A Project Report on

RECONFIGURABLE INTELLIGENT SURFACE AIDED RECEIVE QUADRATURE INDEX MODULATION FOR 6G NETWORKS

Submitted in partial fulfillment of the requirements for the award of the Degree of

Bachelor of Technology
in
Electronics and Communication Engineering

By

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ADITYA ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Affiliated to JNTUK Kakinada, Accredited by NAAC with ‘A’ Grade)

Aditya Nagar, ADB Road, Surampalem

2019 – 2023

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2019 – 2023

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

CERTIFICATE

This is to certify that the thesis entitled "**RECONFIGURABLE INTELLIGENT SURFACE AIDED RECEIVE QUADRATURE INDEX MODULATION FOR 6G NETWORKS"** is being submitted by

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in partial fulfillment of the requirements for the award of degree of **B. Tech** in Electronics and Communication Engineering from **Jawaharlal Nehru Technological University, Kakinada** is a record of bonafide work carried out by them at Aditya Engineering College.

The results embodied in this Project report have not been submitted to any other University or Institute for the award of any degree or diploma.

PROJECT GUIDE	**HEAD OF THE DEPARTMENT**
Dr. G. Vishnu Vardhan M.Tech., Ph.D	**Dr. N Radha M.Tech., Ph.D**
Associate Professor	**Professor**

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M2: Train on technology through collaborations

M3: Promote innovative research & development

M4: Involve industry institute interaction for societal needs

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Vision:

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M2: Promote cutting edge technologies to serve the needs of the society and industry through innovative research.

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N. Radha.

Head of the Department

Head of the Department
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Aditya Engineering College (A9)

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Department of Electronics & Communication Engineering

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PO 5	Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modelling, to complex engineering activities, with an understanding of the limitations.
PO 6	Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice.
PO 7	Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of, and need for sustainable development.
PO 8	Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.
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PO 10	Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
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PO 12	Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

N. Radha

Head of the Department

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Provide sustainable solutions in the field of Communication and Signal Processing

PSO2:

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PEO3:

Communicate effectively and demonstrate leadership qualities with professional ethics.

N. Radha
Head of the Department

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COURSE OUTCOMES PROJECT PART 1

Regulation: AR19	L	T	P	C
Course Code: 191EC7P04	0	0	4	2

CO1	Identify a real life / engineering problem
CO2	Perform extensive investigation with prior knowledge
CO3	Interpret problem formulation and solution through critical thinking
CO4	Develop the work plan, schedule and estimate the cost
CO5	Identify the resources required to initiate project work

PROJECT PART 2

Regulation: AR19	L	T	P	C
Course Code: 191EC8P05	0	0	14	7

CO6	Apply the domain knowledge to arrive at a framework to solve the problem
CO7	Design solution using research-based knowledge and modern tools and interpret the results
CO8	Assess the obtained solution in the context of engineering framework addressing the societal and environmental concerns adhering to professional ethics
CO9	Demonstrate communication skills effectively to work as a team, for guide interaction and presentations.
CO10	Prepare technical documentation/reports with effective written communication skills

CO-PO MAPPING

PROJECT PART-I 191EC7P04														
CO/PO	**PO1**	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**
CO1	2	3		2					2	2		1	3	1
CO2	2	2		3					2	2	1	1	3	1
CO3		3	2			2	3					1	3	1
CO4	1	1							2	2	3	1	3	1
CO5	1	1			2						3	1	3	1
PROJECT PART-II 191EC8P04														
CO/PO	**PO1**	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**	**PSO1**	**PSO2**
CO6	1	2	3	2	1				2	2	1	1	3	1
CO7	1	2	3		3	1		1	2	2	2	2	3	1
CO8	1	1	3	1	2	1		1	2	2	2	2	3	1
CO9	1	1	1	1				2	3	3	2	2	3	1
CO10	1	1	2	1	1			1	1	3	1	1	3	1

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Aditya Nagar, ADB Road, Surampalem

Department of Electronics & Communication Engineering

Academic Year: 2022-23 B. No.: B19

Project Title: **Reconfigurable Intelligent Surface aided Receive Quadrature Index Modulation for 6G networks**

Type of Project: **Design Oriented/Research Oriented**

Project Guide: Dr. G Vishnu Vardan

Project Team:

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ABSTRACT

One of the most critical aspects of enabling next-generation wireless technologies is developing an accurate and consistent channel model to be validated effectively with the help of real-world measurements. From this point of view, remarkable research has recently been conducted to model propagation channels involving the modification of the wireless propagation environment through the inclusion of reconfigurable intelligent surfaces (RIS). By aiding RIS with Receive Quadrature Index Modulation (RQIM), one of the Spatial Modulation technique using single antenna at transmitter side and selecting particular receiving antenna at receiver side by dividing RIS into two parts – In phase (I) and Quadrature (Q) which lead to low Signal to Noise Ratio(SNR), high bitrate and low Bit Error Rate (BER).

We can extend the concept of RIS-RQIM by replacing RQIM with other novel Spatial Modulation techniques to achieve better performance in terms of SNR, bitrate and BER and thereby further enhancing the spectrum and energy efficiency of next generation wireless systems.

Signature of the team members

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NOMENCLATURE

KPI	Key Performance Index
RIS	Reconfigurable Intelligent Surface
RQRM	Receive Quadrature Reflecting Modulation
ASM	Advanced Spatial Modulation
SM	Spatial Modulation
SSK	Space Shift Keying
NOMA	Non- Orthogonal Multiple Access
CNOMA	Cooperative Non- Orthogonal Multiple Access
MIMO	Multiple Input Multiple Output
BER	Bit Error Rate
SNR	Signal to Noise Ratio
ABS	Ambient Back Scattering
APM	Amplitude Phase Modulation
NG	Next- Generation
SE	Spectral Efficiency
EE	Energy Efficiency
CSI	Channel State Information
QoS	Quality of Service
QAM	Quadrature Amplitude Modulation
SISO	Single Input Single Output
MISO	Multiple Input Single Output
SIMO	Single Input Multiple Output
LTM	Long Term Evolution
AF	Amplify and Forward
BS	Base Station
EM	Electromagnetic
AP	Access Point
DRL	Deep Reinforcement Learning
HP	Hybrid Procoding
MU	Multiple User
MSE	Mean Squared Error
PS	Phase Shift
GP	Gradient Projection

RF	Radio Frequency
SEP	Symbolled Error Probability
FD	Fully Digital
IM	Index Modulation
AWGN	Additive White Gaussian Noise
4G	Fourth Generation
5G	Fifth Generation
6G	Sixth Generation

CHAPTER-1

INTRODUCTION

1.1 Motivation

5G and 6G are the next generations of wireless technology, and they have the potential to bring about significant changes in the way we use and interact with technology. Here are some of the reasons why people are motivated about 5G and 6G:

Faster Speeds: 5G and 6G promise to offer significantly faster data speeds than the current 4G networks. This means that you will be able to download large files, stream high-quality video, and use other bandwidth-intensive applications with ease.

Lower Latency: Latency is the time it takes for data to travel from one device to another. With 5G and 6G, latency will be significantly reduced, which means that communication between devices will be much faster and more responsive.

Greater Capacity: The increased bandwidth offered by 5G and 6G will allow more devices to connect to the network simultaneously. This means that there will be less congestion and more reliable connectivity [1].

Improved Reliability: 5G and 6G networks will be designed to be more resilient and reliable than previous generations. This will be especially important for critical applications such as healthcare and transportation.

New Use Cases: 5G and 6G will enable new use cases that were not possible with previous generations of wireless technology. For example, 5G will enable the development of autonomous vehicles and smart cities, while 6G will likely support applications such as holographic communication and advanced AI [2].

Overall, 5G and 6G have the potential to revolutionize the way we use and interact with technology, and this is why many people are excited about their development and implementation.

Reconfigurable Intelligent Surfaces (RIS), due to their ability to adjust the behavior of interacting electromagnetic (EM) waves through intelligent manipulation of the reflections phase shifts, RIS have shown promising merits at improving the spectral efficiency of wireless networks [3].

