Joint User Throughput Maximization In Reconfigurable Intelligent Surfaces (RIS) Assisted Networks

By

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THESIS ACCEPTANCE CERTIFICATE

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Declaration

I hereby declare that work carried out in this thesis has not been submitted in support of any degree or professional qualification either at this institution or elsewhere.

Dedication

I dedicate this thesis to my loving parents, friends and honorable teachers for their everlasting love, devotion, and inspiration.

Acknowledgement

I am truly grateful to Allah Almighty for granting me with the endurance and motivation to complete this thesis, as well as His mercy and benevolence, and His Prophet (PBUH), without whose grace I could not have undertaken this effort. My sincere thanks goes to my Supervisor Dr.Muhammad Imran and my Co-supervisor Dr. Mudassar Ali for their constant encouragement and dedicated guidance, which enabled me to undertake this research. This dissertation would not have been possible without their continuous support, patience and insightful analysis. Throughout the thesis writing process, their guidance and brain storming motivation remained with me like a beacon. I could not imagine having an enlightened mentors for my MS thesis.

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My family and friends' unwavering support has been crucial, enabling me to finish my Master's degree in Electrical Engineering, particularly in thesis, and their unwavering encouragement has fuelled my feeling of ongoing commitment over the years.

Abstract

Current 5G cellular networks must be upgraded to sixth-generation networks as the number of users and data rate demands are increasing dramatically. In comparison to 5G networks, 6G networks would be able to deploy at higher frequencies, resulting in significantly increased capacity, As the RISs (reconfigurable intelligent surfaces) concept has recently received a lot of attention as a possible solution for 6G wireless communications and it is a new technology that can be configured to optimize the wireless propagating environments, improve the connections between users and base stations (BS), and adjust wireless settings to improve spectrum and throughput of a network. RISs are emerging as a solution for Tera Hertz technologies. It can pave the way to envision the throughput and maximizing users targets for B5G/6G networks. Therefore the joint user and the throughput maximization problem with RIS assisted based B5G/6G wireless network is investigated in this thesis subject to power transmission, QoS, and phase shift at RIS constraints. The objective is to maximize joint user and throughput of a RIS aided multi-user network having a multi-antenna base station (BS) Few articles examine user and throughput maximization in the innovative environment of wireless communications helped by RIS at this time, Hence our research work focuses on RIS-assisted wireless transmission, to collaboratively improve the admitted users and the throughput for all users as compared to the conventional communication system. The problem as stated is non-convex resulting in the MINLP problem. In general, MINLP problems are NP-hard problems. A Mesh adaptive direct search (MADS) algorithm is proposed to efficiently solve this problem. Extensive simulation work validates the proposed algorithm, demonstrating that it is effective in terms of joint user and throughput in a RIS-assisted network. Results achieved from the simulation shows that by incorporating RIS in a network increases throughput and maximizes the admitted users in a wireless network. By increasing the number of RIS elements the throughput is also increased. Our proposed MADS algorithm outdo the advanced algorithms and computational complexity is reduced.

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Notations

M	No of Antennas
K	Total number of users
N	No of Reflecting Elements
ϕ	Phase Shift of RIS
k_N	Reflecting Amplitude of nth RIS unit
θ_N	Angle of nth RIS unit
p_k	transmit power
$h_{d,k}$	Channel from the BS to k-th user
$h_{r,k}$	Channel from the RIS to k-th user
G	Channel from the BS to the RIS
s_k	transmit data symbol
h_k	Channel Gain
$h_k(\phi)$	Effective Channel of the k-th mobile user
d_0	According to the antenna far field, close in reference distance
d	The spacing between the transmitter and the receiver

α	Path loss Exponent
$s(\phi)$	Received Signal at BS
N_0	Noise generated during transmission
G_0	Antenna Gain
γ_k	SINR (Signal-to-Interference-plus-noise ratio)
ζ	For shadowing, use a zero mean gaussian random variable
R_k	The k-th Mobile user's total information rate
r_k	Information rate of k-th user
P_{max}	Maximum transmit power of the system
P_k	Power received by kth user from BS
a_k	Binary Indicator.
$F(p,a_k)$	Utility function
y	Admitted Users

Acronyms

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Forth Generation
5G	Fifth Generation
6G	Sixth Generation
AO	Alternating Optimization
ADMM	Alternating Direction Method Of Multipliers
ATP	Adaptive Transmission Protocol
BS	Base station
BCD	Block Coordinate Descent
CMA	Coverage Maximization Algorithm
CDMA	Code Division Multiple Access
DL	Down-link
EE	Energy Efficiency

EH	Energy Harvesting
ERs	Energy Receivers
ESA	Exhaustive Search Algorithm
GD	Gradient Descent Method
GPS	Generalized Pattern Search
HetNets	Heterogeneous Network’s
IoT	Internet of Things
JPPBO	Joint Phase-shifts Power, and Bandwidth Allocation Optimization
KPIs	Key Performance Indicators
LTE	Long Term Evolution
MADS	Mesh Adaptive Direct Search
MEC	Mobile Edge Computing
MDs	Mobile Devices
MN	Modified Newton
MIMO	Multiple-Input-Multiple-Output
MINLP	Mixed Integer Non-Linear Programming
MM	Majorization Minimization
NOMADS	Non-linear Optimization Using Mesh Adaptive Direct Search
OAA	Outer-Approximation-Algorithm
OFDMA	Orthogonal Frequency Domain Multiple Access

PA	Power Allocation
QoS	Quality of Service
RF	Radio Frequency
RIS	Reconfigurable Intelligent Surface
RA	Resource Allocation
RISMA	RIS-Aided Multi-User Alternating Optimization Algorithm
SE	Spectral Efficiency
SWIPT	Simultaneous Wireless Information and Power Transfer
SCUs	Small Cell Users
SOCP	Second Order Cone Programming
STM	Strongest Tap Maximization
SFP	Sequential Fractional Programming
SDR	Semi-Definite Relaxation
SCA	Successive Convex Approximation
SROCR	Sequential Rank-One Constraint Relaxation
UE	User Equipment
UA	User Association
UAV	Unmanned Aerial Vehicle
WCDMA	Wide-band Code Division Multiple Access
WiMAX	Worldwide interoperability for Microwave Access

WMMSE	Weighted Minimum Mean Square Error
WSR	Weighted Sum Rate

Chapter 1

Introduction

This chapter presents a brief introduction to the work accomplished in this thesis. Section 1.1 explains the concept of Communication Networks present in past, present and in future time, The communication network evolution from 1G to 6G is explained in this subsection1.1.1 and subsection1.1.2 explains the current research progress towards 6G Networks. Section 1.2 explains the main concept of RIS. Section 1.3 explains efficient resource allocation in RIS based B5G and 6G wireless communication networks.The main motivation of thesis is explained in Section 1.4 . Section 1.5 highlights the shortcomings of the existing literature, the problem formulation is discussed in section 1.6. The main contribution of the thesis is elaborated in section 1.7. Finally, section 1.8 gives the idea regarding the organization of the thesis.

1.1 Background

In the recent years, the magnificent success of Wireless Communication in the The global market has indeed been observed. Though after years of development, the amount of cellular devices is Even in certain countries, the number of communication devices is still steadily expanding. Depends on consumers' demand for constant wireless access, it has outgrown its population. The development of the Internet of

Everything (IoE) network, which connects millions of individuals and billions of devices, is driving up the need for higher data rates for the users connected to a wireless network [1] . The need for greater data throughput, reduced latency, and secure connectivity is growing every day in the global age of a substantial amount of data.

1.1.1 Evolution of Networks from 1G to 5G

Wireless communication was conceptually developed premised on Marconi's pioneer demonstration of wireless telegraph. After this in 1948 Shannon coined the term "information theory" that offer wireless access, a 1G conventional wireless cellular network was used. 1G was primarily used for voice communications and had low quality, minimal system capacity, and constrained services. 1G systems comprised purely analog networks had throughput upto to 2.4 kb/s and thus no digital processing. In the early 1990s, voice communications were overtaken by the 2G digital cellular network. 2G was able to provide secure communication services in addition to traditional phone services, such as short messaging service (SMS), due to digitization. Circuit switched networks with a throughput of up to 384 kbps are known as 2G networks. [1].

Third-generation mobile networks (3G) are popular in the early twenty-first century represented by wide-band CDMA code-division multiple access technology, CDMA 2000, time-division synchronous CDMA (TD-SCDMA), and Worldwide Interoperability for Microwave Access (WiMAX) permitted different data capabilities, including internet connectivity, videoconferencing, and wireless broadcasting . With the help of 3G it provides the services which was much more data-driven and capable of delivering a reliable service with higher data rates compared to 1G and 2G networks. 3G networks have throughput up to 2Mb/s.

In 4G/Long-Term Evolution (LTE) networks initialized in 2009, multiple-input and multiple-output (MIMO) antenna architecture, orthogonal frequency-division multiplexing (OFDM) and all-internet protocol (IP) technology were jointly applied to achieve high-speed mobile data transmission9 . 4G has been a significant success both technologically and commercially.Wireless communications are becoming popular with the growth of tablets and smartphones, enabling a significant 4G network data throughput, as well as information and communication technologies that accompany 4G have contributed to transform society [2]. Throughput of 4G networks reaches up to 100 Mb/s.Because current LTE wireless networks are unable to handle such high levels of data traffic, wireless communication is transitioning to new fifth-generation (5G) networks. In contrast to present 4G , 5G networks are predicted to deliver faster data rates, a 5x reduction in end-to-end latency, and a 10x increase in device battery life.In the 5G era, indoor and data services in densely populated locations will remain the primary focus. However, there have been a lot of cutting edge communication and networking technologies that have yet to be integrated into 5G requirements. The key factors are supply and demand oriented. Despite the fact that 5G have pursued a steady evolutionary framework that helps to supply even more and faster service be-

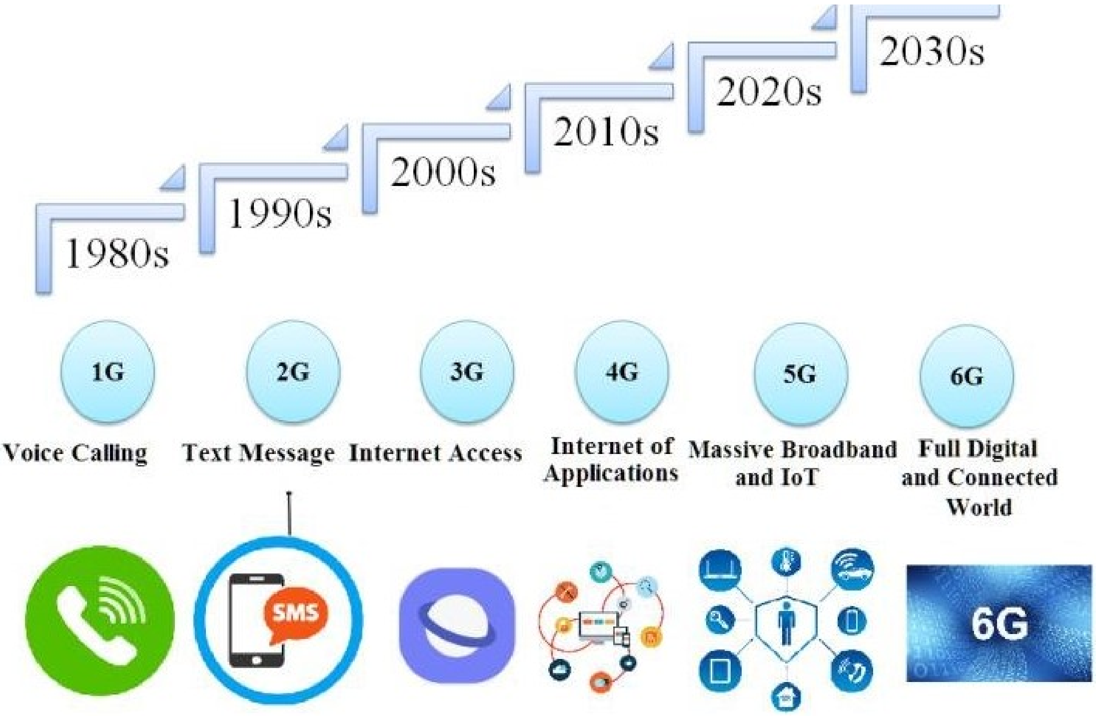

Figure 1.1: An Overview of 1G-6G Devices and the Corresponding Technology Breakdown.

yond 4G, it does not contain any ground-breaking technologies. Instead, it maintains the core performance enhancing methods that have been in place since 4G, with performance gains coming from increased spectrum and hardware resources.

