Addis Ababa University
Addis Ababa Institute of Technology
School of Electrical and Computer Engineering

Performance Evaluation of Precoding Techniques for 5G Massive MIMO Downlink System

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Thesis Submitted to Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Electrical and Computer Engineering

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Declaration

I, the undersigned, declared that this MSc thesis is my original work, has not been presented for the fulfillment of a degree in this or any other University and all sources and materials used for the thesis are duly acknowledged.

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This thesis work has been submitted for examination with my approval as a University Advisor.

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Abstract

Massive multiple-input-multiple-output (MIMO) systems use a few hundred antennas to simultaneously serve many wireless broadband terminals, using sophisticated coding at the transmitter and substantial signal processing at the receiver, the MIMO channel can be provisioned for higher data rates, resistance to multipath fading, lower delays, and support for multiple users. In multi-user MIMO, a multi-antenna transmitter communicates simultaneously with multiple receivers (each having one or multiple antennas). This is known as space-division multiple access (SDMA) and here Precoding algorithms will be very essential for supporting multi-stream (or multi-layer) transmission in multi-antenna wireless communications, since the research aim is to find the key options to increase the performance of the upcoming 5G wireless system, this research work will focus on one of this options which are downlink distribution Precoding techniques for massive MIMO system, by assuming that both the base station and the user terminals are equipped with an antenna array. Precoding algorithms for SDMA systems can be sub-divided into linear and nonlinear Precoding types. The capacity-achieving algorithms are nonlinear, but linear Precoding approaches usually achieve reasonable performance with much lower complexity. This research work will present a comparative study of different linear Precoding techniques for massive MIMO wireless systems. The performance of the Precoding scheme is evaluated and compared with an iterative Precoding scheme designed to provide a maximum achievable rate gain by exploiting the expanded spatial degrees of freedom.

Keywords: 5G wireless networks; massive MIMO and linear Precoding.

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List of Abbreviations

BS	Base Station
UT	User Terminal
LoS	Line of Sight
LTE	Long Term Evolution
DoF	Degree of freedom
D2D	Device to Device
EMF	Electromagnetic Field
SNR	Signal to Noise Ratio
SINR	Signal to Interference Noise Ratio
SDMA	Space division multiple access
MIMO	Multiple Input Multiple Output
MU-MIMO	Multiuser multiple-in and multiple-out
MRT	Maximal Ratio transmission
ZF	Zero Forcing
MMSE	Minimum Mean Square Error
DPC	Dirty Paper Coding
TDD	Time Division Duplexing
FDD	Frequency Division Duplexing
5G	Fifth Generations
OFDM	Orthogonal frequency division multiplexing
IoT	Internet of the Things
CSI	Channel State Information
QCSI	Quantized Channel State Information
SDN	Software Defined Network
NFV	Network Function Virtualization
RRH	Remote Radio Head
BBU	Baseband Unit
PDF	Probability density function

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Chapter 1

1. Introduction

1.1 Background Information

It is usually agreed that the provision of the broadband wireless component will rely on the use of multiple antennas at both the transmitter and receiver sides. Multiple inputs and multiple outputs (MIMO) may be a very promising technique to mitigate channel fading and thus improving the cellular system capacity. Massive multiple-input-multiple-output (MIMO) systems use a couple of hundred antennas to simultaneously serve an outsized number of wireless broadband terminals [1]. Massive multiple input multiple output (MIMO) systems use a couple of hundred antennas to concurrently provide wireless broadband terminals. It has been incorporated into standards like future evolution (LTE) and IEEE802.11 (Wi-Fi). In multiuser MIMO networks, the spatial degrees of autonomy presented by multiple antennas are often advantageously exploited to strengthen the system capacity, by scheduling multiple users to simultaneously share the spatial channel. Massive MIMO is an innovative technology that helps within the achievement of upper system throughput and reliable transmission for 5G and beyond wireless networks. Although theoretically attractive, deploying MIMO during a billboard cellular system is fundamentally different because the transmission in each cell acts as interference to other cells, and thus the whole network is essentially interference restricted. While the matter of interference is inherent to cellular systems, its effect on MIMO is more significant because each neighboring BTS antenna element can act as a singular interfering source, thereby making it difficult for the mobile to estimate and suppress them. The downlink Linear Precoding for cellular massive MIMO systems, which efficiently reduces obstruction, offers a great sum-rate gain by exploiting the stretched spatial degrees of freedom. Precoding in massive MIMO systems is a beamforming approach that permits multi-stream transmission. In case of conventional MIMO systems, mutually nonlinear Precoding and linear Precoding techniques are used not including preferences, even if nonlinear methods, like lattice-aided methods and dirty paper coding (DPC) have better performance with higher implementation complexity. We used the Massive MIMO system under Linear Precoding, such as maximal ratio Transmission (MRT), minimum mean squared error (MMSE), and zero-forcing (ZF). Of course, there are other linear precoding like matched filtering, conjugate beamforming. Precoding with such power-efficient amplifier constraints results in improvement within the power efficiency of the whole system. Techniques at the downlink intend to focus each signal at its preferred terminal and mitigate interference to other terminals.

1.2 Motivation

In the past few decades, we have witnessed an explosion in wireless devices and communication modes and services. All these have been enabled by ever-evolving wireless networks enabled by novel wireless technologies in combination with technology standardization efforts. Massive Multiple input multiple output (MIMO) has been within the forefront of enabling wireless system technologies, mutually in theory and practice. MIMO requires equipping base stations (BS), and possibly, user terminals (UTs) with multiple antennae or antenna elements. A broad range of MIMO techniques has been developed over the years that can provide substantial benefits concerning their SISO (single- input-single-output) counterparts by exploiting transmission and/or reception from multiple antennas or antenna elements. At one end these include diversity benefits, leading to improved communication link reliability. On the other end, they include multiplexing gains by simultaneously allowing transmission of multiple user streams over the same transmission resources, thereby increasing the cell spectral efficiency.

The design and analysis of massive multi-user MIMO systems may be a novel research area that is attracting substantial interest. MIMO technology can offer an exciting boost in rate as a result of the spatial multiplexing gain, and in communication reliability through the range gain. It is now incorporated into practical cellular networks. Conventional cellular networks use orthogonal multiple-access techniques, i.e., each user is scheduled on a different time-frequency resource. However, when the BS is equipped with more antennas, more degrees of freedom are available and hence, more users can be scheduled on the same time-frequency resource. Such systems are referred to as MU-MIMO systems.

1.3 Problem of statement

The concept of distributed antenna systems (DAS) refers to MIMO systems comprising multiple antennas co-located at one end of the radio link and several geographically scattered base stations (BSs), each with multiple antennas collocated. This kind of system has the benefit of macro diversity that's intrinsic to the broadly spaced antennas. It also has more flexibility to deal with inter-cell interference, which is the main limiting factor of user terminals (UTs) at cell edges, thus leads to a decrease in the overall system capacity [2]. To further improve the performance of the conventional cellular architectures several single and multiuser and for significant improvement in the achievable rate of the entire system Precoding techniques have been proposed. Precoding is one of the ways to improve transmission using this CSIT. This channel state information at the transmitter (CSIT) can be utilized to boost the performance of a massive MIMO system applying a variety of precoding techniques. The Precoders adapt the transmission to the channel using CSIT to advance the performance of the system and helps to diminish the inter-user interference by focusing the energy on the desired terminal.

1.4 Objectives

1.4.1 General objectives

In the upcoming years i.e., ahead of 4G, some of the major objectives and demands that require to be addressed are improved capacity, improved data rate, decreased latency and better quality of service, to meet these demands drastic improvements got to be made in cellular network specification. The core objective of this thesis work is to review and analyzing the existing MIMO Precoding techniques at large antenna arrays that will be considered the first accomplishment of the work and the secondly to investigate 5G readiness of Ethiopia and give recommendation for future 5G network rollout in Ethiopia. This task aims to evaluate the efficiency of the benchmark algorithms that are developed so far in this area.

1.4.2 Specific Objectives

The specific objectives of this research are.

- Analysis of the performance of precoders for massive MIMO under wireless channel impairments and a various number of receive and transmit antennas.
- Evaluate the above algorithms for single-cell massive MIMO systems that aim to estimate and analyze the single-cell interference and its mitigation techniques.
- Compare and analysis of efficient linear precoders for massive communications that include downlink beamforming for massive MIMO systems.
- Analysis the 5G readiness in Ethiopia and give recommendation for future network rollout.

1.5 Literature review

This section presents an overview of Massive multiple-input-multiple-output (MIMO) systems and a review of related work done around linear precoding techniques.

Overview of Massive MIMO wireless system
Today and in the recent future, to fulfill the presumptions and challenges of the near future, the wireless-based networks of today will have to advance in various ways. Recent technology constituents like high-speed packet access (HSPA) and long-term evolution (LTE) will be launched as a segment of the advancement of current wireless-based technologies [3]. Massive MU-MIMO is considered an auspicious technology for the next generations of cellular systems. With massive MIMO, we expect systems that use antenna arrays with a couple of hundred

antennas simultaneously serving many tens of terminals at the same time-frequency resource. The basic footing behind massive MIMO is to procure all the benefits of conventional MIMO but on a much better scale.
Overall, massive MIMO is an enabler for the event of future broadband (fixed and mobile) networks, which can be energy-efficient, secure, and can be robust to the spectrum efficiently. As such, it is a trigger for the upcoming digital society infrastructure that will link the Internet of people and the Internet of Things with clouds and other network infrastructure. Many altered configurations and deployment scenarios for the actual antenna arrays used by a massive MIMO system can be intended.

1.6 Review of existing related work

Under the article [3], 5G Network: Architecture and Emerging Technologies, a detailed survey has been done on the performance requirements of 5G wireless cellular communication systems that have been defined in terms of capacity, data rate, spectral efficiency, latency, energy efficiency, and Quality of service. 5G wireless network architecture has been explained with massive MIMO technology, network function virtualization (NFV) cloud, and device to device communication and depicts that the demands to 5G networks will be twice more firm for traffic in the user plane and 10 times more firm in the subscriber traffic plane Certain short-range communication technologies, like Wi-Fi, Small cell, Visible light communication, and millimeter-wave communication technologies, has been also discussed, which provides a promising future in terms of better quality and increased data rate for inside users and at the equivalent time reduces the pressure from the outside base stations. Some key emerging technologies have also been discussed which will be utilized in 5G wireless systems to satisfy the probable performance desires, like massive MIMO and Device to Device communication and interference management, spectrum sharing with cognitive radio, ultra-dense networks, multi-radio access technology, full-duplex radios, millimeter-wave communication and Cloud Technologies in general with radio access networks and software-defined networks.

The authors of Scaling up MIMO: Opportunities and challenges with very large arrays, in [4] seen that the interaction between antenna elements can incur significant losses, both to channel orthogonality and link capacity. For large MIMO systems this is often especially problematic since, with a fixed overall aperture, the antenna spacing must be reduced. Moreover, the severity of the coupling problem also depends on the chosen array geometry, e.g., linear array versus planar array. Their numerical examples show that for practical antenna terminations (i.e., with no coupling cancellation), the primary impact of coupling is in power loss, in comparison to the case where only spatial correlation is accounted for. Notwithstanding, it is found that moderate coupling can help to reduce correlation and partially offset the impact of power loss on capacity.

They have also set up a small measurement campaign using an indoor 128 antenna element base station and 6 single-antenna users. Channels are (generally) not IID, and thus there is a performance loss compared to ideal channels. However, the same trends appear, and the measurements indicated a stable and robust performance.

It shows there are still many open issues concerning the behavior in realistic channels that need further research and understanding, but the overall system performance seems very promising.

The authors in [5] studied Array Beamforming Synthesis and related areas. The existing beamforming techniques for PTP MIMO lack providing efficient beam formers especially in certain situations such as under different power constraints or array sizes, certain types of channels, and random initializations. To solve this problem, they proposed an iterative algorithm that specifies transmit and receive beamformers based on various channel information available to the transmitter and the receiver.

The proposed approach in [6] optimally switches between beamforming and Orthogonal Space-Time Block Coding by varying the periodicity of feedback intervals and ranging the amounts of channel state information for mobile users to determine the optimum diversity feedback. The approach proposed a replacement adaptive symbol mapping scheme for PTP MIMO by disordering the transmitted symbols during a frame using dynamic mapping (either by changing the allocation order of the symbols on the antennas or by applying a scrambling process that reverses the symbols sign). The aim of doing this was to increase the symbols' received power and to reduce the interference between the symbols.

There are new Precoding techniques introduced within the literature for millimeter-wave massive MIMO. In [7], the authors proposed a hybrid precoding scheme combining both analog and digital Precoding to overcome the high signal attenuation that happens at mm-Wave frequencies is using a non-complex sub-array. This work reiterated the advantage of hybrid analog/digital Precoding work that optimizes the achievable capacity of each antenna array by employing the concept of consecutive interference cancellation.

Most previous studies on BTS coordination assume global coordination which eliminates inter-cell interference. However, in realistic cellular systems, issues such as the complexity of joint processing across all the BTSs, the difficulty in acquiring full CSI from all the mobiles at each BTS, and time and phase synchronization requirements will fill coordination extremely difficult, especially for an outsized network. Therefore, it is of great interest to develop coordination schemes at a local scale, to lower the system complexity and maintain the benefits of BTS coordination. For the uplink, an overlapping coordination cluster structure was proposed, where each BTS is at the center of a unique cluster, and coordinated combining is performed to suppress interference for the central BTS of each cluster. With such an overlapping cluster

structure, each user is in the interior of a cluster and enjoys interference reduction, but the cluster number is as large as the number of BTSs and it cannot be easily extended to the downlink.
In the downlink coordination over a 3-cell cluster was investigated with both ZF and DPC, but no inter-cluster coordination was considered.

Massive MIMO may be a promising candidate technology for next-generation wireless systems. Recently, there has been an excellent deal of interest in this technology. though there's a lot of analysis work on this subject, many problems still ought to be tackled before reducing large MIMO to observe.
In the article [8] 5G-enabled devices and smart-spaces in social-IoT, this literature review presents the most motivations in carrying sensible devices and the correlation between the user encompassing context and also the application. It focuses on context-awareness in sensible systems and house discovery paradigms, the most motivation carrying these sensible devices, and target context-awareness in sensible systems and house discovery paradigms; on-line versus offline, the femtocell usage and energy aspects to be thought of, and the current social IoT applications.

Mainly the researchers during this article believe that the thought of watching sure varieties of sensible phone activities can minimize the user's considerations concerning accessibility and follow in smart environments. the downside of the present strategies is their intrusive and tumultuous nature, because of users might have to be interrupted from what they're doing to supply a chunk of data like an identification. though some strategies area unit less tumultuous (such as face recognition), they're still intrusive because the use of a camera or alternative device varieties suggests that extremely customized data is collected and hold on by the system to be utilized in the verification method of any context-aware system. This conjointly raises queries with regards to users’ perception and tolerance to such strategies as individual’s area unit involved concerning, however, where else, and by whom their data is getting used. Similarly, context-aware systems ought to collect a spread of data concerning the user’s current standing and activities, several of which can be considered personal. New proposals area unit needed to deal with this issue by solely grouping data associated with the user’s access to resources, that has got to be collected in any case. Moreover, the article concludes that Energy potency of femtocell networks in IoT, considering energy metrics, energy consumption models, energy potency schemes for readying, factors that affect the energy consumption of femtocell networks, and energy potency of UE beneath femtocell coverage. The energy potency of femtocell in IoT still must be investigated.

The article [9] beneath the International Journal of Engineering Trends and Technology (IJETT) conjointly mentioned the Performance Analysis of large MIMO with completely different Pecoders beneath good and Imperfect CSIT conditions. The analysis has compared the amendment in capability with the rise of SNR, the amount of Base station antenna, range of users, and the range of users having incomplete CSIT. Moreover, the output of the analysis points out that MRT performs higher in Low SNR and ZF performs higher in high SNR and shows that ZF doesn't continually perform higher in high SNR.

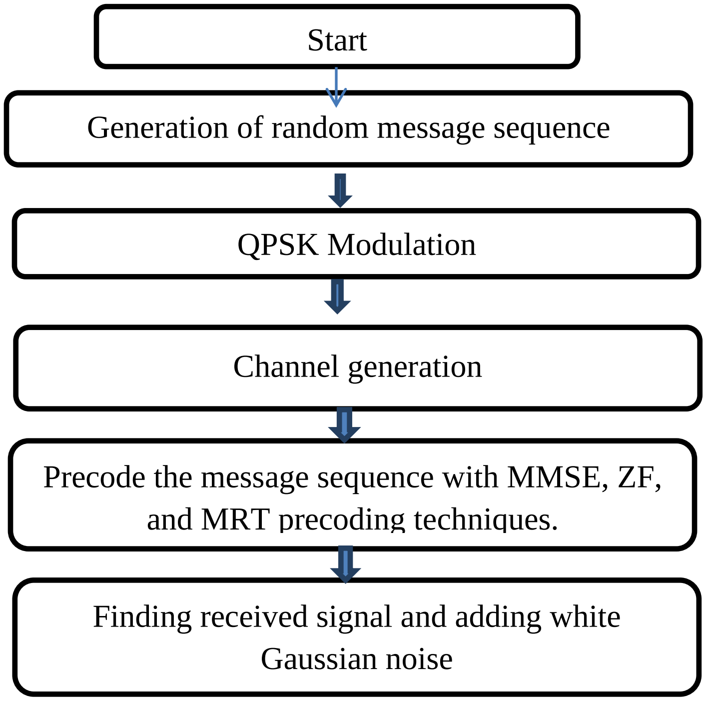
[10], Future Generation laptop Systems the author tries to target context-awareness in sensible systems and house discovery paradigms. A typical smartphone today is supplied with an Associate in Nursing array of embedded sensors (e.g., GPS, accelerometers, gyroscopes, RFID readers, cameras, and microphones) beside completely different communication interfaces (e.g. Cellular, Wi-Fi, Bluetooth, etc.). Thus, a smartphone may be a vital supplier for sensory information that awaits employment in several important applications. Online activities kind of major a part of our lifestyle. Social networks and cooperative sites like Twitter, Facebook, and Google+ area unit improbably well-liked on-line forums, giving straightforward and compelling ways for innumerable users to post content and act with one another. The authors believe that additionally to providing engaging mediums for someone-to-person interactions, social networks conjointly supply unexampled opportunities for social information analysis. 5G comes because of the demand for higher and quicker wireless affiliation. As expressed within the articles by the time 5G is embraced, there'll be tens or many billions of devices that need the employment of 5G technology, not solely owing to persona usage however conjointly thanks to several new applications as expressed within the article [11] one among the main new applications is which will contribute to the current high range of devices is that the extremely anticipated net of Things (IoT). The term IoT has been loosely utilized in several research project areas additionally as selling and sales. IoT will merely be outlined as a dynamic international network infrastructure with self - configuring capabilities supported by normal and practical communication protocols. Their area unit estimates that fifty billion devices are wirelessly connected to the web by 2020. this implies a bigger range of acquainted Wireless Networks is deployed, generating nice amounts of information to watching devices or personnel. because the article normally, wearable sensors as an area unit promising technology within the field of user behavior analysis and watching. Shortly, many mobile applications are passionate about these little wearable devices, through that user habits, user quality, application usage, and context awareness are often additionally investigated.

