Democratic and Popular Republic of Algeria
Ministry of Higher Education and Scientific Research

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Dissertation Submitted to the Department of Electronics in Partial Fulfillment of the Requirement for the Master Degree in Systems of Telecommunication

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Algorithms of Detection in Massive MIMO for New Wireless Communication Systems Based on Approximated Matrix Inverse

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Academic year: 2019-2020

DEDICATION

First and Foremost, I thank Allah for every single thing especially for who I am today, because my success is only by Him. Many thanks go also to Dr, Tami who guided, help and motivate me to carry on this research. Indeed, I appreciate his efforts and time that he gave to me, also for being a friend as well as a supervisor.

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DEDICATION

This work is dedicated to my parents and to all of my friends who believed on me and supported me in my career.

By: ZELLAG Mohamed

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ABSTRACT

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The new services provides by new wireless communication like 5G required a huge data rate with high quality of services such as the speed of internet, internet of things (IoT), and the facilities provided by some applications used for communication. Many techniques are proposed to reply this demand as Massive MIMO system where a very high number of antennas are used. These important numbers of antennas grow dramatically the complexity of detectors.

The aim of this academic research is to investigate the impact of approximate matrix inverse on reducing the complexity of detection in massive MIMO in new wireless communication systems. The standard detectors algorithms like ZF and MMSE inverse with high complexity the big size matrix of massive MIMO channel. New kinds of algorithms such as Neumann series Gauss Seidel methods give an approximate inverse channel matrix with low complexity of calculation comparing to standard ones.

Key Words: *5Generation, MASSIVE MIMO,* Channel Matrix, Neumann Series algorithm, and Gauss Seidel method

List of Abbreviation

3GPP	3^{rd} Generation Partnership Project
5G	Five Generation
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BS	Base Station
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CSI	Channel State Information
DL	Downlink
DoF	Degrees of Freedom
EE	Energy Efficiency
eNB	Evolved Node B
EPC	Evolved Packet Core
FDD	Frequency -Division Duplex
gNB	Node B
GSM	Global System for Mobile Communications
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet Of Things
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MIMO	Multi Input Multi Output
MISO	Multi Input Single Output
M-MMSE	Multicell Minimum Mean-Squared Error
MR	Maximum Ratio
MU-MIMO	Multi-User MIMO
NFFT	Non-Equispaced Fast Fourier Transform

NGMN	Next Generation Mobile Networks
NOMA	Non-Orthogonal Multiple Access
NR	New Radio
OFDM	Orthogonal Frequency-Division Multiplexing
RB	Resource Block
RF	Radio Frequency
RZF	Regularized Zero-Forcing
SE	Spectral Efficiency
SIMO	Single Input Multi Output
SISO	Single Input Single Output
SMS	Short Message Service
SNR	Signal-to-Noise Ratio
SU-MIMO	Single User MIMO
SVD	Singular Value Decomposition
TDD	Time-Division Duplex
UL	Up Link
UT	User Terminal
WLAN	Wireless Local Area Network
ZF	Zero Forcing

GENERAL INTRODUCTION

GENERAL INTRODUCTION :

The primary issue with the ongoing development of the wireless network is that it is dependent upon either increasing bandwidth (spectrum) or densifying the cells to achieve the required area throughput. These resources are rare and are reaching their saturation point within a few years. Also, increasing bandwidth or densifying the cells increases the cost of the hardware and increases latency. The third factor, which can improve area throughput, that is, spectral efficiency, has remained mostly untouched and unchanged during this rapid development and growth of the wireless network. An efficient wireless access technology that can increase the wireless area throughput without increasing the bandwidth or densifying the cell is essential to achieve the ongoing demands faced by the wireless carriers.

Massive Multiple-Input Multiple-Output (MIMO) is the most enthralling wireless access technology to deliver the needs of 5G and beyond networks. Massive MIMO is an extension of MIMO technology, which involves using hundreds and even thousands of antennas attached to a base station to improve spectral efficiency and throughput. This technology is about bringing together antennas, radios, and spectrum together to enable higher capacity and speed for the incoming 5G [1,2]. The capacity of massive MIMO to increase throughput and spectral efficiency has made it a crucial technology for emerging wireless standards[3,4]. The key here is the considerable array gain that massive MIMO achieves with a large number of antennas [5]. Massive MIMO is a key enabling technology for 5G and beyond networks, and as intelligent sensing system primarily rely on 5G and beyond networks to function, massive MIMO and intelligent sensing system are inextricably linked. The data collection from the large number of smart sensors using traditional multi-access schemes is very impractical as it leads to excessive latency, low data rate, and reduced reliability. Massive MIMO with huge multiplexing gain and beamforming capabilities can sense data from concurrent sensor transmission with much lower latency and provide sensors with higher data rates and reliable connectivity. Massive MIMO systems will perform a crucial role to allow information gathered through smart sensors to be transmitted in real-time to central monitoring locations for smart sensor applications such as an autonomous vehicle, remote healthcare, smart grids, smart antennas, smart highways, smart building, and smart environmental monitoring.

This academic project is divided into three main parts. In the first chapter we addressed the meaning of the 5G as well as its role in enhancing the quality of the mobile phone. The second chapter focuses on exploring Massive MIMO and its positive impact on the 5G. In the third chapter, we demonstrated a graph which shows some ways of 5G detection beside comparing them to each other and evaluating them.

CHAPTER 1

GENERAL BACKGROUND ABOUT 5 GENERATION

CHAPTER 1: GENERAL BACKGROUND ABOUT 5 GENERATION

1.1: INTRODUCTION

The mobile network is a wireless technology capable of providing a voice and / or data network by radio transmission. The mobile phone is one of the best known applications in the mobile network. Previously, circuit switching was used to transmit voice over a network, and then we used both circuit switching and packet switching for voice and data. Currently, packet switching is only used. This is how the spectrum went from 1G to 4G. Today and in the years to come, wireless networks need to be improved to meet the demand for increased data throughput, improved capacity, reduced latency and quality of service. We are in the 4th generation of wireless communication, research is being carried out to develop new standards for the next generation beyond 4G, with the growing demand of subscribers, 4G will be definitively replaced by 5G at the using advanced technologies.

The exponential growth of wireless data services driven by mobile Internet and smart devices has triggered the investigation of the 5G cellular network. Around 2020, the new 5G mobile networks are expected to be deployed. 5G networks will have to support multimedia applications with a wide variety of requirements, including higher peak and user data rates, reduced latency, enhanced indoor coverage, improved energy efficiency and so on.

The primary technologies and approaches to address the requirements for 5G systems can be classified as follows [6-7]: addition of small cells and a provision for peer-to-peer (P2P) communication (e.g., device-to-device [D2D] and machine-to-machine [M2M] communication-enabled multi-tier heterogeneous networks); simultaneous transmission and reception (e.g., full-duplex[FD]communication); massive multiple-input multiple-output (massive-MIMO)and millimeter-wave (mm-wave) communications technologies .

1.2: EVOLUTION OF MOBILES COMMUNICATION

Over the past 15 years, the behavior of individuals in society has evolved and so has the use of their mobile phones. This is why many specialists and engineers have worked hard to facilitate our data transfers. Indeed, at a time of globalization where more than half of the exchanges are made by roaming, it is impossible for us to communicate otherwise than by internet network.

The first generation of networks: 1G was the start of a great revolution in the world of telephony. It had analog operation and was made up of many large devices:

- Appeared in 1976, AMPS (Advanced Mobile Phone System)

- The TACS (Total Access Communication System)
- Subsequently in 1983, ETACS (Extended Total Access Communication System)

The second generation was 2G. Created in 1980, its cellular system is based on digital technology for the link as well as for the voice signal. It is then finished with analog technology. It uses the following standards:

- GSM (Global System for Mobile communications)
- CDMA (Code Division Multiple Access)
- GPRS (General Packet Radio System) standard

The IMT-2000 (International Mobile Telecommunications for the year 2000) specifications of the ITU (International Union of Communications) was in charge of the criteria to be taken into account with regard to 3G as third generation , The main 3G standard in Europe is called UMTS (Universal Mobile Telecommunications System).

The for generation was 4G, is the one currently used and expanding around the world, 4G is currently only available in certain cities. This development guarantees a greater exchange of data since the speed does not have to be shared as in 3G or internet data and telephone conversations were separated. 4G speeds range from 100Mb / s to 1GB / s.

Now the 5G technology is a “key technology” that could allow mobile telecommunications speeds of several gigabits of data per second: up to 1,000 times faster than mobile networks in 2010 and up to 100 times faster than 4G by 2020, 5G is the new generation of wireless communications. It lays the foundation for new customer experiences such as augmented reality games, the networking of machines in industry, and smart devices. This technology will also provide the basis for digitization in many areas of our lives.

1.3: CELLULAR NETWORKS

In cellular or more generally mobile networks, the terminals of the users located in a given geographical area are served by several base stations Each base station simultaneously serves a certain number of terminals located in the coverage area of the base station, such as illustrated in figure 1. Such a coverage area is called a cell, which makes it possible to partition a large geographic area into cells.

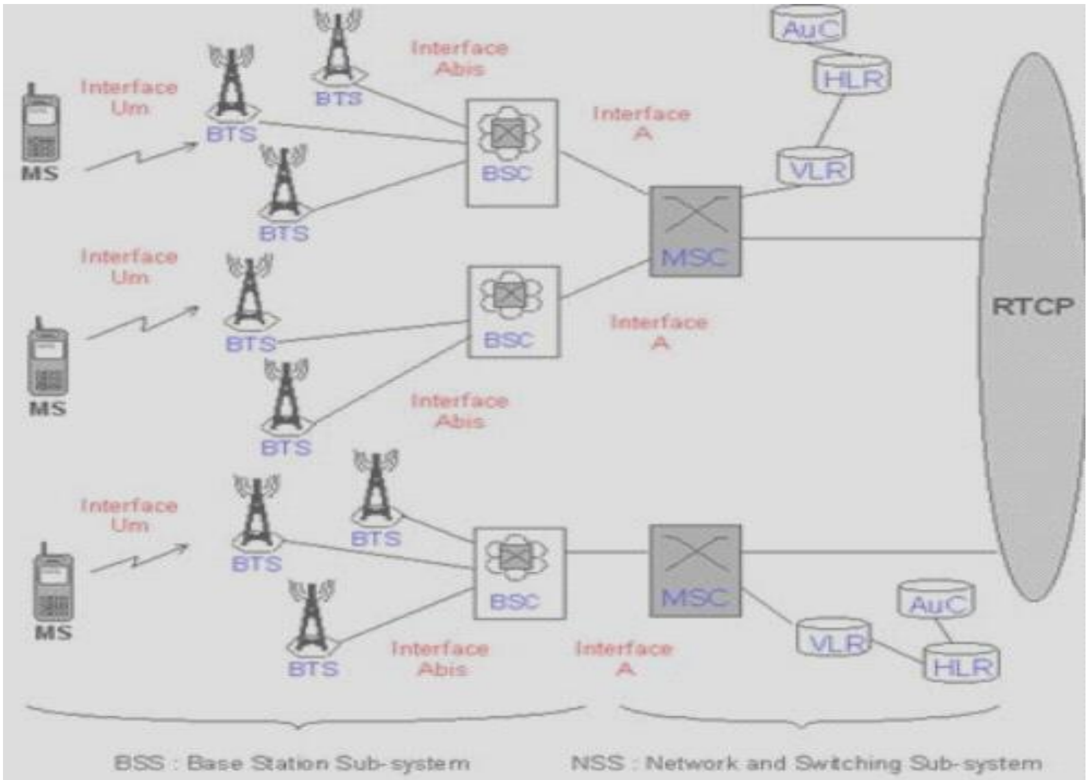

Figure 1- A Mobile Radio Network

Communication between the terminals and BS is bidirectional or in duplex format. On the downlink (DL), the base station transmits signals to the affected terminals, while on the uplink (UL), the terminals transmit signals to the base station, in general, TDD and FDD are used as duplex transmission schemes.