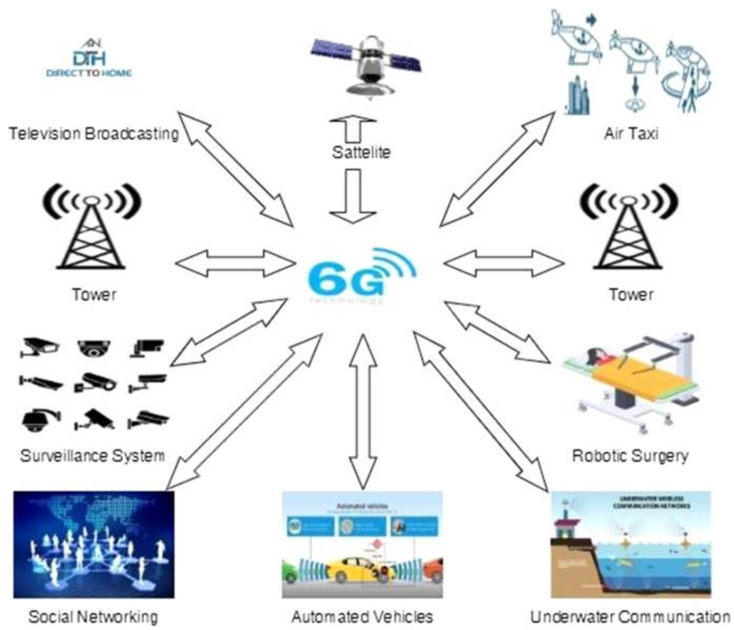


Fig.1.1 An overview on 6G technology

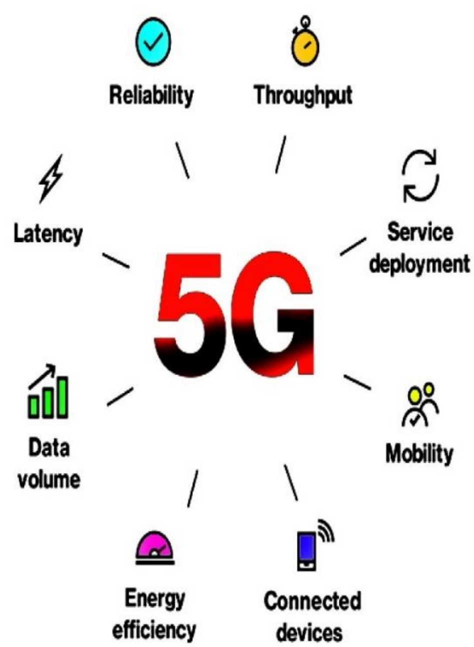


Fig.1.2 An overview on 5G technology

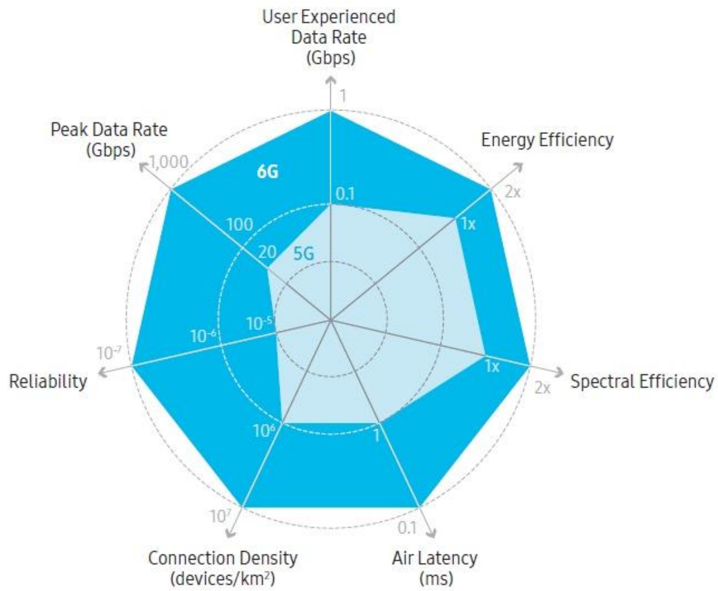


Fig.1.3 KPI for 5G vs 6G

1.2 Introduction of RIS

A reconfigurable intelligent surface (RIS) is a two-dimensional array of electromagnetic elements, such as antennas or reflectors, that can reflect and manipulate electromagnetic waves. RIS is also known as meta surfaces or intelligent reflecting surfaces. These surfaces can be used to enhance wireless communication systems, improve radar and sensing applications, and enable new applications in areas such as smart buildings, transportation, and healthcare [4].

The elements of the RIS can be controlled and reconfigured in real-time to reflect or scatter the incident electromagnetic waves in a specific direction, creating a desired radiation pattern. This allows for the manipulation of the propagation of electromagnetic waves, resulting in improved signal quality and reduced interference. Moreover, RIS can be used to create a virtual array antenna with improved gain and directivity without using physically large arrays.

RIS has the potential to revolutionize wireless communication systems by enabling high-speed and reliable communication even in challenging environments. Moreover, it can be integrated with existing wireless communication infrastructure, making it a cost-effective solution for improving wireless communication systems.

1.3 Spatial Modulation

Spatial modulation (SM) is a wireless communication technique that uses the spatial domain to transmit information. It is a form of multiple-input, multiple-output (MIMO) technology that exploits the spatial dimension of the wireless channel to transmit data.

In SM, instead of transmitting data on all the antennas simultaneously, only one antenna is used to transmit data at a time. The index of the transmitting antenna is used to carry information, resulting in a form of modulation. For example, if there are N antennas, then log2(N) bits can be transmitted using SM [5].

The advantages of SM include its simplicity and low complexity, as it does not require complex signal processing at the receiver. Moreover, it can provide high spectral efficiency and can overcome some of the limitations of conventional MIMO systems, such as high complexity and power consumption.

However, SM also has some limitations, such as its sensitivity to channel estimation errors and its susceptibility to interference and fading. Furthermore, it requires a large number of antennas to achieve high data rates, which may not be practical in some applications. Overall, SM is a promising technology that has the potential to improve the performance of wireless communication systems, especially in high-speed applications, where high spectral efficiency is critical.

1.4 Problem Statement

Bandwidth is one of the major factors which affects the transmission rate of the data. With the development of new services and continuous increase in the number of devices being used, the overall data rate is increased at a high steady rate. Different communication schemes such as media-based modulation, spatial scattering modulation, beam index modulation, RIS based spatial modulation have been developed. These schemes use the variations in the indices of the transmitted or received signals by utilizing the reconfigurable antennas. RQIM scheme provides a alternative dimension to transmit the information by choosing the indices of the corresponding systems building blocks [6].

1.5 Objectives and Scope

To propose a novel spectral efficient, energy efficient and reliable wireless communication system with aid of RIS and SM

To Evaluate the bit error rate (BER) performance of the proposed system with using extensive Monte Carlo simulations.

To compare the proposed system with other potential RIS benchmark systems in terms of BER performance.

1.6 Organization of the Project

The remaining part of the project is organized as follows:

Chapter 2	In this chapter, a detailed literature review of all the conventional methods is given along with their advantages and disadvantages for comparison.
Chapter 3	In this chapter, an introduction about wireless communication and the basic MIMO technology and Index modulation is discussed along with the related communication involved in it. The software used for simulating the results is MATLAB. Additionally, a brief idea regarding this MATLAB software is discussed here.
Chapter 4	In this chapter, the system model for the proposed RIS- RQIM at the receiver side scheme is discussed.
Chapter 5	In this chapter, the computer simulation results for the basic RIS, RIS-SSK, RIS- SM and the proposed RIS- RQIM scheme are presented. Additionally, the gain achieved by the proposed system with respect to the basic RIS, RIS- SSK and RIS- SM systems is shown.

Chapter 6 This chapter concludes the main idea of the proposed system and also addresses the direction for future work research problems.

CHAPTER 2
LITERATURE SUEVEY

2.1 RIS- SSK

Space shift keying (SSK) as a new modulation scheme, which is based on spatial modulation (SM) concepts. Fading is exploited for multiple-input multiple- output(MIMO) channels to provide better performance over conventional amplitude/phase modulation (APM) techniques. Reconfigurable intelligent surface (RIS)-assisted transmission and space shift keying (SSK) appear as promising candidates for future energy-efficient wireless systems [7].

The concept of index modulation (IM) that leverages upon the ON/OFF state of the transmission entities to convey information has created completely new dimensions for energy-efficient transmission. As a prominent member of IM, spatial modulation (SM) uses the transmit antennas of a multiple-input multiple-output (MIMO) system in an innovative fashion [8]. In SM, only a single transmit antenna is activated for each transmission of a constellation symbol, and the index of the active antenna is used to convey extra information bits. By limiting the active antenna to simply transmit an unmodulated sinusoidal carrier signal, SM evolves into space shift keying (SSK) that employs the index of the active antenna only for information transfer.

2.2 RIS-SM

In wireless communications, reconfigurable intelligent surfaces (RIS) are emerging as a promising technology that is made possible by the advent of software controlled metamaterial sheets for controlling the wireless channels dynamically. In future applications, IoT devices will have small sizes and limited power supply. To make these devices spectrally and energy efficient in accordance with the advanced 5G and 6G specifications, ambient backscattering (ABS) technique along with spatial modulation (SM) and space shift keying (SSK) for data transfer assisted with RIS [10].

The dynamic control of wireless channels is a trending field of research which has been made possible by the advent of metamaterial-based reconfigurable intelligent surfaces (RIS) [9]. Moreover, for future applications in 5G and beyond, the device size constraints and power supply issues also need to be resolved before RIS can be deployed at large scale.

RIS-assisted ambient backscattering (ABS) communication framework utilizing advanced spatial modulation (ASM) techniques for spectral-and energy-efficient communication. Here, ABS technique is leveraged for harnessing the power from ambient RF waves, while ASM techniques are deployed to ensure high spectral efficiencies by activating more than one but not the full set of antennas for transmission.

2.3 Extended Methods

2.3.1 MIMO transmission through RIS

Reconfigurable intelligent surface (RIS) is a new paradigm that has great potential to achieve cost-effective, energy-efficient information modulation for wireless transmission, by the ability to change the reflection coefficients of the unit cells of a programmable meta surface. Nevertheless, the electromagnetic responses of the RISs are usually only phase-adjustable, which considerably limits the achievable rate of RIS-based transmitters [11].

In conventional wireless transmitters, every RF chain has two independent baseband signals to modulate the carrier signal, i.e., the IQ components, thus realizing independent modulation of the amplitude and phase of the carrier signal. Therefore, QAM can be naturally achieved through the conventional wireless transmitters. However, QAM is hard to achieve using RIS-based transmitters.

2.3.2 NOMA RIS

Reconfigurable intelligent surfaces (RISs) constitute a promising performance enhancement for next-generation (NG) wireless networks in terms of enhancing both their spectral efficiency (SE) and energy efficiency (EE).

A system for serving paired power-domain non-orthogonal multiple access (NOMA) users by designing the passive beamforming weights at the RISs [12].

The demand for next-generation (NG) networks having high energy efficiency (EE) has been rapidly increasing. A variety of sophisticated wireless technologies have been proposed for NG networks, including massive multiple-input multiple-output (MIMO) and millimeter wave (mm Wave) communications. Recently, cost-efficient reconfigurable intelligent surfaces (RISs) have been proposed for cooperative NG networks. To enhance both the spectral efficiency (SE) and EE of NG networks, non-orthogonal multiple access (NOMA) has been proposed as a promising technique of opportunistically capitalizing on the users' specific channel state information (CSI) differences. NOMA networks are capable of serving multiple users at different quality-of-service (QoS) requirements in the same time/frequency/code resource block.

2.3.3 RIS assisted CNOMA Systems

RIS assisted cooperative non- orthogonal multiple access (CNOMA) systems. The total transmit power by jointly optimizing the active beamforming vectors, transmit-relaying power, and RIS phase shifts is minimized by assisting RIS with CNOMA systems.