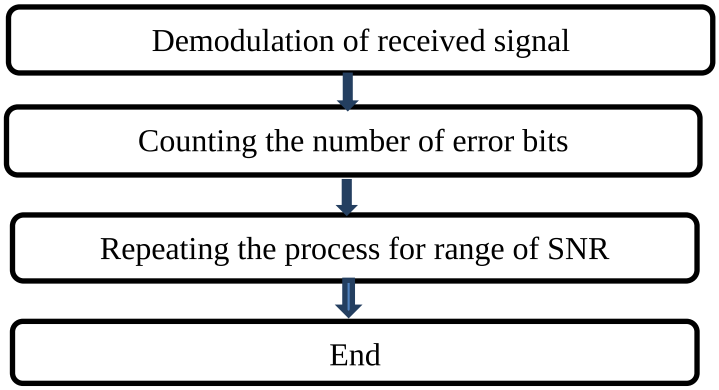
Application as a Service (AppaaS) described in [12] provides an overview of the most appropriate system architecture we can think of for smart spaces utilizing smartphones. The architecture involves the user device loaded with an AppaaS mobile application, in addition to a space/context management server. The AppaaS mobile application comprises a graphical user interface (GUI) which is used to take inputs from users, a Space Handler which collects different context information from users, and Service Delivery makes sure that services are delivered in the form of applications relevant to the user's context.

The research believes that the idea of monitoring certain types of smartphone activities will minimize the user's concerns about accessibility and tracking in smart environments. New proposals are required to address this issue by only collecting information related to the user's access to resources, which must be collected in any case. Collecting such information does not require the users to perform additional disruptive activities in the process of verifying their identity.

1.7 Methodology

This section presents the illustrious models that the analysis uses, since elaborated information of the channel state info at the bottom station (BS) or access purpose (AP) is incredibly necessary because of it permits the joint process of all users' signals which ends up in important performance improvement and magnified information rates. If the channel state info is accessible at the BS/AP, it is wont to expeditiously eliminate or suppress multi-user interference (MUI) by beamforming or by exploitation Precoding. The Precoding additionally permits us to perform most of the advanced process at the BS/AP which ends up during an interpretation of users end. Linear Precoding techniques have a bonus in terms of procedure complexness. Non-linear techniques have higher procedure complexness and need some sign overhead however will give higher performance than linear techniques. Linear Precoding techniques are going to be wont to study the performance improvement of the 5G wireless network.





The formal methodologies to be used to achieve the objectives of the research are.

✓ **Literature review**; The goals of this thesis are to analyze the effects in a massive MU-MIMO downlink system with linear precoding, so we try to include the different literature ideas that revolve around massive MIMO also navigates various articles, journals, simulation tools and other resources related to the Multi-user multiple-input multiple-output (MIMO) systems provide high capacity with the benefits of space division multiple access including different Precoding techniques.

✓ **System modeling and simulation**; we simulate the channel models with computer software. We calculate the Achievable rate and the energy efficiency to analyze the effect of a massive MU-MIMO downlink system over different channel models. includes mathematical modeling of the system. To consider channel estimation errors, we used the Rayleigh channel model and simulating the model of precoding techniques using MATLAB 19b.

✓ **Performance comparison**; includes comparing the performance of massive MIMO Precoding techniques such as maximal ratio combining (MRC), matched filtering, conjugate beamforming, minimum mean squared error (MMSE), and zero-forcing (ZF)with transmitter power, user rate, spectral efficiency, and energy efficiency.

✓ **Analysis and interpretation of the results;** To analyze the massive MU-MIMO downlink system, we investigate the performance of linear precoding. Linear precoding is simple processing where the transmitted signal vector is obtained by multiplying the information data vector with a linear precoding matrix. Conventionally, in single-user systems, each user maximizes the data throughput for itself, but in the case of the MU-MIMO system, the transmitter cannot transmit all users with maximum data throughput simultaneously. It requires further processing to transmit the correct data. There always exists a tradeoff between the system performance and implementation complexity.

Linear precoding is simple and hence, it has a low deployment cost. We consider the performance improvement attains by introducing different massive MIMO linear Precoding techniques will be discussed.

- ✓ **Limitations;** in massive MIMO the further the antennas are utilized, the greater the spatial focusing can be so that a higher array is built in practice. The utilizes of nonlinear but power efficient RF front end amplifiers are desired to reduce power consumption in this high bit rate setup (Note that energy per bit will reduce in proportion to the square bit rate. Hence, the transmit power must be high-level at Gigabit data rates.) Therefore, to prevent signal distortion at nonlinear amplifiers Precoding with such power-efficient amplifier constraints indicates to enhancement and this Precoding technique's complexity grew while the number of antennae improved.

Chapter 2

2. 5G in sub-Saharan Africa

2.1 Introduction

One and all loves speedy internet, so it's no wonder that every major telecom in the world is running to make it even faster. Smartphones, watches, homes, and cars are progressively requiring stable internet connections. To duct in enough bandwidth for that valuable wireless feed, we're going to need a completely new form of the wireless signal that's where 5G comes in.

The cellular wireless generation (G) generally refers to a change in the fundamental nature of the service, non-backward like-minded transmission technology, and new frequency bands. New generations have appeared every ten years since the first move from 1981-An analog (1G) to analog (2G) network. After that, there was (3G) multimedia support, spread spectrum transmission, and 2011 all –IP Switched networks (4G) comes. The last few years have witnessed phenomenal growth in the wireless industry, both in terms of mobile technology and its subscribers. There has been a clear shift from fixed to mobile cellular telephony, especially since the turn of the century. By the end of 2010, there were over four times more mobile cellular subscriptions than fixed telephone lines. Both the mobile network operators and vendors have felt the reputation of efficient networks with equally efficient design. This resulted in Network Planning and optimization-related services coming into sharp focus [13]. Next-generation mobile networks are usually revealed to as 4G and are envisioned as a multitude of heterogeneous systems accommodating through a horizontal IP-centric architecture. The 5G core is to be a Reconfigurable, Multi-Technology Core. The core might be a convergence of new technologies such as Nanotechnology, Cloud Computing, and Cognitive Radio, and based on All IP Platform. These new technologies and the above-mentioned requirements pose several challenges toward 5G development.

2.2 Motivations and Requirements of 5g Mobile Networks

There are two major motivations for 5G mobile networks. Primarily, as mentioned above, the upcoming mobile network will deal with brand new services e.g., massive sensor communication and vehicular to anything communication requiring shorter setup time and delay, as well as diminished signaling overhead and energy consumption. Besides, it will have many more use cases, including managing multi-cell and multi-user together, network deployments with Multi-RAT coexisting or multi-layer networks, also called Heterogeneous Networks (Het Nets). Various services and complicated deployment scenarios require the future 5G systems to have the skills i) to support 10-100 times transition rate than today; ii) to ensure a low delay (millisecond level); iii) to support 10-100 times more devices than today; iv) to provide 1000 times traffic density; v) to support up to 500km/h fast mobility of User Equipment (UE). At the same, it is desirable to have 99.999% coverage, while energy con- assumption and cost for the infrastructure should not increase [14]. Secondly, operators expect to reduce network operating costs and improve spectral efficiency within an area, to maintain optimal performance in future cellular structures by more flexible resource usage and more advanced self-organization functions.

Usually, a single element antenna possesses poor directivity with a relatively wide and wide radiation pattern. For 5G technology, high directivity is strongly required. This can be achieved through constructing antenna arrays, in a suitable electrical and geometrical configuration, without the need for optimizing the size of antenna elements, which is the incentive behind the use of Massive MIMO. Since it was first introduced, the use of massive antennas has been receiving important interest in wireless technology. Mobile Cellular Network evolution has been categorized into ‘generations’ as

2.3 Fifth Generation (WiMAX, WWWW, RAT)

The 5G (Fifth Generation Mobile and Wireless Networks) can be a complete wireless communication without limitation, which fetches us perfect real-world wireless Worldwide Wireless Web (WWWW). 5G represents the future main phase of mobile telecommunications standards ahead of the 4G/IMT-Advanced standards. At present, 5G is not a term officially used for any specification or in any official document yet made public by telecommunication companies or standardization bodies such as 3GPP, WiMAX Forum, or ITU-R. Each recent release will further boost system performance and add new abilities with different application areas.

The 5G networks stand for fifth-generation mobile technology and can outperform earlier versions of wireless communication technology. The new technology provides diverse abilities and encourages full networking among countries globally. Accordingly, 5G architecture constitutes both licensed and unlicensed frequency bands. In a recent study from 2016, the Federal Communications Commissions (FEC) announced the use-case of 60 GHz spectrum with the range of 57 GHz–71 GHz for the unlicensed wireless category [19]. The networks are likely to execute very great service quality. To entertain these 5G services for the new generation communication system, various new technologies have been anticipated, namely Millimeter-wave communication, Hentet's, Massive multiple-input multiple-output (MIMO), and visual light communication.

5G Next-Generation Communication Networks will be a global game-changer from a technological, economic, societal, and environmental perspective. The so-called vertical markets and industries will experience a drastic transformation thanks to 5G-enabled technical capabilities available to trigger the development of cost-effective new products and services. [20] Presents a detailed analysis of uses cases and comparable requirements for representative vertical markets for instance Factories of the Future, Automotive, Health, Energy, and Media & Entertainment.

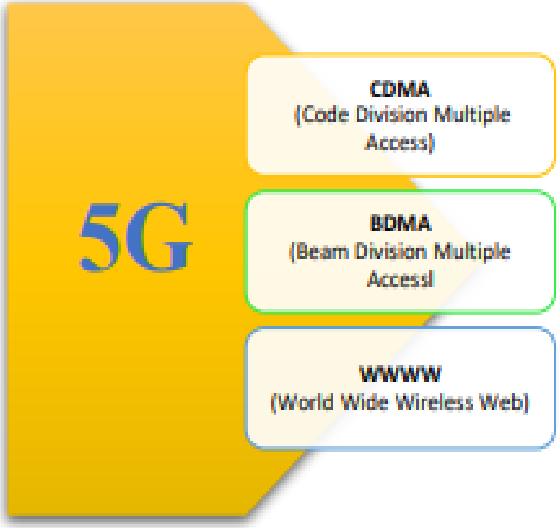


Figure 2. 1: Technology standard under 5G [20]

Table.2. 1: Comparison of all generations of mobile technologies [53]

Technology Feature	1G	2G	3G	4G	5G
Start/ Deployment	1970 – 1980	1990 – 2004	2004-2010	Now	Soon (probably 2020)
Data Bandwidth	2kbps	64kbps	2Mbps	1 Gbps	Higher than 1Gbps
Technology	Analog Cellular Technology	Digital Cellular Technology	CDMA 2000 (1xRTT, EVDO) UMTS, EDGE	Wi-Max LTE Wi-Fi	WWWW (coming soon)
Service	Mobile Telephony (Voice)	Digital voice, SMS, Higher capacity packetized data	Integrated high quality audio, video and data	Dynamic Information access, Wearable devices	Dynamic Information access, Wearable devices with AI Capabilities
Multiplexing	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit, Packet	Packet	All Packet	All Packet
Core Network	PSTN	PSTN	Packet N/W	Internet	Internet

If all goes well, telecommunications companies hope to debut the first commercial 5G networks in the early 2020s. Right now, though, 5G is still in the planning stages, and companies and industry groups are working together to figure out exactly what it will be. But they all agree on one matter: As the number of mobile users and their demand for data rises, 5G must handle far more traffic at much higher speeds than the base stations that make up today’s cellular network to achieve this, wireless engineers are designing a suite of brand-new technologies. [21]

2.3.1System Capacity and Data Rate

Beyond 2020 mobile networks need to support a thousand-fold increase in traffic, relative to 2010 levels, and a ten to hundred-fold increase in data rates even at high mobility and in crowded areas, if current trends continue. This requires not only more capacity within the radio access network (RAN), but equally important, also within the backbone, backhaul, and front haul. Pricing schemes are often used to manage and potentially reduce the growth in data consumption, as has already been demonstrated by operators within the market. However, as customers are willing to shop for the provisioned service instead of the info volume, pricing models might not be effective to suppress the traffic in the future. The present consensus is that a blend of more spectrum, higher spectrum efficiency, network densification, and offloading are necessary to covenant with these challenges within the RAN. Opportunities for more spectra include higher frequency bands (e.g., mmw), unlicensed spectrum, and aggregation of fragmented spectrum resources using carrier aggregation techniques. Dual connectivity of terminals to multiple base stations can exploit aggregated use of spectrum deployed at different base stations.

2.4 Applications of next-generation network

The next-generation applications are set to evolve in a multiplatform environment. 4G applications will be available across various wireless technologies like LTE, Wi-Fi, etc., and also in devices like cell phones, laptops, e-readers, digital cameras, printers, and so on. 4G applications are very likely to be extended and improved versions of the existing 3G services, but it is still unclear what the capacity of 4G will hold for the mobile world. Some of the applications of next-generation networks are: [22 - 24]

Virtual Presence: these incomes that 4G and 5G always provide user services, even if the user is off-site. 5G supports Virtual navigation users with virtual navigation that can let users to gain access to a database of the office, business shops, and others of huge towns. This requires high-speed data transmission.

Tele-Medicine: currently 4G and 5G supports distant health nursing of patients. A user needs not to go to the hospital instead a user can get videoconference support from a doctor at anytime and anywhere.

Tele-geo processing applications: This is a combination of GIS (Geographical Information System) and GPS (Global Positioning System) in which a user can get the location by inquiring.

Crisis management: Natural disasters can cause a cessation in communication systems. nowadays, it may perhaps require several days to fix the system. But in 5G it is anticipated to reestablish such disaster issues in short seconds.

Education: For individuals who are fascinated in 5G provides a great opportunity. Citizens everywhere in the world can maintain their education online in a cost-effective manner.

Artificial Intelligence: More applications combined with artificial intelligence (AI) as human life will be surrounded by artificial sensors that could be communicating with mobile phones.

Security: Police, fire, rescue, ambulance, and medical emergency services covered by this category require a high degree of reliability and availability. Just as 4G is adopted for public protection, and 5G radio access in near future became crucial component of the devices accessible for security services, law prosecution, and emergency personnel to use.

Economic growth: The Economic growth is also one of the encouraged sectors since these technology modifications will permit customers and suppliers to advantage from greater value wireless data and content services.

2.4.1 Challenges in next-generation communication

The difficulties in the design of the terminals are related to the management of trade between the flexibility of the spectrum usage and required space and power to a given platform. New methods offer design dimensions that allow the system to adapt to the opportunities and requirements of the terminals in a manner that shall maximize spectral efficiency and maximize battery power.

As a result of the growing level of acceptance of wireless technologies in different fields, challenges, and types of wireless systems associated with them are changing. In heterogeneous wireless networks, the concept is "always best connected" (always associated with the best quality), aimed at client terminals, and is proposed in different research [25].

In 4G business models, important issues are related to privacy and security, creating industry standards of excellence, and meeting them in all facets of the technology, dealing with handset limitations, improving poor use experience reported by users for many different phones, and importantly the lack of awareness of mobile data services among people. 5G Wireless Access key challenges include an avalanche of Traffic, explosion of several devices, and diversity of requirements such as latency, reliability, and low cost and energy consumption. This multiplicity of requirements is in turn stretching the limits of available technologies. The vision of Super Core is based on the IP platform. All network operators (GSM, CDMA, Wi-Max, Wireline) can be connected to one Super core with massive capacity. This is the realization of a single network infrastructure. The concept of the super core will eliminate all interconnecting charges and complexities, which right now network operator is facing. It will also reduce the number of network entities in the end-to-end connections, thus reducing latency considerably. 5G network will not be only of more speed but also capable of carrying more data. This generation was estimated to be rolled out around 2021. In 5G, the network might solve the problem of frequency licensing and spectrum management issues [26]. The 5G terminals may possibly have software-defined radios. Also, it has error-control schemes and distinct modulation schemes.

The first competitors involve small cells, millimeter waves, massive MIMO, full-duplex, and beamforming. To understand how 5G will differ from today’s 4G networks, it’s helpful to walk through these five technologies and consider what each will mean for wireless users, but in this paper, we suggest massive MIMO can have more advantages than the other technologies and we will see the detail in the next chapter. In [27], these five technologies are described as followed.

2.5 5G in sub-Saharan Africa

Digital technologies are having an intense impact on the way people live, work, play, and communicate. This is very true in Sub-Saharan Africa where such technologies progressively offer access to life-enhancing services for people and communities that might rather be excluded, thanks to infrastructure, skills, and funding shortages. Key trends in the region’s digital landscape, including a youthful demographic and the increasing digital interruption of industries, point to a growing mandate for next-generation connectivity.

Vodacom and MTN launched the first major 5G networks in Sub-Saharan Africa in 2020. And, 5G trials have been conducted elsewhere in Sub-Saharan Africa, including in Gabon, Kenya, Nigeria, and Uganda.

Corresponding to GSM 2020 report at the end of 2019, 477 million people in Sub-Saharan Africa subscribed to mobile services, accounting for 45% of the population. The mobile market in the region will achieve several crucial milestones over the next five years: half a billion mobile subscribers in 2021, 1 billion mobile connections in 2024, and 50% subscriber penetration by 2025. These accomplishments will be underpinned by operators’ sustained investment in network infrastructure. Despite the economic insecurity made by the Covid-19 crisis, operators in the region will invest $52 billion in infrastructure rollouts between 2019 and 2025. However, mass adoption of mobile 5G is not imminent in the region. With major unused 4G capacity and 4G implementations still relatively low, the focus in the near term for operators and other stakeholders is to increase 4G uptake. This will require strategies to make 4G devices more inexpensive and the provision of significant digital content to drive demand for enhanced connectivity services. More than 160 communications service providers across the world have launched 5G services and more than 300 5G smartphone models have been announced or launched commercially, according to Ericsson. Before the end of this year, it adds, there will be more than 500 million 5G users globally. At 43%, most mobile phone connections in sub-Saharan Africa are on 3G, with 15% on 4G and less than 1% on 5G and the rest on 2G, according to Ericsson report. By 2025, there will be just fewer than 30 million mobile 5G connections in Sub-Saharan Africa, equivalent to almost 3% of total mobile connections. Sub-Saharan African is expected to be the region with the lowest adoption of the 5G mobile phone technology over the next five years, a latest report says, this is mostly because of the high cost of deploying 5G technology and the higher cost of 5G phones [28].

