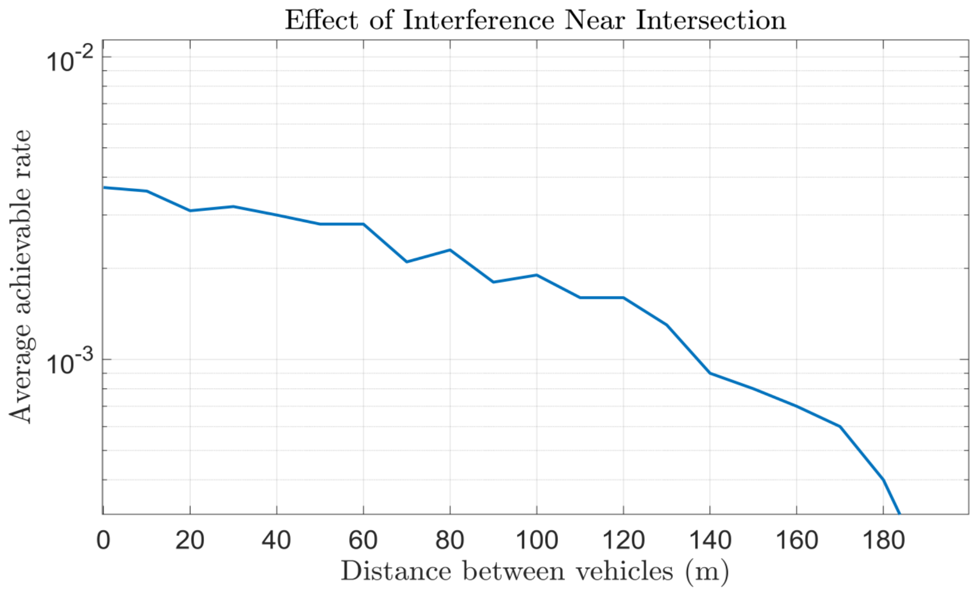


Figure 4. 14 Distance between Vehicles versus Average Achievable Rate

The graph on figure 4.14 shows the effect of interference in vehicular communication systems when vehicles are near an intersection, in terms of the distance between the vehicles and the average achievable rate. The x-axis represents the distance between the vehicles in meters, and the y-axis represents the average achievable rate in logarithmic scale. The graph shows that as the distance between the vehicles decreases (i.e., the vehicles are closer to the intersection), the average achievable rate decreases due to the high interference probability. This is because the interference probability is higher when the vehicles are near the intersection, as shown by the code where the interference probability is set to a high value when the distance between the vehicles is less than or equal to the distance between the vehicles.

The graph also shows that the average achievable rate decreases exponentially with the distance between the vehicles, which is expected due to the logarithmic scale of the y-axis. This means that even small changes in the distance between the vehicles can have a significant impact on the average achievable rate. Overall, the graph demonstrates the importance of considering the effect of interference in vehicular communication systems, especially when vehicles are near intersections, and highlights the need for effective interference mitigation techniques to improve the communication performance.

CONCLUSION AND RECOMENDATION

Conclusion

The vehicular network is one of the most promising technologies for intelligent transportation system (ITS). And intelligent transportation system has been attracting much attention because of the various applications for vehicles, passengers, and pedestrians. A secure and efficient Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure communications are the key to support road safety and traffic efficiency applications in ITS.

The services and applications in vehicular communication can mainly be classified into two types. Safety services are the first which require an extremely low latency, such as the vehicle collision warning, obstacle detection and driving assistances. The other is the infotainment services which prefer link reliability to the latency, such as file transmissions, social entertainments, and online services. Vehicular communications offer several applications regarding accident prevention, such as sending safety messages that alert vehicles about accidents happening in their surroundings. However these applications require high bandwidth and high spectral efficiency to insure high reliability and low latency communications. Due to this reason different researchers have been proposed conventional OMA, non-cooperative NOMA and cooperative NOMA multiple access schemes to optimize resource utilization and reduce interference.

In this study the performance of vehicular communication improved using cooperative transmission on NOMA system. In order to test the performance the comparison is done with conventional OMA and Non-Cooperative NOMA. The comparison of Conventional OMA, Non Cooperative NOMA, and Proposed Cooperative NOMA is simulated under Rayleigh and Nakagami-m fading channel for M-QAM (4-QAM, 16-QAM, 64-QAM, 128-QAM, and 256-QAM) modulation order. The analysis is carried out based on outage probability, bit error rate.

The cooperative NOMA is proposed to improve the performance of vehicular communication. The performances of Conventional OMA, Non-cooperative NOMA and Proposed Cooperative NOMA are analyzed using the performance metrics namely: Bit Error Rate, Outage Probability, and Average Achievable Rate. Simulation result shows that the performance of proposed Cooperative NOMA systems outperforms over Conventional OMA and Non-cooperative NOMA in Bit Error Rate, Outage Probability, and Average Achievable Rate analysis. Outage probability

Analysis shows that the performance of vehicular communication improved by 96% by using cooperative transmission in NOMA system.