1.1.2 Current research on 6G networks

As 5G technologies will have to be fully implemented globally. Furthermore, there seem to be various concerns with 5G networks that must be addressed. As a result, it prompted us to research the concerns associated with 6G technology. Researchers have started to study the forthcoming of 6G communication network as the As commercialization of 5G communication networks progresses, technologies for next-generation (i.e., 6G) communications are also being investigated by researchers to study the forthcoming of 6G communication network and to accomplish communications that are speedier and more dependable [3]. A numerous researchers already have shared their thoughts for 6G, and extensive research initiatives already have started. In current research they mainly focus on lifetime of battery of mobile device and the services they provided. Rather than data rate and throughput of a network. Over the next 10 to 25 years, 6G would be the most important study field. The prime requirements of 6G technology are 1 THz operating frequency and data rate of 1 Tb/s. The operational frequency of 1 THz and the maximum throughput of 1 Tb/s are the two most important parameters for 6G technology.

More notably, 6G technology will make the Internet of Things possible. The potential applications of 6G is shown in Fig (1.2). However, from the standpoint of technical development, now is the time to start thinking about what the future beyond 5G (B5G) or 6G mobile networks should be in order to meet the need for wide area networks by 2030. The 6G will provide advanced services such as immersive mixed reality, high-fidelity mobile holograms, and digital replication [4] .

For 6G, the Key Performance Indicators (KPIs) used in the 5G communication net-

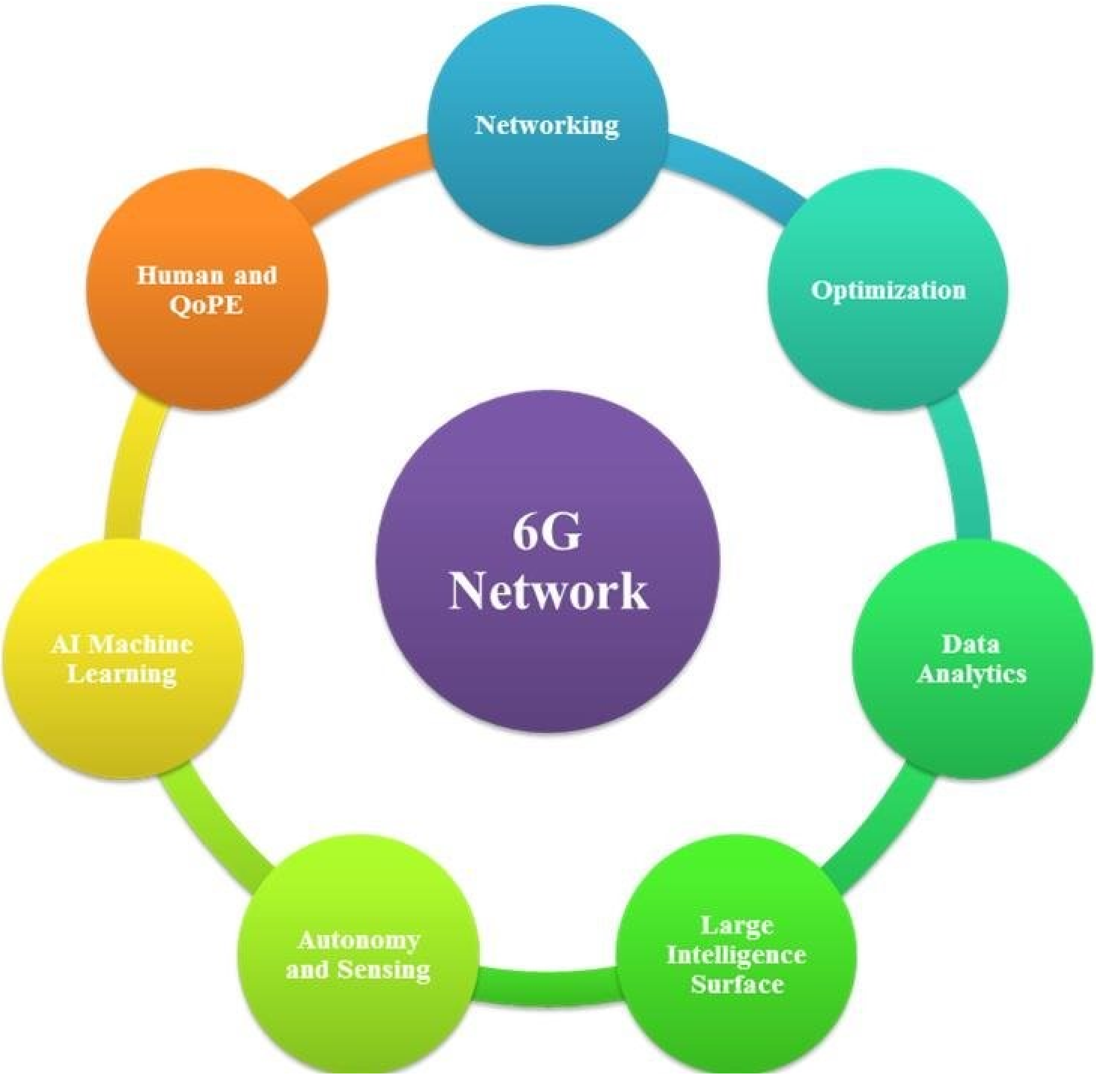

Figure 1.2: Potential Applications of 6G.

work will be accurate and authentic, and more research will be done to enhance the efficiency of pre-owned KPIs. The following table shows some KPIs of 5G and 6G networks

1.2 Main Concept

6G technologies are expected to enhance accessibility and data rate requirements while also allowing users to access with one another from anywhere.The main concern for the wireless network is the competency of administrating large volumes of

Table 1.1: Key Performance Indicators

KPIs	**5G**	**6G**
Peak Data Rate	10Gb/s	1Tb/s
End to End Delay	10ms	<1ms
Latency	1ms	0.1ms
Reliability	$1-10^{-5}$	$1-10^{-9}$
Mobility	500km/h	1000km/h
Spectral Efficiency	30b/s/Hz	100b/s/Hz

data and connectivity of data rate for each device. Many technologies have been examined and investigated for the future of 6G wireless communication networks among them are Reflecting Intelligent Surfaces (RIS) can be viewed as a hard ware foundation for computation hungry applications in wireless communication networks [5]. RIS had also subsequently evolved as a highly promising solution for allowing a cost-effective intelligent and programmable wireless environment. Different from the existing technologies, RIS has the potential to realize the diverse applications of 6G at low hardware cost and energy consumption, As illustrated in Fig (1.3). RIS, often known

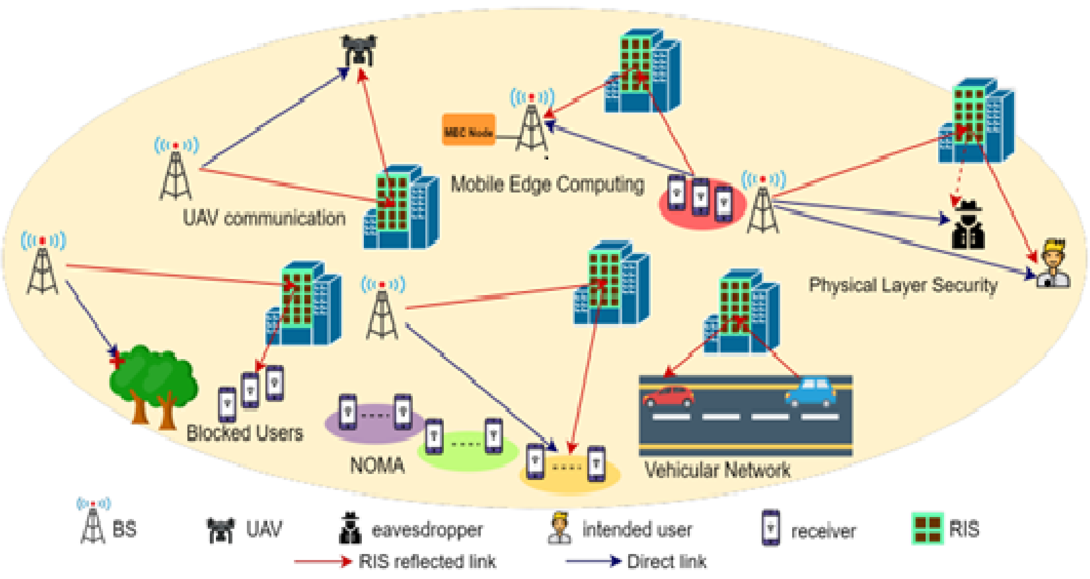

Figure 1.3: Emerging applications of RIS for 6G wireless networks.

as a large intelligent surfaces (LIS), is made up of many RIS units, that are controlled by programmable varactor diodes. Electro-magnetic response, i.e. phase shift towards incident signals, may be software-defined for each element each of which may modify the incident signal independently. In general, the modification might be in phase, amplitude, or frequency. Most studies to date have treated the change as a phase shift exclusively to the incident signal, implying that a RIS costs no transmit power. The wireless environment can be intelligently controlled using RIS to increase the strength of the signal delivered at the destination [5]. In reality, RIS has a lot of potential in terms of attaining a broad range of attractive features that will help 6G achieve significant efficiency gains, such as:

- **Coverage Elongation:** By constructing a virtual line-of-sight (LoS) link to avoid signal obstruction between nodes, coverage can be extended to accommodate inter-connectivity and super duper data rates.
- **Interference Reduction:** By effectively nullifying interference, interference reduction can improve the user's QoS, while reducing co-channel interference and improving signal receipt strength.
- **Localizing Advancement:** By providing controlled reflecting signals and functioning as the central node for localized sense, location efficiency can be improved for vertically and commercial processes.

It's in stark comparison to prior strategies that improved wireless communications by manipulating the transmitter or receiver's settings. It can be readily affixed to walls, buildings, or interior ceilings due to RIS. It is simple to incorporate into an existing network because of its flexible replacement, deployment, and scalable cost. It is a key enabler technology for providing the goal of 1 THz operating frequency and data rate of 1 Tb/s.