1.4: 5 GENERATION

5G is the next generation of mobile broadband that will eventually replace, or at least augment, your 4G LTE connection. With 5G, you'll see exponentially faster download and upload speeds. Latency, or the time it takes devices to communicate with wireless networks, will also drastically decrease.5G wireless technology is meant to deliver higher multi-Gbps peak data speeds, ultra low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience to more users. Higher performance and improved efficiency empower new user experiences and connects new industries.

1.5: 5 GENERATION CONNECTING THE COMMUNITY

5G will provide the speed, low latency and connectivity to enable a new generation of applications, services and business opportunities that have not been seen before.

Three main use cases are envisaged for 5G:

1. Massive machine-to-machine communications - or simply the Internet of Things (IoT), which consists of connecting billions of treated people without resorting to human intervention, which is extraordinary. These communications will revolutionize industrial processes and applications today, including agriculture, construction and business communications.

2. Extremely reliable low latency communications - these are very important components including real-time device control, industrial automation, vehicle-to-vehicle communications in addition to security systems, autonomous driving and even more secure transportation networks . Low latency communications also pave the way for a new world where remote medical care, procedures and treatment are all possible.

3. Improved mobile broadband - this technology offers much faster data rates and more capacity to keep the world connected. New applications include fixed wireless Internet access for homes, broadcasting applications without a broadcast pickup truck, and more connectivity for people on the go.

For communities, 5G technology will ensure the connection of billions of devices in our cities, schools and smart homes, as well as even more secure smart vehicles, it will also allow the improvement of medical services and education in more to provide a safer and more efficient environment to live in.

For businesses and industries, 5G and IoT will provide a wealth of data allowing these businesses and industries to better understand their activities like never before. Companies will work and make important decisions based on this data, innovate in agriculture, smart farms and manufacturing, laying the groundwork for attractive cost reductions, better customer experience and " sustainable growth.

New and emerging technologies such as virtual and augmented reality will be accessible to everyone. Virtual reality offers connected experiences that weren't possible before. With 5G and VR, you can visit your favorite city, watch a live football game with the feeling of being on the pitch, or even examine real estate and wander around in a new house, all while being comfortably installed on your sofa.

5G will allow us to stay connected in tomorrow's smart cities, homes and schools, and take advantage of opportunities we haven't even thought of yet.

Figure 2- Applications of 5G

1.6: 5 GENERATION GOALS

The main manufacturers and operators of the wireless communications sector are currently developing the objectives and standards for the fifth generation of mobile networks (5G). The standardization stage started within different consortia of operators and manufacturers (3GPP, NGMN, etc.) will make it possible to set up regulations by 2020. The first objective to be achieved concerns the up and down speed allocated to each user. to ensure high speed internet access from a smart phone or tablet. In a context of use with little or no mobility, the target speed at the edge of the cell per user is greater than 100 Mbit / s and the maximum speed per user must exceed 10 Gbit / s. In the case of use with high mobility (for example, in the case of communications between vehicles), the improvement of the architecture of the network should in particular make it possible to reduce the latency of the communication. The objective is to obtain a transmission delay of less than 10 ms. For other IoT applications (telemedicine, security, etc.), a high level of reliability will also be required. Major changes to the network architecture and the introduction of new wireless technologies will be required in today's 2G / 3G / 4G networks to achieve these goals. The cost and energy consumption of the components of this new network and the Associated mobile terminals will be decisive points in reaching an economically viable solution.

1.7: HOW 5 GENERATION WORKS ?

Most operators will initially integrate 5G networks with existing 4G networks to provide a continuous connection. The structure of a mobile network is made up of two main parts, the "Radio Access Network" and the "Core Network".

The radio access network - consists of several types of equipment, including small cells, pylons, masts and dedicated indoor application systems that connect mobile users and wireless devices to the core network.

Small cells will be characteristic components of 5G networks, especially with the new millimeter waves (mmWave) whose connection range is very short. In order to preserve the continuity of the connection, the small cells will be distributed in the form of clusters depending on where the users need a connection, which will make it possible to complete the macro-network which offers extensive coverage.

5G macrocells will use MIMO antennas (multiple inputs, multiple outputs) that have multiple elements or connections to send and receive more data at the same time. The advantage for users is that more people can connect to the network simultaneously while maintaining high speed. MIMO antennas are often called "massive MIMO" because of the large number of antenna elements and connections, but their physical size is similar to existing 3G and 4G base station antennas.

The core network - this is the mobile data exchange network that governs all mobile voice, data and Internet connections. For 5G, the "core network" is being reconsidered to better integrate with Internet services and services "in the cloud" and also includes servers distributed throughout the network, which improves times response (thereby reducing latency).

Many advanced 5G features will be managed at the core network level, including virtualizing network functions and slicing the network for different applications and services.

Network slicing - this allows the network to be intelligently segmented for a given industry, business or application. For example, emergency services could work on a network slice independently of other users.

Network Function Virtualization (NFV) - this is the ability to instantiate network functions in real time at any desired location on the operator's cloud platform. Network functions that previously worked on specific hardware, such as firewalls and encryption in business premises, can now work on software on a virtual machine. NFV is very important for enabling the efficiency, speed and agility necessary to support new business applications and is an essential technology for a core network ready to host 5G.

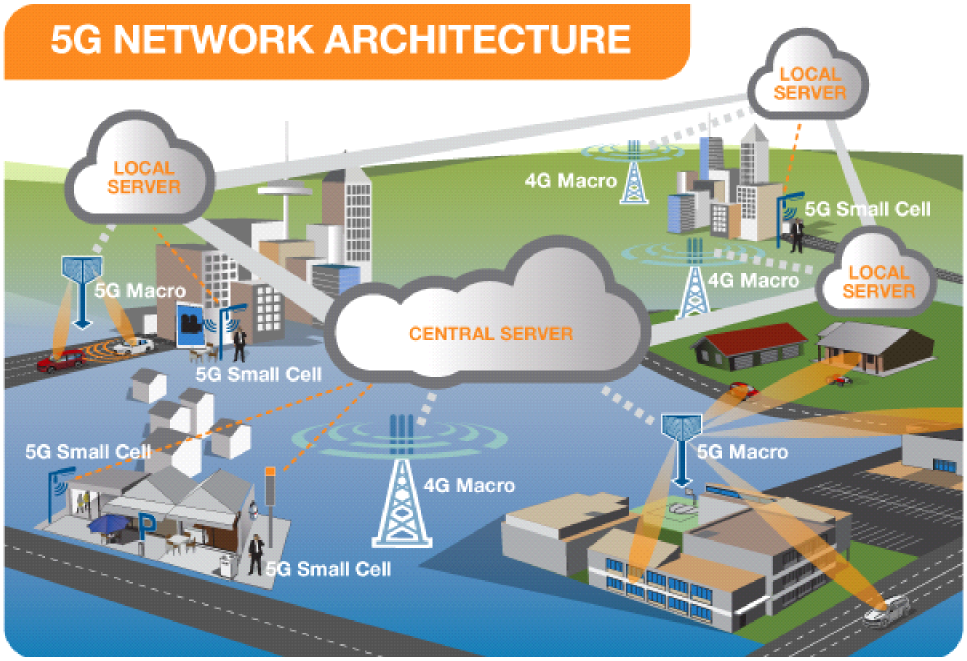

Figure 3- 5G Network Architecture

1.8: 5 GENERATION INTEGRATION WITH 4 GENERATION

When a 5G connection is established, the user equipment (or device) connects to both the 4G network to provide control signaling and to the 5G network to help provide fast data connections by increasing existing 4G capacity . When 5G coverage is limited in certain locations, data is transported as it is currently on the 4G network to avoid connection interruption. With this design, the 5G network complements the existing 4G network.

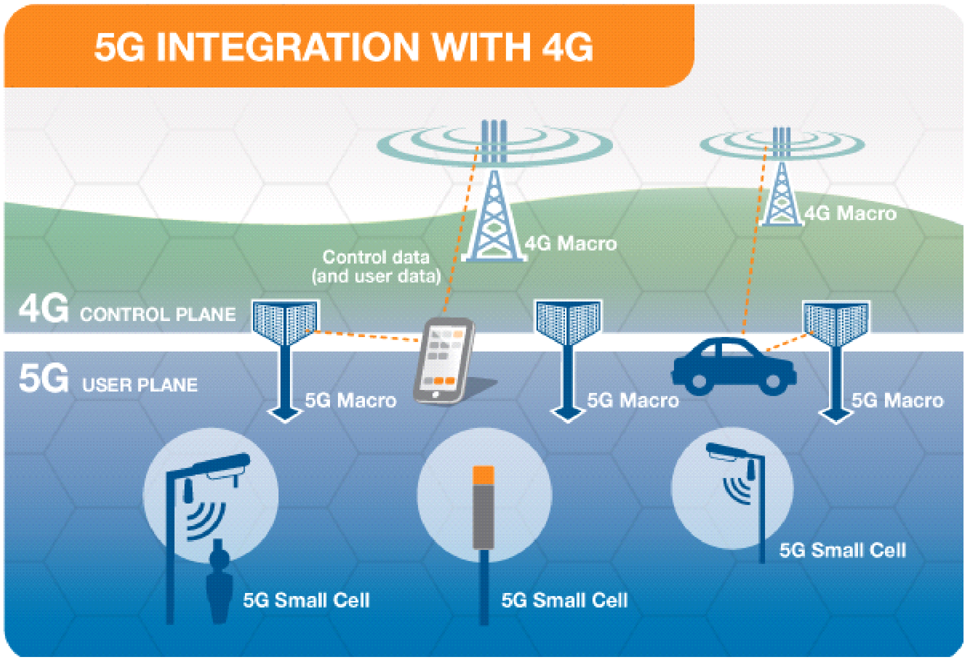

Figure 4- 5 Generation Integration with 4 Generation

5G networks are designed to coexist with 4G networks thanks to a wide range of macrocells, small cells and specific systems installed in buildings. Small cells are mini base stations designed to provide highly localized coverage, typically from 10 meters to a few hundred meters, which can complement a larger macro network. Small cells remain extremely important for 5G networks because millimeter frequencies (mmWave) have a very limited connection range.

Mm Wave : millimeter Wave With the explosive growth in demand for mobile data traffic, the contradiction between capacity requirements and spectrum scarcity is becoming increasingly important. Bandwidth bottleneck becomes a key problem for 5G mobile networks On the other hand, with a huge bandwidth in the millimeter band (mmWave) from 28 GHz to 300 GHz, millimeter wave communications (mmWave) have been proposed as an important part of the 5G mobile network to provide communication services. multi-gigabit such as high definition television (HDTV) and ultra high definition video (UHDV). Most of the current research focuses on the 28 GHz band, the 39 GHz band, the 60 GHz band and the band E (E-band) (71-76 GHz and 81-86GHz). The use of millimeter bands is one of the disruptive technologies of 5G. Millimeter bands have never been taken into account for the deployment of mobile networks for reasons of technological maturity and quality of propagation. Millimeter bands provide spectrum and their use would achieve the very high speeds expected with 5G. In return, their use requires the development of all the necessary technologies, miniaturized, at low cost and with energy consumption compatible with portable terminals (amplifiers, encoders, signal processing, antennas). In particular, because of the poor propagation quality of millimeter waves, each cell will have reduced coverage, which will require the implementation of beamforming techniques, to better focus the energy transmitted by the antennas.