In Sub-Saharan Africa, mobile subscriptions will persist to grow over the forecast period as mobile penetration is fewer than the global average. In the first quarter of 2021, more than 20 percent of the global net additions were recorded in Africa. 4G accounted for around 15 percent of subscriptions at the end of 2020. Over the forecast period, mobile broadband subscriptions are predicted to increase, reaching 76 percent of mobile subscriptions. While 5G and 4G subscriptions will continue to expand over the next 6 years, HSPA will stay the dominant technology with a share of over 40 percent in 2026. Sub-Saharan Africa also has a very high growth rate, but from a comparatively small base, with total mobile data traffic rising from 0.87EB per month in 2020 to 5.9EB in 2026. Average traffic per smartphone is anticipated to reach 9GB per month over the forecast period. [29] Our focus is to provide an analysis and evaluation of the status, readiness, and prospects for 5G in Ethiopia. And to provide a recommendation based on other neighboring countries' experience for the future.

2.6 Journey of Telecom in Ethiopia

To review telecom operator in Ethiopia journey of Ethio telecom, in 1894-1942 Telecommunications service was introduced in Ethiopia by Emperor Menelik II in 1894 when the construction of the telephone line from Hara to the capital city, Addis Ababa was initiated. Then the inter-urban network was resumed to expand adequately in all new paths from the capital. Many crucial centers in the Empire were interlinked by lines, thus facilitating long-distance communication with the operators at transitional stations often acting as verbal human repeaters among the distant calling parties.

1889 - First telephone service started within emperor Menelik's palace

1890 - Full telephone started connecting government offices

1894 - Post, telegraph, and telephone central administration established

1902 - The first long-distance line built connecting Addis Ababa with Djibouti

1997 - Internet service launched

1998 - Mobile service introduced in Ethiopia

2006 - NGN project increased fixed and mobile infrastructure capacity

2010 – Ethio telecom established through a transformation program

2015 - 4G LTE service launched

2020 - 4G LET advance

2021 - 4G LET advance Regional Rollout

As we realize that digitalization could enhance the livelihoods of Ethiopians while expanding entry to financial, healthcare, education services and Ethio telecom partnership with various vendors can bring Ethiopia faster to the a digital world. In May 2021, a world consortium named the worldwide Partnership for Ethiopia, comprising Safaricom Plc, Vodacom Group, Vodafone Group, Sumitomo Corporation, and CDC Group, was granted a license to operate telecom services in Ethiopia. This is the first brand-new telecoms license in the country, which understood in initiating competition to the market.

Rendering to the Ethiopian government, the crucial policy objectives that encompass the telecom improvements envisage augmenting Ethiopia's digital development; growing telecommunications accessibility for sections of society and empower the achievement of the sector; establishment of an international standard telecom industry rivetted on capacity and quality; as well as permitting the nation to produce capital from the sector.

The playground will change whenever the upcoming new operators join Ethio telecom as operators and the market share will be shared with these new operators. we have got information’s that the telecom has prepared a five-year market share analysis and took some experience from neighboring countries. Ethio telecom announces that it is taking both defensive and offensive strategies that keep its competitive advantage. Besides that, the network rollout manager Ato Fedlu Mohammed tells us there is already matured device penetration so that Addis Ababa is ready for 5G network coverage and Ethio telecom has planned to lunch 5G in 2022 in Addis Ababa.

Ethio telecom announced the number of customers has reached 56.2millon and Ethio telecom has achieved a growth of 22% compared to the same period last year and achieved 108% of the company target. Overall, Ethio telecom revenue grew by 18.4% relative to last year. There are 54.3 million Mobile voice subscribers and the fixed broadband subscribers number increased from 374thousend to 912 thousand in June 2021. As the data shows regular telephone subscribers and data, internet users now in Ethiopia are 25 million. Over the past three years, the number of customers has continued to grow. In the 2010 fiscal year, the total customer base was 37.9 million and now it has grown by 48 percent to 56.2 million. The tele density rate or the number of main telephone lines for every one hundred in Ethiopia is now 54.8% based on Ethio telecom data.

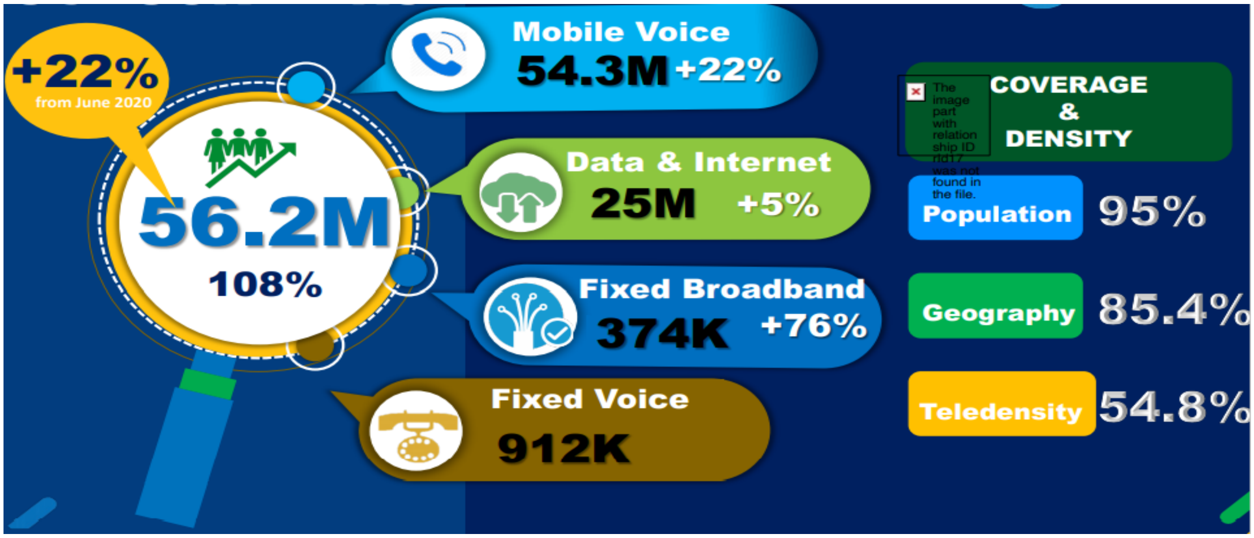


Figure 2.2 number of subscribers increment in Ethiopia for last three years.

The above data shows the number of mobile users in Ethiopia is rapidly increasing; Driving factors behind the growth of mobile broadband subscriptions include a young, growing population with increasing digital skills and more affordable smartphones. The establishment of a modern, reliable, and rapidly expanding telecommunications infrastructure contributes considerably to the promotion of a variety of economic growth.

As GSM stated approximately half a billion citizens will be utilizing the mobile internet in Sub-Saharan Africa by 2025 and a third will take place from Nigeria and Ethiopia. This shows mobile internet users in Ethiopia are increasing so fast.

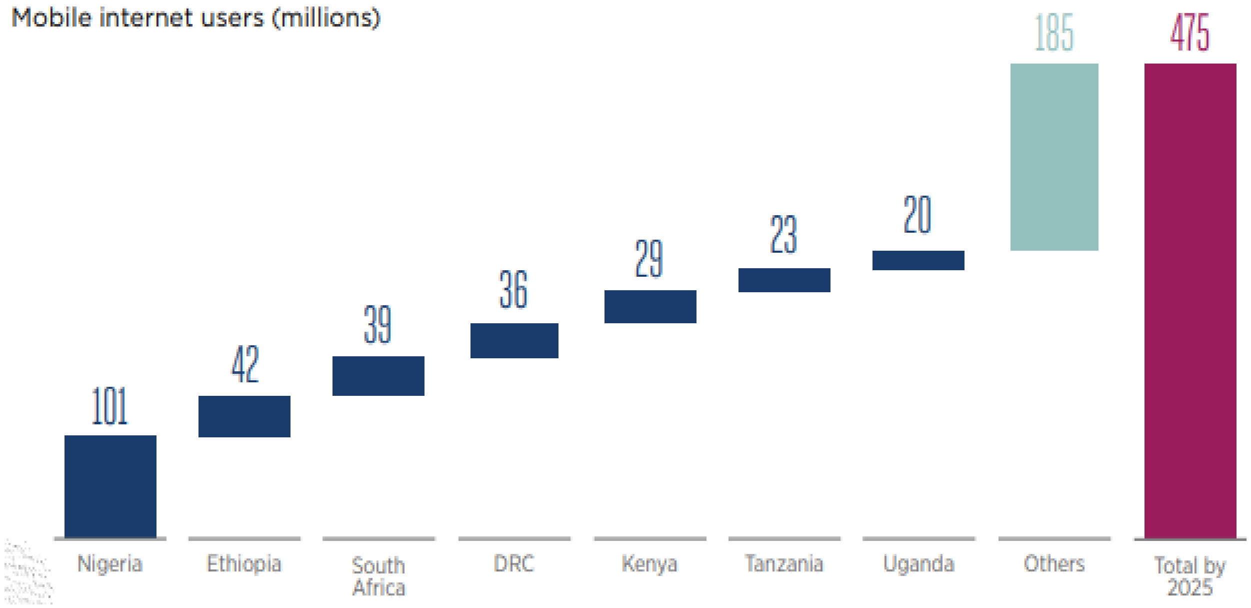


Figure 2.3 mobile internet users (millions) in sub–Saharan African countries by 2025.

2.6.1 Customer Base Growth in Ethiopia since July 2018

As we said above the number of subscriber's increases for the past three years from 37.92 million to 56.2 million in June 2021which is around 48.2 % Growth. There are significant other service growths let's see three different telecom services for instance: mobile voice service, mobile broadband service, and fixed broadband service. Mobile voice service subscribers increased from 36.37 million to 54.3 million which is 49.3% growth and mobile broadband users increased from 17.81 million to 25 million which is 40% growth and last fixed broadband service users increase from 66.2 thousand to 374% thousand which is 465%.

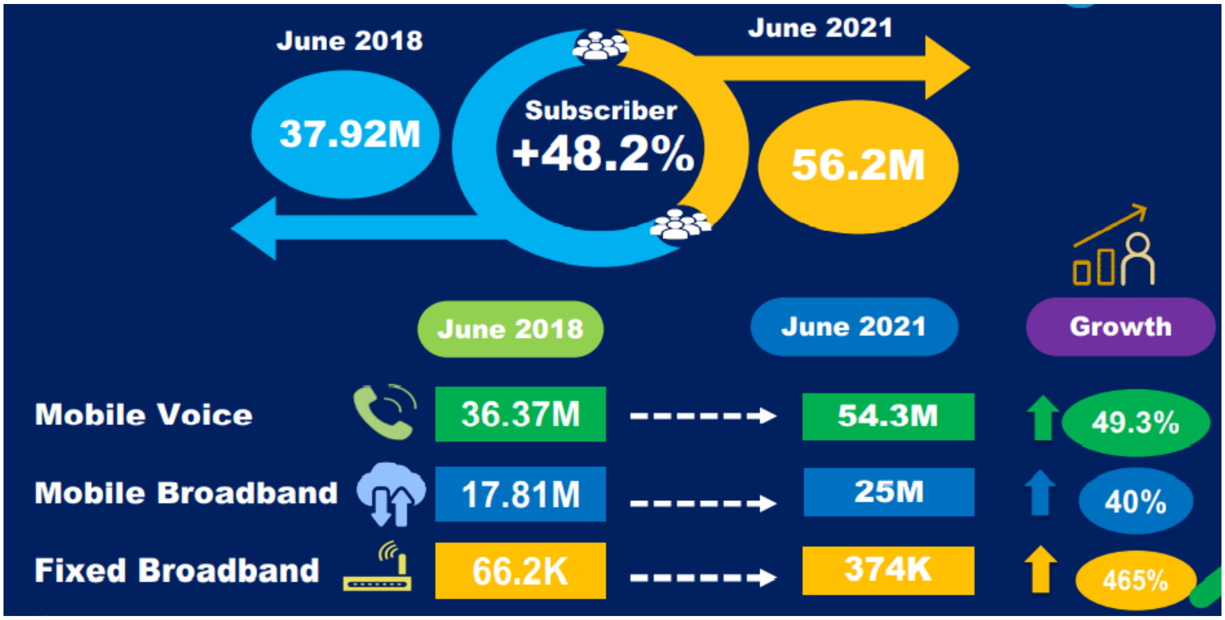


Figure2.4 mobile service subscriber increment in Ethiopia since July 2018

In addition, by expanding and consolidating heavily invested infrastructures, network coverage, and capacity to increase as well as leverage infrastructure to generate additional revenue and improve service quality a total of 132 projects are underway, including 4G LTE and 4G LTE advance expansion, mobile stations expansion, installation of smart poles including the construction of modular data center, and business support next-generation business support system projects are the most important and completed projects.

2.6.2 LTE Mobile network Expansion in Ethiopia

4G LET network expansion in Ethiopia was started in 2015 and its coverage was only on specific hotspot sites in Addis Ababa. Earlier three years Ethio Telecom has broadcasted a three-year tactical strategy to reform the company and lead with business orientation and a ambitious attitude, grounded on data traffic growth and demand, Ethio Telecom has rollout 4G network capacity in Addis Ababa and other regions, and improve network coverage and capacity and now, Addis Ababa is fully covered with 4G advanced network including different regional sites. in Ethiopia's regional area there are 186 advanced LTE network-covered Sites and 776 4G LTE network-covered cites. Generally, there are around 855 sites are covered by 4G LTE network. Another project expansion is expected both by Ethio telecom and upcoming new operators.

Improving network capacity to meet the ever-increasing demand for data service work is underway. In addition to the expansion, network infrastructure upgrades have been carried out; including 4G LTE advanced for the first time in addition to Addis Ababa, in northwest, northeast, east, central northeast and southwest, west, northeast, east, southwest, south, northwest north-west regions of 68 cities launched on. To enable customers to benefit from the service, 4G LTE Advanced has been launched in the region Cities. The service in other regional cities is ongoing.

Ethio telecom has team up with Ericsson to strengthen its 4G services coverage into the Southwest region of Ethiopia. Specifically, Ethio telecom will use Ericsson’s radio system products and solutions for its 4G network deployment, of which the core expansion will be carried out in Ethio telecom’s regional data centers and those in Addis Ababa. Ethio telecom collaborates with Ericsson in expanding 4G/LTE Advanced service. It’s hoped This will bring high-speed internet to the Southwest region, which will be vital for achieving Ethiopia’s digitalization ambitions while improving the reach of various services.

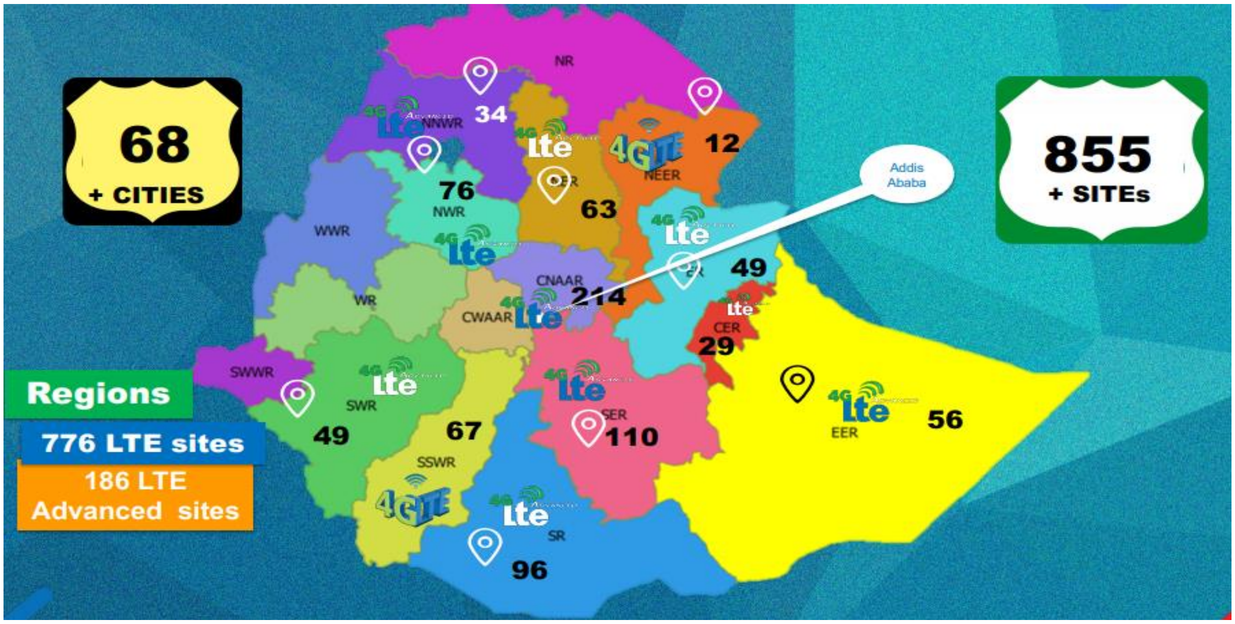


Figure 2.5 4G network expansion in Ethiopia

Since Ethio telecom was the only operator for centuries in Ethiopia and now other operators have joined the country, it must work to more modernize its network by transitioning from its current operations support systems to the more advanced and high capacity by Bing partner with a different couple of the leading providers of Information and Communication Technology (ICT) vendors for services to be provided. And Ethio telecom has revealed that over 103 cities are allotted under the company’s program to enjoy 4G/LTE advanced telecom services.

2.7 5G Infrastructure Readiness in Ethiopia

5G in Sub-Saharan Africa is predictable; it's a natural advancement from previous technology generations. However, the 5G era is not believed it's forthcoming in most markets in the region as existing technologies can support existing use cases and demand for mobile internet connectivity That said, the delay before large-scale 5G deployment could have positive inferences for the region: it might allow the technology to mature and be fully tested in other markets. It would also allow economies of scale to be realized in 5G equipment and devices, potentially sinking costs for operators and consumers.

Many African countries dearth the infrastructure required to ensure smooth and reliable Internet coverage. the same situation for Ethiopia, which needs a major infrastructure upgrade to take advantage of 5G and its dividend. Ethiopia is still struggling to provide even the basic conditions for advanced connectivity in most ruler areas. Although Ethiopia is one of the most rapidly developing African countries and currently gave a license to three different telecommunication operators, it has yet to reach the standard required for the smooth implementation of 5G. It needs some moment, and it will also require the establishment of extensive government support.

Ethio telecom for the first time built a smart pole at Enttoto Park which can support 5G network, considering high network traffic by visitors while keeping the natural look of the park. And it’s already ready for the next generation 5G technology network rollout. And there is a plan by Ethio telecom to install more camouflage towers in such ecosystem areas. Considering this as an example it's planned to fulfill smart city infrastructure requirements such as traffic management, security camera, road lights, environmental weather measurements, screen bords, etc. combing all these services to be served by the smart poles in each city cooperating with various governmental and private institutions.

Currently, as Ethio telecom RAN planning and engineering manage told us Addis Ababa is ready for 5G and some sites only need software activation to lunch 5G, it is planned by Ethio telecom to launch 5G in Addis Ababa in 2022. The company believed there is matured network device penetration for 5G to be implemented and low standard devices are binge replaced by devices that fit the standard, next the trial will be stated in Addis Ababa.

However, several existing services in the regions are not readily accessible from mobile devices. With growing smartphone adoption and the impending arrival of 5G services, there is a clear opportunity for governments in the region to take a holistic approach to digitize services and make mobile the default access platform.