As a promising technique for supporting massive connectivity and enhancing spectrum efficiency, non- orthogonal multiple access (NOMA) has also received a considerable attention [13]. To further improve the performance of NOMA systems, an appealing extension for NOMA systems, namely, cooperative NOMA systems, was proposed in the key idea of CNOMA is to rely on the NOMA-weak users acting as DF relays to assist the NOMA-weak users.

2.3.4 Paradigm Through Software-Controlled Meta Surfaces

Electromagnetic waves undergo multiple uncontrollable alterations as they propagate within a wireless environment. Free space path loss, signal absorption, as well as reflections, refractions and diffractions caused by physical objects within the environment highly affect the performance of wireless communications. Currently, such effects are intractable to account for and are treated as probabilistic factors. The key-enabler is the so-called HyperSurface tile, a novel class of planar meta-materials which can interact with impinging electromagnetic waves in a controlled manner. The HyperSurface can effectively re-engineer electromagnetic waves, including steering towards any desired direction, full absorption, polarization manipulation and more. Multiple tiles are employed to coat objects such as walls, furniture, overall, any objects in the indoor and outdoor environments. An external software service calculates and deploys the optimal interaction types per tile, to best fit the needs of communicating devices.

A HyperSurface which supports software descriptions of metasurface EM functions, allowing a programmer to customize, deploy or retract them on-demand via a programming interface with appropriate callbacks [14]. These callbacks have the following general form: outcome ← callback (action_type, parameters)

The action_type is an identifier denoting the intended function to be applied to the impinging waves, such as STEER or ABSORB. Each action type is associated to a set of valid parameters. For instance, STEER commands require:

i) an incident wave direction,

ii) an intended reflection direction, and

iii) the applicable wave frequency band. ABSORB commands require no incident or reflected wave direction parameters.

2.3.5 Beamforming design for multiuser transmission through RIS

The sum transmit power of the network is minimized by controlling the phase beamforming of the RIS and transmit power of the base station. This problem is posed as a joint optimization problem of transmit power and RIS control, whose goal is to minimize the sum transmit power under signal-to-interference-plus-noise ratio (SINR) constraints of the users.

It is urgent for the next-generation wireless network to support high spectral efficiency and massive connectivity. Due to the demand of high data rate and serving a massive number of users, energy consumption has become a challenging problem in the design of the future wireless network. Recently, reconfigurable intelligent surface (RIS)-

assisted wireless communication has been proposed as a potential solution for enhancing the energy efficiency of wireless networks. RIS is a new paradigm that can flexibly manipulate electromagnetic (EM) waves [15]. Researches of RIS-assisted wireless communications mainly follow into two aspects: RIS as a passive reflector and RIS as an active transceiver.

On one hand, RIS can serve as a passive reflector. An RIS is a meta-surface equipped with low-cost and passive elements that can be programmed to turn wireless channels into a partially deterministic space. In RIS-assisted wireless communication systems, a base station (BS) sends control signals to an RIS controller so as to optimize the properties of incident waves and improve the communication quality of users. The RIS acting as a reflector does not perform any decoding or digitalization operation. Hence, if properly deployed, the RIS promises much lower energy consumption than traditional amplify-and-forward (AF) relays.

2.3.6 RIS historical channel observation

RIS is a passive radio technique, which can intentionally tune the electromagnetic behavior of the wireless environment with meta-materials. Recently, IRS has been considered as a promising technique to enhance the quality-of-service of users with low power consumption and deployment cost. Specifically, most existing works investigate the joint optimization of the transmitter at the access point (AP) and the phase matrix of the IRS while assuming perfect channel state information (CSI) is available. In these works, the key design challenge is the nonconvex unit-modulus constraint on the reflection coefficients of the IRS elements [16]. By using similar mathematical tools for analog precoding problems in traditional massive multipleinput multiple-output systems, joint optimization algorithms have been developed for transmit power minimization problems energy efficiency problems, weighted sum-rate maximization problems , and secrecy rate maximization problems , in IRS-aided systems. Intelligent-reflecting surface (IRS)-assisted single-user multiple-input single-output downlink communication system, in which multiple IRSs are deployed to improve the propagation condition.

2.3.7 RIS assisted multiuser MISO systems

Recently, the reconfigurable intelligent surface (RIS), benefited from the breakthrough on the fabrication of programmable meta-material, has been speculated as one of the key enabling technologies for the future six generation (6G) wireless communication systems scaled up beyond massive multiple input multiple output (Massive-MIMO) technology to achieve smart radio environments [17]. Employed as reflecting arrays, RIS is able to assist MIMO transmissions without the need of radio frequency chains resulting in considerable reduction in power consumption. In this paper, we investigate the joint design of transmit beamforming matrix at the base station and the phase shift matrix at the RIS, by leveraging recent advances in deep reinforcement learning (DRL). We first develop a DRL based algorithm, in which the joint design is obtained through trial-and error interactions with the environment by observing predefined rewards, in the context of continuous state and action. Unlike the most reported works utilizing the alternating optimization techniques to alternatively obtain the transmit beamforming and phase shifts, the proposed DRL based algorithm obtains the joint design simultaneously as the output of the DRL neural network.

Recent years have witnessed the successful deployment of massive multiple input multiple output (Massive-MIMO) in the fifth generation (5G) wireless communication systems, as a promising approach to support massive number of users at high data rate, low latency and secure transmission simultaneously and efficiently. However, implementing a Massive MIMO base station (BS) is challenging, as high hardware cost, constrained physical size, and increased power consumption scaling up the conventional MIMO systems by many orders of magnitude, arise when the conventional large-scale antenna array is used at the BS.

2.3.8 RIS aided mmWave communication system

The hybrid precoding (HP) design for the reconfigurable intelligent surface (RIS) aided multi-user (MU) millimeter wave (mmWave) communication systems. Specifically, we aim to minimize the mean- squared error (MSE) between the received symbols and the transmitted symbols by jointly optimizing the analog-digital HP at the base station (BS) and the phase shifts (PSs) at the RIS, where the non-convex element-wise constant-modulus constraints for the analog precoding and the PSs are tackled by resorting to the gradient-projection (GP) method.

Millimeter-wave (mmWave) communication, with the capability of exploiting a large stretch of the underutilized spectrum, is a potential technology to meet the high data rate demand of current and future wireless networks [18]. While mmWave suffers from severe path loss, their small wavelength allows the deployment of a large-scale antenna array to provide the high array gain and improve the link quality. Nevertheless, unlike sub-6 GHz communications where fully-digital (FD) processing is employed, the prohibitive cost and power consumption of the hardware components in mmWave bands make the analog-digital hybrid processing a viable solution to reduce the number of power-hungry radio frequency (RF) chains at the mmWave base-station (BS).

2.3.9 Transmission through large intelligent surfaces

,The transmission through large intelligent surfaces (LIS) that intentionally modify the phases of incident waves to improve the signal quality at the receiver, is put forward as a promising candidate for future wireless communication systems and standards. For the considered LIS-assisted system, a general mathematical framework is presented for the calculation of symbol error probability (SEP) by deriving the distribution of the received signal-to-noise ratio (SNR) [19]. Next, the new concept of using the LIS itself as an access point (AP) is proposed. Extensive computer simulation results are provided to assess the potential of LIS-based transmission, in which the LIS acts either as an intelligent reflector or an AP with or without the knowledge of channel phases. Our findings reveal that LIS based communications can become a game-changing paradigm for future wireless systems.

Although the initial stand-alone 5G standard, which brings more flexibility into the system design by exploiting millimeter-waves and multiple orthogonal frequency division multiplexing numerologies, has been completed during 2018, researchers are relentlessly exploring the potential of emerging technologies for later releases of 5G. These potential technologies include non-orthogonal multiple access, optical wireless communications and hybrid optical/radio frequency (RF) solutions, alternative waveforms, low-cost massive multiple-input multiple-output (MIMO) systems, terahertz communications, and new antenna technologies. Even though future 6G technologies look like as the extension of their 5G counterparts at this time, new user requirements, completely new applications/use-cases,and new networking trends of 2030 and beyond may bring more challenging communication engineering problems, which necessitate radically new communication paradigms in the physical layer.

CHAPTER 3

BACKGROUND

3.1 MIMO

MIMO stands for Multiple Input and Multiple Output technology which is used to improve the transmission and reception of signals using multiple antennas at the transmitter as well as receiver. The single input and single output (SISO) communication systems are available before the arrival of MIMO. In SISO, there will be only one transmit antenna and one receiver antenna. The receiver equation for any kind of wireless communication system is given by

$$y = hx + n \tag{1}$$

where h is fading coefficient. Before MIMO, there were other types of advanced antenna technology with different configurations such as multiple input and single output (MISO) and single input and multiple output (SIMO).

The antennas at each end of the communication system are combined to minimize errors, optimize data speed and improve the capacity of radio transmissions by enabling data to travel over many signal paths at the same time. MIMO technology is used for Wi-Fi networks and cellular 4G, Long-Term Evolution (LTE) and 5Gtechnology in a wide range of markets. The initial work on MIMO systems focused on basic spatial diversity in which the MIMO system was used to limit the degradation caused by multipath propagation [20]. However, this was only the first step as system then started to utilize the multipath propagation to advantage, turning the additional signal paths into what might effectively be considered as additional channels to carry additional data. The main idea behind MIMO wireless systems is the use of multiple antennas located at different points. Accordingly, MIMO wireless systems can be viewed as a logical extension to the smart antennas that have been used for many years to improve wireless communication. The transmission over a wireless channel will lead to multipath fading. By employing multiple antennas in both transmitter and receiver we can overcome the problem of multipath fading in MIMO technology by obtaining diversity gain. Means multiple paths are created for the signals to transmit. Previously, these multiple paths introduce interference. By using MIMO, these additional paths can be used as an advantage. They can be used to provide additional robustness to the radio link by improving the signal to noise ratio, or by increasing the link data capacity.