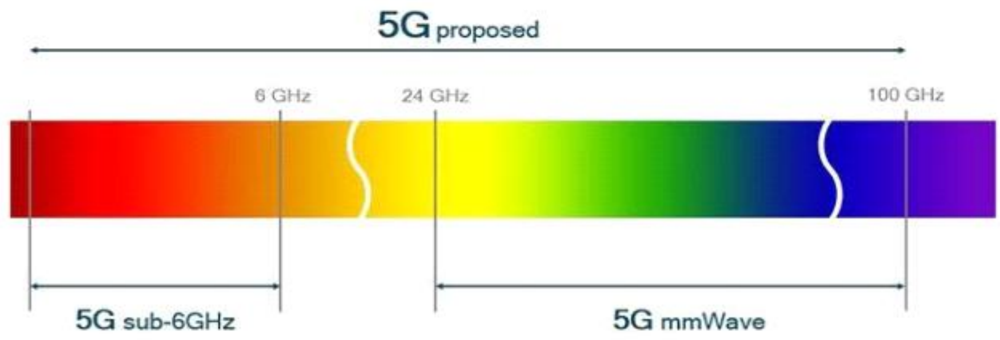

Figure 5- mmWave

1.9: 5 GENERATION SPECTRUM

The initial 5G frequency bands are offered around 600 to 700 MHz, 3 to 4 GHz, 26 to 28 GHz and 38 to 42 GHz, which will significantly increase capacity compared to current mobile technologies. The expanded spectrum and increased capacity will increase the number of users, the volume of data and the speed of connections. It is also expected that there will be future reuse of existing low band spectrum for 5G purposes and to support future uses as usage of existing networks decreases.

Increasing the spectrum above 30 GHz in the millimeter wave band will provide local coverage as this type of wave only works over short visibility distances. Future 5G deployments may use millimeter wave frequencies in bands up to 86 GHz.

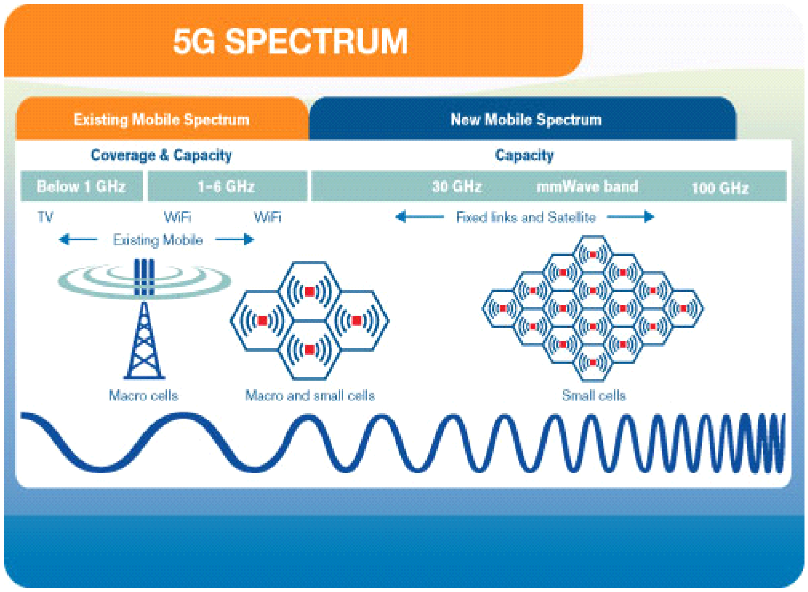

Figure 6- 5 Generation Spectrum

5G will use the following pioneering frequency bands:

- Average frequencies or "Coverage and Capacity Layer" relies on frequencies in the 2 and 6 GHz band (eg, 3400-3800 MHz) to deliver the best compromise between capacity and cover
- High frequencies or "Super Data Layer" relies on frequencies in the band above 6 GHz (eg, 24.25-29.5 GHz and 37-43.5 GHz) in order to address specific use cases requiring very high data rates .These are millimeter frequencies
- Low frequencies or "Coverage Layer" operates frequencies in the 2 GHz band (e.g. 700 MHz and 1400 MHz) providing very high coverage.

5G is the first mobile technology to operate in frequencies that are low, high and above all very high (6 GHz and more). The latter, a real technological breakthrough even if these frequencies are at low distance propagation, responds to the incessant increase in bit rates and the inflation of the volumes of data exchanged. For transmission and collection networks, fiber is preferred with FTTS (Fiber to the site) technology, and radio links will always be useful.

1.10: 5 GENERATION SYSTEM

The 5G system must support all EPS (4G) capacities with the following exceptions:

- SR-VCC and / or CS-Fallback: No mobility can be ensured between the 5G domain with the circuit domain
- handover between 5G-RAN and GERAN (2G) or between 5G-RAN and UTRAN (3G): The only possible mobility is between 4G, 5G and WiFi radio.

Access to the 5G core network via GERAN or UTRAN: The 5G core network only offers an interface for 4G, 5G and WiFi access.

The 5G system therefore only supports three types of access: E-UTRAN, WLAN and NR (New Radio) Voice is implemented via IMS and mobility can only be package-package. Figure 7 shows the high-level architecture that can be used as a reference model.

The figure shows the elements NextGen UE, NextGen RAN (Access network), NextGen Core (Core network) and their reference points.

N2: Reference point for the control plane between NextGen (R) AN and NextGen Core (NGCN)

N3: Reference point for the user plane between NextGen (R) AN and NextGen Core.

N1: Reference point for the control plane between NextGen EU and NextGen Core.

N6: This is the reference point between NextGen Core and the data network (PDN, Packet data Network).

The data network can be an operator's public or private external data network or an intra-operator data network, e.g., for the provision of IMS services. This reference point corresponds to SGi in the 4G context. The architectural principales are as follows:

- The EU can be attached to the network without having an established session for data transmission (important in particular for IoT devices).
- The EU can only communicate with 5GC if the EU supports the NAS (Non-Access Stratum) protocol N1.
- RANs (Rado Access Networks) can only communicate with the 5G core network called NGCNou 5GC only if it supports interfaces N2 (Plancontrôle) and N3 (User plan).

The only radio stations authorized to interface with 5GC are LTE and its evolutions (LTE-Advanced, LTE-Advanced Pro), New Radio based on future LTE and mmWave evolutions and finally WiFi (both WiFi trusted and WiFi untrusted). In the case of untrusted WiFi access, an interworking element has been specified called N3IWF (Non-3GPP Interworking Function).

- The 5GC network provides access to external IP networks (e.g., Internet, Intranet, IMS) called Data

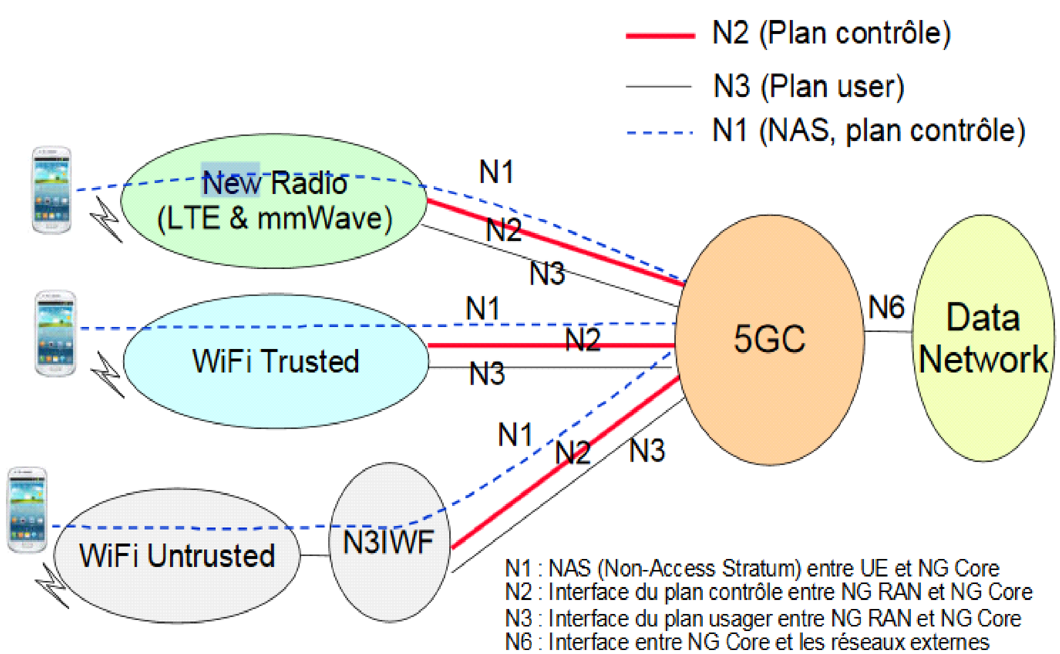

Figure 7- 5GC Architecture

1.11: DEPLOYMENT OF 5G IN NSA MODE THEN IN SAC MODE

As some operators have an aggressive New Radio deployment schedule, they are looking to deploy it commercially before the availability of the 5G core network which will follow later. There are two ways to deploy 5G radio: non-standalone mode (NSA) and standalone mode (SA) as shown in Figure 6. In NSA mode, New Radio (known as gNodeB (gNB)) is collocated with eNodeB (eNB) and connects to the 4G core network (ePC) via the S1-U interface for user plane traffic. The communications of the control plane (e.g., for EMM and ESM) between the EU and the network remain on LTE radio, and therefore the 4G core network. In this model, the 5G radio acts as a secondary radio so the only goal is to boost the speed and capacity. This does not require a 5G core network and is an attractive solution for some operators. To deploy 5G in SA mode, a 5G core network is required. Some operators will choose this mode for their initial 5G deployment, in particular to deploy services only 5G in a geographically limited area without interworking with 4G. In the long term, there is a need for integration with the ePC in order to allow mobility between 4G and 5G access and integration with the advanced LTE RAN which will connect directly to the 5G core network. the 5G core network is expected to be the common core network for all types of access. Thus the investment will be transferred from the EPC to 5GC in line with the migration rate of the customer base. Furthermore, in order to provide new advanced services, such as those requiring high mobility, very short latency and independence from access, the operator will have to deploy 5GC .

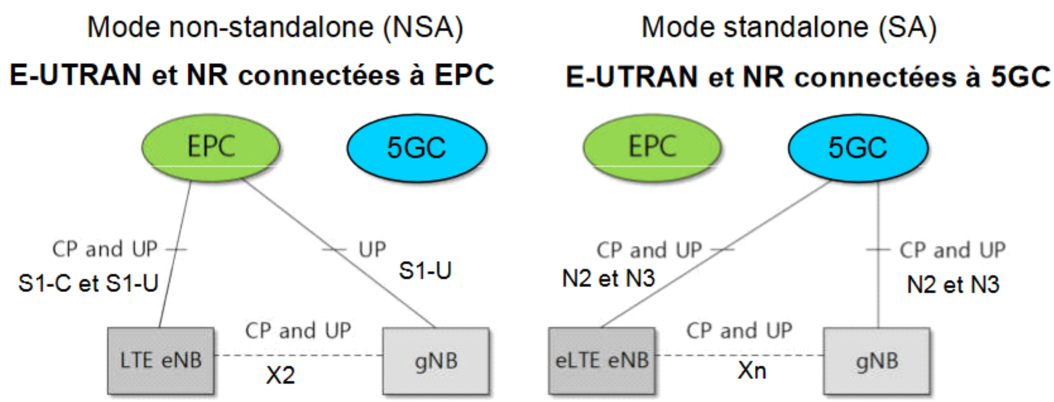

Figure 8- Mode NSA and Mode SA

1.12 : THE ADVANTAGES OF 5 GENERATION

- Faster: Data rates up to 10x faster than 4G
- More connected objects: Billions of connected objects
- More responsive: Almost in real time to play online and eventually, driving autonomous cars
- Greener: Reduces costs and energy consumption

1.13: THE WEAKNESSES OF THE FUTURE 5 GENERATION NETWORK

Despite the new perspectives opened up by the fifth generation of the mobile network, many questions and doubts are raised regarding this technology.

The question of the harmfulness of electromagnetic waves could be raised again because 5G relies on high frequencies (3.5 GHz approximately).

The question of security also comes into play insofar as this system will allow the exchange of a large volume of data, of all types, but also and above all of "sensitive" data (health data, State data for example). This raises the question of how easy it is to hack the data transmitted within this network.