RIS may be designed to shape the channel by regulating the back scattering, direction of signal , and by electromagnetic waves scattering , which can be used to efficiently reduce D2D interference and meet high data speeds. In principle, the electrical size of the unit reflecting elements deployed on RIS is between $\lambda/4$ and $\lambda/8$, where λ is a wavelength of Radio-Frequency (RF) signal [6] . In comparison to traditional antenna-array systems, a RIS can deliver more dependable and space-intensive communication As a result, the usage of RIS for future 6G wireless networks has been identified as a viable technology. RIS is commonly used for two types of wireless networks: a) as an RF chain-free transmitter; and b) as a passive beam former acquired from source) to the target destination. Some of the potential benefits of RIS are:

- **RIS assistance B5G/6G Networks:** Mobile Networks with RIS can affect several elements of wireless network,such as throughput, bandwidth, QoS restrictions and security of physical layer. In a mobile network, D2D links must share same spectrum resources as mobile links. RIS can modify element phase shifts and provide advantageous beam steering, reducing aggravated interference produced by D2D connections.

- **RIS-aided MEC networks:** Automatic household appliances, smart mobility, automated driving, smart health monitoring systems, intelligent transportation, industrial automation, and emergency management are all possibilities for the upcoming IoT network. In terms of computing capacity and resource allocation, MEC is a feasible option. A RIS-assisted MEC system can greatly outperform a traditional MEC system that does not use RIS.

- **RIS-aided mm-Wave:** mm-Wave and Terahertz transmissions are intriguing alternatives for rate-hungry wireless systems such as online games and virtual worlds, because to the abundance of available bandwidth in the high frequency band. When direct path between BS and user are obstruct, RIS in conjunction with mm-Wave networks provides an operating channel to establish communication. Furthermore, in the event of poor service conditions, the RIS passive beamforming gain can increase network performance, allowing for dependable and energy-efficient communication at a low cost.

- **RIS-aided UAV networks:** By adding RISs, UAV-enabled wireless communication is enhanced. The capacity of RIS to destructively integrate signals can be used to reduce the Inter-cell interference that develops in future UAV-authorize networks due to prevailing channel capacity between BS and UAVs in nearby cells.
- **Other applications:** RIS can be used in conjunction with technologies like OFDM, NOMA, MIMO, SWIPT to increase the network capability. RIS will help these wireless technologies to increase their spectral performance and coverage area while saving money and energy.

RIS can boost the average attainable rate and cut the data transmission time in half In general, when direct connections have poor quality, a RIS automatically configures the wireless environment to aid transmissions between the sender and the receiver. Currently, throughput has received a lot of attention after the concept of RIS as a viable technique for cellular networks beyond 5G and to ensure QoS transmission to each mobile user by maximizing the throughput and number of admitted users in a network. There exist a few recent works on joint user and throughput maximization in RIS-assisted networks.

1.3 Resource Allocation:

For successful and reliable communication, each user needs better resources Ideally, we would like to jointly distribute the various wireless resources in the network, i.e., power, spectrum, back haul, cache,throughput, energy efficiency and computation resources to maximize the aggregate data rate in the network. RIS is the primary solution in deploying the 6G and In resource allocation for wireless communication networks.

1.4 Motivation

In response to the dramatic increase of use of smartphone devices and technologies and to the ongoing development of autonomous vehicles and Internet of Things (IoT) devices. RIS is considered as a promising technology for 6G wireless communication. Using the advantages of RIS to configure the wireless environment smartly it can increase strength of the signal delivered at the destination. The present growth of mobile and smart devices and the need for higher rate data transmission on mobile networks in the near times motivated us to further study about RIS. RIS aided communication should be human-centric, which means that traditional communications systems will continue to play a prominent role in 6G so we have to enhance the coverage of a network rapidly and in a cost effective manner and RIS can yield this since they need neither analog-to-digital/digital-to-analog converters nor power amplifiers.

1.5 Shortcomings of Existing Literature

Some early-attempt studies have studied the system model described in this research, and after reviewing their literature we observe the short comings in the existing technique.

In [7] an iterative method is used which can quickly determine the feasibility of the information rate and these are BCD and MN method. The optimized RIS can improve the feasibility probability by 40% to 50%. By using this technique but the main drawback of using BCD is that it may take longer time for convergence and it can be complicated. The computational complexity of BCD and MN is much higher. To optimize the feasible sum rate for all the users the authors used AMO (alternating manifold optimization) and SCA (successive convex approximation) methods In terms of sum-rate, the suggested alternating optimization methods surpasses state-ofthe-art techniques, but the complexity of each phase is the biggest disadvantage of SCA[8].

In [9] the GD method, local search algorithm is used for the task of enhancing the weighted rate of the D2D network. Due to frequent updates, in Gradient descent method the steps taken towards the minima are very noisy due to which, it may take longer time to achieve convergence to optimal solution. SCA, SDR method and swap matching-based Algorithms are used to enhance both system throughput and efficiency. The SDR method converges slowly and Computational. Complexity of proposed techniques has not discussed[10] .In [11, 12, 13, 14, 15] many techniques have been discussed to enhance the throughput and data rate for a network but the problem associated with these are there longer span time and higher computational Complexity.

In [16] the formulated minimal SINR maximization issue is devised. The two concepts for changing the reflective surfaces based on SDR and SCA has been proposed, the suggested algorithm is unable to obtain the static solutions, and the complexity is somewhat high, especially for large-size RIS.

With aim to enhance the rate has been studied, the authors used SDR technique along with STM method. The main drawback with STM method is that it experience small loss in terms of performance of system[17].

They suggested the alternating weighted MMSE method for Maximizing throughput for MIMO System but this method is not a practical solution. Indeed, the iterative nature of the algorithm combined with complex operations such as matrix inverses at every iteration lead to significant delays which render the solution meaningless in a fast fading channel [18].

The CMA method is used to enhance the cell coverage. The drawback in this method is that as the received SNR is negatively associated with the distance between BS and the RIS, cell coverage declines [19]. In an effort to reduce the overall mean squared error of network (MSE) they used to create , RISMA and Lo-RISMA, that can either find simple and efficient solutions but it may take longer time for convergence [20]. In [21] The problem of maximizing system throughput was achieved by the design of the power allocation and reflection coefficient method. The problem associated with this

method is that it takes longer span time.
The main problem associated with the BCD,SDR and SROCR technique discussed in [22]is its computational complexity. In order to achieve better SINR Dinkelbach Based RA is used. Dinkelbach's algorithm is introduced as an efficient method for solving large scale MINLP problems but the drawback associated with this technique is higher cost of computation [**?**]. In [**?**] to get a high-quality solution, a JPPBO technique has been put forwarded. This algorithm uses extensive computational resources.

1.6 Problem Formulation

To the best of our knowledge, the existing work lack the joint user and throughput maximization problem, also all existing techniques could not either completely cater the computational complexity and convergence analysis or lagged effective resource allocation models, the time span was longer to achieve the desired results.
After examining literature review it is concluded that existing techniques could not either completely tackle the computational complexity and convergence analysis. The time span for some existing techniques was long. Despite of this most models considered the fixed location of RIS, whereas our proposed model considers the random location of RIS which gives flexibility and reliability to our proposed system model.

1.7 Contributions

The main contribution of this thesis are as follows.

- We formulate the joint user and throughput maximization problem for RIS based beyond 5G/6G wireless networks subject to power, RIS phase shift and QoS constraints. The RIS-assisted multi-user communication system is investigated, in which a Base Station (BS) equipped with multiple antennas supports numerous mobile users using only a single antenna.

- We introduced the Mesh adaptive direct search (MADS) algorithm to obtain the global optimum solution to the given problem. The issue of throughput maximization is a kind of mixed integer nonlinear programming (MINLP) that can be handled with MADS. The suggested algorithm has a substantially lower complexity than the traditional technique.
- User association and throughput are optimized so that the majority of users can be handled while the network's QoS is improved.
- Extensive simulations are used to test the effectiveness of the suggested algorithm, which delivers the best optimal answer and effectively distributes power and resources to the user.
- By using different network parameters and by considering RIS reflection factors, we contrast the effect of our proposed model,with the model without using RIS in a wireless network and by comparing other algorithms performance with our proposed algorithm.
- The performance of Proposed Model is benchmark for our algorithm. The simulation results indicate that RIS can improve the throughput of network significantly, even for the scenario where the direct links of users are weak. Besides this, the results suggested that our proposed algorithm converges quickly and improves efficiently the joint user and throughput of an RIS assisted network.

1.8 Thesis Outlines

The rest of the thesis is organized as follows:

- Chapter 2 describes Literature Review which contains recent study of RIS that have already been carried out into different categories and also highlights the difference between recent work and our proposed work of RIS and its existing literature's shortcomings and frequency limited existing literature's problems.

- Chapter 3 describes the system model and the proposed technique for joint user and throughput maximization in RIS assisted networks that guarantee the higher system throughput and user maximization as compared to conventional communication network.
- Chapter 4 presents the numerical simulation and discussion to illustrate the applicability and efficiency of the proposed solutions.
- Chapter 5 presents the conclusions and future research directions of our work.

Chapter 2

Literature Review

This chapter illustrates the essential background information on which the presented work is formed: in particular, sections 2.1 recalls the needs of the KPIs to be optimized in this thesis, sections 2.2 provides the general idea of resource allocation and its parameters. It also provide an insight how we can efficiently distribute the resources in wireless communication network. Several performance indicators, including as throughput, fairness, and QoS, can be optimized with tolerable complexity using the resource allocation policy. Section 2.3 discusses the literature related to capacity maximization, 2.4 recalls the literature related to latency minimization and of other related work regarding RIS and section 2.5 recalls the literature related to throughput maximization in RIS assisted network. Section 2.6 contains some of the constraints common in all the literature. Finally, the summary of the literature is concluded in the table at the end of this chapter.

2.1 Background

As discussed earlier that as commercialization of 5G communication networks progresses, technologies for next-generation (i.e., 6G) networks are also being investigated to accomplish communications that are speedier and more dependable. To increase the capacity and date rate many wireless technologies have been suggested therefore joint user and throughput maximization in RIS assisted network, has emerged as a significant metrics for wireless network. The aim of throughput maximization is to save bandwidth and reduce power consumption.

Some early-attempt studies have studied the system model described in this research, in which diverse objectives are considered whereas several investigations imply that all associated channels' complete channel state information (CSI) is available. A few articles have surfaced in the literature based on RIS-assisted networks that maximize the throughput and admitted users of the network.We examine both relevant studies in throughput maximization and user maximization in RIS assisted wireless communication networks because our study integrates both users, throughput maximization, and wireless communications assisted by RIS.

2.2 Resource Allocation Management

To effectively execute network resources, future wireless networks will require Joint User And Throughput Maximization In Reconfigurable Intelligent Surfaces (RISs) Assisted Beyond 5G/6G Networks. Resource allocation rules are at the heart of wireless communication systems, since they strive to ensure the requisite QoS at the user level while also assuring effective and optimized network operation to maximize operators' income. In wireless communications, resource allocation management can cover a wide range of network functions, including scheduling, transmission rate control, power control, bandwidth reservation, user association control, transmitter assignment, handover, throughput, energy efficiency and computation resources to maximize the achievable rate in a wireless network. [4]

As discussed earlier RIS is a technology for allocating resources for wireless systems that can be reconfigured and have gained a lot of attention in academics and industry recently.The idea of resource allocation is demonstrated in the figure 2.1.