In addition, Ethiopian governments should look to broaden the range of services covered by e-government initiatives, to cover areas such as health services, identity registration, and voter registration/digital voting. relating to 5G and other relevant standards. Other national governments and regional economic unions should consider similar initiatives, in collaboration with key stakeholders and mobile ecosystem players.

On a global scale, with 5G services now widely available, and mobile 5G deployments underway in all regions, operators, service providers, and users alike are facing the early phase of massive 5G adoption. Further before genuine 5G deployments, there are three substantive concerns for mobile operators in the region to realize and prepare for [30]

- Preparing the network for 5G
- Cost-effective infrastructure deployment
- Operational complexity with 2G/3G/4G/5G.

2.7.1 Preparing the network for 5G

The 5G network demands substantial infrastructure deployment to light its requirements (dense small cells, Massive Multiple-Input Multiple-Output (MIMO) capacity, and millimeter-wave spectrum). There is a requirement for Ethio telecom to realize the most cost-effective deployment solutions, which will entail different scenarios for different geographical areas (e.g., dense urban, per-urban, informal settlements, and rural areas). And letting the upcoming Operators in the region begun upgrading their networks to multi-generational RAN, which enables them to run 2G, 3G, and 4G on the same radio. For 5G however, Ethio telecom will need to further upgrade its networks to multi-standard 5G-ready basebands and radio antennae, which can handle multiple bands. There is also a need to build out adequate transport networks to run 5G for example, fiber to the site, cell densification, virtualized core network, and data centers for edge services. As operators raise the coverage and capacity of their 4G networks, it is also important to invest in the latest LTE-Advanced technologies such as carrier aggregation and massive multiple-input multiple-output (MIMO).

2.7.2 Cost-effective infrastructure deployment

The financial demands of 5G deployment on mobile operators will be significant, requiring a high level of investment by operators but with uncertain returns. To strengthen their digital policy desires, governments throughout the region ought to take intervene to alleviate the regulatory cost obligation confronted by the mobile industry in the deployment of next-generation networks in broad-spectrum, and ultimately facilitate the rollout of 5G networks.

Ahead next-generation network deployments in Ethiopia and the first phases of 5G rollouts will need substantial capital investment by mobile operators. The upcoming Operators in the region will be expected to invest a lot.

Operators will invest in new network capabilities, deploy fiber deeper into their networks, and build more cell sites to support network densification. Given the challenging financial situation, operators, vendors, and other ecosystem players will need to explore ways to ease the financial burden. It can be

- Network sharing

  These days the industry landscape has generally been designed by infrastructure-based contest between operators, but the 5G era will likely see the launch of new models of network ownership, with private 5G networks likely to thrive in some regions. Passive infrastructure sharing and the use of tower companies is already a feature in Ethiopia but will develop into more pervasive, particularly to address some of the specific coverage disputes in the region.
- Energy efficiency solutions

  operators must continue to invest in energy-saving solutions. Such moves will support commitments to reduce greenhouse gas emissions by 30% in absolute terms by 2020 and 50% by 2030. Given the unreliable electricity grid in many countries in the region, and the reliance on diesel generators (with the associated challenges of supply reliability, security, and fuel theft), operators in Ethiopia should seek ways to run their networks from renewable sources, especially solar.
- Innovative network financing models

  Vendors can reflect new ways of financing network investment outside traditional vendor financing. These include the lease-to-own-model, whereby the vendor funds the network build and then goes to a revenue share arrangement with the operator until the equipment vendor recovers the investment cost, with ownership then transferring to the operator.

2.7.3 Operational complexity with 2G/3G/4G/5G

The assessment of operating a combined 2G, 3G, 4G and 5G network will reduce an operational obstacle to operators inside the region. The initial deployment of 5G will face the complexity of managing legacy networks, the necessity to integrate legacy networks with the new 5G network, and therefore the resources and expertise required to deal with these challenges.

Operators in Ethiopia should develop a transparent roadmap for justifying their legacy 2G or 3G networks before mass market 5G rollout. Such a roadmap could have an implied bonus, when regulation permits, as spectrum are often reframed for 5G rollout. It also means operators within the region got to take steps to exchange circuit-switched communications with IP communications to assure voice and messaging service continuity within the 5G era, although high device costs could weigh down adoption.

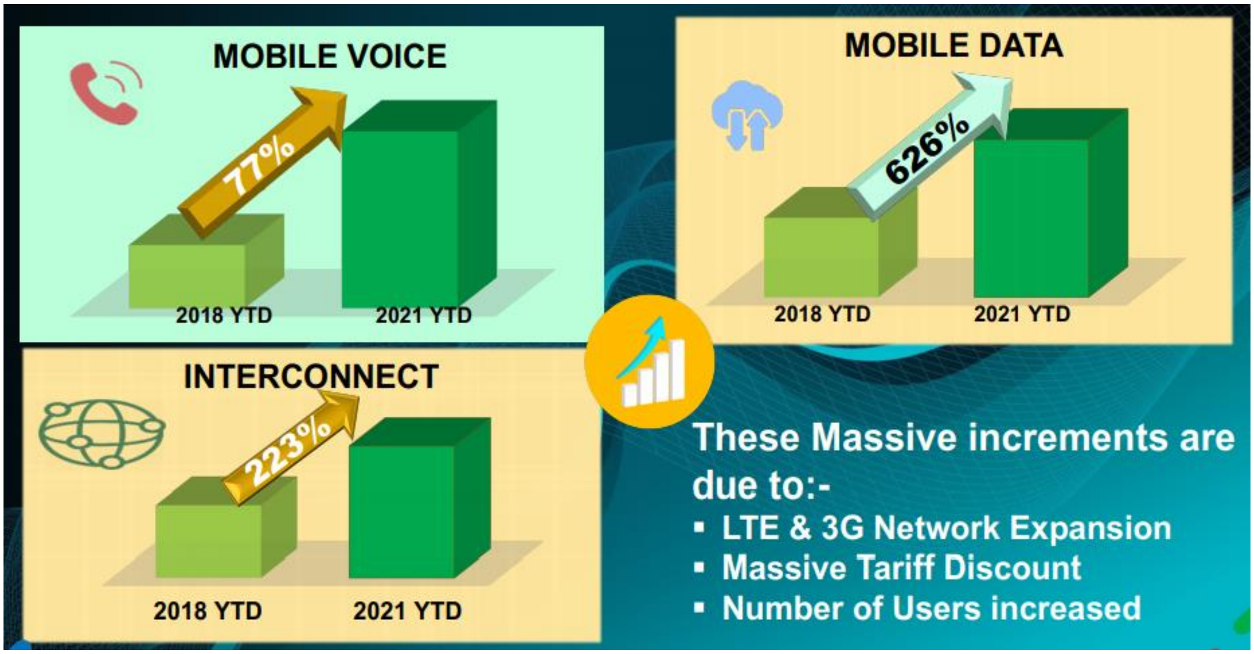
It is reasonable to execute a standalone 5G network in designated usage scenarios, as for enterprises within the mining sector where there's no consideration for integrating legacy 2G, 3G, and 4G networks. Though, the feasibility of replacing 4G to 5G is harder for mass market scenarios, especially within the user segment. Though it's turning to appear like intelligent approach, specifically for operators with but 5% 4G adoption and less than 20% population coverage, it'll be challenging to understand thanks to technical, commercial, and regulatory challenges.

The analysis concerning spectrum management shows that 5G will be enabled by new radio technologies, stable and secure sources of power, and greater availability of spectrum. splintered frequency bands have been categorized as something that will have adverse effects on the implementation and acceptance of 5G. The last amount of 80-100 MHz of adjacent spectrum in the mid bands, and 400 MHz to 1GHz in the high bands are expected to fully provide for 5G, and to achieve speeds that are twenty times faster than existing 4G technologies. Current spectrum assignments do not necessarily boost benefits for industry players. Further, affordability has been raised as a concern regarding spectrum pricing and fees.

2.8 Traffic Growth in Ethiopia since June 2018

These Various services have different requirements in terms of speed, coverage, and reliability, which in turn will demand different network solutions (the evolution of the existing network, and potentially the creation of new networks) and different deployment models (including many small cells), an appropriate network infrastructure (which will include both fiber and wireless connectivity to the core network) and access to different spectrum bands and it's clear all these requirements need a lot of investment but even if customers should get the service in fair tariff.

Total mobile data traffic growth in Ethiopia has grown by 626% from 2018 to 2021. And mobile voice traffic increased by 77% from 2018 to 2021. It’s initiated by two aspects, the number one is superior increase in the number of smartphone clients, involving growth in rural areas, and an increase in average usage per smartphone due to LTE & 3G network expansion number of users increased.



These Massive increments are due to:-

- LTE & 3G Network Expansion
- Massive Tariff Discount
- Number of Users increased

Figure 2.6 Traffic Growth in Ethiopia since June 2018

2.9 Tele birr transaction in Ethiopia

Digital payments and broader financial services provide an opportunity for operators in Sub-Saharan Africa to diversify beyond connectivity, offset stagnating core revenues and increase their presence in the digital ecosystem. For several operators, mobile money suggests a solid platform from which to impact the chances in the digital payment ecosystem. In Kenya, M-Pesa accounts for just over a third of Safaricom’s service revenues, emphasizing the increase potential of digital financial services for operators. [31]

As Ethio telecom reported the tele birr can support its customers to easily pay their utility bills to organizations at any moment they want, anywhere through tele birr account. Its typical applications include paying water, electricity, gas, insurance, and tuition fees for the time. As of July 12/2021, the number of tele birr users reaches around 6.58 million and there have been 12,7 million transactions and when we see the transaction value in birr it's around 357 million birrs. More than 1 million cellphone subscribers in Ethiopia have registered for a new mobile money service less than a week after its launch by state controlled Ethio Telecom, currently, there are around 7 million tele birr users in Ethiopia as the company has said. This is a good improvement since its launched May 11/2021 so within four-month the number of Tele birr users reached 7 million and This will open opportunities for partnership with banks and other financial services companies, its already integrated with most of the banks in Ethiopia.

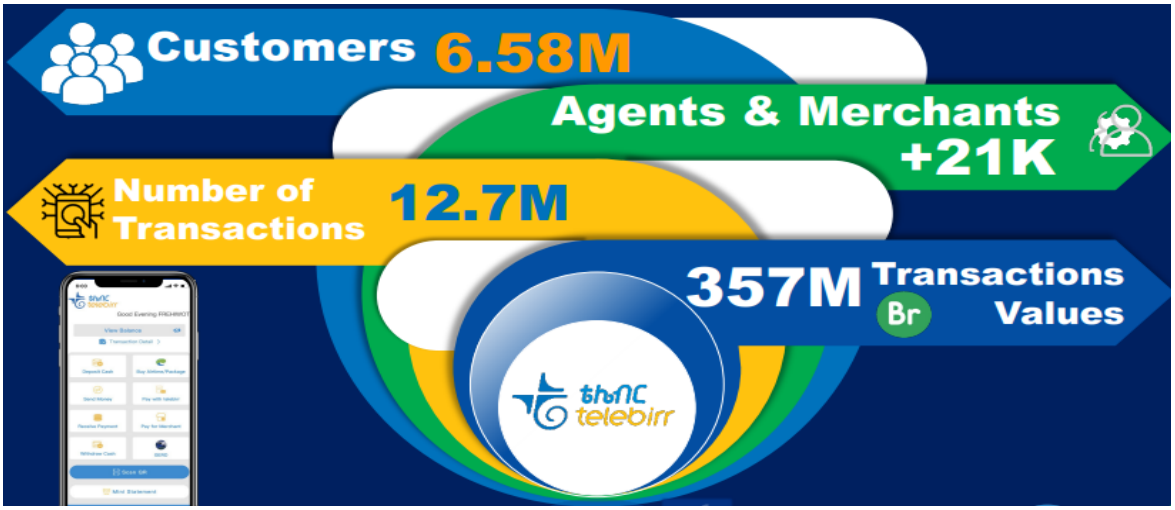


Figure 2.7 mobile money - tele birr transaction

Ethiopia rates as well as the least countries in the world in terms of the use of digital financial services, corresponding to a latest survey by the World Bank. Digital payments and broader financial services suggest a chance for Ethio telecom and new operator in Ethiopia to expand further than connectivity, offset stagnating core profits and strengthen their existence in the digital ecosystem. For various operators, mobile money offers a solid platform from which to influence the chances in the digital payment ecosystem. In Ethiopia, tele birr and is understood it will account for significant Ethio telecom's service revenues, underlining the growth potential of digital financial services for operators.

2.10 Market readiness is crucial to maximize value in the 5G era

The GSMA 5G Market Readiness Index shows that a few countries are stepping rapidly for a state of preparedness, with 4G approval engaging mass market and operators moving ahead with network renovation programs. By 2025, there could be commercial 5G services in at least seven markets, such as Kenya, Nigeria, and South Africa, with 28 million 5G connections (equivalent to 3% of total mobile connections) between them. For Ethiopia to start 5G network rollout, market readiness is necessary to determine the timing for the transition to 5G. This will improve boost value from 5G services for users, operators, and the bigger society. [32]

2.10.1 The consumer segment will be a long-term play

The biggest problem through upgrading from one generation to the other in Ethiopia could be the affordability of smartphones customers must have available smartphones that can let them use both the advanced 4G and 5G network technologies.

Smartphone adoption in Sub-Saharan Africa is rising but lags the global average (64% at the end of 2019) by a considerable margin. Affordability, especially of 4G-enabled devices, stays as a key impediment to smartphone implementation. As GSM reported the average selling price of smartphones has reduced significantly in recent years, with the influx of sub-$100 devices from Chinese brands such as Techno and Infinix, and the increasing momentum beyond the KaiOS-powered smart feature phones. Though, a lot of users are still unable to afford the one-off upfront cost of purchasing a device.

GSM stated Sub-Saharan Africa will have nearly 700 million smartphone connections by 2025 as affordable devices and smartphone invest in schemes accelerate acceptance; In Ethiopia Smartphones as a percentage of total connections are expected to increase from 38% to 61% in 2025.

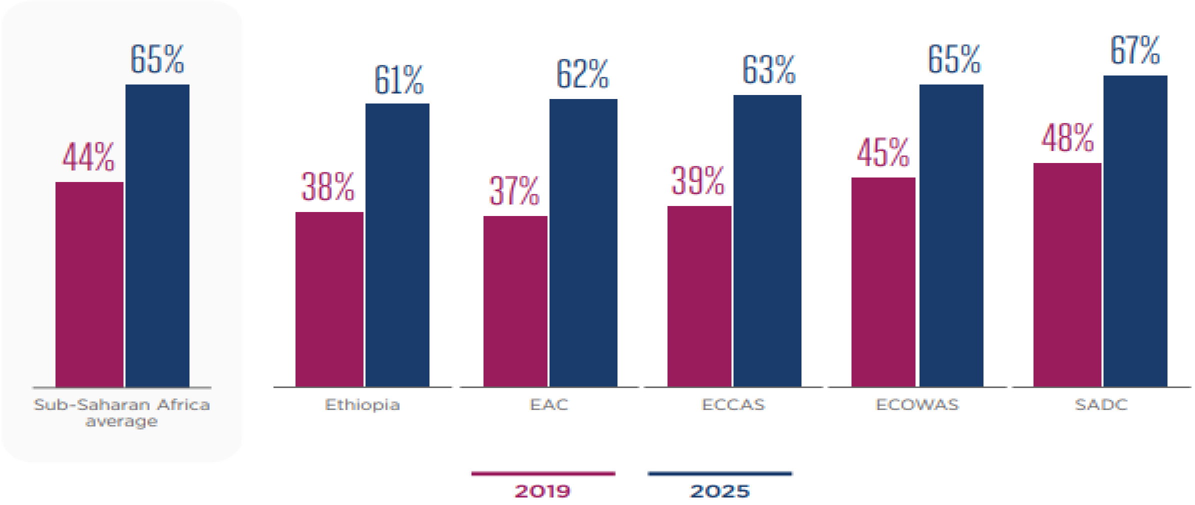


Figure 2.8 Smartphones as a percentage of total connections by GSM

The customer segment will be a long-term act as 5G adoption at the early stages of network deployment will be held behind by an absence of affordable devices and immersive use cases, such as augmented reality (AR) and virtual reality (VR). Device subsidy will be important to 5G adoption in the consumer segment, but the primary emphasis will likely focus on customer premise equipment (CPE) for FWA to the home, given the predominance of prepaid subscriptions in the mobile segment. In the meantime, 4G will maintain to deliver better speed mobile broadband, encouraging the numerous and improving connectivity needs of citizens and the economy.

2.10.2 The mobile ecosystem should lay the foundations now

Ecosystem alliance on key supply and demand-side initiatives can facilitate 5G network deployment and stimulate adoption in Ethiopia. Previously from 5G network introductions, operators and network apparatus vendors within the county got to make strategies to shape prevailing network infrastructure for 5G, adopt cost-effective infrastructure deployment solutions, and develop a framework to accomplish the complication of functioning multiple networks 2G, 3G, 4G, and 5G concurrently. Additionally, next Generation network deployments and therefore the first phases of 5G rollouts would need major capital investment, because of rising strain on profits and margins, vendors, operators, and other ecosystem players will get to discover ways to ease the financial burden. This may include partnerships to develop use cases within the consumer and enterprise segments, initiatives to bring affordable devices to plug, and active network sharing and joint equipment sourcing to drive down deployment costs. Governments can performance a lively role through this development, through direct funding support or through developing collaboration to existing research initiatives. In Ethiopia, the telecoms regulator, should set up a Forum, with Working Groups to debate matters concerning 5G and other important standards. Other national governments and regional economic unions should consider parallel initiatives, together with key stakeholders and mobile ecosystem players.

2.11 Setting spectrum policy for 5G & Maximizing spectrum efficiency

Policymakers should be encouraged to permit voluntary spectrum pooling between Ethio telecom and other upcoming operators to help drive faster services and maximize spectrum efficiency. To provide reasonable, prevalent, and high-quality mobile broadband services, mobile operators require reasonable and inevitable access to sufficient radio-frequency spectrum. High spectrum costs have been connected to more costly, lower-quality mobile broadband services and may restrict 5G rollout and take-up. Spectrum public sale should permit the market to work out spectrum costs. Governments should primacies rapid, high-quality 5G service rollouts over income maximization when awarding 5G spectrum.
"Ericsson began the partnership with Ethiopia and Ethio telecom in 1894. Fast forward nearly 130 years later and we have together launched one of the most advanced 5G ready networks in the region," said Todd Ashton, vice president and head of Ericsson South and East Africa. The launch of commercial 5G services in Ethiopia in the coming year will be an important milestone for Sub-Saharan Africa. However, policymakers must start planning now.

Making sure the needed spectrum resources are available under the right conditions when the time is right to launch will lower broadband costs, increase coverage, and boost connectivity.

5G needs a significant amount of new harmonized mobile spectrum, so ensuring the timely availability of prime bands including those whose use requires defragmentation should be prioritized. Regulators must intend to make available 80–100 MHz of contiguous spectrum per operator in the prime 5G mid-bands (e.g., 3.5 GHz) and around 1 GHz per operator in the high bands (e.g., mm Wave spectrum). Sub 1 GHz spectrum is also required to safeguard coverage and guarantee everyone can eventually retrieve 5G.