1.14: CONCLUSION

With the increasing demands of subscribers, 4G will be definitively replaced by 5G using advanced technologies, such as massive MIMO technology, direct communication (Device-to-device), millimeter wave communication, multiple access by beam division in massive MIMO technology. 5G provides flexibility with its heterogeneous architecture. 5G must also allow numerous innovations to arrive, support the connection of all autonomous and connected vehicles, and enable health development.

CHAPTER 2

DIFFERENT DETECTORS TECHNIQUES ON MASSIVE MIMO

CHAPTER 2: DIFFERENT DETECTORS TECHNIQUES ON MASSIVE MIMO

2.1: INTRODUCTION

Multiple Input Multiple Output (MIMO) is a key technology that has been used since the third generation (3G) wireless networks to enhance performance of the wireless transceivers. The idea is to use multiple antennas in the transmitter and the receiver to increase the spectral efficiency, the range and/or the link reliability. However, due to multiple interfering messages being transmitted from different antennas, the MIMO receiver is expected to use a detection mechanism to separate the symbols which are corrupted by interference and noise. The MIMO detector has been a topic of great interest during the past 50 years. **[11]**

Massive MIMO has become a hot research topic in last few years, while this chapter reviews a number of key topics of massive MIMO, none of them extensively discuss the detection techniques. A comprehensive review, discussion of the existing linear precoding mechanisms for massive MIMO according to different cell scenarios have been presented in.

2.1 THE ADVANTAGES OF MASSIVE MIMO

The advantage of a MIMO network over a regular one is that it can multiply the capacity of a wireless connection without requiring more spectrum. Reports point to considerable capacity improvements, and could potentially yield as much as a 50-fold increase in future.

The more antennas the transmitter/receiver is equipped with, the more the possible signal paths and the better the performance in terms of data rate and link reliability.

A Massive MIMO network will also be more responsive to devices transmitting in higher frequency bands, which will improve coverage. In particular, this will have considerable benefits for obtaining a strong signal indoors (though 5G's higher frequencies will have their own issues in this regard).

The greater number of antennas in a Massive MIMO network will also make it far more resistant to interference and intentional jamming than current systems that only utilise a handful of antennas.

It should be noted, too, that Massive MIMO networks will utilise beamforming technology, enabling the targeted use of spectrum. Current mobile networks are rather dumb in the way they apportion a single pool of spectrum between all users in the vicinity, which results in a performance bottleneck in densely populated area. With Massive MIMO and beamforming such a process is handled far more smartly and efficiently, so data speeds and latency will be far more uniform across the network.

2.3: BENEFITS OF MASSIVE MIMO FOR 5G NETWORKS AND BEYOND

Some of the benefits of massive MIMO technology are:

- **Spectral Efficiency:** Massive MIMO provides higher spectral efficiency by allowing its antenna array to focus narrow beams towards a user. Spectral efficiency more than ten times better than the current MIMO system used for 4G/LTE can be achieved.
- **Energy Efficiency:** As antenna array is focused in a small specific section, it requires less radiated power and reduces the energy requirement in massive MIMO systems.
- **High Data Rate:** The array gain and spatial multiplexing provided by massive MIMO increases the data rate and capacity of wireless systems.
- **User Tracking:** Since massive MIMO uses narrow signal beams towards the user; user tracking becomes more reliable and accurate.
- **Low Power Consumption:** Massive MIMO is built with ultra lower power linear amplifiers, which eliminates the use of bulky electronic equipment in the system. This power consumption can be considerably reduced.
- **Less Fading:** A Large number of the antenna at the receiver makes massive MIMO resilient against fading [8].
- **Low Latency:** Massive MIMO reduces the latency on the air interface [9].
- **Robustness:** Massive MIMO systems are robust against unintended interference and internal Jamming. Also, these systems are robust to one or a few antenna failures due to large antennas[10].
- **Reliability**: A large number of antennas in massive MIMO provides more diversity gain, which increases the link reliability[9-10].
- **Enhanced Security:** Massive MIMO provides more physical security due to the orthogonal mobile station channels and narrow beams [11].
- **Low Complex Linear Processing:** More number of base station antenna makes the simple signal detectors and precoders optimal for the system.

2.4: TYPES OF MIMO

There are four basic antenna configuration models that include: SISO - Single Input Single Output

✓ SIMO - Single Input Multiple Output

✓ MISO - Single output with multiple inputs

✓ MIMO - Multiple Input Multiple Output

The term MU-MIMO is also used for a multi-user version of different forms of antenna technology relating to one or more inputs and outputs. These are related to the radio link. In this way, the input is the transmitter when it is transmitted in the link or signal path and the output is the receiver, it is located at the output of the wireless link. Therefore, the different forms of single / multi-antenna links are defined below [12].

2.4.1: MIMO – SISO

The simplest form of radio link can be defined in MIMO terms as SISO - Single Input Single Output. This transmitter works with an antenna, just like the receiver shown in figure 9.

Figure 9- SISO - Single Input Single Output

The advantage of a SISO system is its simplicity. SISO does not require any treatment in terms of the various forms of diversity that can be used. However, the performance of the SISO channel is limited. Interference and fading will have a greater impact on the system than a MIMO system using some form of diversity, and the channel capacity is limited by Shannon's law - the throughput depends on the channel bandwidth and the signal-to-noise ratio[12].

$$C = B\ log_2(1 + SNR)[bit/s] \quad \textbf{(2.1)}$$

Where C is the channel capacity, B is the channel bandwidth and SNR is the signal-to-noise ratio.

2.4.2: SIGNAL INPUT MULTIPLE OUTPUT (SIMO)

The SIMO or MIMO version with multiple outputs and a single input occurs when the transmitter has a single antenna and the receiver has multiple antennas as shown in Figure 10. This is also referred to as diversity reception. It is often used to enable a receiver system receiving signals from several independent sources to combat the effects of fading. It has been used for many years with short-wave listening/receiving stations to combat the effects of fading and ionospheric interference [12].

Figure 10- SIMO - Single Input Multiple Output

SIMO has the advantage of being relatively easy to implement, although treatment is required in the receiver. The use of SIMO may be quite acceptable in many applications, but when the receiver is located on a mobile device such as a mobile phone handset, processing levels may be limited by the size, cost and charge of the battery.

SIMO can be used in two forms:

- ✓ **Switched diversity SIMO:** This form of SIMO looks for the strongest signal and switches to this antenna
- ✓ **Maximum ratio combining SIMO:** This form of SIMO takes the two signals and adds them together to give the combination. In this way, the signals from both antennas contribute to the overall signal.

2.4.3: MULTIPLE INPUT SINGLE OUTPUT (MISO)

MISO is also called transmission diversity. In this case, the same data are transmitted redundantly from both transmitting antennas Figure 11. The receiver is then able to receive the optimal signal, which it can then use to extract the required data

Figure 11- MISO - Multiple Input Single Output

The advantage of using MISO is that the multiple antennas and redundancy processing are moved from the receiver to the transmitter. In cases such as cellular telephone user equipment, this can be a significant advantage in terms of antenna space and reducing the level of processing required by the receiver for redundancy coding. This has a positive impact on battery size, cost and life, as the lower processing level requires less battery power[12].

2.4.4: MULTIPLE INPUT MULTIPLE OUTPUT (MIMO)

MIMO is a radio antenna technology that uses multiple antennas at the transmitter and receiver to allow a variety of signal paths to carry data Figure 12, with separate paths selected for each antenna to allow the use of multiple signal paths [12].

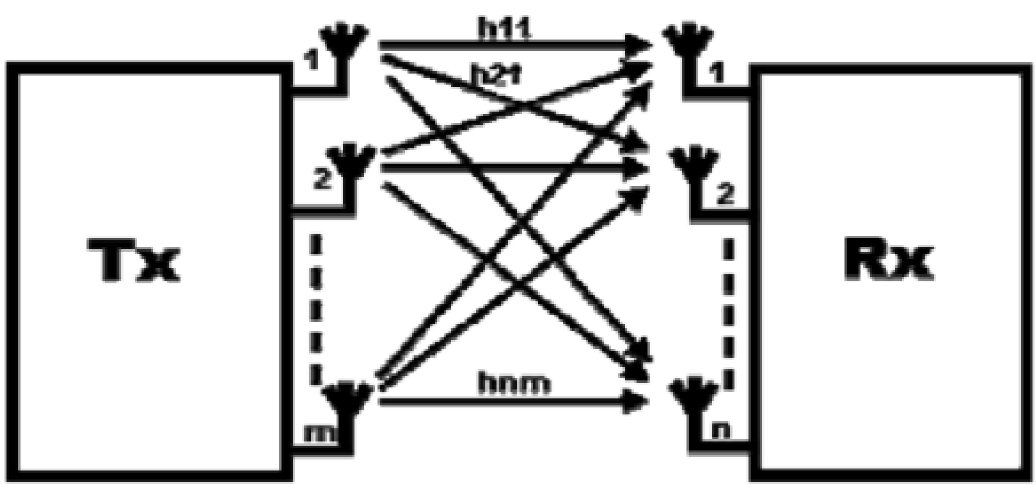

Figure 12- MIMO- Multiple Input Multiple Output

One of the fundamental ideas of space-time signal processing in wireless MIMO systems, in which time is complemented by the spatial dimension inherent in the use of multiple antennas distributed in space, i.e. the use of several antennas located at different points. Consequently, wireless MIMO systems can be seen as a logical extension of the smart antennas that have been used for many years to improve wireless technology located between a transmitter and a receiver, the signal can take several paths. It is found between a transmitter and a receiver the signal can take several paths. Also, by moving the antennas even a small distance, the paths used will change. The variety of paths available results from the number of objects appearing on the side or even in the direct path between transmitter and receiver.

In the past, these multiple paths were only used to introduce interference. By using MIMO, these additional paths can be used advantageously. They can be used to strengthen the radio link by improving the signal-to-noise ratio or by increasing the data capacity of the link.

The two main MIMO formats are given below [13]:

- ✓ **Spatial diversity:** Spatial diversity is often used in this narrow sense refers to transmitting and receiving diversity. Both methodologies are used to improve the signal-to-noise ratio and are characterized by improving the reliability of the system with respect to different forms of fading.
- ✓ **Spatial multiplexing:** This form of MIMO is used to provide additional data capacity by using different paths to carry additional traffic, i.e. increasing the data throughput capacity.

One of the main advantages of MIMO spatial multiplexing is that it is able to provide additional data capacity. MIMO spatial multiplexing achieves this by using multiple paths and using them efficiently as additional "channels" to carry data. The maximum amount of data that can be carried on a radio channel is limited by the physical limits defined in Shannon's Law.

Multiple Input Multiple Output (MIMO) antenna systems are used in the wireless standard, including IEEE 802.11n, 3GPP LTE and WiMAX mobile systems. The technique supports enhanced data throughput even under conditions of interference, signal fading and multipath.

Shannon's law defines the maximum rate at which error-free data can be transmitted over a given bandwidth in the presence of noise. It is generally expressed in the form shown in equation (2.1), which shows that an increase in the SNR of a channel results in marginal gains in channel throughput. Therefore, the traditional way to achieve higher data rates is to increase the bandwidth of the signal. Unfortunately, increasing the bandwidth of the signal of a communication channel by increasing the symbol rate of a modulated carrier increases its sensitivity to multipath fading.

For high-bandwidth channels, a partial solution to the multipath problem is to use a series of superimposed narrow-band subcarriers. Not only does the use of overlapping OFDM subcarriers improve spectral efficiency, but the lower symbol rates used by the narrow-band subcarriers reduce the impact of multipath signal products [14].

MIMO communication channels provide an interesting solution to the multipath problem by requiring multiple signal paths. MIMO systems use a combination of multiple antennas and signal paths to gain knowledge about the communication channel. By using the spatial dimension of a communication link, MIMO systems can achieve data rates significantly higher than traditional Single Input, Single Output (SISO) channels. In a 2 x 2 MIMO system, signals travel along several paths from the transmitter to the receiver antennas.