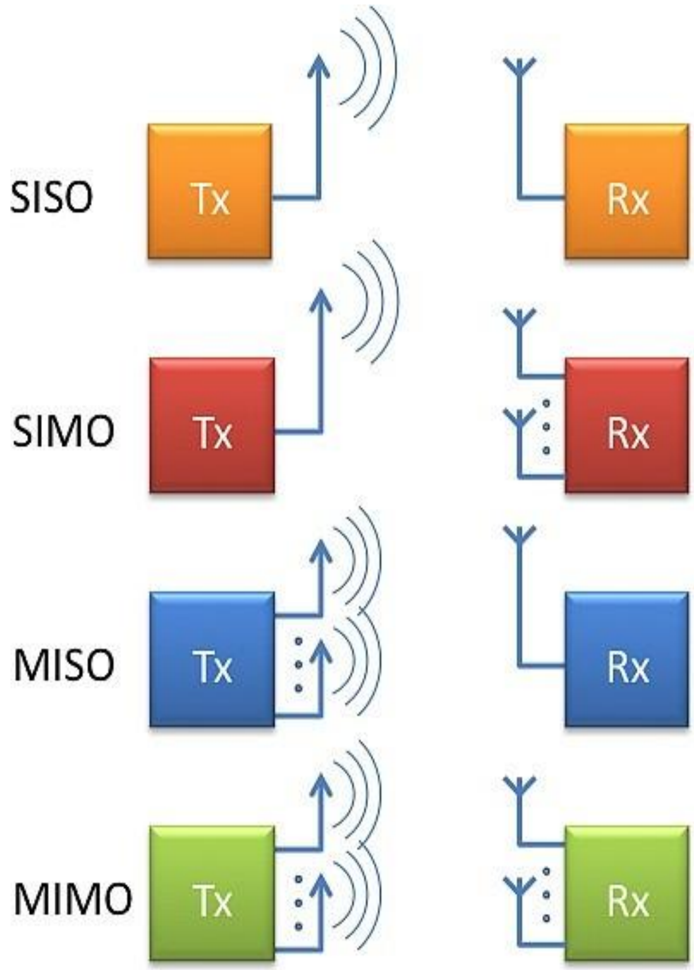
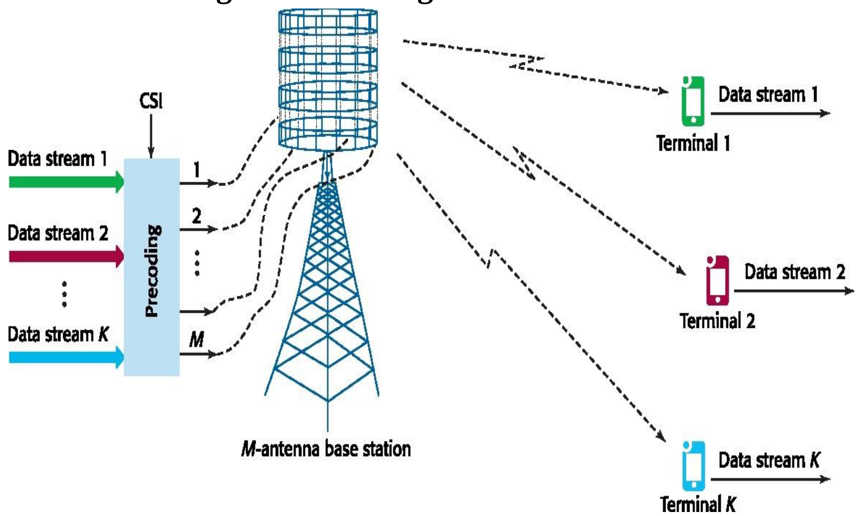


Fig.3.1 Block diagrams of SISO, SIMO, MISO and MIMO

3.2 Massive MIMO

Massive multiple-input multiple-output (MIMO) is an emerging technology that scales up MIMO by possibly orders of magnitude compared to the current state of the art. In this article, we follow up on our earlier exposition, with a focus on the developments in the last three years; most particularly, energy efficiency, exploitation of excess degrees of freedom, time-division duplex (TDD) calibration, techniques to combat pilot contamination, and entirely new channel measurements [21].

Fig 3.2 Block diagram of Massive MIMO



With massive MIMO, we think of systems that use antenna arrays with a few hundred antennas simultaneously serving many tens of terminals in the same time-frequency resource. The basic premise behind massive MIMO is to reap all the benefits of conventional MIMO, but on a much greater scale. Overall, massive MIMO is an enabler for the development of future broadband (fixed and mobile) networks, which will be energy-efficient, secure, and robust, and will use the spectrum efficiently. As such, it is an enabler for the future digital society infrastructure that will connect the Internet of people and Internet of Things with clouds and other network infrastructure. Many different configurations and deployment scenarios for the actual antenna arrays used by a massive MIMO system can be envisioned. Each antenna unit would be small and active, preferably fed via an optical or electric digital bus.

3.3 Index Modulation

In Index Modulation (IM), only single RF chain is utilized at the transmitter side as only a single transmit antenna is activated per transmission, which makes the system less expensive. IM is a low-rate spectral efficient system, where only one antenna is activated at one particular time of instance. The IM has been combined with different traditional communication technologies like an IM aided non orthogonal multiple access (NOMA) with Full-Duplex Relay to decrease the bit- error rate [22].

In recent times, the concept of IM is being introduced with the RIS-based systems. This integration results in 3 scenarios, where in the concept of IM is implemented at the transmitter side, at the receiver side and to the RIS. The RIS - IM scheme applied to the RIS is already introduced in, where not all meta surface elements are activated but the positions of the element which have to be activated are determined by the information which needs to be transmitted.

3.4 RIS

The future of mobile communications looks exciting with the potential new use cases and challenging requirements of future 6th generation (6G) and beyond wireless networks. Since the beginning of the modern era of wireless communications, the propagation medium has been perceived as a randomly behaving entity between the transmitter and the receiver, which degrades the quality of the received signal due to the uncontrollable interactions of the transmitted radio waves with the surrounding objects[4].

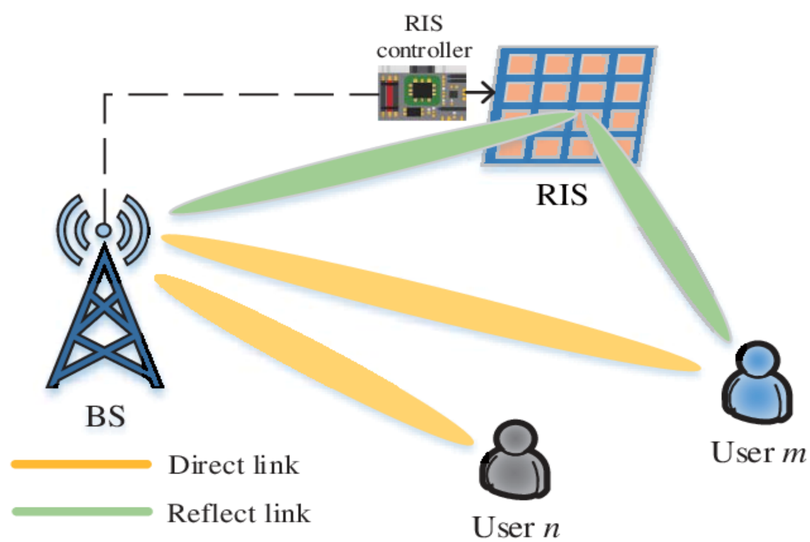


Fig.3.3 RIS Network

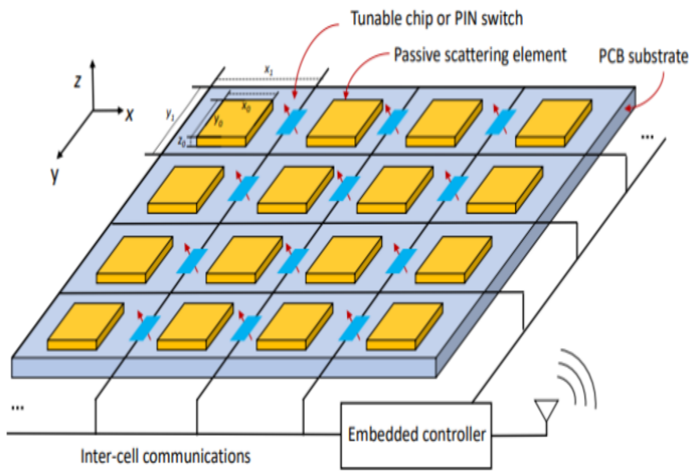


Fig.3.4 RIS Block Diagram

The recent advent of reconfigurable intelligent surfaces in wireless communications enables, on the other hand, network operators to control the scattering, reflection, and refraction characteristics of the radio waves, by overcoming the negative effects of natural wireless propagation. Recent results have revealed that reconfigurable intelligent surfaces can effectively control the wavefront, e.g., the phase, amplitude, frequency, and even polarization, of the impinging signals without the need of complex decoding, encoding, and radio frequency processing operations. Motivated by the potential of this emerging technology, the present article is aimed to provide the readers with a detailed overview and historical perspective on state-of-the-art solutions, and to elaborate on the fundamental differences with other technologies, the most important open research issues to tackle, and the reasons why the use of reconfigurable intelligent surfaces necessitates to rethink the communication-theoretic models currently employed in wireless networks.

3.5 MATLAB

Matlab or Matrix Laboratory is a high- level programming language connecting of an interactive environment mainly used for numeric computation, programming, and visualization. It has been developed by Math Works. The basic functions of Matlab are plotting of functions and data, the creation of user interfaces, matrix manipulations. It

also provides support for interfacing with other programming languages in C, C++, Fortran, and Java. Besides, it also used to analyze data, create models and applications, and also develop algorithms. Along with all this, introduction to Matlab also provides numerous built-in functions for mathematical operations involving numerous calculations, performing numerical methods, generating plots, and a lot of other functions. Matlab also has a very good scope in the automotive domain using rapid control Prototyping or RCP used extensively in medical, automotive, and aerospace domains.

Main Components of Matlab

Matlab provides a lot of functionalities that can help in computational mathematics. Below are the most common functions and mathematical calculations used in Matlab.