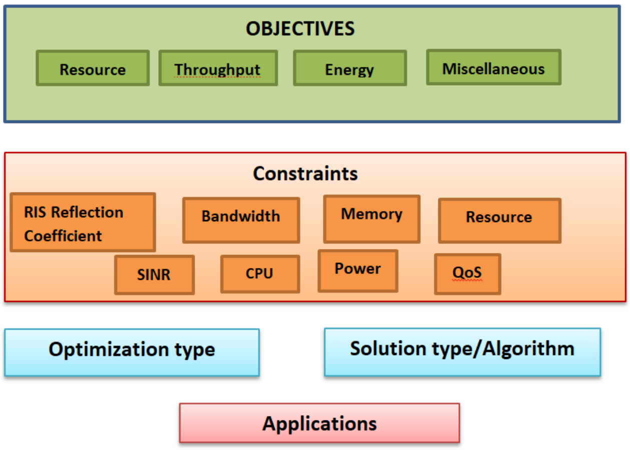

Figure 2.1: Resource Allocation Model Illustration.

2.3 Capacity Maximization

In [7] the RIS is adjusted by the edge server to increase its earnings and rate of MEC Network while preserving the benefits of computation offloading for Mobile Devices and ensuring that each MD receives a unique data rate.The optimization type is non-convex. To solve this, the authors proposed an iterative method that can quickly determine the feasibility of the information rate needs and discover the best solution which is the BCD and MN method, The RIS-assisted techniques can greatly enhance the information rate by the BS to MD while also successfully increasing the edge server's profit. The main drawback of using BCD is that it may take longer time for convergence and it can be complicated. The computational complexity of BCD and MN is much higher.

In [8] a millimeter-wave (mm-Wave) non orthogonal multiple access (NOMA) systems with RIS is being studied. The objective is to optimize the feasible sum rate for all the users subject to minimum transmission power and rate constraints. The author's design an alternating optimization approach to handle this non-convex issue. AMO and SCA methods are used to solve this problem. The transmit signal in mm-Wave NOMA communications frequently suffers from substantial path loss, which is solved via RIS. In terms of sum rate, the suggested alternating optimization methods surpass state of-the-art techniques, The performance improvements of RIS assisted NOMA systems could be boosted by carefully selecting the placement of RIS. The complexity of each phase is the biggest disadvantage of SCA technique.

In [9] The task of enhancing the weighted rate of the D2D network is developed by optimizing all link transmit powers as well as elements of discrete phase shifts. To produce a sub-optimal solution for the non-convex issue, the authors in that paper proposed an alternate optimization method. By using number of RIS elements based on providing multiple signals to RIS a bad channel could be converted into a good channel condition.By using proposed algorithms performance of the system improved. When the threshold is smaller the GD method may take longer time to achieve convergence to optimal solution.

In [10] multi-cell RIS-assisted NOMA networks is investigated, to improve the wireless service and to enhance the sum rate subject to QoS and conditions for SIC decoding and transmission power constraints is proposed in that paper. The suggested resource allocation algorithms like SCA and SDR outperform the benchmarks. The proposed techniques have the potential to greatly enhance both system throughput and efficiency but the main drawback associated with the SDR method is that it converges slowly and computational complexity of proposed techniques has not discussed.

In [11], the RIS-assisted SWIPT MIMO systems WSR maximizing problem has been discussed. In this authors devised an algorithm known as the BCD for optimizing the pre-coding transmit matrices regarding BS and in the RIS the matrix of phase shifts in different ways. This algorithm ensures that it is, at the very least, locally optimal. Using the benefits of RIS improves the SWIPT system's performance, and the suggested method converges quickly, making it ideal for practical implementations but the detriment of this BCD method that it may take longer time for convergence and it can be complicated.

In [12], both the ideal and imperfect CSI configurations are studied in the RIS-assisted multi-user downlink MISO system. However, because the RIS is passive and lacks a channel, flawless CSI is not always attainable. This problem is solved using the BCD and is applied to the faulty CSI setup, and the average WSR is maximized using the stochastic SCA technique but the main drawback of BCD approach is that it is not always convergent to the best solution. Near the ideal, it may be slower and the complexity for both methods is somewhat high, especially for large-size RIS.

In [13], a viable RIS scenario with its accompanying limits, the asymptotic optimal of achievable rate in a down-link RIS system is investigated. The authors presented a modulation method that results more realistic sum-rate than a traditional approach without RIS. They also devised a resource allocation technique it can manage the trade off between individual performance fairness and the effectiveness of the network. The proposed technique satisfy the minimum rate requirement for each user and system performance also improves while number of users increases but the weakness of this technique is its computational complexity. The future of this work will be to entail applying our findings to more realistic circumstances, like the MIMO OFDM network.

In [14], the least weighted average of the coordinated beamforming at the transmitter and the reflected beamforming on the RIS side is maximized. RIS will be used to help with multi-cell communication in this paper. Owing to the interaction among these vectors, the formulated minimal SINR maximization issue is devised . The authors suggested efficient AO-based algorithms. In particular, the authors made use of SOCP to improve transmit beamforming. The two concepts for changing the reflective surfaces based on SDR and SCA have been proposed. The SCA guarantees convergence technique for improving reflecting beamforming concerning RIS. The SDR technique yields pretty decent results; however, the suggested algorithm is unable to obtain the static solutions, and the complexity is somewhat high, especially for large-size RIS.

In [15], the OFDM assisted with the RIS model intending to enhance the rate has been studied, and the authors suggested a new transmission protocol that will shorten the time for data transmission. The maximum data transmission rate that can be achieved by RIS has also been maximized with the help of proposed algorithms. The SDR technique along with STM is used. The SDR and STM algorithms are efficient and provide optimal solution, STM method provides better low complexity compared to SDR but the main drawback is that it experiences a small loss in terms of performance of the system.

In[16], the fundamental challenge in the resource allocation (RA) problem in HetNets is determining power allocation and user association mechanisms to achieve better SINR has been discussed. By intelligently combining channels, it is highly desirable to investigate the usage of RIS to give more pathways and develop stronger combined channels. Two computationally efficient RA techniques for maximizing the transmit power at the downlink in an IRS-enabled HetNet were given, Under the single-user system, the SBS and phase shifts at the RIS and the instances involving many users, respectively. As the bigger reflecting element offers more reflecting signals, the overall data rate attained by the SCUs rises. The suggested technique i.e Dinkelbach method may increase the overall data rate of SCUs while maintaining QoS at macrocell user (MCU). The suggested technique is proposed as an effective way for addressing extensive MINLP issues, but it has the shortcoming of a greater computational cost.

2.4 Latency Minimization And Other Related Work

In [17] the latency-minimization issue was defined based on this model, subject to RIS phase shift constraint. To address this non-convex problem, the BCD method is used, and then low-complexity iterative algorithms MM and MN methods are used to optimize the computing and communications settings separately. The authors with the simulation results proved that our RIS-assisted MEC system can outperform a traditional MEC system that does not use RIS. A design based on the minimization of energy for RIS-assisted MEC systems will be designed as part of our future study.

In [18] The problem of learning error minimization is formulated. The very non-convex optimization problem produced by the nonlinear learning error was addressed with efficient techniques i.e AO, ADMM and SCA algorithms. The SCA method is used to solve the problem of power allotment. Th AO algorithm converges faster which is moderately coherent while ADMM converges slower to the optimal solution. In [19] using one BS and one UE, the coverage of a downlink RIS-assisted network has been studied. By evaluating the orientation of RIS and horizontal distance, the cell coverage can be increased. The CMA method is used to enhance the cell coverage. The authors analyzed that the RIS indeed be positioned vertically about the BS's direction. In comparison to the random technique, it provides more mobile coverage. The drawback of this method is that as the received SNR is negatively associated with the distance between BS and theRIS, cell coverage declines, Therefore we should put a modest distance between the RIS and BS.

In [20] they investigate a scenario for MISO user equipment's (UEs) using RIS to deal with non-line-of-sight paths. To reduce the overall mean squared error of the network (MSE) they used to create, RISMA and Lo-RISMA, that can either find simple and efficient solutions but it may take longer time for convergence. Besides this also looked at the benefits of RIS in dealing with NLOS difficulties in crowded urban contexts, where huge IoT deployments are predicted shortly.

2.5 Throughput Maximization

In [21], the authors look into the trade-off between the performance of network and energy resources in downlink transmissions for the RIS-NOMA model. The problem of maximizing system throughput was achieved by the design of the power allocation and reflection coefficient method that is both efficient and effective. When the RIS is close to the user, there exists a strong relationship between RIS and the user. As a result, by carefully selecting the location of the RIS, the system's performance can be considerably improved.The problem associated with this method is that it takes longer span time.

In [22] the authors studied, achieving a commutation between complexity and performance in multi-user RIS-assisted wireless power communication networks (WPCNs). This paper looked at a wireless powered hybrid NOMA and TDMA network that was aided by the RIS, the throughput of the network has been maximized. An efficient algorithm was proposed to tackle the mentioned tough problem using the Block Coordinate Ascent (BCA) , SDR, and SROCR techniques. It outperforms other benchmark algorithms in terms of throughput. It's also been discovered that grouping users into multiple clusters produce more independency for the joint RIS beamforming and allotment of time. The main problem associated with the technique discussed in this paper is its computational complexity. It can be carried out on the BS, with the results being communicated to the RIS and users through a secure control line.

Following a thorough examination in this section and reviewing Table 2, the subsequent research shortcomings discovered in previous work are presented to the best of our knowledge:

- The existing work lacks the resource allocation model for throughput maximization, power allocation and user maximization at the same time for RIS assisted wireless network.
- The existing techniques could not either completely cater the computational complexity and convergence analysis or lagged the effective resource allocation models,the time span was long to achieve the desired results.
- Most models considered the fixed location of RIS as compared to random location of RIS which does not gives flexibility and reliability to the system.

It can be determined that the present growth of mobile and smart devices and the need for higher data transmission on mobile networks in near times motivated us to further study about RIS, and As a result of the gaps discovered in previous research, this study looks at joint user and throughput maximization problem in RIS assisted Network. RIS transforms uncontrollable wireless channels into a smart radio environment that can be controlled. Motivated by the benefits of RIS we investigated a multi-user communication system. The objective of the proposed work is to maximize the joint user and throughput of a RIS-assisted network in terms of resource allocation and ensure QoS for each user.

2.6 Common Objective Functions and Constraints

Some frequent goal functions and constraint functions in network optimization issues can be derived after reading the literature survey in the previous section. The following are some of the most popular objective functions:

- **RIS Phase shift and Amplitude:** To fully utilize the ability of RIS to intelligently configure the wireless environment, we consider that the reflecting amplitude can take values between $\{0,1\}$ and the reflecting angle can take values between $\{0,2\pi\}$.
- **QoS Constraint:** It ensures that the user's data rate is accurate and must be greater than or equal to the operator-defined minimum threshold. If the data rate cannot be provided due to channel conditions, greater than or equal to the threshold then the user will be denied access to the specified BS.
- **Transmit Power Minimization:** This limitation ensures that the overall transmit power of the BS should be less than or equal to the power of all connections of the BS. Consequently, the user's transmit power must be lower than or equal to its overall transmit power.
- **Associated Users:** Associated Users constraint for communication is that, a single user must be connected to a single BS. Typically, it is a binary restriction

with a value of {0,1}.