Using this channel knowledge, a receiver can retrieve independent streams from each of the transmitter antennas. A 2 x 2 MIMO system generates two spatial streams, effectively doubling the maximum bit rate of what can be achieved with a traditional 1 x 1 SISO communication channel.

The maximum channel capacity of a MIMO system can be estimated based on N space streams. A basic approximation of the MIMO channel capacity is a function of the spatial flows, bandwidth and signal-to-noise ratio (SNR). It is illustrated in the following equation [15]:

$$\mathbf{C} = \boldsymbol{N}\,\boldsymbol{B}\,\mathbf{log_2}(\mathbf{1} + \boldsymbol{SNR}) \text{ [bit/s]} \quad (2.2)$$

Where **C** is the channel capacity, **N** is the number of spatial streams, **B** is the channel bandwidth, and **SNR** is the signal-to-noise ratio.

Taking into account the MIMO channel capacity equation, it is possible to study the relationship between the number of space streams and the throughput of different implementations of SISO and MIMO configurations. [15]

2.5: MASSIVE MIMO

Massive MIMO is scaled up version of the conventional small scale MIMO systems, its multiuser communications solution that employs a large number (practically some dozens or hundreds, theoretically up to thousands) of antenna elements to serve simultaneously multiple users with a flexibility to opt what users to schedule for reception at any given time. The most common massive MIMO concept assumes that the user terminals have just a single antenna1 and that the number of antennas at the BS is significantly larger than the number of served users.

The introduction of massive MIMO had a tremendous impact on the research and development community during past decade. As a result, many next generation communication technologies, such as 5G below 6 GHz adopted massive MIMO as their key technology. Most of the massive MIMO literature focuses on mobile broadband type highs rate problems with large data packets such that channel estimation and training makes clearly sense. The other application of interest is the massive machine-type communications (MMTC) wherein large number of connected devices is only sporadically active [15].

Standard MIMO networks typically use two or four antennas to transmit data and the same number to receive it. Massive MIMO, on the other hand, is a MIMO system with a particularly high number of antennas. Massive MIMO increases the number of transmitting antennas (tens or more than 100 elements) on a base station Figure 13. Massive MIMO offers two major innovations [15]:

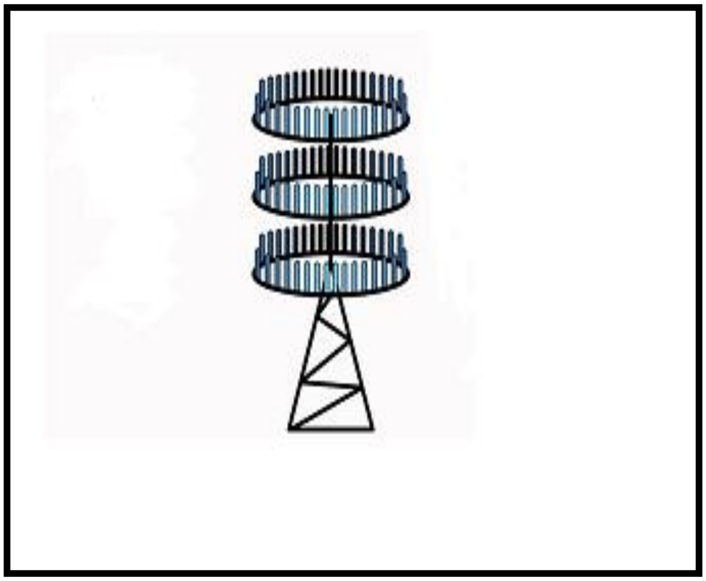

Figure 13- An Illustration of Massive MIMO

2.5.1: BEAMFORMING

Beamforming is the ability of the base station to adapt the radiation pattern of the antenna [16]. Beamforming helps the base station to find a suitable route to deliver data to the user, and it also reduces interference with nearby users along the route [17], as shown in Figure14. Beamforming has several advantages for 5G networks and beyond. Depending upon the situation, beamforming technology can be implemented in several different ways in future networks.

For massive MIMO systems, beamforming helps with increasing spectrum efficiency, and for millimeter waves, it helps in boosting data rate. In massive MIMO systems, the base station can send data to the user from various paths, and beamforming here choreographs the packet movement and arrival time to allow more users to send data simultaneously. Since the millimeter waves cannot penetrate through obstacles and do not propagate to longer distances due to a shorter wavelength, beamforming here helps to send concentrated beams towards the users. Thus, beamforming helps a user to receive a strong signal without interference with other users.

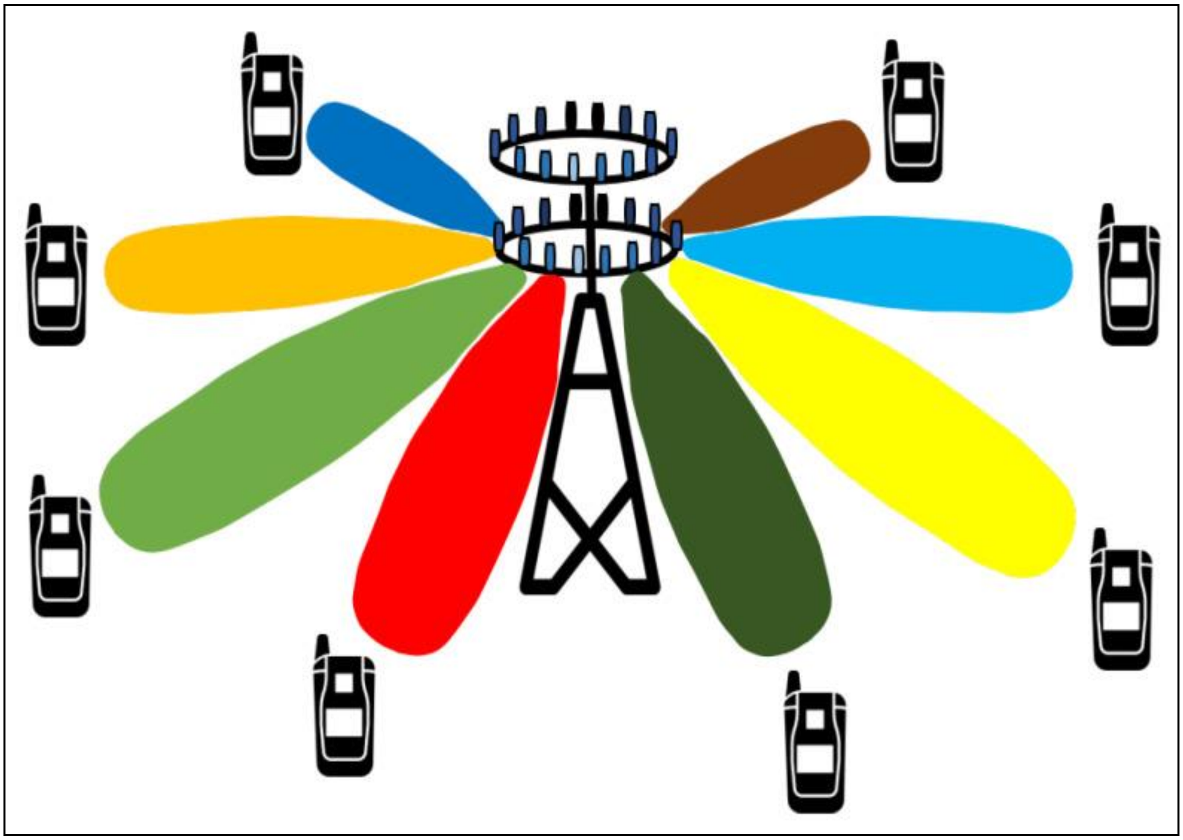

Figure 14- Massive Multiple Output–Multiple Output (MIMO) Beamforming.

2.5.2 : MULTI-USER MIMO (MU-MIMO)

Further increases the total capacity per base station by enabling communication with multiple devices using the same resources, creating a virtually unified device side. Simultaneous use of antennas from multiple devices enables the creation of large-scale virtual MIMO channels. The combination of these two innovations allows to increase wireless transmission speed by increasing the number of base station antennas without consuming more bandwidth or increasing modulation values [18].

2.6: WHY MASSIVE MIMO?

Massive MIMO technology relies on increasing the spatial multiplexing gain and the diversity gain by adding the number of antennas at the BS to serve users with relatively simple processing of signals from all the antennas. The potential benefits of massive MIMO can be summarized as follows [19]:

- **Capacity and link reliability:** Massive MIMO increase the diversity gain, and hence, provides link robustness as it resists fading. It is approved that the capacity increases without a bound as the number of antennas increases, even under a pilot contamination, when multi-cell minimum mean square error (MMSE) precoding combining and spatial channel correlation are used [19].

- **Spectral efficiency:** Massive MIMO improves the spectra efficiency (SE) of the cellular network by spatial multiplexing of a large number of user equipment's per cell. Numerous antennas create more spatial data streams, more throughput, more multiplexing gain, and hence achieve high spectral efficiency. It is shown that the overall spectral efficiency in massive MIMO can be ten times higher than in the conventional MIMO where tens of users will be served simultaneously in the same time-frequency resources [19].

- **Energy efficiency:** Due to coherent combining, the transmitted power is inversely proportionate to the number of transmit antennas. As the number of transmit antennas increases, the transmit power will be significantly reduced. The power per antenna should be µ 1nt (?), where nt is the number of antennas. Also, the throughput could be increased by increasing the number of transmit antennas and without increasing the transmit power. Each antenna uses extremely low power, i.e. milliwatts. Therefore, the energy efficiency increases and equivalently system reliability [19].
- **Security enhancement and robustness improvement:** Manmade interference and intentional jamming are serious concerns in modern wireless communication systems. Massive number of antenna terminals leads to a large number of degrees of freedom which can be used to cancel the signals from intentional jammers. In addition, massive MIMO systems are also inherently robust against passive eaves dropping attacks because of beamforming. However, the eaves dropper can take countermeasures by exploiting the high channel correlation in the vicinity of the user or the weakness of channel estimation. [19]

- **Cost efficiency:** Massive MIMO eliminates the need for bulky items such as coaxial cables which used to connect the BS components, and hence reduces the system implementation cost. In addition, massive MIMO uses cheap milliwatts amplifier instead of a multiple expensive highs power amplifier. Moreover, it has a potential to reduce the radiated power 1000 times and at the same time drastically maximize the data rates [19].

- **signal processing:** a large number of antennas eliminate the interference effects, fast fading, uncorrelated noise and thermal noise, and hence simplifies the signal processing. in addition, it is favorable propagation environment occurs when the channel responses from the base station to user terminals are different (mutually orthogonal, i.e., the inner products are zero). However, non-orthogonal channel vectors lead to advanced signal processing to suppress the interference [19].