1.Dealing with Matrices and Arrays

2.2-D and 3-D Plotting and graphics

3.Lineat Algebra

4. Algebraic Equations

5 Non-linear Functions

6. Statistics

7.Data Analysis

8.Calculus and Differential Equations

9.Numerical Calculations

10.Integration

11.Transforms

12.Curve Fitting

13.Various other special functions

Fig.3.5 MATLAB logo

Advantages of MATLAB

1. Matlab is a complier-independent tool and doesn't require any complier to execute like as required in C, C++.Codes are written in sentences and executed one by one.

2. Being complier-independent makes Matlab more efficient and productive.

3. Matlab is fourth-generation high-level language.

4. Matlab coder is used to converting the code that is written in Matlab to Java,

5. Python, C++, NET, etc. making the Matlab language more versatile.

6. Different languages can be used to implement scientific theories, and after building the library files or .dll files, those can be directly implemented in Matlab using other language.

Disadvantages of MATLAB

1. Cross-compiling of Matlab code to other languages is very difficult and requires deep Matlab knowledge to deal with errors produced.

2. Matlab is used mainly for scientific research and is not suitable for development activities that are user-specific.

3. Matlab is an interpreted language; thus, it can be very slow.

4. Poor programming practices can contribute to making Matlab unacceptably slow.

5. Matlab is more expensive. The license is very costly, and users need to buy each and every module and need to pay for the same.

CHAPTER-4

IMPLEMENTATION OF RIS-RQIM

4.1 System Model

Fig 4.1 Illustrates the considered system model, which comprises a single- antenna radio frequency (RF) source, an N- element RIS, and N_r- antenna destination, where N, $N_r \geq 2$. Due to an obstacle, there is no direct link between the RF source and the destination. The RF source transmits an unmodulated carrier signal, and the RIS reflects the signal in a deliberate manner to convey information bits. In this paper, since the RIS is close to the RF source, and thus considered as a part of the transmitter, we ignore the fading effects between the RF source and the RIS.

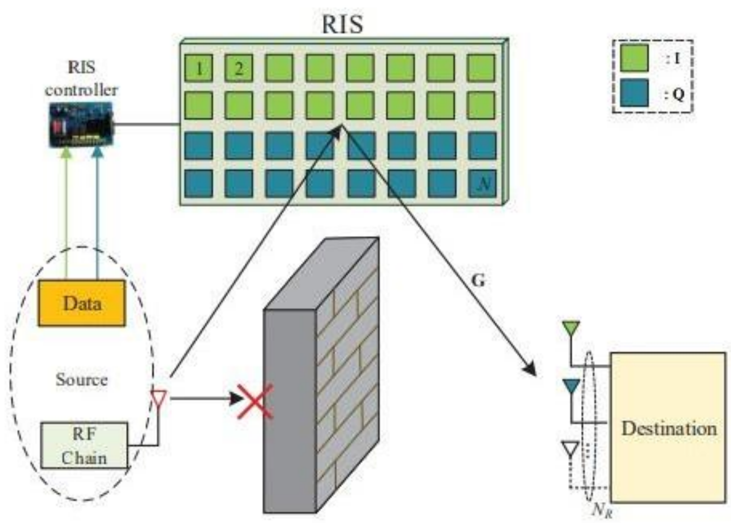


Fig 4.1 Block Diagram of RIS-RQIM

4.2 RIS- RQIM with polarity

In RIS-RQIM system with polarity, additional bit is conveyed through polarity. Hence the spectral efficiency is given by,

$$\gamma = 2\log_2(N_r + 1) \tag{2}$$

where N_r is the number of receive antennas and should be a power 2. P_I, P_Q are polarity bits, $P_I, P_Q \in \{0, 1\}$. $2(\log_2 N_r)$ bits are used to select two receive antennas r_1 and r_2 in in-phase dimension (I) and quadrature dimension (Q) respectively, $r_1, r_2 \in \{1, 2, 3, \dots \dots, N_R\}$

The reflection coefficients of I and Q branches of the RIS is given by

$$\phi i = j(-1)^{P_Q} \exp\left(-j\theta_{r_1, i}\right), \;\; i = \frac{N}{2} + 1, \dots, N \tag{3}$$

and

$$\phi i = j(-1)^{P_Q} \exp\left(-j\theta_{r_2, i}\right), \;\; i = \frac{N}{2} + 1, \dots, N \tag{4}$$

The received signal at the l^{th} receive antenna can be modeled as

$$y_l = (-1)^{P_I} \sum_{i=1}^{N/2} |g_{l,i}| \exp\left(j\left(\theta_{l.i} - \theta_{r_1,i}\right)\right) + j(-1)^{P_Q} \sum_{i=\frac{N}{2}+1}^{N} |g_{l,i}| \exp(j\,(\theta_{l,i} - \theta_{r_2,i})) + w_l \tag{5}$$

Where w_l Additive White Gaussian Noise (AWGN) at the l^{th} receive antenna following zero mean and unit variance

4.2.1 Low Complexity Detector for RIS- RQIM with polarity:

Even though maximum likelihood detector is considered as optimal detector, it suffers from high computational complexity. Hence, a low complexity detector is proposed to detect antenna indices $\hat{r}_1, \hat{r}_2$ and the polarity bits $\hat{P}_I, \hat{P}_Q$. As RIS is used to beamform the signal only at the selected receive antennas r_1 and r_2, received signal power at these antennas are suppose to higher than other receive antennas, that is

$$\hat{r}_1 = \arg\max_{l=r_1} |\Re(y_l)|, \;\; l \in \{1,2, \dots, N_r\} \tag{6}$$

$$\hat{r}_2 = \arg\max_{l=r_2} |\Im(y_l)|, \;\; l \in \{1,2, \dots, N_r\} \tag{7}$$

where $\Re(y_l)$ and $\Im(y_l)$ indicates real and imaginary parts of y_l respectively. The polarity bits can be easily decoded as

$$\hat{P}_I = \begin{cases} 0, & \Re(y_l) \geq 0 \\ 1, & \Re(y_l) < 0 \end{cases} \tag{8}$$

$$\hat{P}_Q = \begin{cases} 0, & \Im(y_l) \geq 0 \\ 1, & \Im(y_l) < 0 \end{cases} \tag{9}$$

4.3 RIS- RQIM without polarity

In RIS-RQIM system without polarity, the spectral efficiency is given by,

$$\gamma = 2\log_2(N_r) \tag{10}$$

where N_r is the number of receive antennas and should be a power 2. P_I, P_Q are polarity bits, $P_I, P_Q \in \{0, 1\}$. $2(\log_2 N_r)$ bits are used to select two receive antennas r_1 and r_2 in in-phase dimension (I) and quadrature dimension (Q) respectively, $r_1, r_2 \in \{1, 2, 3, \dots \dots, N_R\}$

The reflection coefficients of I and Q branches of the RIS is given by

$$\phi i = \exp\left(-j\theta_{r_1,i}\right), \quad i = \frac{N}{2} + 1, \dots, N \tag{11}$$

and

$$\phi i = \exp\left(-j\theta_{r_2,i}\right), \quad i = \frac{N}{2} + 1, \dots, N \tag{12}$$

The received signal at the l^{th} receive antenna can be modeled as

$$y_l = \sum_{i=1}^{N/2} |g_{l,i}| \exp\left(j\left(\theta_{l.i} - \theta_{r_1,i}\right)\right) + j \sum_{i=\frac{N}{2}+1}^{N} |g_{l,i}| \exp(j\,(\theta_{l,i} - \theta_{r_2,i})) + w_l \tag{13}$$

Where w_l Additive White Gaussian Noise (AWGN) at the l^{th} receive antenna following zero mean and unit variance

4.3.1 Low Complexity Detector for RIS- RQIM without polarity:

Even though maximum likelihood detector is considered as optimal detector, it suffers from high computational complexity. Hence, a low complexity detector is proposed to detect antenna indices $\hat{r}_1, \hat{r}_2$ and the polarity bits $\hat{P}_I, \hat{P}_Q$. As RIS is used to beamform the signal only at the selected receive antennas r_1 and r_2, received signal power at these antennas are suppose to higher than other receive antennas, that is

$$\hat{r}_1 = \arg\max_{l=r_1} |\Re(y_l)|, \quad l \in \{1,2,\dots,N_r\} \tag{14}$$

$$\hat{r}_2 = \arg\max_{l=r_2} |\Im(y_l)|, \quad l \in \{1,2,\dots,N_r\} \tag{15}$$

where $\Re(y_l)$ and $\Im(y_l)$ indicates real and imaginary parts of y_l respectively.

CHAPTER-5

RESULTS AND VALIDATION

In this section we evaluate the BER performance of RIS-RQIM with priority and without priority over Rician fading channel is assessed through Monte Carlo simulations which are carried out by transmitting at least 10^4 symbols for each Signal- to- Noise Ratio (SNR). The base station (BS) is assumed to have a transmitting antenna whereas the destination receiver has multiple antenna (NR = 4,8,16,32). The distance between BS and RIS is assumed to negligible i.e., transmission is being done from RIS itself. Hence, channel between base station and RIS is not considered. The parameters necessary for simulation are highlighted in table 1.

Table 5.1 Simulation Parameters

Parameters	Typical Value/Configurations
Number of transmit antennas (N_T)	1
Number of receive antennas (N_R)	4, 8
Number of Reflecting elements(N)	64,128,256
Spectral efficiency	4,5,6,7 bpcu
Number of symbols	10^5
Channel Model	Rayleigh, Rician fading channels

5.1 BER Performance of RIS

In Fig 5.1, While simulating the results, we considered the SNR range as-45 to -20 dB with step size of 2. Further, we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The target BER value is taken as 10^{-3}. When the number of meta surface elements are 64 the BER value is obtained at -27dB and when the elements are 128, the BER value is obtained at -34dB and when the elements are 256, the BER is obtained at -40.5dB.