Summary of the literature review is given in table 2.1:

Following a thorough examination of Literature Review and reviewing Table 2.1, the subsequent research shortcomings discovered in previous work are presented to the best of our knowledge:

- The existing work lacks the resource allocation model for throughput maximization, power allocation and user maximization at the same time for RIS assisted wireless network.
- The existing techniques could not either completely cater the computational complexity and convergence analysis or lagged the effective resorce allocation models,the time span was long to achieve the desired results.
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Table 2.1: Study Table

Ref	Objective	Constraints	Optimization type	Throughput maximization	U.A.	PA	RIS	Multi Antenna BS	DL	Solution/Algorithm
7	Maximize earning and rate to MDs	Information rate, SINR	Non-Convex				✓	✓	✓	BCD, MN
8	Maximize the achievable sum-rate	minimum rate, transmission power, RIS phase shift	Non-Convex	✓		✓	✓	✓	✓	AMO, SCA
9	Maximize the total system rate	QoS, SINR, power, discrete phase shift	Non-Convex (MINLP)	✓		✓	✓			GD method, local search algorithm, sum rate maximization algorithm.
10	Maximize the achievable sum rate and to improve coverage in NOMA network	Max power, QoS	Non-Convex (MINLP)	✓	✓	✓	✓		✓	SCA, SDR method and swap matching-based Algorithms
11	Maximize WSR of RIS and enhance performance of ERs	total power, phase-shift, harvested-power	non-convex	✓			✓	✓	✓	BCD Algorithm
12	Maximize the WSR of mobile users	QoS, transmit power	Non-Convex	✓			✓	✓	✓	WMMSE-Algorithm, BCD, SCA Methods
13	Maximize system sum-rate in downlink system	Transmit-power, RIS Control Link Capacity, SINR	Non-Convex	✓		✓	✓	✓	✓	Reflection Phase Selection Algorithm, RA Algorithm
14	Maximize the minimum weighted received SINR at users	transmit power at BSs, reflection constraint at RIS	Non-Convex				✓	✓	✓	SOCP,SDR ,SCA Methods
15	Maximize the average achievable rate	Power, unit-modulus reflection coefficient constraints	Non-Convex (MINLP)	✓		✓	✓	✓		ATP, STM, SDR Methods
16	Maximize SINR and sum rate of SCUs	Transmit-Power, SINR, phase shifts at the RIS	Non-Convex	✓		✓	✓	✓	✓	Dinkelbach Based RA for the Single-user RIS HetNet, Iterative Based RA for Multiuser Algorithm
17	Minimize weighted computational latency	edge computing capability, RIS phase shift	Non-Convex				✓	✓		BCD, MM, MN
18	Maximize the learning performance	Transmit power, SINR, RIS element constraint	Non-Convex			✓	✓	✓	✓	AO, SCA, ADMM based Algorithms
19	Maximize the cell coverage in downlink network	transmit power, reflection coefficient at RIS	Non-Convex				✓			CMA
20	Minimize the SMSE of RIS-aided systems	Phase shift at RIS, Power	Non-convex				✓	✓	✓	RISMA, Lo-RISMA Algorithm
21	Maximize System Throughput	Transmit Power Budget, Reflection Coefficient at RIS	Non-Convex	✓		✓	✓	✓	✓	Novel Resource Allocation Algorithm
22	Maximize the throughput of the network	Reflection Coefficient at RIS, transmit power and information transmission	Non-Convex	✓		✓	✓		✓	SROCR, RIS Reflect Beamforming and Time Allocation Algorithms
This Work	Maximize Joint user and throughput	Power, QoS, Phase Shift at RIS	Non-Convex (MINLP)	✓	✓	✓	✓	✓	✓	MADS

Chapter 3

System Model And Proposed Technique

3.1 System Model

This thesis considered a wireless network model with the base station (BS) equipped with multiple antennas and K single-antenna mobile users and analyses a RIS-aided multi-user MISO communication system. The communication link between mobile users and the BS is assisted by RIS, as shown in Fig 3.1. We suppose that all of the channels are flat-fading in a quasi-static manner. As a result, the BS can get channel status information (CSI). Let's assume the BS has$M$ antennas and the RIS has$N$ reflecting elements. The wireless channel between the BS and users can be LOS or non-line-of-sight (NLOS). Assuming the direct link is weak between BS and users so that the efficiency of RIS could be observed, the CSI is accessible that tells about the characteristics of signal transmitted from transmitter to receiver and also we assume that no beamforming is done at the transmitter side. The channel between the BS to the *k-th* is represented by $h_{d,k} \in \mathbb{C}^{1\times M}$, and similarly, from the RIS to k-th user, as well as between the BS and the RIS is represented by, $h_{r,k} \in \mathbb{C}^{1\times N}$ and $G \in \mathbb{C}^{M\times N}$,respectively. Here $\mathbb{C}$ represents the set of all complex numbers. Proposed system model is shown in

Fig (3.1). As shown in the diagram the signal is transmitted from the BS to the RIS and then RIS will modify the incident signal by changing the phase shift and the reflected signal is then travel to the mobile user

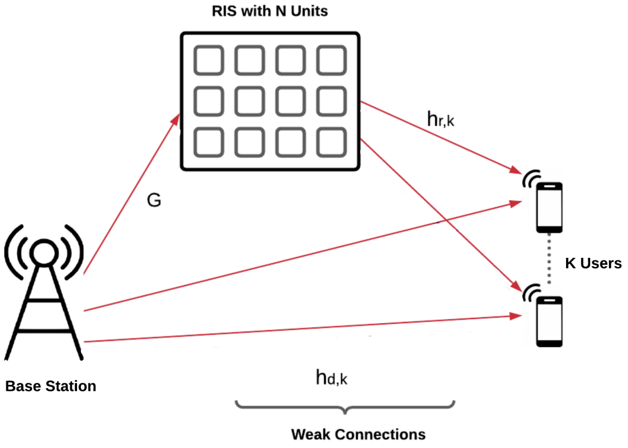

Figure 3.1: System Model Illustration.

3.2 Resource Allocation Model

The proposed model accommodates for downlink, RIS based network. A wireless network consisting of BS with M number of antennas and K number of mobile users. The BS sends the signal to RIS having N reflecting elements at the RIS and then to the users as the direct link between the users and the base station is weak. The phases of incoming signals could be changed with the help of the RIS system of passively reflective elements, which aids communication. Space wave communication or near-line-of-sight (NLOS) wireless channels connect the transmitters and receivers. We look at a RIS aided model that can intelligently customize channel configuration by adjusting the reflecting elements of phase shifts. By considering a RIS with N elements or units, the phase shift matrix of a RIS as a diagonal matrix $\phi \in \mathbb{C}^{N\times N}$ is represented by [7]

$$\Phi = diag(\phi), for \phi = [k_1 e^{j\theta 1}, .., k_N e^{j\theta_N}] \tag{3.2.1}$$

θ_N and k_N are the reflection coefficient of a RIS where k_N denotes the reflection amplitude and θ_N, the phase shift of *n-th* RIS element respectively, and where N= {1,2,..., $N\}$. Given that the system is subjected to quasi-static flat fading channels. The BS manipulates the reflected signal by changing the amplitude and phase of the RIS elements. Here x, $h_k(\phi)$, $s(\phi)$ represent transmitted signal, channel equations, and received signal respectively. While $h_k(\phi) \in \mathbb{C}^{M\times 1}$.

$$x = \sum_{k\in K} p_k s_k \tag{3.2.2}$$

$$h_k(\phi) = G\Phi h_{r,k} + h_{d,k} \tag{3.2.3}$$

$$h_k = h_k(\phi)\zeta G_0(\frac{d_0}{d})^{\alpha} \tag{3.2.4}$$

$$s(\phi) = \sum_k x h_k(\phi) + N_0 \tag{3.2.5}$$

At the receiver, $N_0 \in \mathbb{C}^{M\times 1}$ represents the white Gaussian noise (AWGN) a, $N_0 \sim \mathcal{CN}(0, \sigma_0^2)$. The BS uses h_k as the channel gain between the kth user and the BS to decode signals associated with the k-th user. $h_k(\phi)$ is a Rayleigh flat fading channel. G_0 be the antenna gain and $\zeta 10^{\frac{\zeta}{2}}$ represents log-normal shadowing, where ζ denotes zero mean Gaussian random variable with σ standard deviation and the channel gain is modeled as shown in eq (3.1.4). The signal-to-interference-plus-noise ratio (SINR) is given as

$$\gamma_k = \frac{p_k h_k}{N_0} \tag{3.2.6}$$

The allowable information rate of the k-th Mobile user r_k is calculated using Shannon's formula.

$$r_k = \log_2(1 + \gamma_k) \tag{3.2.7}$$

The system's overall data rate R_k is calculated as follows:

$$R_k = \sum_{k=1}^{K} a_k r_k \tag{3.2.8}$$

A Binary Indicator is used that tells that the user k is connected or not to the RIS at a time Subject to

$$a_k \in \{0,1\}, \forall k \in K \tag{3.2.9}$$

where K = {1,2,..., K}.

3.3 Problem Formulation

The number of transmitted bits over a period of time or the amount of data flow down a network. Throughput is measured in *bits/sec*. In differentiation to conventional communication model, in which typically the main aim is usually to optimize throughput or energy efficiency in a wireless network. As compared to conventional methods, This paper formulates a problem that maximizes the joint user and throughput, based on mode selection in RIS assisted Network. Our work generalizes the system model of multi-input-single-output (MISO) of a RIS-assisted wireless network.
First and foremost, we want to increase the rate or throughput. The problem at hand can be stated as follows:

$$Throughput = \max_{p,a_k} \sum_{k=1}^{K} r_k \tag{3.3.1}$$

Let y denote the admitted users in a simulation then, Mathematically joint user and throughput maximization problem can be written as:

$$Jointuserthroughput = \frac{y}{K} r_k \tag{3.3.2}$$

We define a utility function that mathematically shows the joint user and throughput maximization problem as follows:

$$F(p,a_k) = \frac{y}{K}\sum_{k=1}^{K} r_k a_k \tag{3.3.3}$$

Utility function accompanied by constraints can be stated mathematically as:

$$\max_{p,a_k,\theta_n,\phi_n} F(p,a_k) \tag{3.3.4}$$

subject to following constraints:

$$C1 : \sum_{k=1}^{K} a_k \leq 1, \forall k \in K \tag{3.3.5}$$

$$C2 : p_k \geq 0, \forall k \in K \tag{3.3.6}$$

$$C3 : \sum_{k \in K} p_k \leq P_{max} \tag{3.3.7}$$

$$C4 : p_k \leq a_k P_{BS} \tag{3.3.8}$$

$$C5 : k_n \in \{0,1\}, \forall n \in N \tag{3.3.9}$$

$$C6 : \theta_n \in \{0,2\pi\}, \forall n \in N \tag{3.3.10}$$

$$C7 : |\phi_n| \leq 1, \forall n \in N \tag{3.3.11}$$

$$C8 : \sum_{k \in K} a_k r_k \geq \sum_{k \in K} a_k R_k \tag{3.3.12}$$

Under the constraints C1 to C8, the goal of function in Eq. (3.3.4) is to maximize joint user and throughput. C1 is the mode selection constraint (RIS selection constraint). Constraint C2 assures that each user has a minimum power, indicating that the power of the*k-th* user must be greater than zero to ensure communication. The maximum transmits power budget is P_{max}, which is larger than the power of the *k-th* user connected to the base station, According to constraint C3, If a user is not attached to RIS then no power is assigned to user, C4 assures that the if the user is connected then power is at high value. C5 and C6 are the k_n and θ_n representing the n-th RIS unit's reflecting amplitude and angle, respectively for n $\in$ N . Constraint C7 is the RIS phase shift constraint and C8 shows that the rate of each user must be greater than the minimum required rate. To effectively use the potential of the reflecting surface to change the wireless environment, we consider that the reflecting amplitude and angle can both be between $\{0, 1\}$ and $\{0, 2\pi\}$. The condition C7 holds because $\phi_n = k_n e^{j\theta n}$ comes from Eq (3.1.1). Besides, in C8 it is to ensure that each MD can fulfill a fundamental communication, the information rate for each MDs should be no less than a requirement r_k. This model, which will be used in our paper, was adopted (with optional changes) in [7].