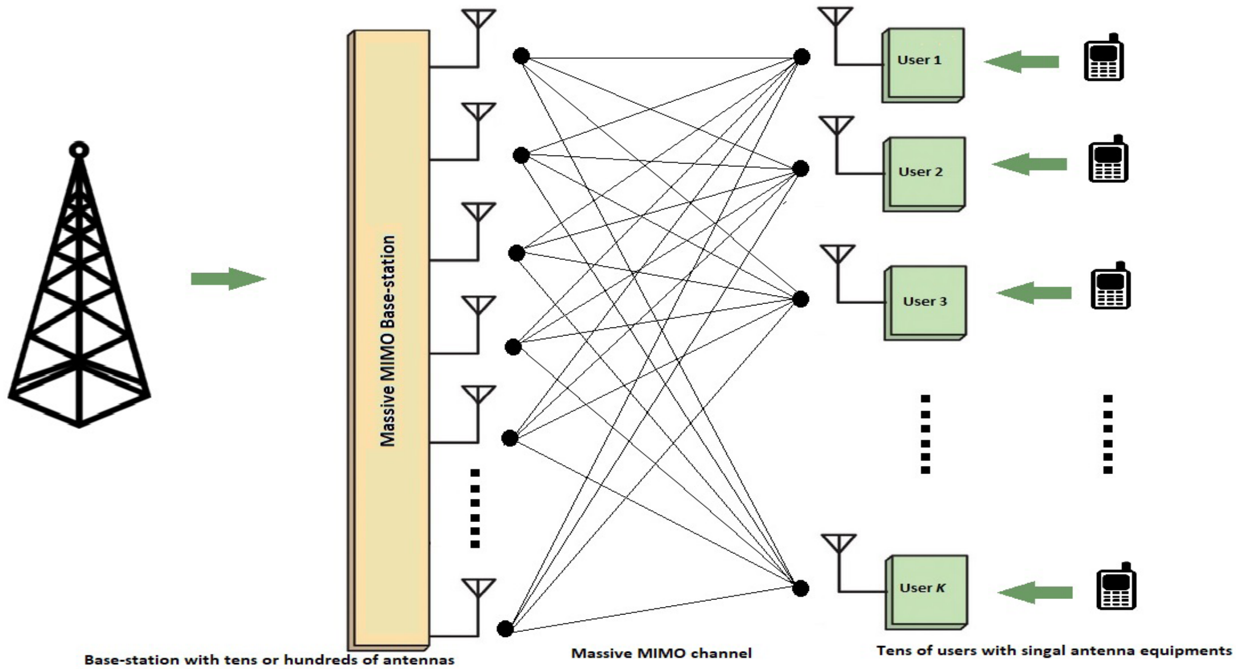

Figure 15- Massive MIMO Architecture

2.7: SYSTEM MODEL

In massive MIMO systems, a large number of antennas are equipped as base stations. The system model is shown in Figure 16. The left side shows the uplink process, while the right side is a downlink process. It can be seen from this image that when users attempt to communicate with the base station, their data stream must first be pre-coded based on the channel status information obtained, which is estimated by sending the pilot sequence.

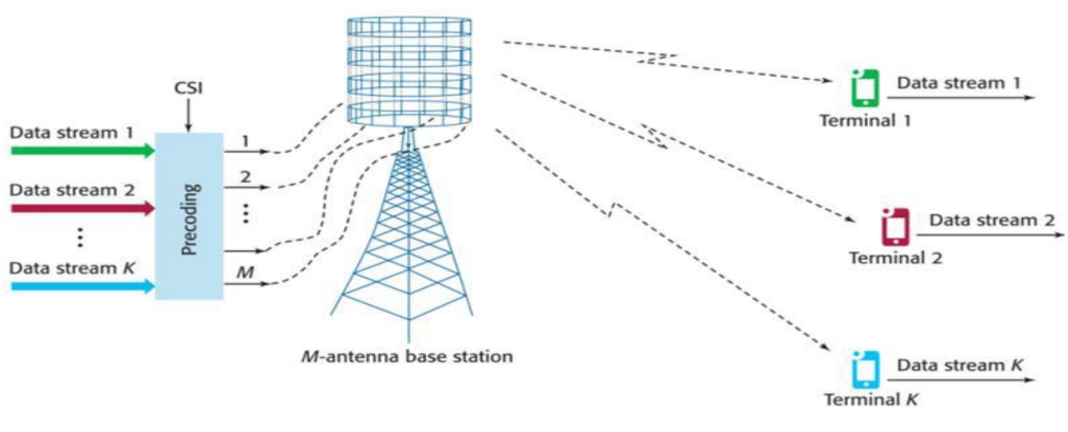

Figure 16- Model of the Massive MIMO System

Based on the system model, we can easily obtain a mathematical model for massive MIMO systems,

$$\bar{\boldsymbol{y}} = \boldsymbol{W}^{\mathbf{H}} \boldsymbol{H}x + \boldsymbol{W}^{\mathbf{H}}n \quad \textbf{(2.3)}$$

x is the transmitted signal, $\bar{y}$ is the received signal, $y\epsilon\mathbb{C}$. $\boldsymbol{W}\in NT*NT$ is pre-coding matrix. $\boldsymbol{H}$ is a channel matrix, H $\epsilon\mathbb{C}NT \times NR$. $\bar{n}$ is a noise vector.**[18]**

2.8: PRECODING

Precoding is a concept of beamforming which supports the multi-stream transmission in multi-antenna systems. Precoding plays an imperative role in massive MIMO systems as it can mitigate the effect created by path loss and interference, and maximizes the throughput. In massive MIMO systems, the base station estimates the CSI with the help of uplink pilot signals or feedback sent by the user terminal. The received CSI at the base station is not uncontrollable and not perfect due to several environmental factors on the wireless channel [19]. Although the base station does not receive perfect CSI, still the downlink performance of the base station largely depends upon the estimated CSI.

Thus, the base station uses the estimated CSI and the precoding technique to reduce the interference and achieve gains in spectral efficiency. The performance of downlink massive MIMO depends upon the accurate estimation of CSI and the precoding technique employed. Although the precoding technique provides immense benefits to massive MIMO systems, it also increases the computational complexity of the overall system by adding extra computations. The computational complexity increases along with the number of antennas. Thus, low complex and efficient precoders are more practical to use for massive MIMO systems. Figure 17 shows the precoding in massive MIMO systems with M-antenna base station and N-users.

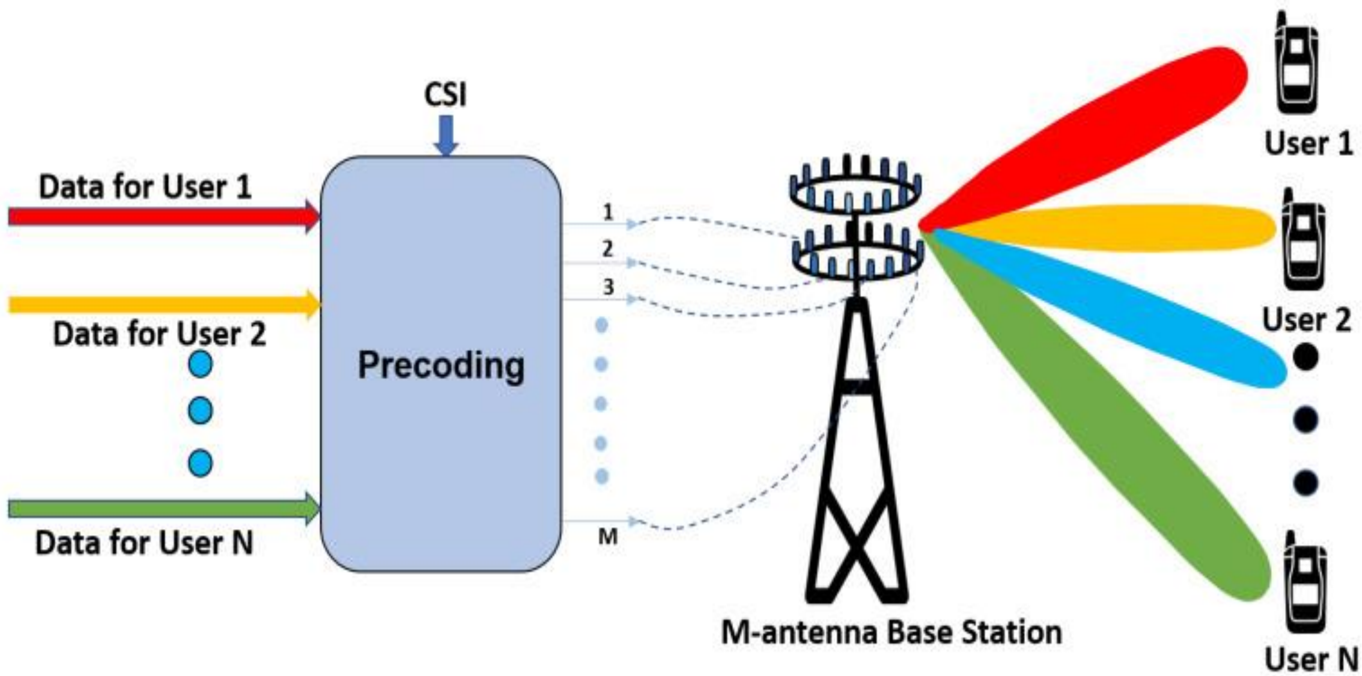

Figure 17- Precoding in a Massive MIMO System With M Antennas at Base Station Communicating with N Users

Many linear and non-linear precoders have been proposed for massive MIMO systems. Although the non-linear precoders like Dirty Paper Precoding (DPP) [20], Tomlinson Harashima precoding (TH) [21-22], and Vector Perturbation (VP) [23] provide better performance, these methods have very high computational complexity when we have large antenna system. The linear precoders such as Maximal Ratio Combining (MRC) [24], Zero-Forcing (ZF) [25-26], Regularized ZF (R-ZF) [27], Water Filling (WF) [28], and MMSE [29-30] have lower computational complexity and can achieve near-optimal performance.

2.9: MASSIVE MIMO CHALLENGES

Massive MIMO systems have been causing quite a stir since the 5G flow targets were introduced. It is a cutting-edge technology, although it meets new generation requirements, it presents new challenges. According to the current literature on massive MIMOs [31],the main research directions for massive MIMOs are:

- Resource management
- Performance and physical limitation
- Pilot contamination
- Energy efficiency
- Spectral efficiency

- Pre-coding and detection
- Antenna Deployment Strategies
- Channel estimation

2.10: SPECTRAL EFFICIENCY

The efficiency of a communication system was traditionally measured by the spectral efficiency expressed in bit/s/Hz, which is directly related to the channel capacity in bit/s. This metric indicates how efficiently the spectrum resource is being used. This criterion provides information on the efficiency of bandwidth use and is expressed as the ratio between the network throughput R and the signal bandwidth [32]:

$$\boldsymbol{SE} = \frac{\boldsymbol{R}}{\boldsymbol{B}} \text{ [bit/s/Hz]} \quad \textbf{(2.4)}$$

Theorem 1: If an MMSE channel estimation is used, the UL ergodic channel capacity of UE $\boldsymbol{k}$ in cell $\boldsymbol{j}$ is bounded by $\boldsymbol{SE_{UL}^{Jk}}$ **[bit/s/Hz]** given by:

$$\boldsymbol{SE_{UL}^{Jk}} = \frac{\tau_U}{\tau_C} \boldsymbol{E}\left\{\log_2\left(1 + \boldsymbol{SINR_{JK}^{UL}}\right)\right\} \text{[bit/s/Hz]} \quad \textbf{(2.5)}$$

Theorem 2: The ergodic channel capacity DL of UE $\boldsymbol{k}$ in cell $\boldsymbol{j}$ is delimited by:

$$\boldsymbol{SE^{DL}} = \frac{\tau_d}{\tau_C} \log_2\left(1 + \boldsymbol{SINR^{DL}}\right) \quad \textbf{(2.6)}$$

Where:

$$\tau_C = \tau_p + \tau_u + \tau_d \quad \textbf{(2.7)}$$

With:

τ_c : Coherence time

τ_p: UL pilot signals

τ_u: UL data signals

τ_d: DL data signals

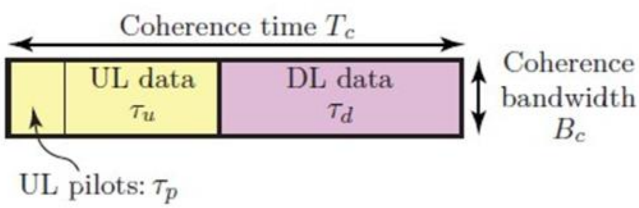

Figure 18- Block de Coherence.