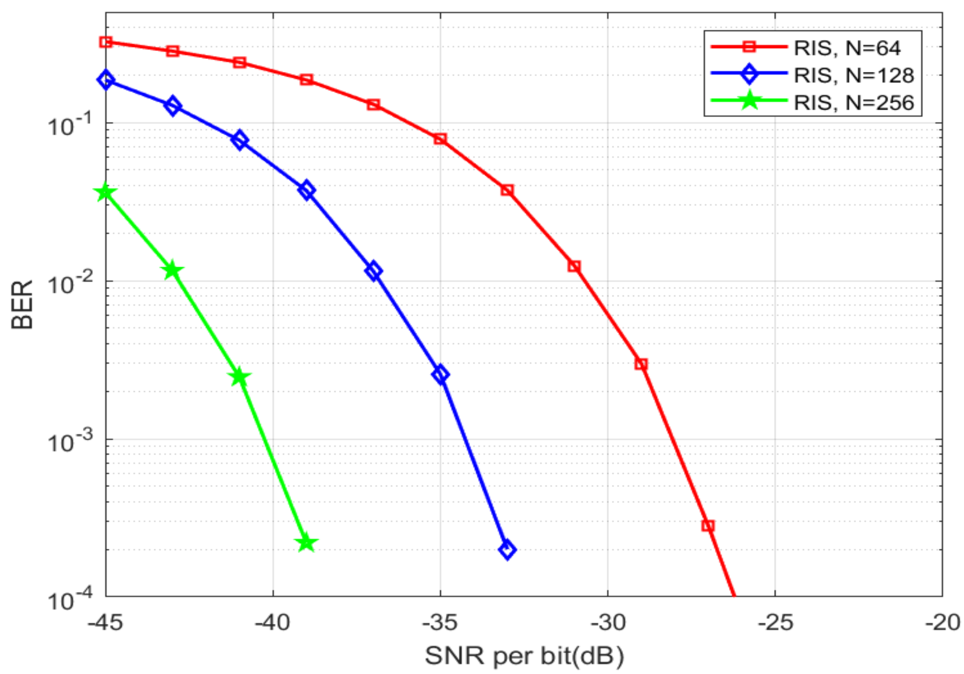


Fig 5.1 BER performance comparison of RIS for $N_r = 4$ varying N=64,128,256

5.2 BER Performance of RIS- SSK

In Fig 5.2, While simulating the results, we considered the SNR range as-45 to -20 dB with step size of 2. Further, we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The target BER value is taken as 10^{-3}. When the number of meta surface elements are 64 the BER value is obtained at -23dB and when the elements are 128, the BER value is obtained at -29.5dB and when the elements are 256, the BER is obtained at -35.5dB.

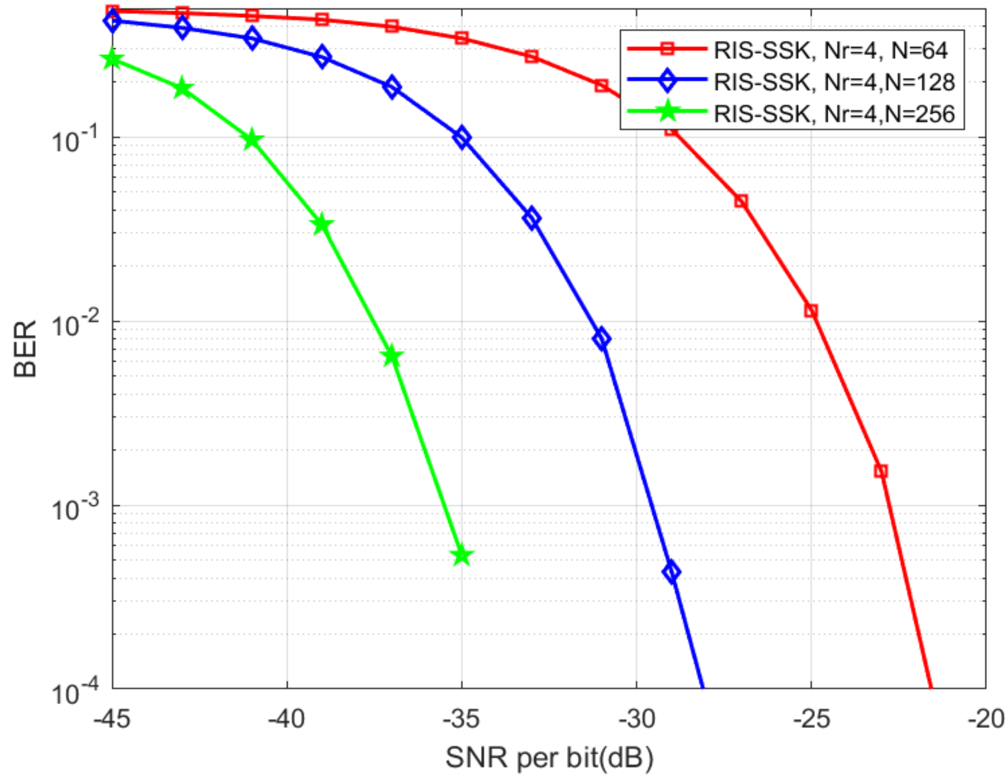


Fig 5.2 BER performance comparison of RIS-SSK for N_r = 4 varying N=64,128,256

5.3 BER Performance of RIS-SM

In Fig 5.3, While simulating the results, we considered the SNR range as-45 to -20 dB with step size of 2. Further, we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The target BER value is taken as 10^{-3}. When the number of meta surface elements are 64 the BER value is obtained at -24dB and when the elements are 128, the BER value is obtained at -30dB and when the elements are 256, the BER is obtained at -36.5dB.

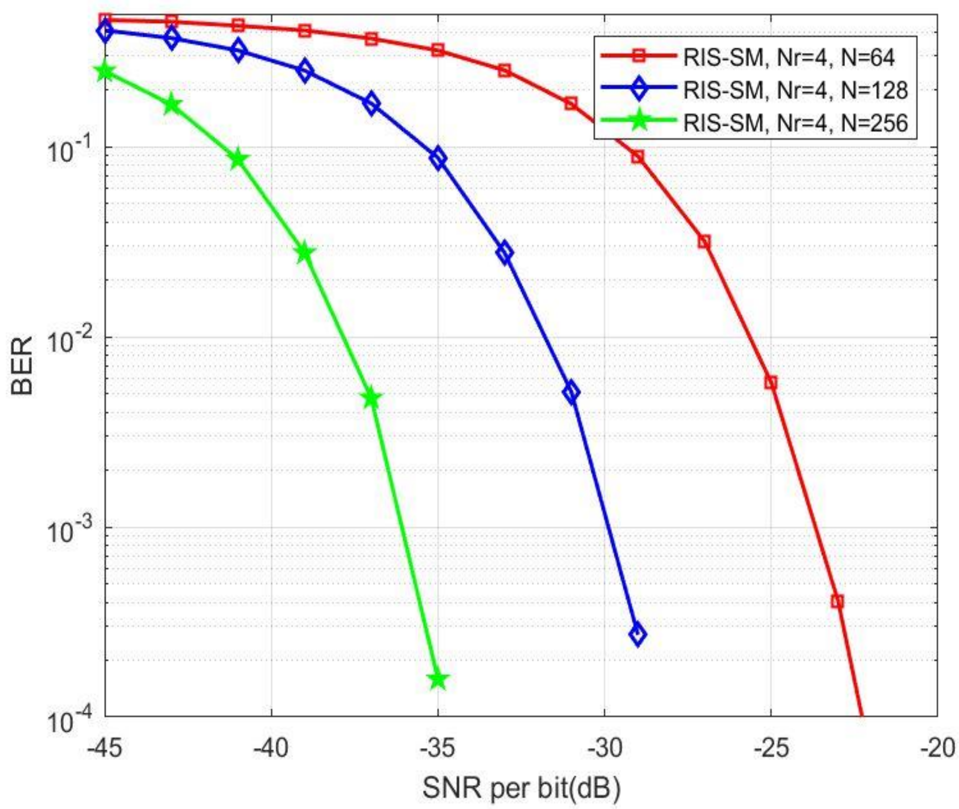


Fig 5.3 BER performance comparison of RIS-SM for $N_r = 4$ varying $N = 64, 128, 256$

5.4 BER Performance of RIS-RQIM-With Polarity

In Fig 5.4, we provide the BER performance curve for the proposed RIS-RQIM scheme. While simulating the results, we considered the range of SNR as -45 to -10 with a step size of 2. Further, we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The target BER value is taken as 10^{-3}.

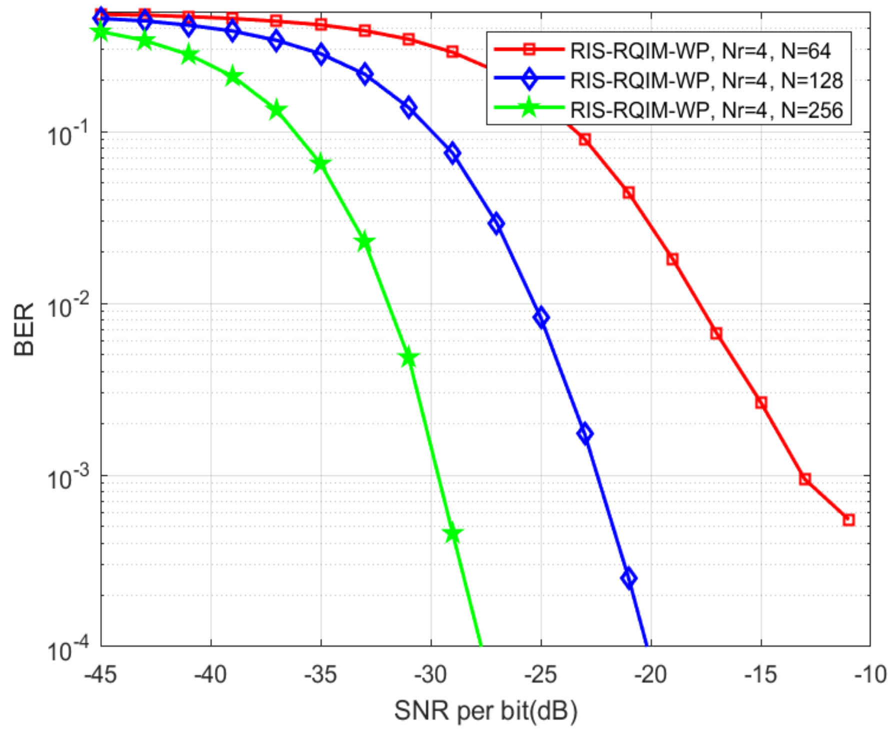


Fig 5.4 BER performance comparison of RIS-RQIM with polarity for $N_r = 4$ varying N=64,128,256

Case 1 : Nr = 4

Here, the number of receive antennas are taken as 4 and the number of meta surface elements are taken as 64 ,128 and 256. Further we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The referred BER value is taken as 10^{-3}.