3.4 Proposed Technique

The problem in 3.3.4 is extremely complicated and difficult due to the non-linear behavior of binary (mode selection, i.e., a_k, integer (users admitted), as well as the non-convex group of rate and power constraints. The outcome of the analysis approach is NP-hardness as the number of binary variables and the values of integer variables rises. Several general-purpose search algorithms are employed in various situations to tackle optimization problems with continuous and discrete variables and nonlinear functions. One of them is the exhaustive search algorithm. It produces and inspects all data configurations in a wide state space that is certain to include the needed solutions, and if you can wait long enough, you will succeed. While exhaustive search is theoretically straightforward and generally successful, it is sometimes regarded as unsubtle when it comes to problem-solving. It fails if we have to seek a large set to analyze because it takes a much longer time. Rather than being time-bound, the exhaustive search is frequently memory-bound. Due to the enormous number of variables, it is unable to identify a globally optimal solution. Hence the Mesh adaptive direct search (MADS) algorithm is proposed to find the optimum global solution and as well as a solution to this problem in this section [23]

.

3.4.1 Algorithm Description

The Joint user and throughput maximization problem belong to a special class of Mixed-integer nonlinear programming (MINLP). The MADS algorithm is used to solve the proposed optimization problem. The MADS algorithm is a directional direct search technique that generalizes the Generalized Pattern Search (GPS) method. The utilization of dense sets of directions rather than a finite number of fixed directions is MADS' key advantage over GPS. This technique iteratively maximizes the goal in equation 3.3.4 by using exploration and exploitation. It's an iterative algorithm that's part of the Derivative-Free Optimization techniques.

It examines the sample points using a mesh, which is a discretization of the space of variables. It controls the resizing and refining of the mesh while doing a robust search on the column of underlying meshes in domain space. Every iteration of the MADS algorithm seeks to enhance the previous renowned solution by beginning the simulation at a limited number of sample points.

A MADS algorithm is divided into two steps for each iteration:

- the SEARCH step
- the POLL step

Trial points can be produced anywhere on the mesh using the search. The poll creates a set of trial points based on the poll directions. These directions get increasingly dense. All evaluated points are on a mesh, but the mesh can be adjusted each iteration. Each search step selects some points on the mesh to evaluate. If an improved point is found, MADS may jump directly to resize the mesh. If no better point is found in the search step, the poll searches for a better point within a fixed distance (the frame) of the current best point. If POLL somehow doesn't achieve in identify a better solution, the iteration will be labeled as failed. Resize the mesh up or down depending on success in the last iteration. Utilizing the Search and Poll steps, the goal of each iterate in MADS is to identify the minimum outcome amid certain sample points on a predetermined mesh of points. The algorithm is supported by a convergence analysis for non-smooth functions based on the Clarke Calculus. Initialization, SEARCH, POLL, and parameter update are the four basic phases of the algorithm. The MADS algorithm description flow chart is presented below [23].

3.4.2 Definition of Mesh

The use of two different kinds of mesh size parameters Δ_k^m and Δ_k^p. Each trial point is on the mesh at the k^{th} iteration of the algorithm

$$M_k = \bigcup_{x_k \in V_k} \{x_k + \Delta_k^m Dz : z \in \ N^{n_D}\} \subset R^n \tag{3.4.1}$$

where V_k is the set of points where the objective function has been computed since iteration k began, and $\Delta_k^m > 0$ is the parameter of mesh size parameter which determines the mesh coarseness, where D is a fixed matrix composed of nD columns that represent the directions. It must satisfy some conditions but generally matches to $[I_n$ - $I_n]$ with I_n the identity matrix in dimension n, and n_D=2n standard coordinate directions, i.e positive and negative.

3.4.3 Search and Poll Step

There are two major steps in every iteration are called search and poll. The search step allows for great flexibility and enhancements to the algorithm. It provides for the formation of a finite number of trial points and provides convergence as the points recline to the mesh. The first step known as search can be problem-specific: It allows a user

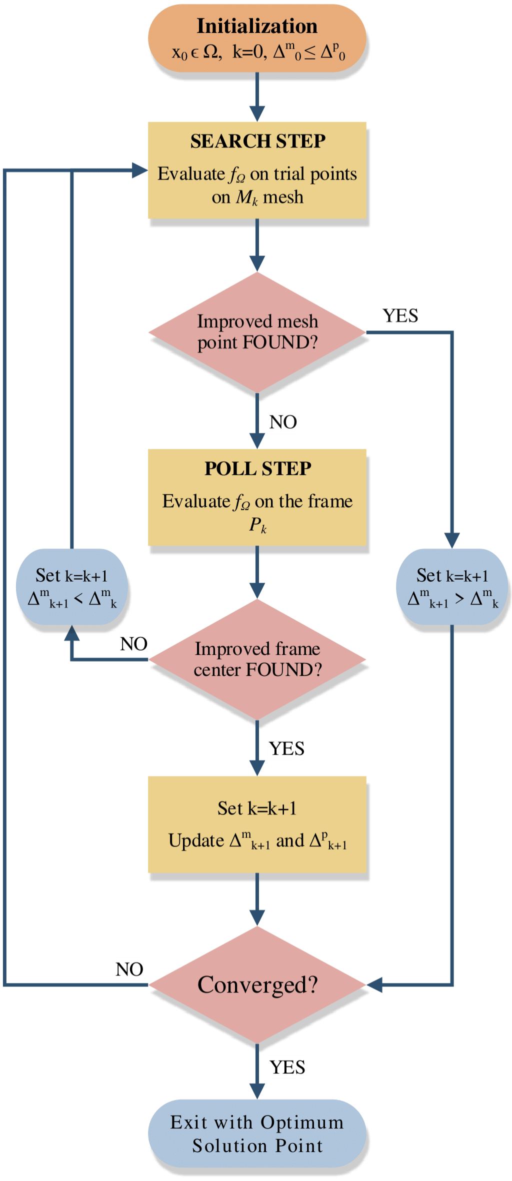

Figure 3.2: Flow Chart of Proposed MADS Algorithm

with some understanding of the best design that can utilize an appropriate search process to inject this information. The poll, the second step, conducts a local evaluation near the existing solution. The theoretical convergence is ensured by the poll step. It constructs a group of candidates P_k, the poll set, which is defined as:

$$P_k = \{x_k + \Delta_k^m d : d \in D_k\} \subset M_k \qquad (3.4.2)$$

where D_k is the positive polling direction set constructed by taking combinations of the directions set D. D_k is dependable on the implementation of MADS. The Δ_k^p is the poll size the parameter that specifies the maximum distance at which trial points of the poll from the current iteration can be generated x_k, which is also known as the poll center. When the poll observes an improved point it then moves x_k, the frame center to the newly upgraded point x_{k+1} for $k+1$ the upcoming iterate. The frame is said to be a *minimal frame* when the POLL step fails to find the better mesh point and then the corresponding frame center x_k is known as *the minimum frame center*. This results in mesh refinement, in which the mesh size is decreased to increase the mesh resolution for the next iteration: $\triangle_{k+1}^m < \triangle_k^m$. As the process progresses, the mesh and poll size parameters evolve independently, resulting in a dense collection of poll directions in the unit sphere once normalized, implying that potentially any direction can be probed.

3.4.4 Update Step

Following the search and polling phases, a final update is carried out. It determines whether the iteration was successful or not, and then adjusts the mesh and poll sizes accordingly. These sizes may be increased if the project succeeds, but they may be reduced if the project fails. The two parameters do not decline at the same rate: the mesh size decreases quicker than the poll size, allowing more and more alternative directions as the mesh thins. In the unconstrained case, a success occurs when the objective is improved (via a simple decrease condition) on the objective. With constraints, a filter-type algorithm called the progressive barrier (PB) is used. During the update step, the success or failure of iteration k is determined. An iteration is declared successful if a new non-dominated point is found. To terminate the algorithm, a variety of stopping criteria might be explored, like the threshold on the mesh size parameter Δ_k^m.

3.4.5 NOMAD

We use the (Nonlinear Optimization by Mesh Adaptive Direct Search) NOMAD solver to implement MADS algorithm to solve our problem. The MADS algorithm is implemented using the NOMAD technique. The MADS approach, which originated from the Generalized Pattern Search (GPS) method, may solve limited black-box optimization problems. MADS works by generating a sequence of meshes of varying sizes over the parameter space. After that, it does an adaptive search over the meshes to find a global optimum. By introducing dynamic scaling and several forms of MADS to be employed for specific sub problems, the NOMAD implementation of MADS improves the method.

3.5 Complexity OF MADS

The complexity of proposed algorithm is described in this section. The number of flops is used to determine the level of complexity. A flip is a legitimate floating-point operation. With an increase in the number of Users, the complexity of the exhaustive search algorithm grows exponentially. GPS is a useful algorithm, but the application of non-smooth analysis techniques revealed its limitations due to the limiting number of possible orientations.

MADS overcomes the GPS limitations of a finite number of poll directions. Unlike the exhaustive direct search technique, which has a time complexity of $O(n)$, the worst-case time required for an exhaustive search grows directly with the size of the collection. As a result, when working with very large collections, they can become unmanageable slow; however, the MADS algorithm can handle large collections present. MADS is a DFO method developed for black-box optimization with universal constraints.

The Exhaustive Search Algorithm (ESA) can find a globally optimal solution, but its complexity grows exponentially as the number of users in the network increases. If $\mathscr{C}$ signifies an algorithm's computational complexity and K denotes the number of users, then the complexity of ESA will be as follows:

$$\mathscr{C}_{ESA} = 2^{2K}$$

As MADS reduces the computational complexity by considering the problem as an unconstrained programming problem. MADS converges in a finite number of iterations, regardless of initial point knowledge or objective function gradient. The Complexity of MADS is given by:

$$\mathscr{C}_{MADS} = \frac{K^2}{\varepsilon}$$

where ε represents the distinction from global optimal solution.
In the case of OAA one flop is consumed for the first five steps of the algorithm. Step six, involving a while loop, consumes 2KM, steps seven, and eight consumes $4KM\beta$ each. Step nine consumes $2KM\beta$, step ten consumes two flops, step eleven consumes two, and step thirteen again consumes one flop. The total count of the flops F_{OAA} is given as:

$$F_{OAA} = 5 + 2KM + 4MZ\beta + 4KM\beta + 2KM\beta + 1 + 2 + 1$$
$$F_{OAA} \approx 2KM + 10KM\beta$$

K in the above expression represents the total number of users; M shows the number of antennas employed on the BS, represents the number of constraints for a given optimization problem, The complexity of the Outer Approximation Algorithm (OAA) is given as follows:

$$\mathscr{C}_{OAA} = \frac{K^2\gamma}{\varepsilon}$$

where γ represents the number of constraints. As a result, MADS' complexity is lower than OAA's, resulting in superior throughput performance.