Mid-range frequencies are today used as the basis for the first commercial 5G networks all over the world. This initial focus, particularly on the 3.5 GHz range, produces the scale needed to bring down the cost of network equipment and mobile devices. Harmonization has always played a key role in the success of mobile networks, and 5G is no different. More spectrums beyond the 80–100 MHz will be required as 5G demand increases. Reusing 4G bands and extending the 3.5 GHz range are important steps. However, adding new bands is equally important.

Beyond connectivity, the mobile industry has engaged with businesses and governments on initiatives to alleviate the impact of the Covid-19 pandemic on citizens. Ethio telecom, also donates 41 million birrs for research to cure the coronavirus using the ministry of health and institute of public health. From mobile money transaction payment renunciations and reductions on data prices for educational and health spots to cash and equipment donations, mobile operators and other industry players have reinforced the most vulnerable in society during the pandemic while also contributing to economic retrieval Attempt.

As such, governments and policymakers should manage spectrum and implement fiscal policies To enhance access to connectivity and drive investment in more resilient digital infrastructure for everyone. Glad to the positive influence of mobile on the financial system, reforming mobile taxation can bring better connectivity levels as well as GDP and tax income. Studies undertaken for the GSMA reveal that the removal/reduction of mobile-specific taxes and fees can stimulate the economy through greater mobile penetration, investment, and tax revenues. Policymakers need to focus their efforts on improving the affordability of mobile connectivity to enhance access to digital services.

As 5G securities as being important for the adoption and success of 5G. Recommendations discussed include the following:

- A clear framework for infrastructure deployment be Put in place, covering the standardization of a digitized way leave and right-of-way.

- It is recommended that the following be adopted to mitigate a range of cyber security risks:
- designing security into policies, regulations, and processes through the amendment of the Electronic Communications
- Screening is undertaken of potential suppliers, to assess their risk profiles, and to ensure that the risk posed to the 5G network is minimized.

The operators must streamline design processes and approach sites to facilitate the swift installation of network apparatus on brand new and current sites. The governing framework should provide certainty for operators to work together on infrastructure planning and voluntarily share their passive and active infrastructure. Common in many countries, infrastructure-sharing arrangements permit mobile operators to jointly use masts, buildings, and antennas, avoiding unnecessary duplication of infrastructure. Infrastructure sharing can also offer additional capability in clogged areas where space for sites and towers is restricted. This practice can also facilitate expanded coverage in earlier underserved areas.

2.12 Challenge and remedies

Of course, various challenges are occurring in Ethiopian telecom industries service such as The Company has experienced several problems during the fiscal year. Fraud, attacks on property, repeated cyber-attacks, and power outages are the mainstays, and attacks on security personnel and the outbreak of corona have challenged service delivery. service interruption and infrastructure damage impacts company revenue and operation and added Trouble on daily operation, cost of doing business customer handling, supply chain, project execution training, and service provisioning affected on the other side the big issue is a commercial power interruption, continuous disruption from total network incident EEU power covers for more than 34% of incidents.

On another as Ethio telecom reported, internal and external Telecom fraud activates including repetitive and various cyber-attack attempts have been made 2.5M average daily cyber-attack on IGW was recorded in 2021.

When we come to resolutions to minimize the effects, swift maintenance and rehabilitation works should be done to restore the services awareness creation and working with law enforcement enhanced communication and collaboration with all those involved in the excavation process, containing one call center, underground capacity owners, and backhoe. Using technology such as damage presentation software and data analysis to measure and improve program effectiveness.

Availing safety materials, services, and awareness creation, and digital communication, offering redesigned (packages) and SIM life active period extending can bring a solution. using alternative power options new tanker, AC, solar adaptation, and Hybrid solutions can also mitigate the power interruption.

new fraud control methodologies deployed, detection capacity enhancement, managing to reduce overall average damage caused by SIM involved in telecom frauds. Using proactive measures to ensure security by proactive threat analysis to understand the dynamic behavior, identify vulnerable systems and dedicate a team to protect them, impose strict role-based account management. Work in collaboration with regional and sub-city governors.

The digitalize data center of Ethio telecom was recently deployed and located at Gola Sefer, Addis Ababa, and is supplied with 16 cabinets per POD, 5 POD (Points of Deployment) which can provide 10 servers per cabinet. The overall power of this resource can turn up to 800 servers. After installing Huawei Net Eco power monitoring system, it can further reduce 35% of operation and maintenance cost. Modular data centers have grown into a mainstream form of data center deployment around the world recently, thanks to its rapid delivery period and better energy conserving ratio.

To mitigate this challenge different deployment options have been researched and adopted. Even though fiber is the most reliable terrestrial transmission technology for both access and backhaul networks, and will see to the achievement of the speeds, services, and applications from 5G, Fixed Wireless Access (FWA) is a compelling alternative to wired solutions, such as next-generation cable, copper-based Giga-fast and various fiber topologies.

Connectivity has become even more crucial during the Covid-19 pandemic, serving as a lifeline for citizens to access essential services. By enabling Homeworking, remote education, online shopping and digital payments, connectivity has been crucial in keeping economies active and mitigating the socioeconomic repercussions of the pandemic. A study published by the ITU in 2019 showed that an increase of 10% in mobile broadband penetration in the continent would yield a 2.5% increase in GDP per capita. Our recommendations will hopefully, assist in enabling Ethiopian’s deployment and uptake of 5G infrastructure and services in the national interest.

Use cases and operating environments request consideration of several extreme factors, including the diversity of settlement patterns, ranging from low-density rural areas to rapidly expanding ultra-dense conurbations, as well as informal settlements with vastly unreliable or non-existent power grid networks. This could be mitigated by making use of spectrum sharing and dynamic, resourceful spectrum access (DSA)), FWA, and satellite access and backhaul.

Chapter 3

3. Overview of Massive MIMO system

3.1 Background

Multiple-input multiple-output (MIMO) communication systems are a crucial area of focus for next-generation Wireless systems, due to their potential for top capacity, increased diversity, and interference destruction. For applications such as cellular telephony and wireless LANs MIMO systems will likely be installed in environments where one base must connect with various users at the same time. MIMO, Multiple-Input Multiple-Output, the technology relies on multiple antennas to simultaneously Transmit multiple streams of knowledge in wireless communication systems [33]. When MIMO is employed to speak with several terminals at an equivalent time, we speak of multiuser MIMO.

The last ten years have seen huge growth within the number of connected wireless devices. millions of equipment's are linked and controlled by wireless networks. At an equivalent time, each device needs a high throughput to support applications like voice, real-time video, movies, and games. Requirements for wireless throughput and hence the number of wireless devices will always improve. Also, there's a rising concern about the energy utilization of wireless communication systems. Thus, upcoming wireless systems require to fulfill three main requirements:

i) having a high throughput
ii) simultaneously serving many users
iii) having less energy consumption

Massive multiple-input multiple-output (MIMO) technology, where a base station (BS) equipped with a very sizable number of antennas (collocated or distributed) serves many users within the same time-frequency resource, can fulfill the above necessities, and therefore, it's a encouraging contender technology for subsequent generations of wireless systems. Along with massive antenna arrays at the BS, for numerous propagation environments, the channels turn out to be beneficial, i.e., the channel vectors between the users and therefore the BS are approximately pair sensibly orthogonal, and hence, linear processing is approximately best. A huge throughput and energy efficiency are often achieved thanks to the multiplexing gain and therefore the array gain [34]. With an easy power control scheme, Massive MIMO offers uniformly good service for all users.

3.2 Going Large: Massive MIMO

Massive MIMO is an emerging technology that scales up MIMO by possible orders of magnitude compared to the current state-of-the-art. In massive MIMO, we assume systems that use antenna arrays with a few hundred antennas, simultaneously serving many tens of terminals at the similar time-frequency resource. The fundamental principle after massive MIMO is to earn all the profits of conventional MIMO but on a much larger scale. Overall, massive MIMO is an enabler for the development of future broadband (fixed and mobile) networks that 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, the Internet of things, with clouds and another network infrastructure. Various configurations and implementation scenarios for the actual antenna arrays used by a massive MIMO system can be envisaged [35].

3.3 Networked MIMO and Massive MIMO

MIMO systems can be cooperative or non-cooperative. Cooperating systems are frequently called Networked MIMO, where a specific user is provided by all BSs within its scope of operation. The typical massive MIMO BSs do not cooperate in this sense [36]. Both systems mitigate interferences of multicellular wireless networks in separate ways and are not to be confused with each other [37]. Networked MIMO imitates distributed antenna arrays by generating clusters of connected BSs. Notice that each BS has a comparatively few numbers of antennas. Channel state information (CSI), as well as data, is divided among the cooperating BSs through backhaul links. This offers to obstruction termination, and then data is passed to the scheduled downlink users cooperatively from the BSs occasionally applying beamforming [38]. On the contrary, massive MIMO systems have a significant M number of antennas per BS, concurrently serving a much smaller K number of users.

Table 3. 1: Comparison between cooperating and non-cooperating multiple-input multiple-output (MIMO) systems [36]

	Cooperating Systems (Networked MIMO)	Non-Cooperating Systems (Conventional Massive MIMO)
1	Multiple fold increase in spectral efficiency.	Less.
2	Less energy consumption.	Less energy saving.
3	Cooperation between BSs with small Antenna arrays.	Noncooperation: Each BS is robust against ICI 1
4	More controls (yields in better performance).	Fewer controls (yields in better Implementation).
5	Less downlink user rate.	Improvement in the downlink user rate.
6	Each user experiences less quality of service.	More user quality of service.
7	Increased system complexity, and the large signaling overhead, which is reduced by Distributed optimization.	Less Complexity.
8	Improved capacity, coverage, and cell Edge throughput.	Improved capacity, coverage, and cell Edge throughput.

3.4 Massive MIMO Antennas

Commonly, for a simpler and practical antenna system, the design of various array elements constituting the antenna array is identical, however, this is not necessary, getting such array end results more freedom in managing the array pattern of an array without changing its physical dimensions. This is done through adopting proper geometrical antenna array configuration. This antenna configuration, along with the pattern of a single element, the separation between various elements and mutual coupling, exhibit a considerable effect on the performance of the system.

A crucial objective beyond the use of Massive MIMO in 5G technology is to monitor the general pattern of the antenna for interference declination and extended distance communication over high frequency. This pattern is highly affected by the array configuration, the separating distance between the antenna elements, the phase and amplitude of the excitation of different elements, and the corresponding pattern of each. In the design process, the chosen configuration should be studied in terms of the total number of antenna elements, the resulting radiation characteristics: radiation pattern, beam width, and gain. Besides, care should be taken in studying the mutual coupling between the elements and how they affect the power of the received signal, the coverage, and the overall channel capacity [39].

3.5 How Massive MIMO Works

In Massive MIMO, TDD operation is preferable. Throughout a coherence interval, there are three strategies: channel estimation, involving both the uplink / downlink training and uplink / downlink data transmission. Our main concern is on the downlink data transmission.

Massive MIMO is adopted in the 5G network, at the Base Station. These huge sized antenna arrays can adapt flexibly to complex environments, and by scaling up the order of the MIMO system and applying beamforming techniques, the signal transmitted from the BSs can be highly focused into small regions of interest, towards each user, leading to greatly reduced interference. Therefore, the spatial multiplexing in each time frequency resource block, along with multi-antenna diversity and beamforming, is predicted to improve the transmission rate, the multiplexing ability, the spectrum efficiency, and boost the signal to noise plus interference ratio SNIR or SINR. Even, a nearly interference-free communication link would be created between the user and its BS, if highly directly beams with low side-lobe levels are used. The performance is often extra enhanced if more antennas are at the BS, and eventually higher data rates required in 5G are often achieved. A further enhancement is often realized by installing more antennas within the users' mobile devices. Besides, because of the channel's orthogonality of different users, increasing the number of antennas can result in simpler transmit/receive processing techniques, even in the presence of interference [40].

Nevertheless, through averaging out much random impairment, Massive MIMO systems can enhance the energy efficiency with potential power savings, while providing a robust and secure communicating link. MIMO have lately earned consideration owing in part to the following advantages.

3.5.1 Advantages pf Massive MIMO

- Massive MIMO can enhance the throughput and concurrently increase the radiated energy efficiency via energy concentrating.
- Massive MIMO can be constructed with relatively reasonable components by substituting high-power (W) linear amplifiers with low-power (mW) counterparts.
- Massive MIMO can simplify the multiple-access layer (MAC) by arranging the users on the whole band without the requirement for feedback.

3.6 Principle of Massive MIMO downlink system

A Massive MIMO system refers to the system where the base station communicates with quite a lot of users simultaneously. The base station and the user can be fortified with multiple antennas. The MU-MIMO system permits many parallel communications at the same time and frequency resource called Space Division Multiple Access (SDMA). Massive MIMO system has many Advantages:

- Multiplexing gain - Increased data rate due to the base station is equipped with many antennas, it sends the independent data streams to many users simultaneously.
- Diversity gain - Link reliability; due to those antennas generate a lot of communication paths that the radio signal can propagate over.
- Array gain - Improving the energy efficiency, due to the base station can focus its transmission power into the spatial direction where each user is located.

3.6.1 System Model

We considered a downlink single-cell M-MIMO model where a BS is equipped with M-antennas to serve K users in the system ($M \geq K$), through Rayleigh fading channels and that the channels will stay constant during a coherence interval of T symbols. A block diagram of such a system model is illustrated in Figure 6.

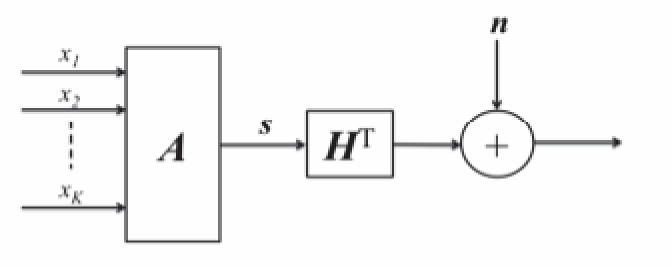


Figure 3. 1: The system model

Let $\mathbf{A}$ ϵ $C^{M \times K}$ be a linear precoding matrix, and x is a K × 1 information vector, where x_k is a data symbol for user k, where $E[|x^k|^2] = 1$. The transmit vector s can be written as $S = \mathbf{Ax}$, and its average transmission power is constrained by $E[||s||^2] = tr(A^H A) = P_{tr}$. Then, the received vector at the K users is given by;

$$Y = H^T s + n \tag{3.1}$$

Where $\mathbf{n}$ is a K × 1 additive noise vector. With our model, we assume that the desired signal vector x and the noise vector n are independent and identically distributed (i.i.d.) complex Gaussian random variables with zero mean and 0.5-unit variance. Further, the transmission power is constrained. We use this model to find the linear precoding matrix to study the performance of a massive MU-MIMO system.

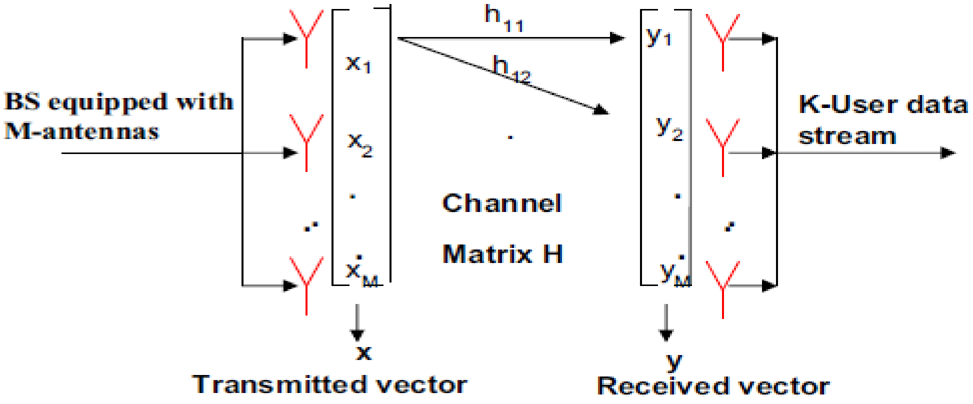


Figure 3.2: Downlink M-MIMO system model with M-antennas and K-users

3.6.2 Channel Estimation

The channel estimation is done on the downlink typically the downlink transmission will occur in two phases: The training phase and the Downlink data transmission phase’s training sequence and data transmission sequence.

The BS requires CSI to identify the signals transmitted from the users in the uplink, and to precode the signals in the downlink. This channel state information is achieved across the uplink training. Each user is allocated an orthogonal pilot sequence and forward this pilot sequence to the BS. The BS recognize the pilot’s sequences transmitted from all users, then assesses the channels based on the received pilot signals. Furthermore, each user may have limited knowledge of CSI to coherently detect the signals transmitted from the BS. This information is often obtained through downlink training or some blind channel estimation algorithm. Since the BS uses linear Precoding techniques to beam form the signals to the users, the user needs only the effective channel gain (which is a scalar constant) to detect its desired signals. Therefore, the BS can use a short time to beam form pilots in the downlink for CSI achievement at the users.

In small-scale MU-MIMO systems where the number of BS antennas is comparatively few, typically, the BS can attain an approximate of CSI via feedback in frequency-division duplex (FDD) operation. More accurately, each user evaluates the channels based on the downlink training, and then it feeds back its channel estimates to the BS over the reverse link. However, in massive MU-MIMO systems, the number of BS antennas is very huge and channel estimation turn into tough in frequency division duplex (FDD) since the number of downlink resources required for pilots will be proportional to the number of BS antennas. Also, the requisite bandwidth for CSI feedback becomes very vast. Th Distinguish is in time-division duplex (TDD) systems own to the channel reciprocity, the BS can obtain CSI in open-loop directly from the uplink training. The pilot transmission overhead is thus proportional to the number of users which is usually less important than the number of BS antennas. Therefore, CSI acquisition at the BS via open-loop training under TDD operation is desirable in massive MU-MIMO systems [41], [42]. Having this CSI acquisition in the uplink, the signals transmitted from the users can be decoded by using these channel estimates. In the downlink, the BS can use the channel estimates to precode the transmit signals. However, the channel estimates are only accessible at the BS. The user also should have an estimate of the channel to consistently decode the transmitted signals in the downlink. To obtain CSI at the users, an easy approach is that the BS forwards the pilots to the users. Then, each user will evaluate the channel based on the received pilots. This is very ineffective since the channel estimation overhead will be proportional to the number of BS antennas. Therefore, most of the research on these systems has understood that the users don’t get the CSI. More specifically, the signal is assigned at each user by only using the statistical properties of the channels [43].