When the number of meta surface elements are 64 the BER value is obtained at -13dB and when the elements are 128, the BER value is obtained at -23dB and when the elements are 256, the BER is obtained at -30dB.

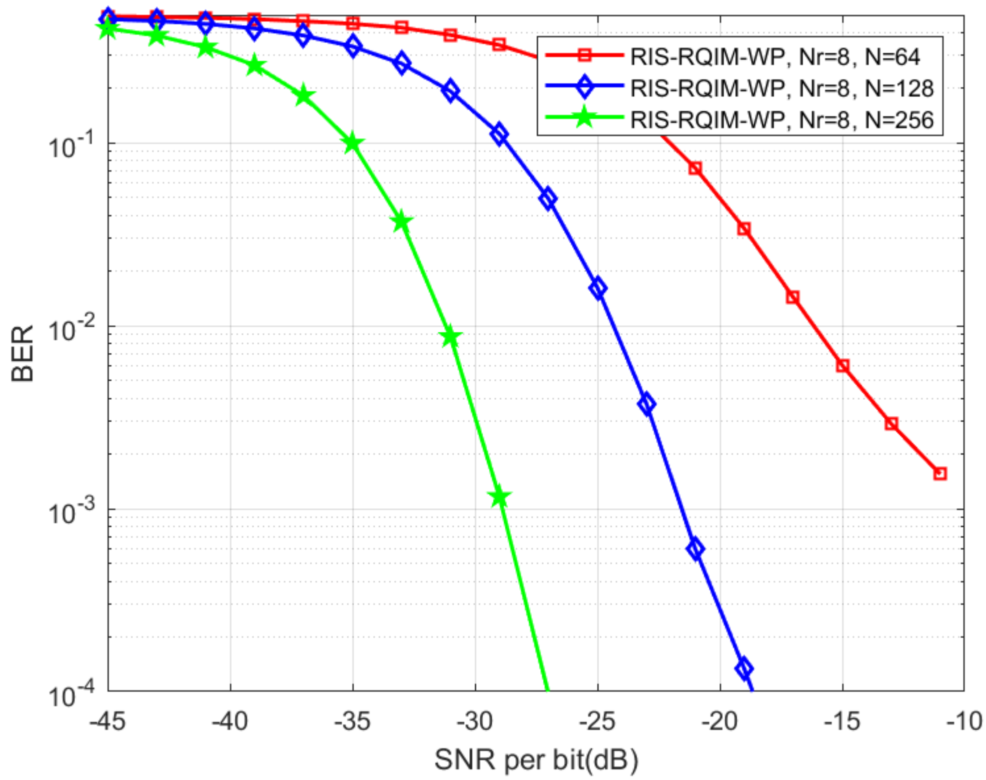


Fig 5.5 BER performance comparison of RIS-RQIM with polarity for N_r = 8 varying N=64,128,256

Case 2 : Nr = 8

Here, the number of receive antennas are taken as 8 and the number of meta surface elements are taken as 64 ,128 and 256. Further we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The referred BER value is taken as 10^{-2}.

When the number of meta surface elements are 64 the BER value is obtained at -10dB and when the elements are 128, the BER value is obtained at -22dB and when the elements are 256, the BER is obtained at -29dB.

5.5 BER Performance of RIS-RQIM-Without Polarity

In Fig 5.6, we provide the BER performance curve for the proposed RIS-RQIM scheme. While simulating the results, we considered the range of SNR as -45 to -5 with a step size of 2. Further, we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The target BER value is taken as 10^{-3}.

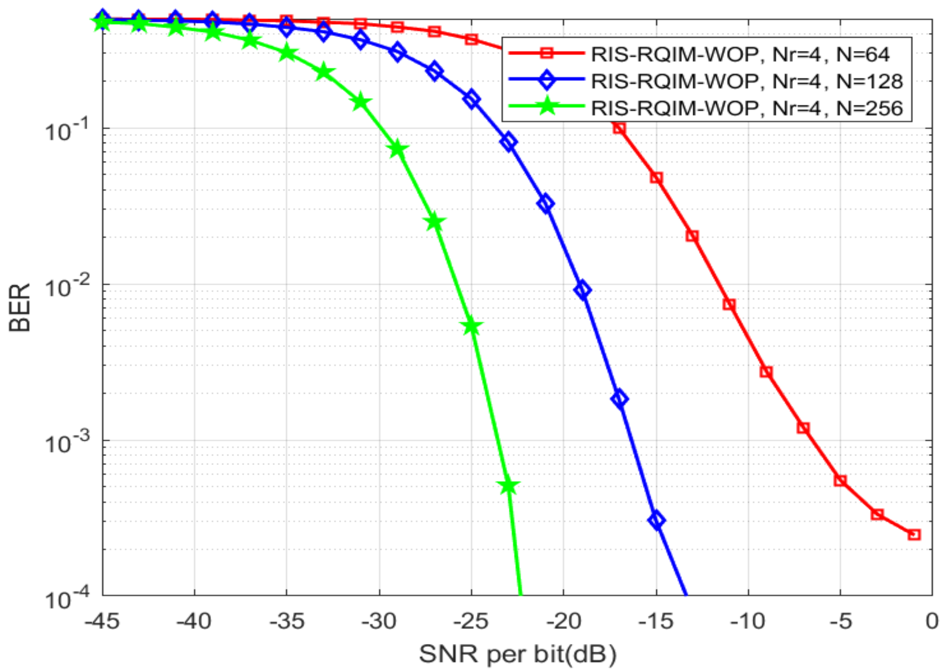


Fig 5.6 BER performance comparison of RIS-RQIM without polarity for $N_r = 4$ varying N=64,128,256

Case 1 : Nr = 4

Here, the number of receive antennas are taken as 4 and the number of meta surface elements are taken as 64 ,128 and 256. Further we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The referred BER value is taken as 10^{-3}.

When the number of meta surface elements are 64 the BER value is obtained at -7dB and when the elements are 128, the BER value is obtained at -16.5dB and when the elements are 256, the BER is obtained at -24dB.

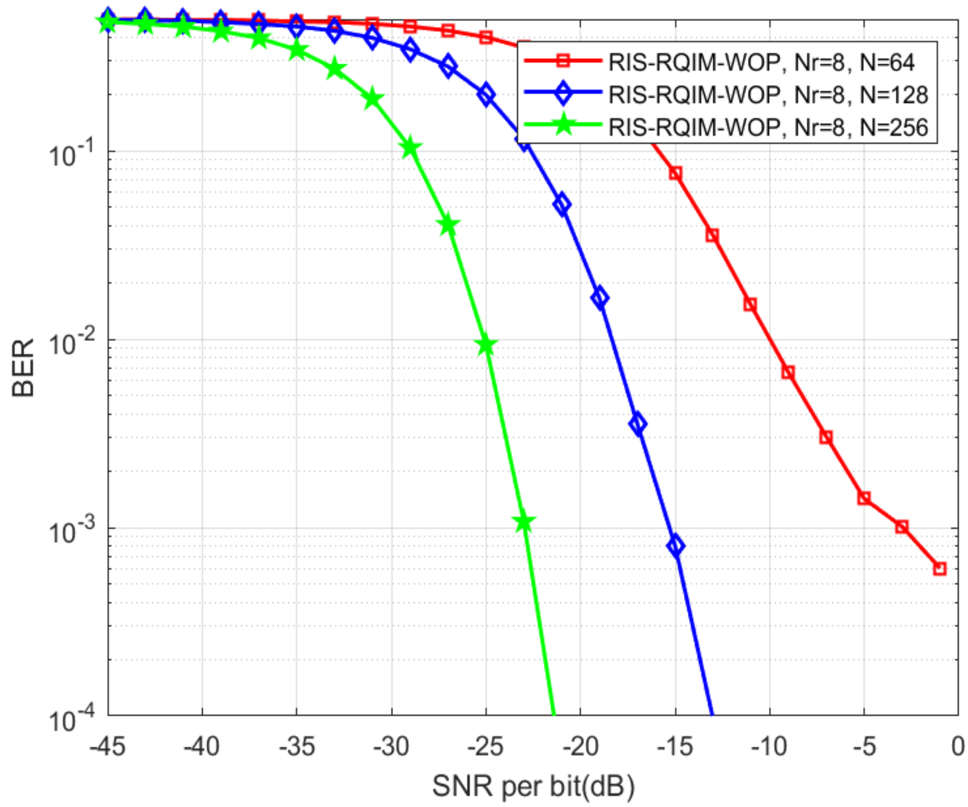


Fig 5.7 BER performance comparison of RIS-RQIM without polarity for N_r = 8 varying N=64,128,256

Case 2 : Nr = 8

Here, the number of receive antennas are taken as 8 and the number of meta surface elements are taken as 64 ,128 and 256. Further we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The referred BER value is taken as 10^{-3}.

When the number of meta surface elements are 64 the BER value is obtained at -3dB and when the elements are 128, the BER value is obtained at -15dB and when the elements are 256, the BER is obtained at -23dB.