Recommendation

It is known that safety services such as the vehicle collision warning, obstacle detection and driving assistances require an extremely low latency communication. And also, infotainment services prefer link reliability to the latency, such as file transmissions, social entertainments, and online services. Vehicular communications offer several applications regarding accident prevention, such as sending safety messages that alert vehicles about accidents happening in their surroundings. However these applications require high bandwidth and high spectral efficiency to insure high reliability and low latency communications. Due to this reason different researchers have been proposed conventional OMA, non-cooperative NOMA and cooperative NOMA multiple access schemes to optimize resource utilization and reduce interference. According to this thesis result proposed cooperative NOMA system outperforms conventional OMA and Non Cooperative NOMA system by around 96% outage probability improvement. The proposed Cooperative NOMA system is the best system to vehicular communication system especially at rod junction to avoid collision, to have low latency, and low interference.

Some points recommended for the future works are:

1. The analysis in this thesis is carried using Rayleigh and Nakagami-m fading channel. While the number of subscribers increases the system should support a very large traffic. Therefore it is recommended for future work to check the performance for higher order QAM like 512 - QAM and 1024-QAM.
2. The analysis in this thesis is carried using Rayleigh and Nakagami-m fading channel model. It is recommended for future work to check the performance of proposed cooperative NOMA over Racian fading channel.

RESEARCH FUND ACKNOWLEDGMENT

This research project is funded by Adama Science and Technology University under grant number ASTU/SM-R/401/22, Adama, Ethiopia

REFERENCES

Abuzainab, N., & Touati, C. (2015). *Multihop Relaying in Millimeter Wave Networks : A Proportionally Fair Cooperative Network Formation Game*.

Approach, E. E., Renzo, M. Di, Member, S., Lu, W., Member, S., & The, A. (2015). *Stochastic Geometry Modeling and Performance Evaluation of MIMO Cellular Networks Using the*. *63*(3), 977–996.

Belbase, K., Zhang, Z., Jiang, H., & Tellambura, C. (2018). Coverage Analysis of Millimeter Wave Decode-and-Forward Networks with Best Relay Selection. *IEEE Access*, *6*(c), 22670–22683. https://doi.org/10.1109/ACCESS.2018.2827026

Belmekki, B. E. Y., Hamza, A., & Escrig, B. (2020a). Performance analysis of cooperative NOMA at intersections for vehicular communications in the presence of interference. *Ad Hoc Networks*, *98*, 102036. https://doi.org/10.1016/j.adhoc.2019.102036

Belmekki, B. E. Y., Hamza, A., & Escrig, B. (2020b). Performance Evaluation of Adaptive Cooperative NOMA Protocol at Road Junctions. *IEEE Vehicular Technology Conference*, *2020-May*, 1–18. https://doi.org/10.1109/VTC2020-Spring48590.2020.9129022

Błaszczyszyn, B., & Mühlethaler, P. (2013). *Stochastic analysis of Aloha in vehicular ad hoc networks*. 95–106. https://doi.org/10.1007/s12243-012-0302-2

Cebe, M., & Akkaya, K. (2017). *Utilizing Advanced Metering Infrastructure to Build a Public Key Infrastructure for Electric Vehicles*. 91–98.

Characterization, I., Networks, G. D., Lattices, O., Lattices, T., Noise, S., Distribution, I., Behavior, E., Control, P., Communication, S., Cancellation, I., & Correlation, I. (2009). *Interference in Large Wireless Networks By Martin Haenggi and Radha Krishna Ganti* (Vol. 3, Issue 2). https://doi.org/10.1561/1300000015

Cheng, H. T., Shan, H., & Zhuang, W. (2011). Infotainment and road safety service support in vehicular networking: From a communication perspective. *Mechanical Systems and Signal Processing*, *25*(6), 2020–2038. https://doi.org/10.1016/j.ymssp.2010.11.009

Choi, C. (2018). *An Analytical Framework for Coverage in Cellular Networks Leveraging Vehicles*. *6778*(c), 1–15. https://doi.org/10.1109/TCOMM.2018.2835456

Choi, J., Va, V., González-Prelcic, N., Daniels, R., Bhat, C. R., & Heath, R. W. (2016). Millimeter-Wave Vehicular Communication to Support Massive Automotive Sensing. *IEEE*

Communications Magazine, *54*(12), 160–167. https://doi.org/10.1109/MCOM.2016.1600071CM

Deng, N., & Haenggi, M. (2017). The meta distribution of the SINR in mm-Wave D2D Networks. *2017 IEEE Global Communications Conference, GLOBECOM 2017 - Proceedings*, *2018-January*, 1–6. https://doi.org/10.1109/GLOCOM.2017.8254189

Ding, Z., Liu, Y., Choi, J., Sun, Q., Elkashlan, M., & Poor, H. V. (2017). *Application of Non-Orthogonal Multiple Access in LTE and 5G Networks*. *February*, 185–191.