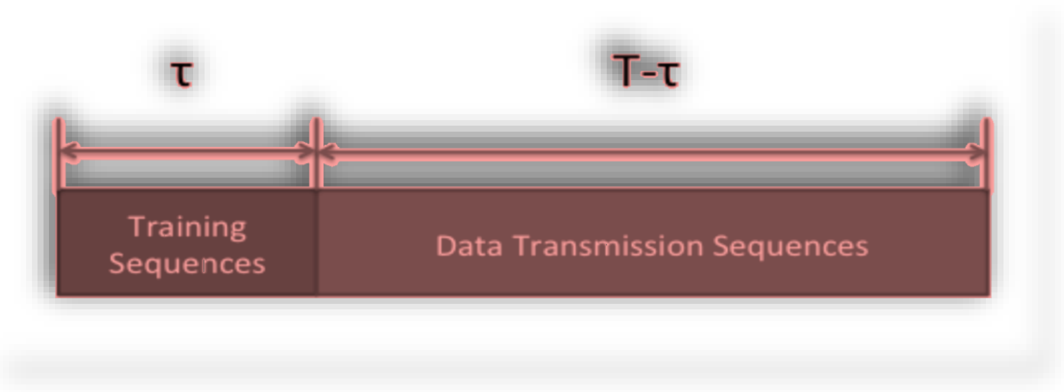


Figure 3.3**:** Downlink transmission protocol

Let τ in duration used for channel estimation. Each user is assigned an orthogonal pilot sequence of τ symbols where $\tau \geq K$. The $M \times \tau$ received pilot matrix at the base station is given by [44].

$$Y_P = \sqrt{P_P}\, H\Phi^T + N_P \tag{3.2}$$

Where $\boldsymbol{\Phi} \in \tau\times K$ is the pilot sequence used by K users satisfying $\boldsymbol{\Phi}^H \boldsymbol{\Phi} = \mathbf{I}_K$; $\mathbf{N}_p \in C^{M\times\tau}$ is the additive noise at the base station; $\boldsymbol{H}$ is an $M \times K$ channel matrix between the K users and the base station; and $p_p = \tau p_u$, where p_u is the transmitted power of each user. From (3.2), the channel can be estimated from [44];

$$Y_P = \sqrt{P_P}\, H + W \tag{3.3}$$

Where $Y_P = Y_P\Phi^* \text{ and } W = N_P\,\Phi^*$

Let $\boldsymbol{y}_k$ and $\boldsymbol{w}_k$ be the *kth* columns of $\tilde{\boldsymbol{Y}}_p$ and $\boldsymbol{W}$ respectively. Then [44],

$$y_{p,k} = \sqrt{P_p}\, h_k + w_k \tag{3.4}$$

If the base station uses MMSE channel estimation, the channel estimate of $\mathbf{h}_k$ is given by [44].

$$\tilde{h}_k = arq \ {}_{\tilde{h}_{k\in\mathbb{C}^M}} \ \min \ \mathbb{E}_{h_{k,}\tilde{y}_{p,k}} \left[\left\|\widetilde{h_k} - h_k\right\|^2\right] \tag{3.5}$$

Finally, we obtain the channel estimate of $\mathbf{h}_k$ as [44]

$$\tilde{h}_k = \frac{\sqrt{\mathrm{P_P}}}{\mathrm{P_P}+1}\tilde{y}_{p,k}$$

$$\tilde{h}_k = \frac{\sqrt{\mathrm{P_P}}}{\mathrm{P_P}+1} h_k + \frac{\sqrt{\mathrm{P_P}}}{\mathrm{P_P}+1} w_k \tag{3.6}$$

With large p_p or τ, we obtain a perfect channel estimate. This is the case that we consider in this thesis.

3.7 Rayleigh Fading Channel

In wireless communication, it is hard to find the channel properties because of multipath propagation in each environment. However, channel models are used for analyzing system performance. From the channel models, which is used for modeling the channel fading, is a Rayleigh fading channel. The model idea is that the summation of many statistically independent reflected and scattered paths with random amplitudes is an independent and identically distributed (i.e.) complex Gaussian random variable. The component of the channel matrix can be arranged in a complex number form.

The PDF of *R* is the same as Rayleigh distributed. By the above properties, the Rayleigh fading channel can be described in terms of amplitude and phase. The Rayleigh fading channel complex coefficient is generated by two Gaussian random variables where each variable has zero mean and variance 0.5. Every Gaussian random variable is set in the real part and imaginary part Then, the coefficient of Rayleigh fading channel is given by; The element of the channel matrix can be written in a complex number form as [45]

$$h_{ij} = c + jd \tag{3.7}$$

Where $c \in \mathbb{N}\left(0,\frac{1}{\sqrt{2}}\right)$ and $d \in \mathbb{N}\left(0,\frac{1}{\sqrt{2}}\right)$

The joint probability density function (PDF) can be written as

$$f_{c,d}\,(c,d) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{c^2+d^2}{2\sigma^2}\right) \tag{3.8}$$

Expressing hij in a polar form we obtain

$$h_{ij} = r \exp(j\theta) \tag{3.9}$$

where

$$r = \sqrt{c^2 + d^2}$$
$$\theta = \arctan \frac{d}{c}$$

From the polar form, we can write the joint PDF of R and θ by

$$f_{R,\theta}(r,\theta) = \frac{r}{2\pi\sigma^2} \exp\left(- \frac{r^2}{2\sigma^2}\right) \tag{3.10}$$

By integration with θ we obtain the PDF of R as

$$\mathrm{P}_R(r) = \frac{r}{\sigma^2} \exp\left(- \frac{r^2}{2\sigma^2}\right) \tag{3.11}$$

Chapter 4

4. Precoding Techniques

4.1 Background

At the downlink data transmission, the BS transmits signals to all *K* users in the similar time frequency resource. More specially, the BS uses its channel estimates in combination with the symbols intended for the *K* users to create *M* precoded signals which are then fed to *M* antennas. The downlink data transmission was discussed in detail in the next Section.

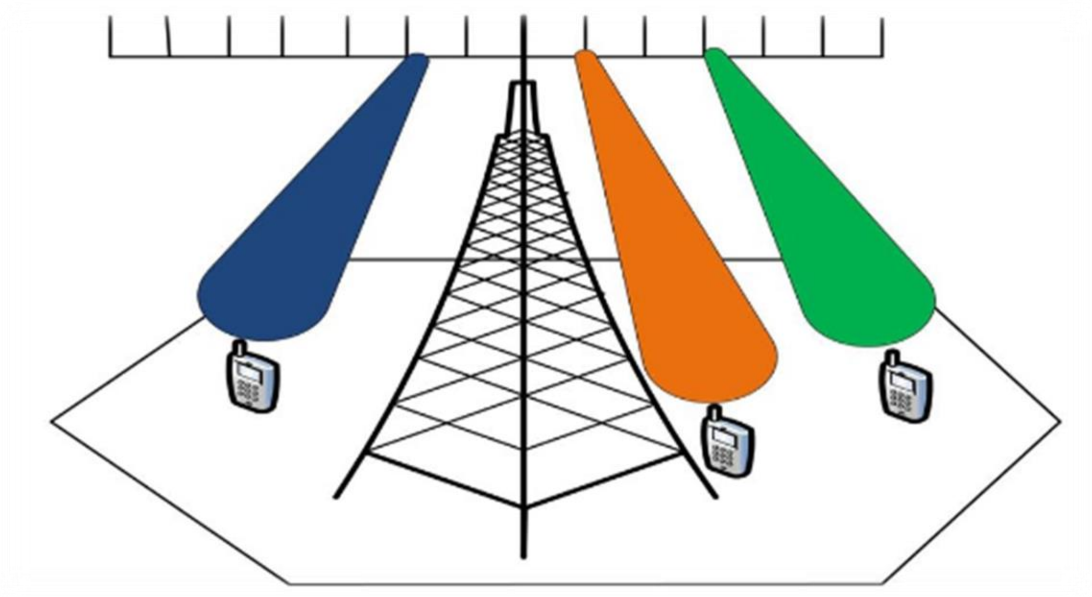


Figure 4.1: MIMO downlink transmission [54]

Consider the MU-MIMO downlink system, which includes one base station equipped with *M* antennas, and *K* single-antenna users. See Figure 9. We undertake that *K* users share the identical time and frequency resources. We are concerned in the system where M >> K. This system implies to a massive MU-MIMO. We beyond assume that the channels will remain constant during a coherence interval of *T* symbols. The downlink transmission will occur in two phases: the training phase and the downlink data transmission phase as stated above.

The base station uses the channel estimates taken from the channel estimation phase to process the signals before transmitting them to K users. We suppose that the base station uses linear precoding techniques. Furthermore, we suppose that the base station has a perfect CSI. This assumption is reasonable under the circumstances that the training power is huge, or the coherent interval is big and hence, we can devote large for training.

Let $\mathrm{A}\ \epsilon\ \mathbb{C}\ \mathrm{M}\ \mathrm{x}\ \mathrm{k}$ be a linear precoding matrix, and $\boldsymbol{x}$ is a K× 1 information vector, where X_k is a data symbol for user k, where $E[|xk|^2] = 1$. The transmit vector $\boldsymbol{s}$ can be written as $\boldsymbol{s} = \boldsymbol{Ax}$, and its average transmission power is constrained by $E\ [||\boldsymbol{s}||^2] = \mathrm{tr}(\boldsymbol{A}_H\ \boldsymbol{A}) = P_{tr}$. Then, the received vector at the K users is given by;

$$\boldsymbol{Y} = \boldsymbol{H}^T\boldsymbol{S} + \boldsymbol{n} \tag{4.1}$$

Where $\boldsymbol{n}$ is a $K \times 1$ additive noise vector. With our model, we assume that the desired signal vector $\boldsymbol{x}$ and the noise vector $\boldsymbol{n}$ are independent and identically distributed (i.e.) complex Gaussian random variables with zero mean and 0.5unit variance. Additionally, the transmission power is constrained. We use this model to get the linear precoding matrix and study the performance of a massive MU-MIMO system.

4.2 Precoding schemes

For the optimum implementation of M-MIMO technology, the choice of precoding scheme plays a key role. Precoding is a technique through which transmit diversity is exploited at the transmitter to forward multiple data streams to the receiver with independent and suitable weighting information streams. The fundamental task of the detector at the receiver is to reduce the effect of the received noise and interference, as well as to remove various forms of distortions due to the channel. Thus, precoding and detection are fundamental techniques for separating data streams and minimize inter-user interference at the BS and receiver user equipment [46].

There are two techniques of precoding: linear types, e.g. ZF, MMSE, MF, and Nonlinear precoding, e.g. SIC, ML, etc.
Multi-user multiple-input multiple-output (MIMO) systems provide high capacity with the benefits of space division multiple accesses. The channel state information at the base station (BS) or access point (AP) is very important since it allows joint processing of all users' signals

which results in significant performance improvement and increased data rates. If the channel state information is accessible at the BS/AP, it can be utilized to effectively reduce multi-user interference (MUI) by beamforming. The Precoding also permits us to perform most of the complex processing at the BS/AP which results in a simplification of users' terminals. Linear Precoding techniques have a benefit in terms of computational complexity. Non-linear techniques have higher computational complexity and require some signaling overhead but can provide better performance than linear techniques.

Linear Precoding is a transmitter-based Precoding scheme for compensating for the multipath interfering effect of the communication channel. Employing linear Precoding techniques in the downlink, the BS transmits linearly precode information data with signal vector x, which is predicated for the K users by [46]

$$\mathbf{X} = \sqrt{\alpha}\mathbf{W}_{\mathbf{q}} \tag{4.2}$$

where W ∈ C ^{MxK} designates the Precoding matrix, q½; q1; q2; . . .; qk denotes the signal vector which encloses the data symbols for the K user, and α represents the normalization constant which has been chosen subject to power constraint E{//X//} = 1. Thus,

$$\alpha = \frac{1}{\mathrm{E}\{tr(\mathbf{W}\mathbf{W}^{T})\}} \tag{4.3}$$

Inserting (4.1) into (3.2), gives,

$$\boldsymbol{y}_{dl} = \sqrt{\alpha \mathrm{P}_d}\ \mathbf{H}^{\mathrm{T}}\mathbf{W}_{\mathbf{q}} + \mathrm{n}_{\mathrm{d}} \tag{4.4}$$

$$y_{dl} = \sqrt{\alpha \mathrm{P}_d}\,\mathbf{H}_k^T\mathbf{W}_k q_k + \sqrt{\alpha \mathrm{P}_d}\ \sum_{k^i \neq k}^{k} \mathbf{H}_k^T\mathbf{W}_{k^i} q_{k^i} + n_d \tag{4.5}$$

Therefore, the signal-to-interference-and-noise ratio (SINR) intended for the kth user from the BS is given by; [46]

$$SINR_K = \frac{\alpha \mathrm{P}_d \left|\mathbf{H}_K^{\mathrm{T}}\mathbf{W}_K\right|^2}{\alpha \mathrm{P}_d\ \ \sum_{K^i \neq k} \left|\mathbf{H}_K^{\mathrm{T}}\mathbf{W}_{\mathrm{K}}\right|^2 + \sigma^2} \tag{4.6}$$

4.2.1 Linear MMSE Precoding

The MMSE Precoding can be generated by regularizing the pseudo-inverse of the channel matrix MMSE precoding is the optimal linear precoding in the MU-MIMO downlink system. This technique is generated by the mean square error (MSE) method. Owing to the average power at each transmitted antenna is constrained; the Lagrangian optimization method is used for obtaining these precoders.

First, we start to consider the MSE of the signal. The MSE can be written as [47]

$$\in = \mathbb{E}\left[\left\|\beta y - x\right\|^2\right] \tag{4.7}$$

Where β is a scalar of Wiener filter.
Firstly, we find ***A*** and β to minimize the MSE under the power constraint. Then,

$$\begin{gathered}\left[\widehat{\mathbf{A}}, \hat{\beta}\right] = \arg \min_{\boldsymbol{A},\beta} \epsilon \\ \text{s.t. } \mathbb{E}[\|\mathrm{s}\|^2] = P_{tr}\end{gathered} \tag{4.8}$$

To solve the optimization problem, the Lagrangian method is used for this problem. Then,

$$\mathcal{L}\,(\mathbf{A}, \beta, \lambda) = \mathbb{E}\left[\left\|\beta y - x\right\|^2\right] - \lambda_{tr}\left(\mathrm{s}^H \mathrm{s} - P_{\boldsymbol{tr}}\right) \tag{4.9}$$

Where λ ϵ R is the Lagrangian factor. To find ***A***, *β*, λ, and _ to minimize the MSE, we take derivatives with respect to ***A***, and λ. As a result, ***A***MMSE can be expressed as [47];

$$\mathbf{A}_{\mathrm{MMSE}} = \frac{1}{\beta} H^* \left(H^T H^* + \frac{K}{P_{tr}} I_K\right)^{-1} \tag{4.10}$$

Where

$$\beta = \sqrt{\frac{tr\left(BB^H\right)}{P_{tr}}} \tag{4.11}$$

Where $B = H^* \left(H^T H^* + \frac{K}{P_{tr}} I_K\right)^{-1}$

4.2.2 Linear ZF Precoding

ZF precoding is one technique of linear precoding in which the inter-user interference can be canceled out at each user. The ZF Precoding is a well-known MIMO Precoding method in the literature. This is probably due to its low complexity nature and ZF Precoding can be implemented without having any prior knowledge of noise statistics. The ZF Precoding is employed at the BS to remove the inter-user interference when transmitting signals in the direction of the proposed user. Mathematically, the ZF pecoders can be expressed as this precoding is assumed to implement a pseudo-inverse of the channel matrix.

ZF approaches MMSE when $Ptr \to \infty$, Therefore, from (4.9),***j***ZF can be expressed as

$$A_{ZF} = \frac{1}{\beta} H^{*}(H^{T}H^{*})^{-1} \tag{4.12}$$

Where

$$\beta = \sqrt{\frac{tr(BB^{H})}{P_{tr}}} \tag{4.13}$$

Where $B = H^{*}(H^{T}H^{*})^{-1}$

4.2.3 Linear MRT Precoding

The MRT is also one of the simplest and oldest Precoding techniques in the literature. It is often called the conventional filter or the maximum ratio transmission (MRT). The MF Precoding technique is applied to maximize the received SNR at the user mobile terminal. It can be determined by finding a solution to the optimization problem. MRT works well in the MU-MIMO system where the base station radiates low signal power to the users.

MRT approaches MMSE when $P_{tr} \to \infty$. Hence, from (4.9), $\mathbf{A}_{MRT}$ can be expressed as

Where

$$A_{MRT} = \frac{1}{\beta} H^* \tag{4.14}$$

$$\beta = \sqrt{\frac{tr(BB^H)}{P_{tr}}} \tag{4.15}$$

Where $B = H^*$

4.3 Achievable Rate

System performance can be defined by several methods. One of the methods to quantify system performance is an achievable rate. The achievable rate is followed by the Shannon theorem. This theory tells the maximum rate, which the transmitter can transmit over the channel. The channel is assumed ergodic, and all parameters are Gaussian random processes. From Shannon theorem, the channel capacity over Additive White Gaussian Noise channel is derived by;

$$\mathrm{R} = \log_2(1 + SNR)\,(bits/s/Hz) \tag{4.16}$$

With the MU-MIMO downlink system, the transmitter must know the channel state information. CSI is the key to multi-user communication. Typically, the transmitter transmits multiple data streams to each user simultaneously and selectively with CSI. All the receivers send the channel estimation feedback to the transmitter on the reverse link, so the transmitter obtains CSI. Hence, the transmitter communicates with all the receivers with perfect CSI. With an MU-MIMO system, the interference consists of additive noise and interference between the users. Then, the achievable rate of *k*th user for MU-MIMO downlink system can be expressed as;

$$R_k = [\log_2(1 + SNR_K)](bits/s/Hz) \tag{4.17}$$

4.4 Spectral efficiency

The SE of an encoding/decoding scheme is the average number of bits of information, per complex-valued sample, that it can reliably transmit over the channel under consideration. The SE is a deterministic number that can be measured in a bit per complex-valued sample. Since there are *B* samples per second, an equivalent unit of the SE is bit per second per Hertz, often written in short form as bit/s/Hz [48].

With a single cell massive MU-MIMO system with perfect CSI, the spectral efficiency is defined as;

$$R_p \ = \ \sum_{k=1}^{k} R_k \ (bits/s/Hz) \tag{4.18}$$

Where R_P is the spectral efficiency in bits/s/Hz and R_k is the achievable rate of user *k*.

4.5 Energy efficiency

The energy efficiency of a system is defined as the sum-rate (spectral efficiency) divided by the transmit power. Generally, increasing transmit power increases the sum-rate. On the contrary, it decreases energy efficiency. The energy efficiency can be written as [49];

$$\eta = \frac{R_p}{p_{tr}} \quad (bits/J/Hz) \tag{4.19}$$

Where P_{tr} is the average transmission power (J/s) at the base station.

4.6 Challenges in Massive MIMO

The major challenges faced by wireless communication systems can be ascribed to two main features, namely, the restricted radio spectrum resource and the complicated wireless propagation environment. With the continued growth of industry and business, the requirement for radio spectrum is increasingly strong, and thus the proper radio spectrum is becoming scarcer and more expensive. When we come to the main challenges of Massive MIMO Pilot Contamination and Unfavorable Propagation can be mentioned.