2.11: FORMAL DEFINITION OF LINEAR MASSIVE MIMO DETECTION

We provide a formal definition of the massive MIMO system model in this section. The aim is to provide a relevant background to the readers for subsequent sections. They have been a reinvigorated interest in the traditional linear detectors since the introduction of massive MIMO systems. Therefore, we also present the linear detection mechanism in this section. We assume massive multi-user MIMO base-station (BS) is serving K single antenna users. The BS has a totals N antennas where K $\leq$ N. Assuming frequency-flat channel, the channel coefficients between K users and N BS antennas forms a matrix (**H**) which can be expressed as

$$\boldsymbol{H} = \begin{bmatrix} h_{11} & h_{12} \dots\dots & h_{1j} \\ h_{21} & h_{22} \dots\dots & h_{2j} \\ \vdots & \vdots & \vdots \\ h_{i1} & h_{i2} \dots\dots & h_{ij} \end{bmatrix} \textbf{(2.8)}$$

Where h_{ij} is the channel gain or loss from j^{th} transmitted antenna to i^{th} receive antenna. The channels are shown in lines between the BS and users . The elements of the channel matrix **H** $\in \mathbb{C}^{N\times K}$ are often assumed to be independent and identically distributed $(i.i.d)$ Gaussian random variables with zero mean and unit variance. However, this is not always the case in truly directive channels. The K users transmit their symbols individually and we can form a symbol vector $x = [x_1, x_2, \dots\dots, x_K]^1$ transmitted by all the users in the uplink or reverse direction.

The BS receives a vector $y = [y_1, y_2, \dots\dots, y_N]$ which is corrupted by channel effects and noise. The relationship between $\boldsymbol{x}$ and $\boldsymbol{y}$ can be characterized as

$$\boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{n}, \quad \textbf{(2,9)}$$

where n is N $\times$ 1 additive white Gaussian noise (AWGN)whose entries are $(i.i.d)$This model is generally adopted to derive a detection algorithm, where the CSI and the synchronization is assumed to be perfect at the BS. The task of a MIMO detector is to determine the transmitted vector $\boldsymbol{x}$ based on the received vector $\boldsymbol{y}$. The maximum likelihood sequence detection (MLSD) is an optimal algorithm to solve the MIMO detection problem. It performs an exhaustive search and examines all possible signals as illustrated by:

$$\hat{x}_{ML} = \arg\min_{x\in O^K} \|y - Hx\|^2 \quad (2,10)$$

Where $\hat{x}$ is the estimated received signal, the **ML** problem is combinatorial in nature and the numerical standard algorithms for the convex optimization are not applicable. Therefore, the complexity of ML is exponential in the number of decision variables O^K.The most conventional low complexity linear detectors such as the MF (Matched Filter), the ZF algorithm and the MMSE algorithm are explained here. [33]

2.11.1: LINEAR ZF DETECTOR

ZF outperforms the MF detector and it aims to maximize the received signal-to-interference ratio (SINR). The ZF mechanism is based on inverting the channel matrix H and thus, removing the effect of the channel. The equalization matrix of the ZF detector is given by

$$A_{ZF}^{H} = (H^H H)^{-1} H^H = H^{+} \quad (2,11)$$

where $H^{+}$is the Moore-Penrose pseudo-inverse of a matrix, the pseudo-inverse is used because **H** is not always a square matrix, i.e. the number of users is not equal to the number of antennas at BS. The estimated signal can be shown as

$$\hat{x}_{ZF} = S\left(A_{ZF}^{H} y\right) \quad (2,12)$$

It is clear that the ZF detector neglects the effect of noise and it works properly in interference-limited scenarios in expenses of higher computational complexity. However, the ZF detector and the MF may produce a noise enhancement in case of a small-valued coefficient channel. Therefore, MMSE detector is proposed to take the effect of noise in the equalization process [34].

2.11.2: MMSE DETECTOR

The main idea of the MMSE detector is to minimize the mean-square error (MSE) between the transmitted x and the estimated signal $H^H y$ as given by

$$A_{MMSE}^{H} = \arg\min_{H\in\mathbb{C}^{N\times K}} \mathbb{E}\|x - H^H y\|^2 \quad (2,13)$$

Where $\mathbb{E}$ is the expectation operator, MMSE detector takes the noise effect into consideration as

$$A_{MMSE}^{H} = \left(H^H H + \frac{K}{SNR} I\right)^{-1} H^H \quad (2,14)$$

where I isthe identity matrix. The output of the MMSE detector can be obtained by

$$\hat{x}_{MMSE} = S(A_{MMSE}^{H} y). \quad \textbf{(2,15)}$$

The MMSE detector is capable of achieving a significantly better performance than the ZF detector when the noise power is large [35].

2.11.3: MF (MATCHED FILTER) DETECTOR

MF handles the interference from other sub-streams as purely noise by making **A = H.** The estimated received signal using MF is given by:

$$\hat{x}_{MF} = S(H^{H} y) \qquad \textbf{(2,16)}$$

Which works properly when K is much smaller than N and it provides a worse performance compared to more complex detectors. MF, also called the maximum ratio combining (MRC), aims to maximize the received SNR of each stream by neglecting the effect of multiuser interference. If the channel is ill-conditioned, performance is severely degraded for a square MIMO system [35].

2.12: LINEAR DETECTORS BASED ON THE APPROXIMATE MATRIX INVERSION

With a large number of transmit antennas, the channel hardening phenomenon can be exploited to cancel the characteristics of a small-scale fading and it becomes dominant when the number of served users (K) is much lower than the number of receive antennas (N). This can be seen a diagonalization of the entries in the Gram matrix or GRAMIAN $G = H^{H}H$, where the non-diagonal components tend to zero and diagonal terms become closer to N, a matrix inversion of the GRAMIAN matrix is required to equalize the received signal.

It exhibits high computational complexity being one of the most complex operations in the linear and simple non-linear MIMO detectors. For the massive MIMO system, this problem becomes more severe as the dimension of the GRAMIAN G increases. Several methods have been proposed to reduce complexity by approximating the inverse of a matrix, rather than computing it. Besides the cost of a matrix inversion, a challenge in matrix inversion lies on when the channel matrix is nearly singular and the system becomes ill-conditioned. In this case, the matrix inversion will not equalize the received signal. In order to overcome the inherent noise enhancement, modified detectors with approximate matrix inversion methods will be an essential. Therefore, detectors based on approximate matrix inversion will be presented and discussed below [35].

2.12.1: NEUMANN SERIES (NS)

The NEUMANN series (NS) is a popular method for approximating the matrix inversion which subsequently reduces complexity of the linear detector. $\boldsymbol{G}$ can be decomposed into:

$$\boldsymbol{G} = \boldsymbol{D} + \boldsymbol{E} \quad \textbf{(2.17)}$$

where $\boldsymbol{D}$ is the main diagonal matrix and $\boldsymbol{E}$ is the non-diagonal matrix. The NS expansion of $\boldsymbol{G}$ is given by

$$\mathbf{G}^{-1} = \sum_{n=0}^{\infty}(-\mathbf{D}^{-1}\mathbf{E})^{n}\mathbf{D}^{-1} \quad \textbf{(2.18)}$$

The polynomial expansion in **(2.18)** converges to the matrix inverse if $\boldsymbol{G}^{-1}$

$$\lim_{n\to\infty}(-\boldsymbol{D}^{-1}\boldsymbol{E})^{n} = \mathbf{0} \quad \textbf{(2.19)}$$

In practice, a finite number of terms is utilized, and, thus, a fixed number of iterations of **(2.18)** is performed. As the number of iterations n increases, high precision of the matrix inverse will be achieved at the expense of extra complexity. The NS based algorithm reduces the computational complexity from O (K^3) to O (K^2) when the numbers of iterations $n \leq 2$. However, the NS method recursion is slow, therefore, high-order recursion method such as Schulz recursion can be used to accelerate the NS recursion in expenses of extra computational complexity, a MMSE Parallel Interference Cancellation (MMSEPIC) based algorithm is proposed to reduce the computational complexity by exploiting the NS expansion to replace the matrix-matrix multiplication of $\boldsymbol{G}$ with a matrix-vector multiplication. This method employed $n \leq$ 3 for a MIMO size of 16 $\times$128. Compared to the ML detector, the computational complexity has been reduced to $O(nKN)$ with a marginal performance loss when n = 3 compared to the MMSE performance. Complexity can be reduced only when n is small [35].

2.12.2: GAUSS-SEIDEL METHOD (GS)

The Gauss-Seidel (GS) method is also known as the LIEBMANN method or the method of successive displacement. The GRAMIAN matrix $\boldsymbol{G}$ can be decomposed into:

$$\boldsymbol{G} = \boldsymbol{D} + \boldsymbol{L} + \boldsymbol{U} \quad \textbf{(2.20)}$$

Where: $\boldsymbol{D}$, $\boldsymbol{L}$ and $\boldsymbol{U}$ are the diagonal component, the strictly lower triangular component, and the strictly upper triangular component, respectively. The GS method can be used to estimate the transmitted signal vector $(\hat{x})$ and its characterized by:

$$\hat{x}^{(n)} = (D + L)^{-1}(\hat{x}_{MF} U \hat{x}^{(n-1)}), \qquad n = 1, 2, \ldots, \text{(2,21)}$$

Where (n) is the number of iterations and $\hat{x}_{MF}$ is shown. If there is no priori information about the initial solution $\hat{x}^{(0)}$, it can be considered as zero.

According to the GS iteration method outperforms the NS method with lower complexity. A detector based on the GS method has been proposed with initial solution based on the NS expansion with two terms. The proposed detector is implemented in the FPGA for 8×128 MIMO system. The parallel version of the GS method is implemented in. It outperforms the implementation terms of throughput for 8×128 system. It has also shown that detectors based the GS method can reduce the complexity to be O(k^2). However, due to the GS internal sequential iterations structure, it is not well suited for parallel implementation [35].

2.13: CONCLUSION

MIMO technology has become essential for WLAN, LTE and 5G communication systems. It has the ability to increase channel throughput, spectral efficiency and robustness against signal fading and interference. Unlike a single-input, single-output (SISO) system, the use of MIMO technology can significantly increase the link capacity of WLAN, LTE and 5G systems. MIMO technology provides various schemes for improving link performance, including diversity handling, spatial multiplexing, and antenna beamforming. Massive MIMO is destined to provide great and improved user experience, delivery of new revenue generated exciting mobile services. Consequently, massive MIMO would remain strong competitor in the next decade for both developed and emerging markets. A significant research dedicated to the receiver's design has been proposed [35]. In this chapter, a review of various detection techniques for massive MIMO systems is provided. Although linear detectors suffer from mediocre performance, the ZF method and the MMSE method are found to play a crucial role in the receiver design due to their relative simplicity.

CHAPTER 3

SIMULATION AND RESULTS

CHAPTER 3: SIMULATION AND RESULTS

3.1: INTRODUCTION

In this chapter, we will present different graphs of our simulation results, obtained by the MATLAB software. The simulations will give the performances of well known detection methods for MASSIVE MIMO systems as ZF and MMSE and two methods of approximation inverse channel which are: NUEMANN series and GUASS SEIDEL approximated Method; their performances will plot BER (Bit Error Rate) in function of different values of SNR (Signal to Noise Ratio).

In the following simulations a number of transmitted antennas $N_t = 50$ is taken with different numbers of received antenna N_r = 100, 200 and 300 with BPSK modulation and a flat fading Rayleigh massive MIMO channel is considered.