Eddine, B., Belmekki, Y., & Hamza, A. (2019). Outage Analysis of Cooperative NOMA Using Maximum Ratio Combining at Intersections. *2019 International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, 1–6.

Eddine, B., Belmekki, Y., Hamza, A., & Escrig, B. (2019). Cooperative vehicular communications at intersections over Nakagami- m fading channels. *Vehicular Communications*, *19*, 100165. https://doi.org/10.1016/j.vehcom.2019.100165

Farooq, M. J., Member, S., & Elsawy, H. (2016). *A Stochastic Geometry Model for Multi-Hop Highway Vehicular Communication*. *15*(3), 2276–2291.

Hasna, M. O., Member, S., & Alouini, M. (2003). *Outage Probability of Multihop Transmission Over Nakagami Fading Channels*. *7*(5), 216–218.

Ikki, S. S., Ubaidulla, P., Aïssa, S., & Member, S. (2013). *Co-channel Interference : Performance Analysis and Optimal Energy Allocation*. *62*(2), 896–902.

Jeyaraj, J. P., & Haenggi, M. (2018). Nearest-Vehicle Communication in Regular Street Systems. *2018 IEEE 88th Vehicular Technology Conference (VTC-Fall)*, 1–5.

Jiang, C., Member, S., Zhang, H., & Han, Z. (2016). *Information Sharing Outage-Probability Analysis of Vehicular Networks*. *9545*(c), 1–13. https://doi.org/10.1109/TVT.2016.2614369

Kimura, T., & Saito, H. (2018). Theoretical interference analysis of inter-vehicular communication at intersection with power control. *Computer Communications*, *117*, 84–103. https://doi.org/10.1016/j.comcom.2017.10.001

Laneman, J. N., Tse, D. N. C., & Wornell, G. W. (2004). *Cooperative Diversity in Wireless Networks : Efficient Protocols and Outage Behavior*. *50*(12), 3062–3080.

Prabhu, G. S., Shankar, P. M., & Member, S. (2002). *Simulation of Flat Fading Using MATLAB for Classroom Instruction*. *45*(1), 19–25.

Rajab, S. (2019). Vehicle to Infrastructure Communications. In *Wireless Networks(United Kingdom)* (pp. 157–179). https://doi.org/10.1007/978-3-319-94785-3_6

Rajiwade, S. S. (2012). *Assessment Framework for Wireless V2V Communication-based ITS Applications*.

Renzo, M. Di, Graziosi, F., Santucci, F., & Member, S. (2010). *A Comprehensive Framework for Performance Analysis of Cooperative Multi-Hop Wireless Systems over Log-Normal Fading Channels*. *58*(2).

Renzo, M. Di, Member, S., Lu, W., Member, S., Guan, P., & Member, S. (2016). *The Intensity Matching Approach : A Tractable Stochastic Geometry Approximation to System-Level Analysis of Cellular Networks*. *1276*(c), 1–21. https://doi.org/10.1109/TWC.2016.2574852

Steinmetz, E., Wildemeersch, M., Quek, T. Q. S., & Wymeersch, H. (2015). *A Stochastic Geometry Model for Vehicular Communication near Intersections*.

Steinmetz, E., Wildemeersch, M., Quek, T. Q. S., & Wymeersch, H. (2021). Packet Reception Probabilities in Vehicular Communications Close to Intersections. *IEEE Transactions on Intelligent Transportation Systems*, *22*(5), 2823–2833. https://doi.org/10.1109/TITS.2020.2976564

Toulouse, E. (2008). *A Framework for Cooperative Communications at the System Level*. 653–658.

Vibin, V., Sivraj, P., & Vanitha, V. (2018). Implementation of In - Vehicle and V2V Communication with Basic Safety Message Format. *2018 International Conference on Inventive Research in Computing Applications (ICIRCA)*, *Icirca*, 637–642.

Yue, X., Liu, Y., & Kang, S. (2017). *Performance Analysis of NOMA with Fixed Gain Relaying over Nakagami- m Fading Channels*. *3536*(c), 1–10. https://doi.org/10.1109/ACCESS.2017.2677504

Zeng, Y., Yi, H., Xia, Z., Wang, S., Ai, B., Fei, D., Li, W., & Guan, K. (2020). *Measurement and Simulation for Vehicle-to-Infrastructure Communications at 3 . 5GHz for 5G*. *2020*.