3.6 Convergence Analysis

In contrast to standard optimization techniques, which depend on first or derivatives that aren't the same as the first derivative means of high order information to achieve thee most desirable solution, The MADS technique can tackle an NLP issue in which objective function is of nonlinear type and MADS does not require any knowledge concerning gradient of the objective function's. Unlike other methods, MADS is part of the direct-search method family, which actively works with the function values returned by the simulation without any knowledge of the problem's attributes. In the non-smooth and mixed variable sense, the convergence analysis, which uses the Clarke non-smooth calculus, generalizes the existing theory for MADS algorithms, and realistic conditions are developed for guaranteeing convergence of a sub-sequence of iterates to a suitably defined stationary point. As compared to GPS, MADS generates a restriction point in the tangent cone in which the derivatives according to Clarke is nonzero over all directions.

In [6], The proposed-MADS technique convergence proof is presented in its entirety. The method converges to the global point $\hat{x}$, where it meets all of the local optimal requirements. MADS convergence is entirely dependent on local features of the goal and constraint functions, not on the starting point x_0 globally, where it satisfies all the local optimal conditions.

The basis of convergence analysis assumes that $x_0 \in \ \Omega$, f(x_0) is finite, and that for all iterates, x_k produced by the MADS algorithm lies in a compact set.

1. MADS produces the poll and mesh size parameters which satisfy

$$\lim_{k\to\infty} \Delta_k^p = \lim_{k\to\infty} \Delta_k^m = 0 \tag{3.6.1}$$

The cost in terms of affability be exist in the analysis of convergence which is premised on the idea that the limitation of frame size (which functions similar to the poll size framework of MADS) approaches zero. As we know that the parameter of mesh size reduces to minimal frames. The above equation provides assurance there seems to be an endless number of frame centers that are as small as possible.

2. The following three types of cones play a crucial part in their convergent examination which are hyper tangent, Clarke, and contingent cones respectively. Furthermore, we shall pay attention in a particular way to individual subsequences when examining MADS:

- Frame centers that are as small as possible
- Mesh size setting
- Normalized refining direction

3. The Converge hierarchy findings depend mostly on the reachable area's local attributes Ω.

The results are based on the idea that on a tangent cone, a set of instructions that must be followed exactly (known as the directions for refinement) is dense. The study of the conditions under which a MADS algorithm-generated subsequence of iterates converges to a stringent local minimizer. The necessary optimality requirement is based on the cone of possible directions rather than any of the three tangent cones used in. One of the most appealing characteristics is that it is possible to be globally converged to a clarification that meets local optimality constraints [6].

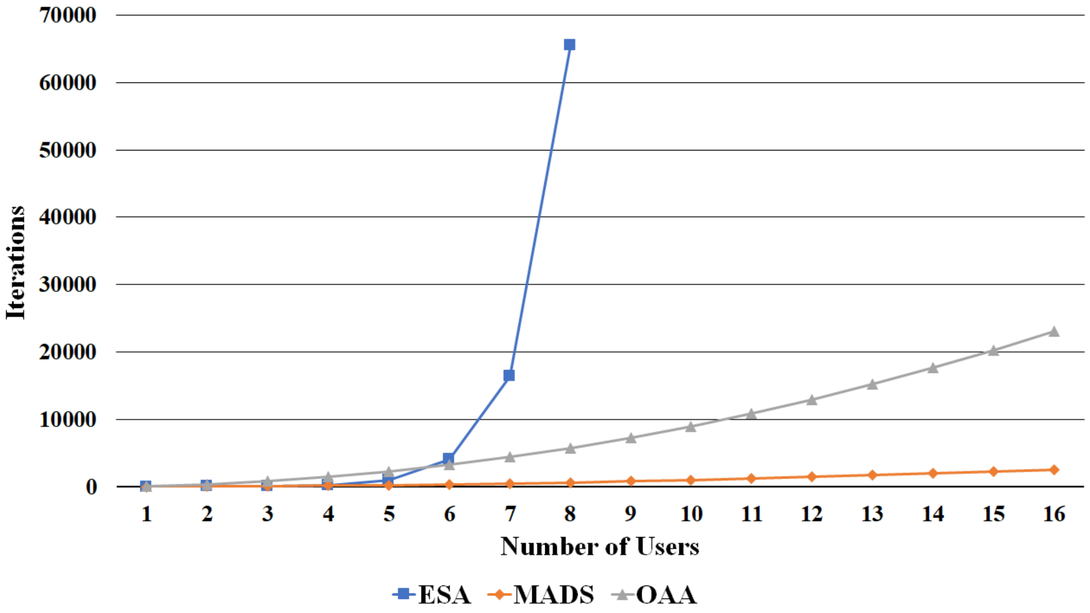

Figure 3.3: ESA, MADS, and OAA computational complexity vs. the number of users

Chapter 4

Numerical Simulations and Discussion

The simulation and numerical results are covered in this chapter to validate the effectiveness of our presented algorithm used to solve the problem as defined in previous chapter as shown in equation (3.3.4) in terms of joint user and throughput maximization for RIS-assisted multi-user MISO network. This chapter also incorporates the comparison of our proposed algorithm with other conventional algorithms to test the efficacy of the method we've proposed.

4.1 Numerical Simulations and Analysis

The results of this study were achieved using a simulation setup to maximize the outcomes in equation 3.3.4 which is a utility function maximization, the dilemma of evaluating the joint user and throughput of the system. We run several simulations to see how well the transmission works in terms of throughput and also evaluate the potential benefits of deploying RIS in wireless networks. To achieve maximum throughput, the results include effective resource allocation and user association. The effect of increasing rate, power and the number of RIS reflecting units are also highlighted. The simulation results also provide some insight into the suggested algorithm's convergence. The problem is solved using an open source nonlinear mixed integer optimization solution called Mesh Adaptive Direct Search (NOMAD) [23].

4.1.1 Simulation Setup

The Table 4.1 summarises the system parameters that were adopted in the simulation. The maximum coverage of the base station is set to 1000 meters in all simulations. The base station's maximum power is set to 10 Watts. The minimum data rate required is 0.2, 0.8,1 Mbps. The antenna far-field distance in meters d_0 is adjusted to 20 m, and $d \gg d_0$. Rayleigh fading channels are considered for all of the channels involved. The Path Loss Exponent (α) in dB is 2 and the shadowing Gaussian Random Variable ζ having mean zero is set to 10 dB. The minimum amount of users allowed is two, and the maximum amount of users allowed is one hundred. The network's users are expected to be evenly dispersed.

Table 4.1: System Parameters

Parameter	**Value**
P_{BS}^{max}	10 Watts
P_k	2,1 Watts
Max BS Coverage	1000m
α	2
ζ	10 dB
d_0	20 m
G_0	50
Min users	2
Users Increment	8
Max users	100
N	$100, 200, 400$
M	4
r_k	$0.2, 0.8, 1$Mbps

4.1.2 Numerical Results and Discussion

The numerical results are provided for the optimization of the joint user and throughput of a network using MADS. The numerical results from this task were performed via a simulation setup to optimize the problem to evaluate the joint user and throughput of a wireless network.We examine the effect of different parameters on system performance. In Fig 4.1, the comparison of the system throughput maximization in the presence of a RIS and without RIS is represented versus the total number of users. After observing the results it can be seen that system throughput achieved by RIS aided network increases significantly as compared to conventional communication systems without the help of RIS.

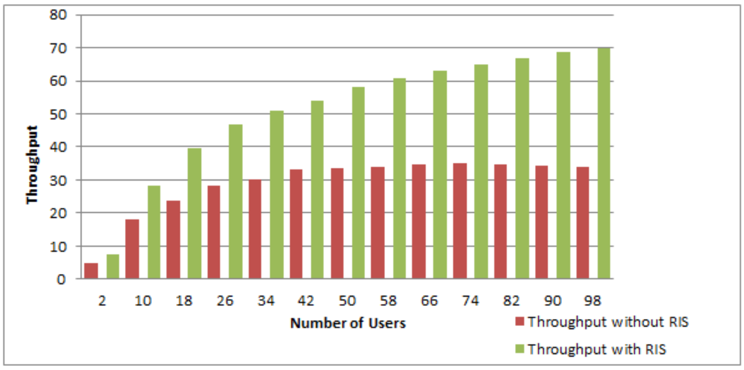

Figure 4.1: Throughput Maximization of System as Mbits/sec with or without RIS Versus diverse number of users.

The fundamental trend of this association is that as the number of users increases, the system's throughput increases. After observing the results it can be conferred that when we apply MADS, we get the same result, i.e., throughput improves as the number of users rises. When the maximum system capacity limit is achieved, it becomes constant. The state of the channel between the BS and the user also affects system throughput. The proposed formulation takes into account the minimum rate limitation to secure QoS.

Furthermore, it can be shown that proposed technique may increase throughput, indicating that proposed optimization algorithm is effective. However, it can be seen that the system throughput attained by RIS-assisted algorithms surpasses the performance of the system without RIS. This means that with N =4 reflecting elements, resource allocation for RIS-assisted systems becomes more flexible, resulting in higher throughput than a conventional network.

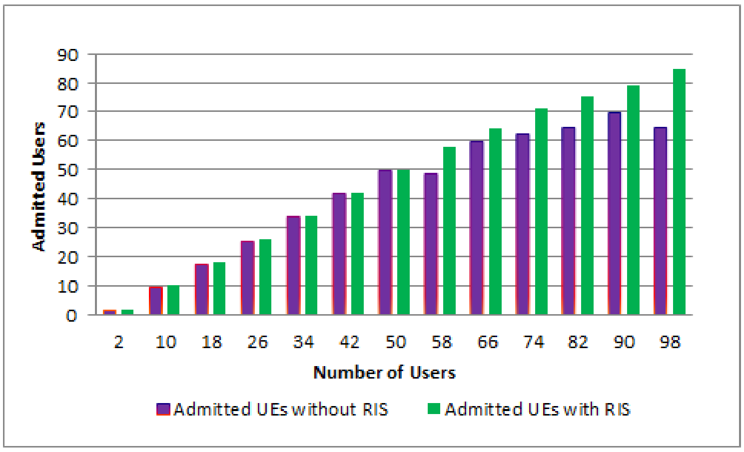

Figure 4.2: Admitted Users Maximization with or without RIS versus the various number of users.

In Fig 4.2 the comparison graph between the no of admitted users without RIS and in the presence of RIS is plotted against the total number of users. After observing the results it can be seen that using RIS with MADS algorithm maximizes the user admitted with an increase in the number of users as compared to the conventional communication network.