5.6 BER Performance Comparison of RIS-RQIM with Polarity and without Polarity

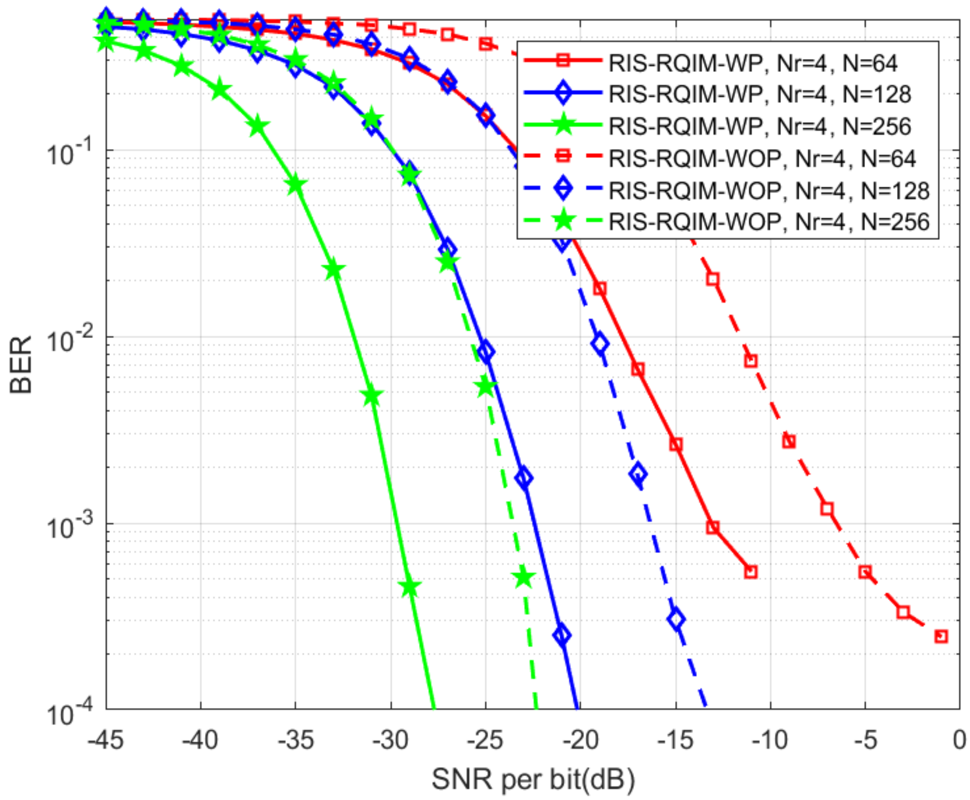


Fig 5.8 BER performance comparison of RIS-RQIM with polarity and without polarity when $N_r = 4$ varying N=64,128,256

Case 1: Nr=4

In Fig 5.8, we provide the BER performance curve for the proposed RIS-RQIM scheme. While simulating the results, we considered the SNR range as -45 to 0 dB. Here, the number of receive antennas are taken as 8 and the number of meta surface elements are taken as 64 ,128 and 256. Further we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The referred BER value is taken as 10^{-3}.

When the number of meta surface elements are 64, RIS-RQIM with priority gained 6dB compared to without priority and when the elements are 128, RIS-RQIM with priority gained 6.5dB compared to without priority and when the elements are 256, RIS-RQIM with priority gained 6dB compared to without priority. The gain values are recorded in table 5.2.

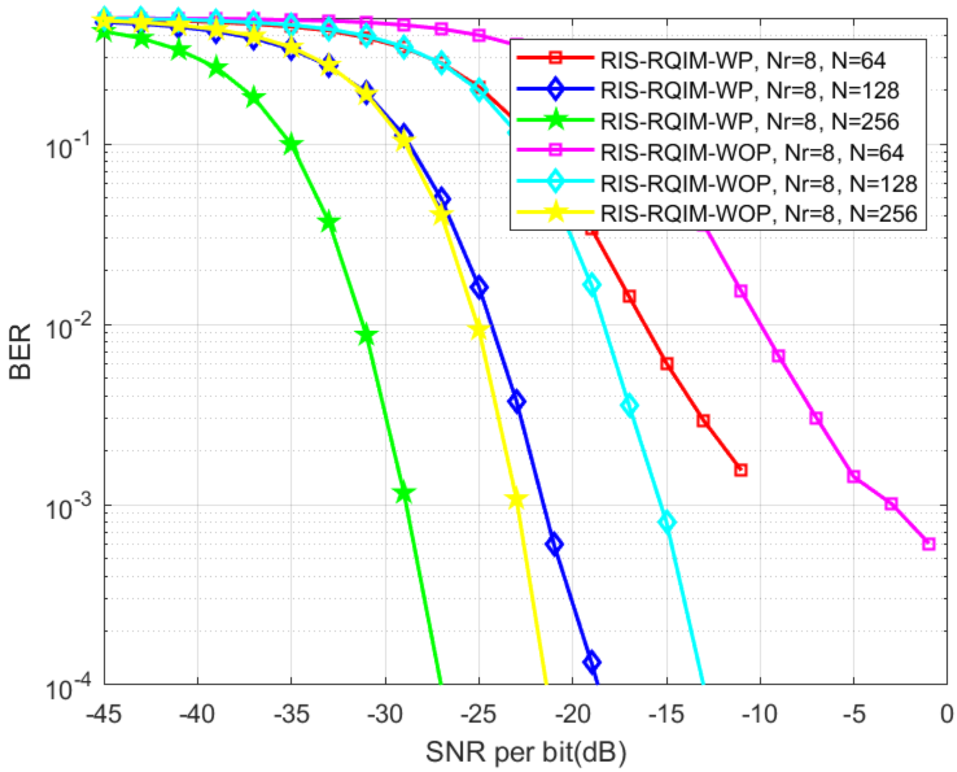


Fig 5.9 BER performance comparison of RIS-RQIM with polarity and without polarity when $N_r = 8$ varying N=64,128,256

Case 2: Nr=8

In Fig 5.9, we provide the BER performance curve for the proposed RIS-RQIM scheme. While simulating the results, we considered the range of SNR as -45 to 0 with a step size of 2. Here, the number of receive antennas are taken as 8 and the number of meta surface elements are taken as 64 ,128 and 256. Further we have varied the number of meta surface elements and the number of receive antennas and observed the simulation results. The referred BER value is taken as 10^{-3}.

When the number of meta surface elements are 64, RIS-RQIM with priority gained 7dB compared to without priority and when the elements are 128, RIS-RQIM with priority gained 7dB compared to without priority and when the elements are 256, RIS-RQIM with priority gained 6dB compared to without priority. The gain values are recorded in table 5.2.

Table 5.2 Gain values of RIS- RQIM with polarity compared to without polarity

<table>
<tr><th rowspan="4">RIS- RQIM with polarity</th><th colspan="6">Gain values in dB</th></tr>
<tr><th colspan="3">Nr=4</th><th colspan="3">Nr=8</th></tr>
<tr><th>N=64</th><th>N=128</th><th>N=256</th><th>N=64</th><th>N=128</th><th>N=256</th></tr>
<tr><td>6dB</td><td>6.5dB</td><td>6dB</td><td>7dB</td><td>7dB</td><td>6dB</td></tr>
</table>

CHAPTER-6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

In this work, RIS-RQIM with polarity and without polarity schemes are introduced to enhance the spectral efficiency, energy efficiency and reliability of the next generation wireless networks. In RIS-RQIM, RIS is used to reflect the carrier signal from the base station to any two antennas at the receiver. Half of RIS elements are used to reflect the inphase component of the carrier to a receive antenna, which is selected by the a part of the incoming bits. Similarly, other half of the RIS elements are used to reflect the quadrature component of the carrier signal to a receive antenna, which is selected by remaining incoming bits. When compared with RIS-SSK, RIS-RQIM offers twice the spectral efficiency. RIS-RQIM with polarity scheme includes additional polarity bit to differentiate between inphase and quadrature components of the carrier signal, thereby providing better BER performance. Monte Carlo simulations are performed to evaluate the performance of the RIS-RQIM with and without polarity schemes in comparison with RIS, RIS-SSK and RIS-SM schemes. From results, it is observed that RIS-RQIM with polarity scheme outperforms conventional benchmark schemes. RIS-RQIM with polarity also outperform RIS-RQIM without polarity in terms of spectral efficiency and BER performance. Hence, RIS-RQIM with polarity can be potential candidate for next generation 6G networks that provide better reliability and better spectral and energy efficiency trade-off.

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Department of Electronics & Communication Engineering

Academic Year: 2022-23 B.No: B19

Project Title: **Reconfigurable Intelligent Surface aided Receive Quadrature Index Modulation for 6G networks**

Type of Project: **Design Oriented/ Research Oriented**

Project Guide: Dr. G. Vishnu Vardan

PROGRAM OUTCOMES			
PO1	Engineering knowledge	PO7	Environment and sustainability
PO2	Problem analysis	PO8	Ethics
PO3	Design/development of solutions	PO9	Individual and team work
PO4	Conduct investigations of complex problems	PO10	Communication
PO5	Modern tool usage	PO11	Project management and finance
PO6	The engineer and society	PO12	Lifelong learning

PROGRAM SPECIFIC OUTCOMES	
PSO1	Provide sustainable solutions in the field of Communication and Signal Processing
PSO2	Apply current technologies in the field of VLSI and embedded systems for professional growth

CONCLUSION STATEMENTS

S.No	Description	Attained COs	Attained POs/PSOs
1	Identified various transportation means mostly used by various commuters.	CO1	PO1
2	Identified the most common problem faced by these commuters.	CO1,CO2	PO2,PO3 PO4,PO5 PO9
3	Researched about ways to let the commuters know about their vehicle location.	CO3	PO2, PO7, PSO1
4	Literatures were reviewed about the tracking of vehicle from 2010 to 2022 by various authors.	CO2	PO2, PO7
5	A new method of tracking commuter’s vehicle is proposed.	CO2,CO3	PO3,PO5 PO8
6	Compared this method with existing methods.	CO2	PO4,PO7
7	New components were added to make a new and better solution for the problem.	CO5	PO3, PO8, PSO1
8	Concluded and analysed the solution and presented it.	CO2,CO4 CO5	PO9,PO10 PO11, PSO2

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