4.6.1 Channel Reciprocity

TDD operation relies on channel reciprocity. There looks to be a rational compromise that the propagation channel itself is basically reciprocal except the propagation is impacted by objects with strange magnetic properties. Though, the hardware chains in the base station and terminal transceivers may not be reciprocal among the uplink and the downlink. Collaboration of the hardware chains does not seem to constitute a serious challenge and there are calibration-based solutions that have already been analyzed to some extent in practically [50]. Specifically, treats reciprocity calibration for a 64-antenna system in some feature and claims an effective experimental implementation Note that calibration of the terminal uplink and downlink chains is not required to attain full beamforming gains of massive MIMO, if the base station equipment is properly adjusted then the array will certainly transmit a coherent beam to the terminal. There will still be some discrepancy within the receiver chain of the terminal, but this can be managed by transmitting pilots through the beam to the terminal the overhead for these supplementary pilots is very little.

4.6.2 Pilot Contamination

In these sections, we tend to the thought of single-cell setups. However, sensible cellular networks contain several cells. Attributable to the restricted convenience of the frequency spectrum, several cells need to share similar time-frequency resources. Thus, multi-cell setups ought to be thought of. in the multi-cell system, as tend to we cannot assign orthogonal pilot sequences for all user's overall cells, thanks to the limitation of the channel coherence interval. Orthogonal pilot sequences need to be reused from cell to cell. Hence, the channel estimate attained in a particular cell is going to be contaminated by a pilot transmitted by users in various cells. The effect known as pilot contamination, decreases system performance.

The result of pilot contamination is a major inherent limitation of huge MIMO. It doesn’t vanish even once the amount of SB antennas raises while not certain. Significant efforts are created to scale back this result. The eigenvalue decomposition-based channel estimation, pilot removal, likewise as pilot contamination precoding schemes area unit projected in [51], the authors have shown that, beneath bound conditions of the channel variance, by employing a variance aware pilot assignment theme among the cells, pilot contamination possibly with efficiency eased.

4.6.3 Unfavorable Propagation

Massive MIMO functions under favorable propagation environments. Though, in implementation there may be propagation environments where the channels are not beneficial. For example, in propagation environments where the numbers of the scatter are tiny in contrasted to the numbers of users, or the channels from various users to the BS share some common scatters, the channel is not promising [52]. One option to challenge this trouble is to distribute the BS antennas over a huge area.

Chapter 5

5. Simulation Results and Analysis

5.1 Simulation setting

To validate the theoretical analysis presented previously, we conducted a system-level simulation using a MATLAB 2019a. Each simulation used 10,000 channel realizations to produce a correct and smooth result. We considered a single cell massive MU-MIMO system, which no intra-cell interference, in two different scenarios over Rayleigh fading channel with ZF, MRT, and MMSE optimal linear precoding schemes. The performance metric considered for analysis includes the Achievable rate, SNR, energy efficiency, and spectral efficiency, the simulation steps are elaborated means in the section below.

The first Simulation will evaluate M-MIMO and conventional MIMO performance, under sum-rate versus SNR. as we discussed in chapter three the basic premise behind massive MIMO is to reap all the benefits of conventional MIMO but on a much greater scale. General, massive MIMO is facilitator for the development of future broadband fixed and mobile networks which will be energy efficient, spectrum efficient, secure and robust. we fix massive MIMO at M =100 and we use (4 x 4) conventional MIMO, it will be defined through the simulation results in fig 10.

In the second situation, we fix the number of base station antenna at M = 40 and we try to vary the number of users for four different values (K = 10, 15, 25, and 40), to realize which precoding performs better by having a higher achievable rate over a given signal-noise ratio (SNR).
We set up the signal-noise ratio (SNR) between -20 to 20 dB. The results will be shown in figure 5.2 up to figure 5.5.
In the Third situation, we compared the achievable rate versus the number of base station and the number of users by keeping the signal-noise ratio SNR fixed at 5 dB shown in figure 5.6 and figure 5.7. And in the last session, we will see the performance of precoders under energy efficiency versus spectral efficiency while the base station antenna M = 20 and 40.

5.2 Simulation Analysis

Diverse Values of parameters used for simulation of The Massive MU-MIMO Downlink System over Rayleigh Fading channel with perfect CSI at the transmitter. We try to fix and to use range for the number of users, the SNR values and base station antenna. Our parameter is allied with advanced LTE standardized which guarantees high mobility with high level speed of data rates and high-capacity IP based services and application are standardized which makes it more related to 5G wireless system.

The simulation algorithm analysis is done as follow first of all we Start the System design by giving Input the values of the variables and allocating the variables we start Channel generation under Perfect Channel State Informant technique and then we Define precoding matrices with power constraints after that we Calculate achievable rate for each user and then Calculate and compare the total system capacity by averaging the result of realizations we Repeat the process by changing different variables to clearly identify the precoders performance change.

5.3 Simulation results

This section analyses and compares the performance of optimal precoding schemes such as ZF, MMSE and MRT in a single cell massive MU-MIMO system which means no intra-cell Interference, over Rayleigh fading channel. We conducted the simulations using MATLAB-2021a. All findings are shown in terms of the achievable rate versus transmission power, the spectral efficiency versus the number of antenna arrays, the spectral efficiency versus the number of users, and the energy efficiency versus the spectral efficiency.

- The achievable rate of user versus SNR
- The achievable rate versus the number of Beas station/number of users.
- Energy efficiency versus spectral efficiency over Rayleigh fading channel for MMSE, ZF, MRT.

5.4 Simulation parameter

This are the parameter used for the simulation based on 4G LTE acceptable standards Table 5.1 simulation parameters

Parameter	**Value**
Number of BS Antenna (fixed)	20 to 40
SNR (Varied)	-20 to 20dB
Rang of BS antenna (Varied)	10 to 100
Range of user when (varied)	50 to 100
Number of Users (fixed)	10
Number of realization	1000

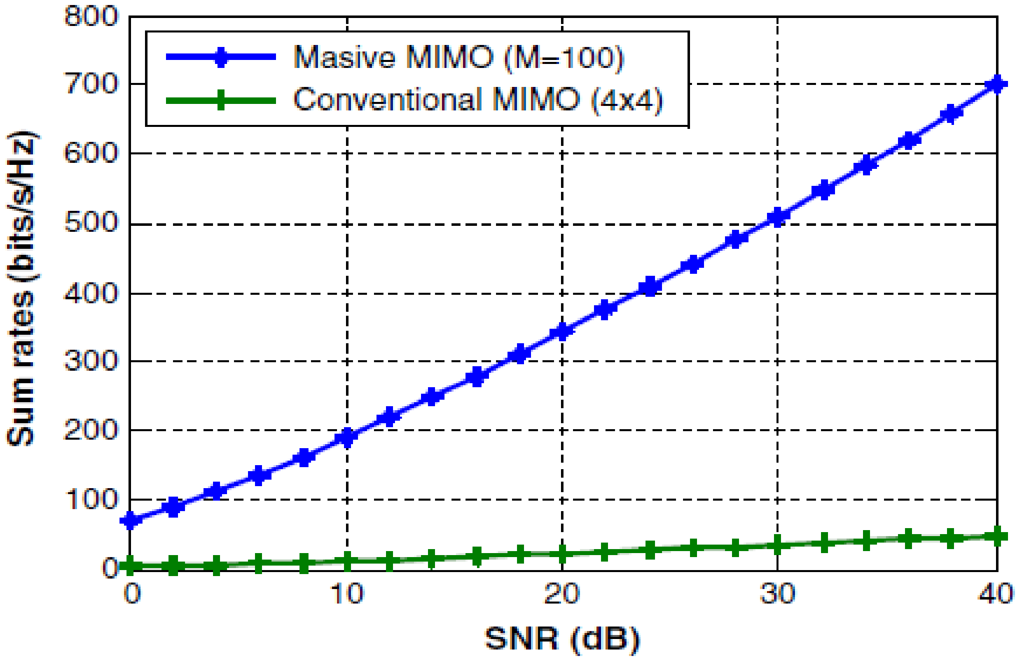


Figure 5.1: Sum rate capacity comparison M – MIMO systems

To begin with, the simulation results of M-MIMO and conventional MIMO performance, in terms of sum-rate capacity versus increasing SNR, is illustrated in Fig. 5.1. As in Fig. 5.1, the achievable sum rate of massive MIMO system outperformed that of the conventional MIMO for any value of SNR. The performance gain of M-MIMO can be attributed to its boosted spatial multiplexing and antenna array gain which maximizes transmission rates as well as its ability to exploit advanced degree of multiuser diversity (large diversity gain) as the number of antennas grows at users.

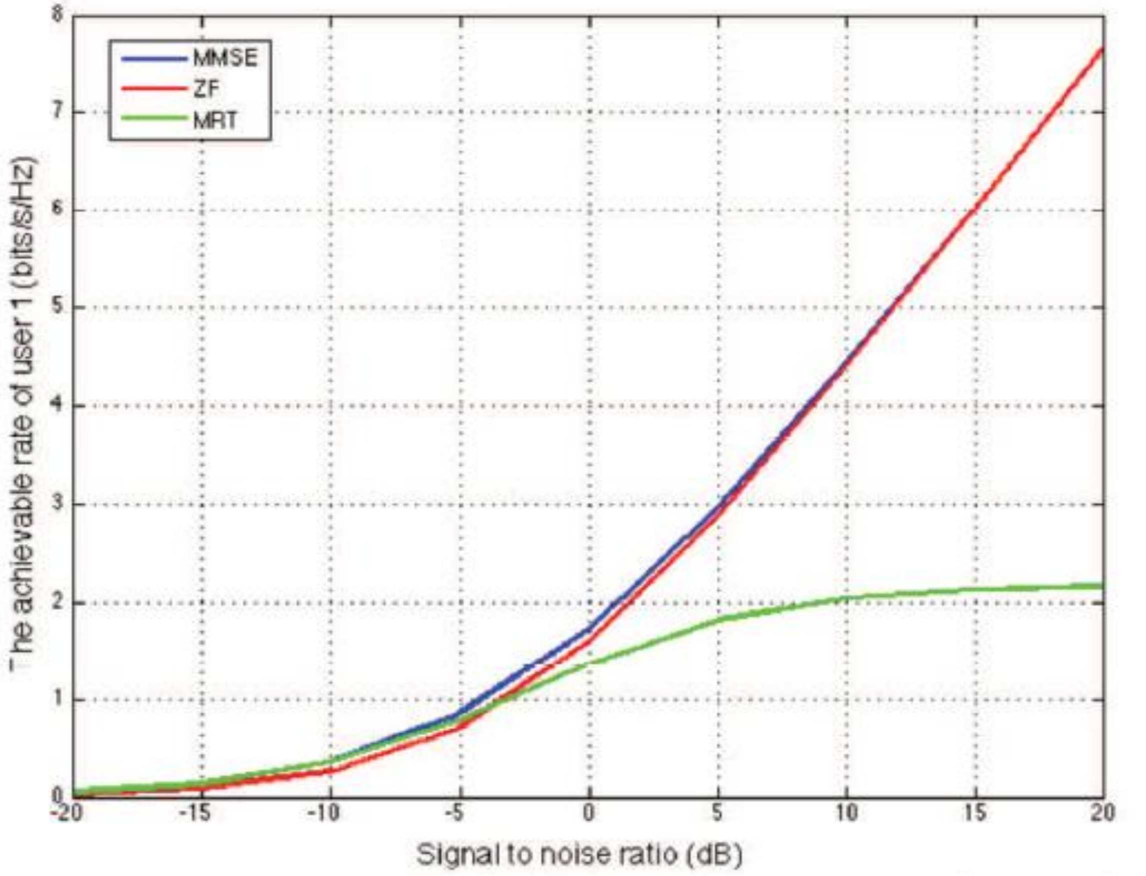


Figure 5.2: The achievable rate of user 1 versus SNR at M = 40 and K= 10

Figure 5.2; illustrate the achievable rate of user 1 when we increase the number of antennas from 20 to 40. All results show that the system performance has improved. The achievable rates for MMSE, ZF, and MRT are increased by increasing the number of base station antennas. Corresponding to the results in Figure 5.3, MMSE gives the highest achievable rate to user 1. For comparison between ZF and MRT, ZF still gives better performances at high SNR while MRT performs a higher rate at low SNR. We observe the point, where ZF performance is better than MRT when moving from 0 to -5 dB SNR. An increasing number of base station antennas made ZF able to be used at low SNR.

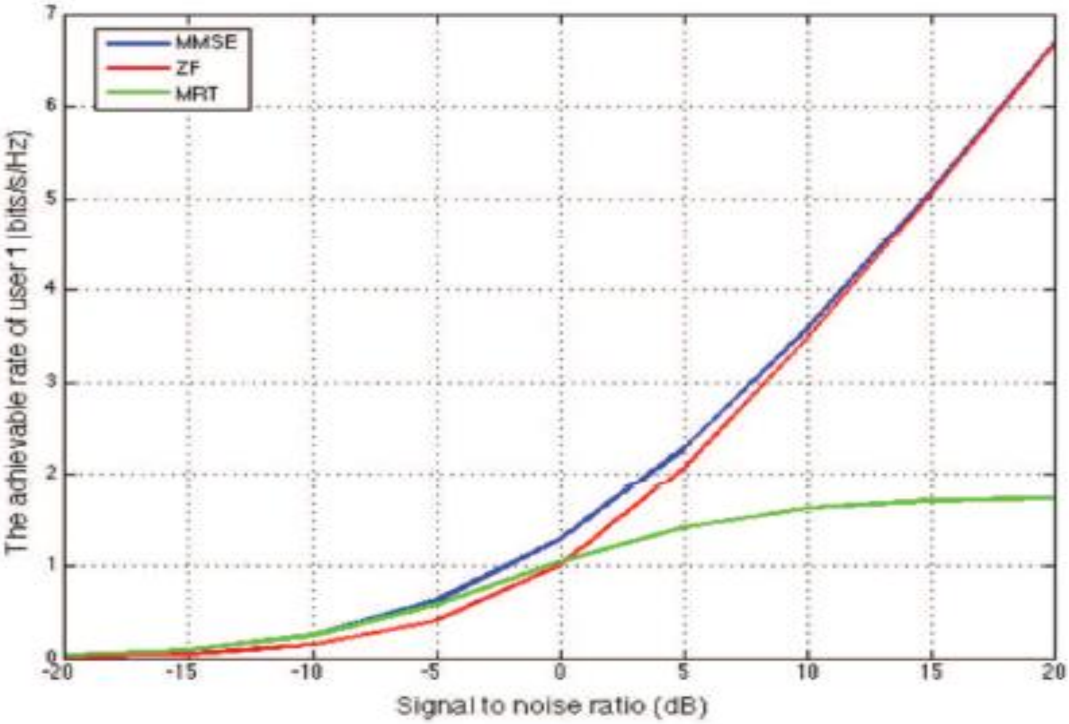


Figure 5.3: The achievable rate of user 1 versus SNR at M = 20 and K = 10.

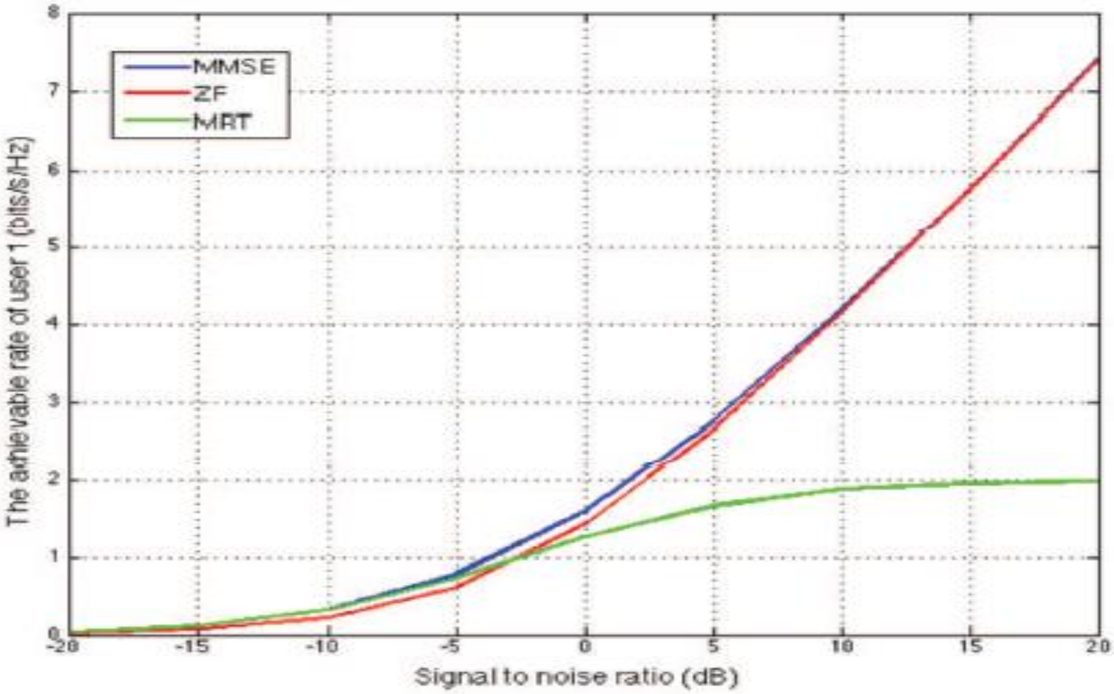


Figure 5. 4: The achievable rate of user 1 versus SNR at M = 40 and K = 15

Figure 5.3 and 5.4 displays the achievable rate of user 1 across the entire SNR range. This system consists of the number of base station antennas *M* = 20 and the number of users' *K* =10. The results show that MRT gives improved performance at low SNR. On the other hand, ZF gives better performance at high SNR. MMSE performs the best achievable rate across the SNR range.