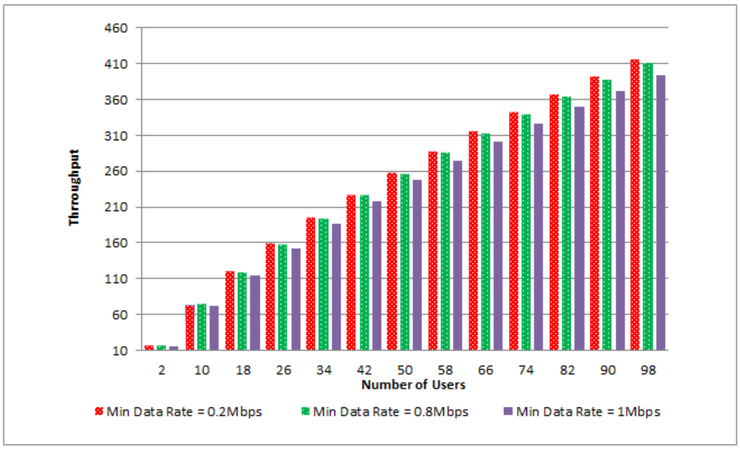

Figure 4.3: Throughput of System w.r.t minimum data rate requirement for each user, i.e., 0.2 Mbps, 0.8 Mbps, and 1 Mbps with RIS.

In Fig 4.3, the throughput of the system with various Quality of Service (QoS) needs and a plot has been created with 0.2 Mbps, 0.8 Mbps, and 1 Mbps minimum data rate requirements against joint user throughput of RIS aided system. In the presence of RIS, throughput appears to decrease slightly as the data rate demand increases. This is because when users do not match the QoS standards, the system rejects them. Throughput can only transfer as much data as the bandwidth allows, which is frequently less.

In Fig 4.4, we show the throughput of the system concerning the high transmit power, where the RIS has 100 reflector elements, the throughput of the system in the presence of RIS increases for the different number of users. It is noted that as P_{BS}^{max} is increased, the system throughput of MADS algorithms increases. The RIS-assisted algorithm outperforms the method without the RIS by a large margin, demonstrating the benefits of using the RIS.

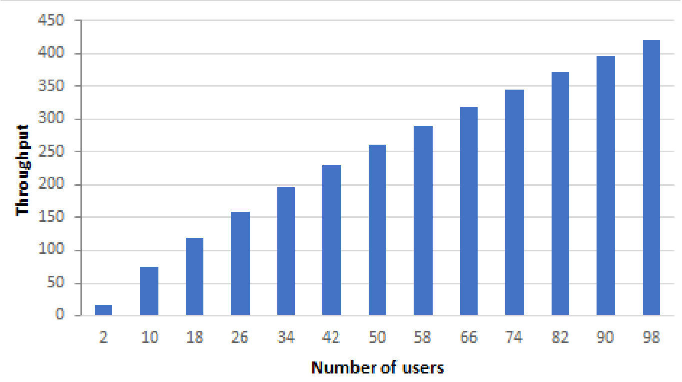

Figure 4.4: System throughput in Mbits/sec for various number of users with RIS w.r.t high power.

The throughput of the system is shown in Fig.4.5 for low transmit power, where the RIS has 100 reflector elements. The throughput of the system falls as the number of users increases. In the presence of RIS, It is revealed that the system's throughput of MADS algorithm reduces less when P_{BS}^{max} declines. The throughput of the system is also shown for low transmit power i.e 5W, where the RIS has 100 reflector elements. As expected, the achievable throughput reduces with decrease in power The reason for this behavior is that major portion of P_{BS}^{max} is used by receivers to ensure minimum

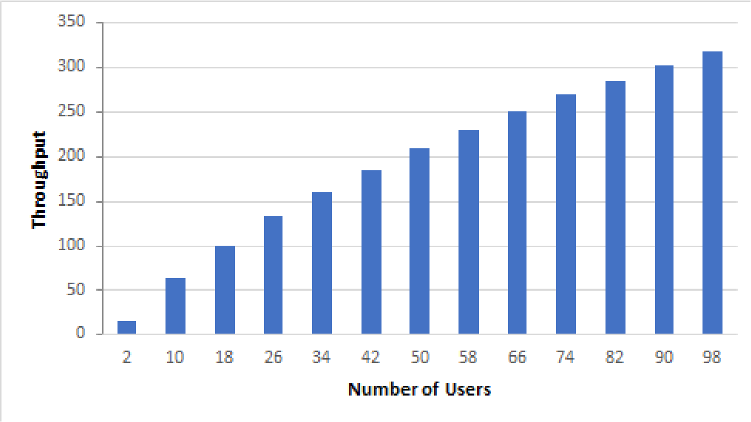

Figure 4.5: **System throughput in Mbits/sec for various numbers of users with RIS w.r.t low power.**

power needed at receiver. The lower the transmission power, the longer the delay in the communication network, but this delay is slightly reduced when RIS is present.

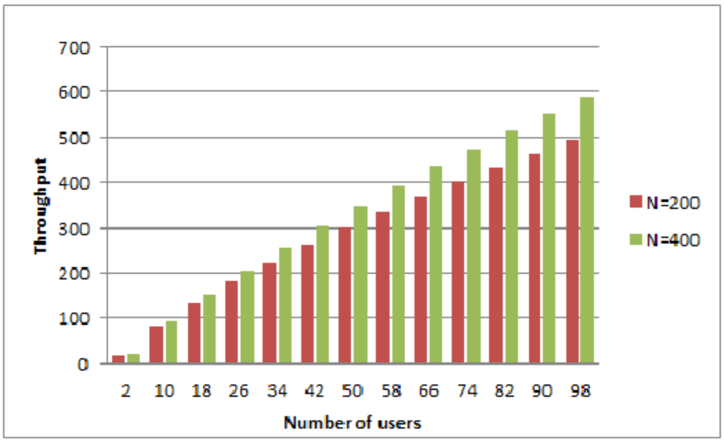

Figure 4.6: **System Throughput in Mbits/sec for different numbers of users w.r.t the number of reflecting elements.**

The throughput of the system with various numbers of RIS reflecting elements are shown in Fig 4.6. The graph depicts the reflecting elements of the RIS against the throughput of the RIS-assisted system, with N=200, 400. The performance of MADS algorithms is compared to the number of reflecting elements N in terms of system throughput. As can be shown, RIS-assisted algorithm increase system throughput with N and greatly exceeds that of the algorithm without RIS. This means that as the number of reflecting elements grows, RIS-assisted systems' resource allocation becomes more variable, resulting in better efficiency.

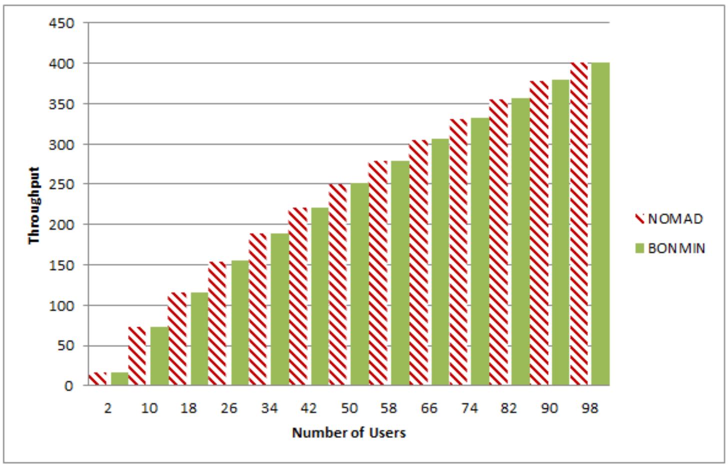

Figure 4.7: Throughput - MADS versus OAA.

Fig.4.7 shows the comparison of two algorithms (MADS and OAA) in terms of joint user and network throughput. Both the algorithms depict a similar trend but as far as OAA it shows slightly higher throughput values as compared to MADS algorithm, But it cost an increase computational complexity by using OAA. This can be justified by the complexity analysis of both algorithms discussed in previous chapter. The following is a summary of the OAA that is by integrating integers and continuous variables, as well as integrating non-linearities in the task, makes such a task extremely complicated. Increasing the number of integer variables (in our scenario, user admittance, and mode selection) quickly raises the problem's complexity. Hence by using proposed MADS algorithm computational complexity is reduced. This slight trade off in throughput values is acceptable.

Chapter 5

Conclusions

In this thesis, we investigated the joint user and throughput maximization problem in RIS assisted multi-user MISO network, which was stated as an MINLP problem. A MADS algorithm is presented to deal with the non-convex dilemma that has been presented. We also analyze the performance of several algorithms regarding the throughput of a network vs the total number of reflecting elements of RIS. The numerical results show that the system throughput produced by the RIS-assisted algorithm improves with N and surpasses the conventional algorithms without RIS significantly. This suggests that as the number of passive reflecting elements increases, the resource allocation for RIS-assisted network turn into more variable, resulting in greater advantages. The number of joint admitted users also increases who are affiliated with RIS. After extensive simulations, the results were examined. The performance of the MADS algorithm has been demonstrated with several system parameters, including the number of users, the minimum needed data rate, power, and the joint maximization of users associated and throughput. Furthermore, the proposed algorithms have the potential to greatly improve system throughput.

5.1 Future Work

Future directions for such a research could include many elements of the system model's nature. In this thesis, the proposed technique have considered the model of downlink system.However uplink system model with different algorithms like OAA can be studied for joint user and throughput maximization. It is interesting to see the results for MultiInput-Multi-Output (MIMO) systems as well as NOMA networks. We expect a lot of research and development for RIS technology to build 6G communications in the coming years The following diagramm shows some future applications of RIS:

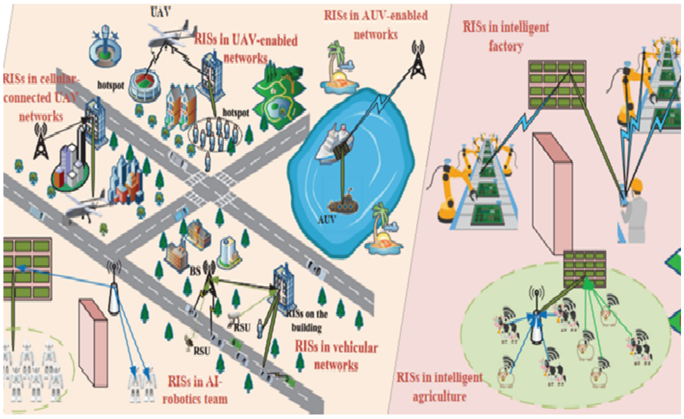

Figure 5.1: Applications of RIS.

- **AI-EMPOWERED RIS-ASSISTED NETWORKS:**AI can make it easier to combine communication, imagery, sensing, and localization.One can, for instance, choose the practical RIS for building the best communication links for the BS and a particular user by using knowledge of the environmental image to recognise the position information of the blocks and users.
- **SWIPT and RIS:** SWIPT is a desirable approach for upcoming IoT networks. The primary bottleneck in actual SWIPT systems, however, is the low EE at the energy receivers and this is solved by the deployment of RIS that reduces the energy beams and expanding power range.
- **UAV and RIS:**By adding RISs, wireless communication for UAVs can be made

better. As instance, the direct link between the UAV and the ground node may be blocked in a dense metropolitan setting, which impairs communication performance. By permitting efficient communication linkages, RIS can be used in this situation to enhance the performance of the communication.

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