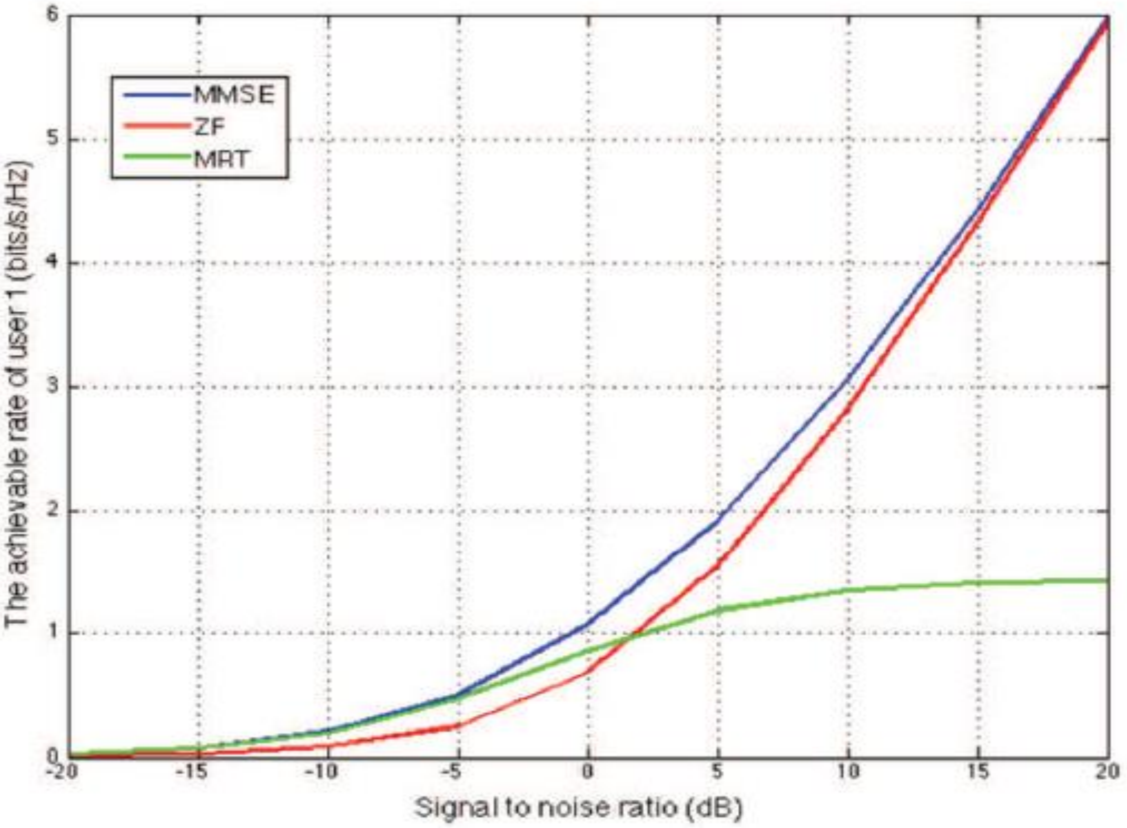


Figure 5.5: The achievable rate of user 1 versus SNR at M = 40 and K = 25

Figure5.5, illustrates the achievable rate of user 1 with *M* = 40 serving *K* = 15. Massive MU-MIMO downlink system performance decreases significantly due to inter-user interference. All the achievable rates of user 1 with linear precoding schemes are reduced about 0.5 bits/s/Hz at 20 dB SNR. Although an increasing number of users reduces the achievable rate of user 1, MMSE gives the highest data rate. At low SNR, MRT performs better while ZF gives better performance in terms of the achievable rate at the high SNR. Notice the gap between MMSE and ZF is extended. Moreover, the SNR range where the achievable rate of user 1 with MRT is greater than one with ZF is extended further.

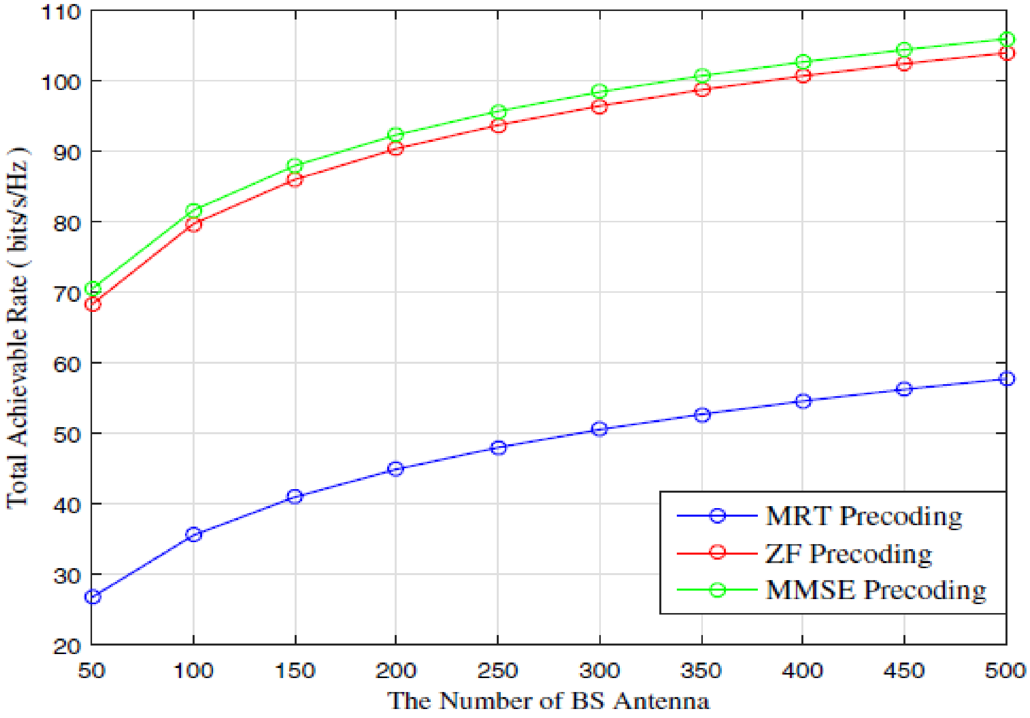


Figure 5.6: Comparison of the total achievable rate versus the number of BS antennas for MRT, ZF, and MMSE precoding schemes for SNR = 5dB and K = 10

Figure5.6, depicts the total achievable rate against the number of BS antennas for three precoding schemes. In our simulations, we assume that the number of users is K = 10 and the input SNR is 5 dB. As we can see, the total achievable rate rises when the number of BS antennas grows, which implies that the large-scale antenna dramatically benefits the achievable sum rate. Moreover, we observe that at the same configuration, the achievable rate with ZF and MMSE precoding schemes is more than double that with MRT scheme, and the total achievable rate with MMSE precoding scheme is continually better than that with ZF precoding scheme, which implies that the MMSE precoding scheme is the best choice for a massive multiuser MIMO system.

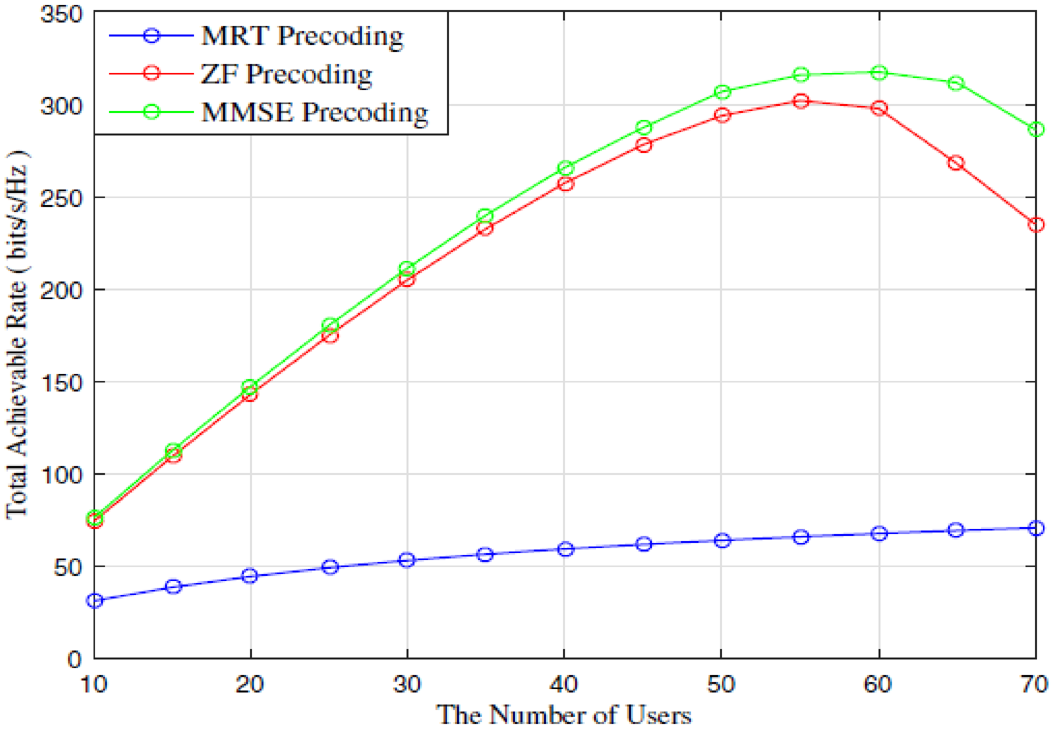


Figure 5. 7: comparison of the total achievable rate versus the number of users for MRT, ZF, and MMSE precoding schemes for Nt = 70 and SNR = 5dB

In Figure 5.7, we represent the total achievable rate varies with the number of users for three precoding schemes. In simulations, the number of BS antennas is *Nt* = 70 and the input SNR is 5 dB, and the number of served users changes from 10 to 70. We can see that the total achievable rate raises with the number of users for MRT precoding schemes since the channel vector among users almost tends to orthogonal and results in interference between users are eliminated. However, there is an optimal number of users that accomplishes the total achievable rate maximization for the ZF and MMSE precoding schemes. This is because when the number of users is minor, increasing the number can effectively improve the spatial diversity and multiplexing gain ordered by the massive MIMO systems.

The total achievable rate is growing rapidly. But when the numbers of users exceed the optimal value, the inter-user interference becomes dominant. Therefore, the total achievable rate for the massive MIMO systems declined gradually.

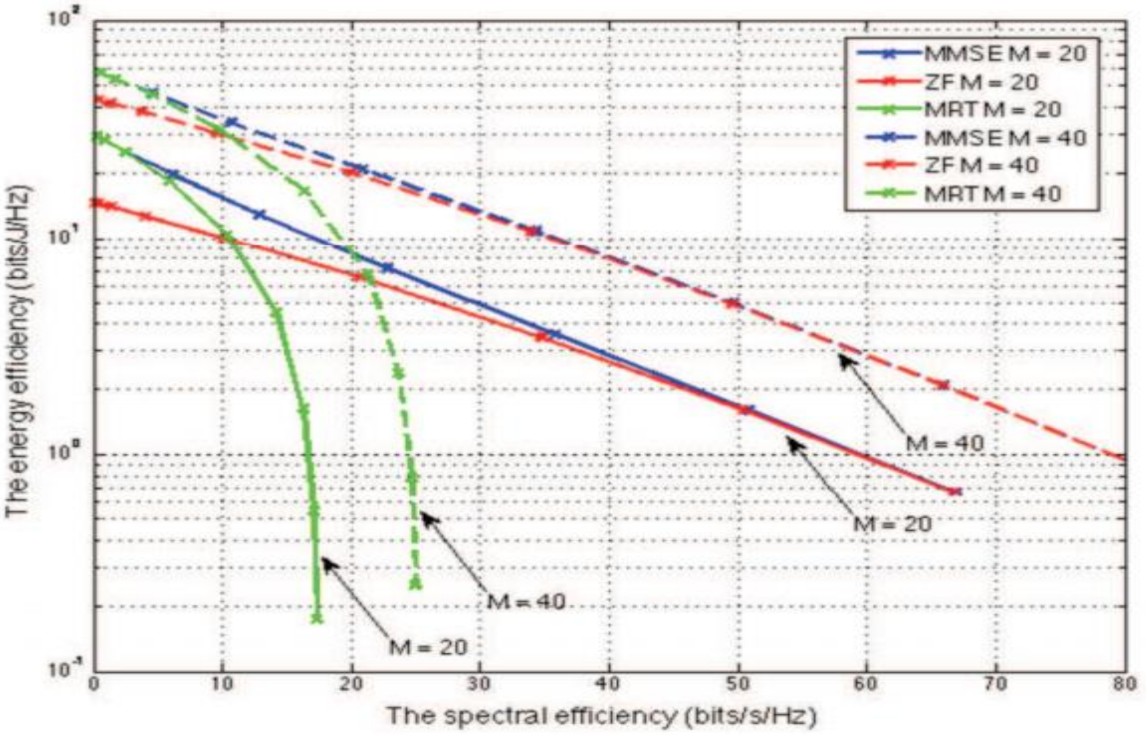


Figure 5. 8: Energy efficiency versus spectral efficiency over Rayleigh fading channel for MMSE, ZF, and MRT at M = 20 and 40.

In Figure 5.8, we study the performance of a massive MU-MIMO downlink system with linear precoding in terms of energy efficiency versus spectral efficiency. We consider M = 20, and M = 40. When the spectral efficiency increased, energy efficiency is reduced.

At high energy efficiency and low spectral efficiency, MRT gives better performance while ZF gives improved performance at low energy efficiency and high spectral efficiency. The outcome shows that an increasing number of base station antennas gain energy efficiency significantly. For example, at spectral efficiency 10 bits/s/Hz, the energy efficiency is 10 bits/J/Hz for MRT precoding with base station antennas M = 20. When M = 40, the energy efficiency increases from 10 bits/J/Hz to 30bits/J/Hz.

Chapter 6

6. Conclusion

6.1 Conclusion

Massive MIMO is an advanced technology that facilitates in the achievement of advanced system throughput and reliable transmission for 5G and ahead wireless networks. A massive MIMO system introduces the opportunity of increasing the spectral efficiency in terms of bits/s/Hz and improving energy efficiency in terms of bits/J/Hz simultaneously. This system can utilize simple processing schemes such as MMSE, ZF, and MRT at the base station and using channel estimation from the uplink. Generally, ZF gives better performance at high transmission power while MRT gives better performance at low transmission power. However, MMSE gives the best performance at low and high transmission power. Therefore, a massive MU-MIMO system is key to the next wireless system. Furthermore, this system offers advantages in terms of achievable rate, spectral efficiency, and energy efficiency.

Linear precoding schemes can still be used to cancel Multi-user interference; however, they result in a reduced throughput or require a higher average power at the transmitter in the massive MU-MIMO scenarios especially for ill-conditioned propagation channels.

There are still challenges ahead to realize the full potential of the technology, e.g., when it comes to computational complexity, the realization of distributed processing algorithms, and synchronization of the antenna units. This provides researchers academia and industry a goldmine completely.

5G is a catalyst for innovation, allowing industry and service providers, communities, and individuals to advance their digital agendas towards economic growth, job creation, and socio-economic development. The role of the 5G in Ethiopia cannot be understood independently from the current state of industrialization, the role of politics and stakeholder organizations, state relationships, multilateral agreements, and more.
The analysis of infrastructure readiness of ethio telecom shows that there are limitations within and around the current 4G infrastructure deployments, leading to a restricted ability to achieve 5G capabilities. It is recommended that a clear framework for infrastructure deployment be developed, covering the standardization of wayleave and rights of way approval processes, removal of barriers imposed by state entities, and standard pricing from landowners.

Ethiopia needs to develop innovative regulatory and nationally streamlined policy frameworks to accelerate new business creation, network, and spectrum innovations, and broadband Internet service deployments.

Even though 5G still being embryonic in its development, there's already a search for testimony to encourage decision-making in government and industry. Although there is still considerable technological, economic, and behavioral uncertainty, exploration of how the potential rollout may take place both spatially and temporally is required for effective policy formulation.

The arrival of 5G subsequent generation of cellular technology means not only will more devices be connected to the web of Things, but also that those devices will be better connected, with higher data transmission speeds, lower latency, and lower power requirements. All of this may produce more efficient and more profitable business solutions than are possible today.

When we see to what extent the current 4G network infrastructure is adequate for the rollout of 5G technologies and networks, most experts believe that, in general, 4G/LTE can provide a basis for the deployment of 5G. At the same time, responses highlighted several limitations, including:

- Significant investment is still needed in passive infrastructure (base stations, fiber, power supply, and edge data centers).
- Utilities to (existing 2G, 3G, and 4G) infrastructure is limited, such that infrastructure sharing will become critical to ensure that all operators can deploy 5G networks. This takes into consideration that emerging architectures and higher frequency bands will require a significant increase in the densification of towers and rooftop infrastructure and the installation of smaller coverage base stations.
- National utilities do not have the necessary self-healing and resilient mesh network topology, that 5G can thrive.
- The drawbacks of current 4G infrastructure, which does not cater for technologies such as carrier aggregation, Massive MIMO beamforming, etc., which are required for the different 5G deployment models.

6.2 Recommendation for future work

In this thesis performance evaluation of linear precoding techniques for 5G downlink MIMO system has been discussed and as we said above Massive MU-MIMO technology is now fascinating substantial attention from both academia and industry. Most of the studies considered uplink performance. In this paper, we studied a massive MU-MIMO downlink system with linear precoding schemes and 5G readiness of Ethiopian telecom network.

- Massive MIMO precoding schemes developed in this thesis consider only a one single cell wireless network. Further works can extend these schemes for a system with more than two cells (i.e., extend it to larger networks) which can improve the spectrum utilization efficiency.

- On the other side coming research goals can be to design a suitable precoding scheme with a decent overall performance and low computational complexity for massive MU-MIMO downlink systems. And, to investigate the high performance achieved through nonlinear precoding techniques. The main challenge of this system is inter-user interference, which significantly reduces system performance. In the downlink, dirty paper coding can be used to reduce the effect of the inter-user Interference However, it induces a significant complexity for the implementation.

On other hand the need for interventions to bridge the digital divide remains urgent and paramount. Continued collaboration between the government and the broader digital telecommunications industry in this area remains essential. Fixed Wireless Access and Satellite will be a recommended option to help bridge the digital divide in areas where optic fiber cannot be deployed. MNOs will be able to take advantage of the satellite’s inherent multicasting broadcast functionality for new IoT use cases, such as connected cars while preserving a high-value wireless spectrum for latency-sensitive services. Alternatively, they can use satellites longer reached to complement the build-out of 5G in remote areas.

Amongst several factors, the spectrum will play a huge role in the operation, development, and roll-out of 5G. The expected peak data rates are driven by the amount of spectrum that is available to the service. The issue of the fragmented spectrum will have adverse effects on the deployment and uptake of 5G. Therefore, the defragmentation and clearing of prime bands by the Authority are needed across all bands that have been identified for 5G. Further, a minimum contiguous assignment of 80-100 MHz of spectrum in the mid-bands and 400 MHz to 1GHz in the high bands are needed to enable optimum, high-speed 5G services. Again, the Authority needs to ensure the renewal of spectrum licenses to provide certainty to the industry players and to facilitate network investment and enable planning. Spectrum pooling is recommended to maximize the benefits of the available spectrum as there is not enough bandwidth for all the mobile operators.

An analysis of possible use cases for 5G reveals that there is much expectation that the quality of Internet coverage will improve significantly, and the cost of broadband services will reduce drastically. This will open the way to a wide range of use cases for 5G, including improved remote working, enhanced distance learning, telemedicine and e-health, surveillance and cyber security, manufacturing, and financial services.

To improve mobile adoption, policy measures should focus on encouraging investment in much-needed infrastructure and improving consumers' ability to access digital services. As such, policymakers should:

- Rethink fiscal policy on mobile connectivity
- Facilitate mobile infrastructure deployment
- Prioritize digitization of person-to-government transaction

Efficient and effective management of spectrum is also key to maximize the opportunities that mobile connectivity can bring to society. Making sure the required spectrum resources are available under the right conditions will lower broadband costs, increase coverage and boost connectivity. The 2020s will see strong growth in the number of Africans connected to mobile broadband. As 4G and 5G grow together throughout the decade to come, spectrum preparation can drive cost efficiency and promote growth.

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