3.2: NEUMANN SERIES APPROXIMATED METHOD

The Neumann-Series (NS) method is based on decomposition of The GRAMIAN matrix $G = H^H H$ into: $D + E$;

Where:

H: is Massive MIMO matrix channel

D: Diagonal component matrix

E: Non-Diagonal component matrix

The NS method can be used to estimate the transmitted signal vector $(\hat{x})$ using the approximated inverse of G: $\mathbf{G}^{-1} = \sum_{n=0}^{\infty}(-\mathbf{D}^{-1}\mathbf{E})^n \mathbf{D}^{-1}$ and the ZF criteria

$\hat{x}_{ZF} = (G)^{-1} H y,$

y: received vector

$\hat{x}_{ZF}$ ZF criteria can be replaced by MMSE criteria $\hat{x}_{MMSE}$

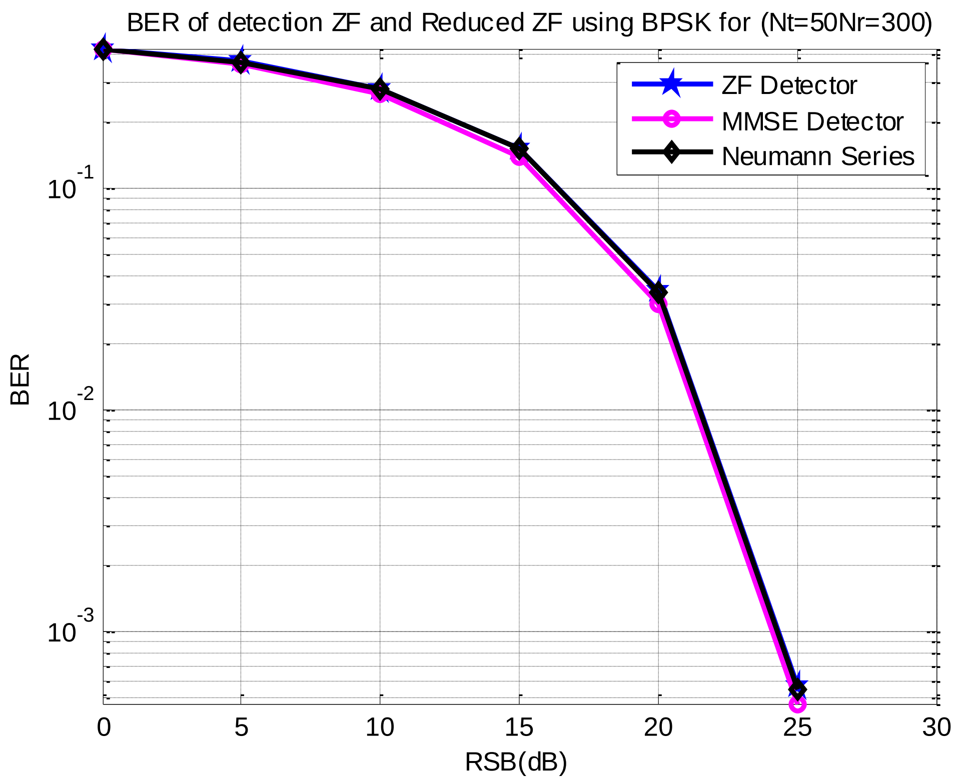

Figure 19- BER Versus RSB of for ZF Detector, MMSE Detector and NEUMANN Series with (Nt=50 Nr=300)

Figure 19 illustrates the BER of classical detectors ZF and MMSE with the Neumann series Nt =50 Nr=300. The results show that BER of different detectors are similar with little performance of MMSE detector.

These results show that when the number of received antennas: $Nr \gg Nt; Nr = 6 \times Nt$,

The approximation of inverse channel based on Neumann series become more and more as real inverse channel:

$$\sum_{n=0}^{\infty} (-D^{-1}E)^{-1} \approx (HH^H)^{-1}$$

For the detector based on MMSE, it's evident that its performance is quite great that the other (ZF and Neumann series) because the impact of the variance of the noise is taken in consideration.

3.3 GUASS SEIDEL approximated Method (GS):

The Gauss-Seidel (GS) method is based on decomposition of The GRAMIAN matrix $G = H^H H$ into : $D + L + U$**; and** H **is Massive MIMO matrix channel**

Where:

D: Diagonal component matrix,

L: Strictly lower triangular component matrix,

U**:** Strictly upper triangular component matrix

The GS method can be used to estimate the transmitted signal vector $(\hat{x})$ and its characterized by:

$$\hat{x}^{(n)} = (D + L)^{-1}(\hat{x}_{MF} U \hat{x}^{(n-1)}),$$

n**:** Number of iterations

$\hat{x}_{MF}$ If there is no priori information about the initial solution $\hat{x}^{(0)}$, it can be considered as zero.

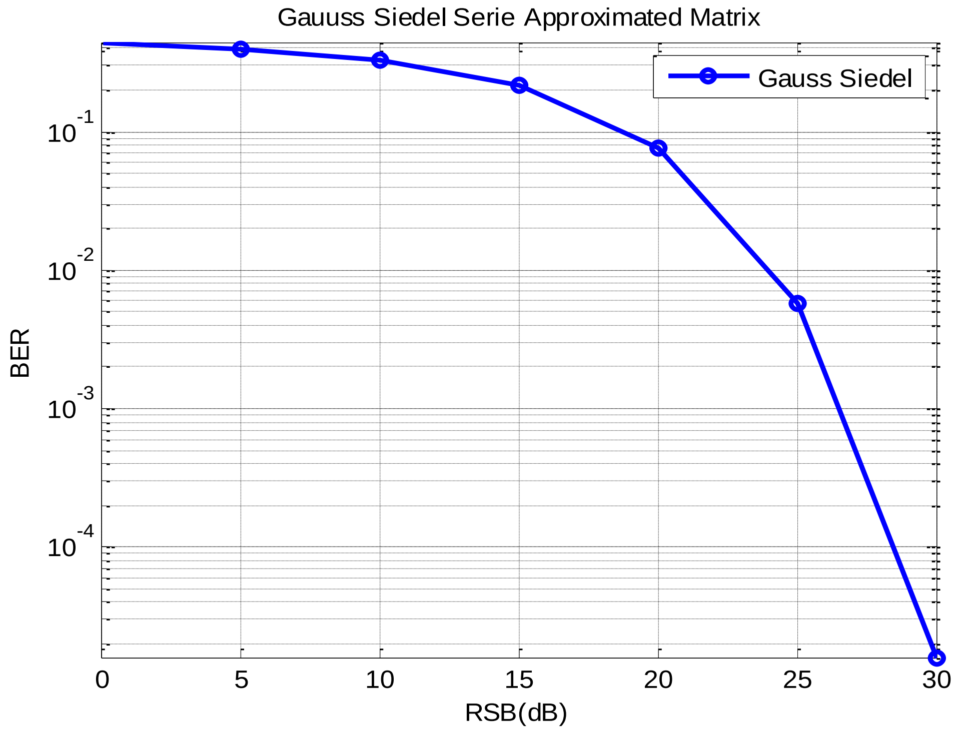

Figure 20- BER Versus RSB of Detector Using GUASS SEIDEL Approximate Matrix for (Nt =50 Nr=100)

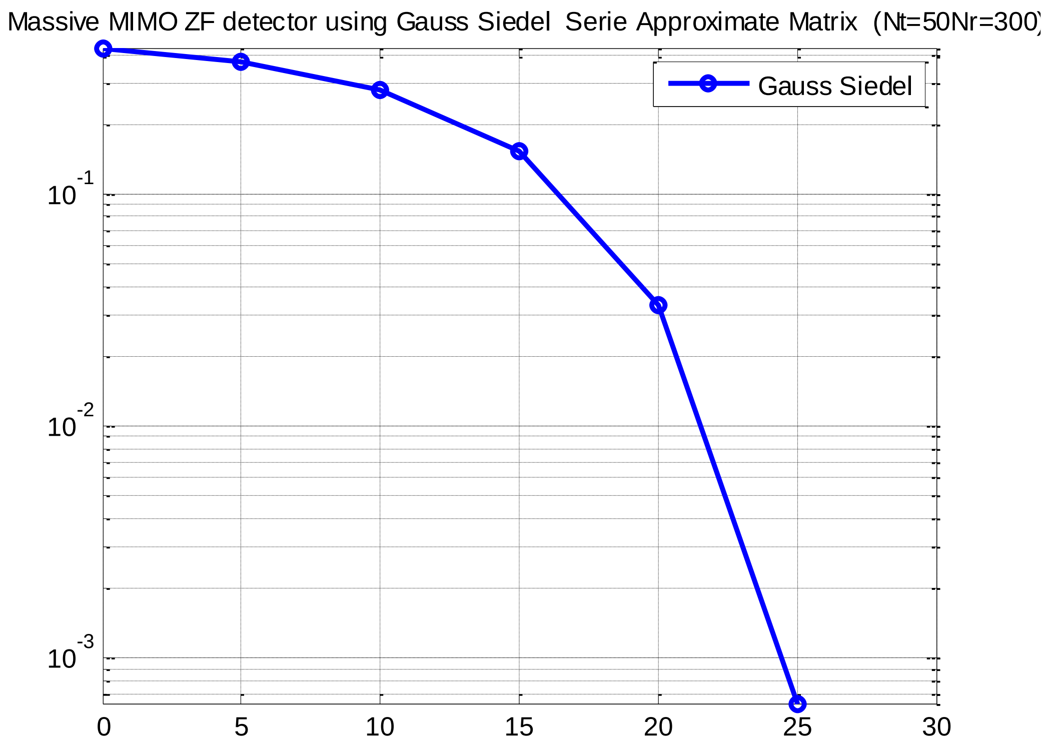

Figure 21- BER Versus RSB of ZF Detector using GUASS SEIDEL Approximate Matrix for (Nt=50 Nr=300**)**

From the Figures **20** and **21** the BER of MASSIVE MIMO detector using GUASS SEIDEL SERIE approximate present that the performance is closely related to the number of received antenna, when the ratio Nt and Nr increase the BER decrease. Also the results show that BER and SNR are inversely proportional. When the SNR increase, the BER automatically decrease this is because the noise impact become less important.

3.4 Comparison between different detection methods

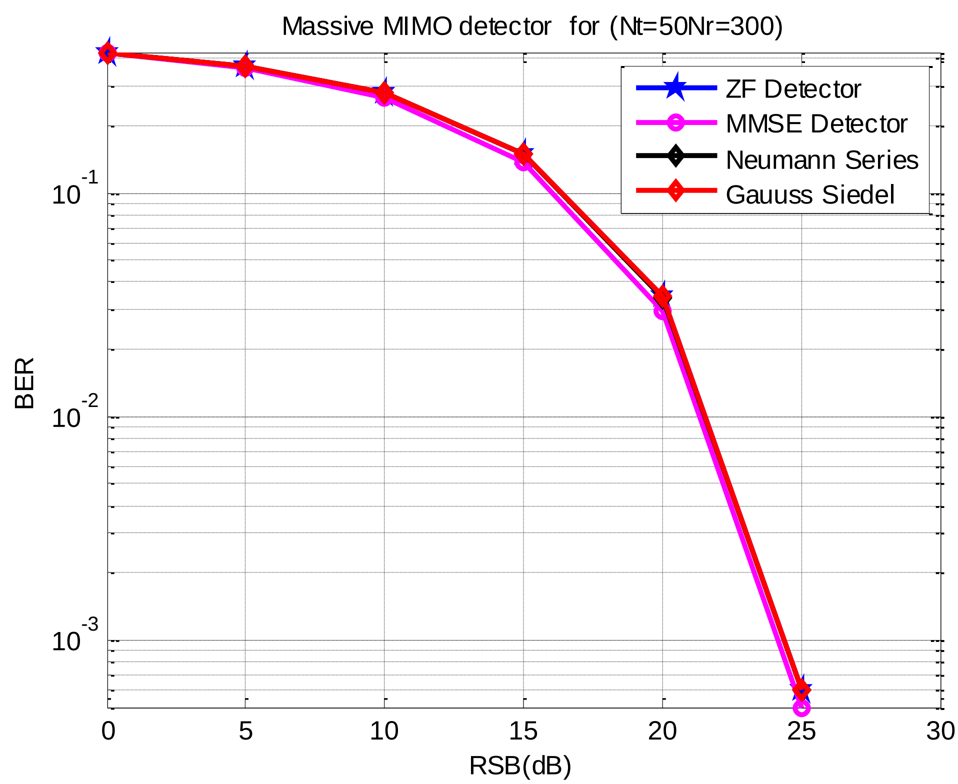

Figure 22- BER Performance Against RSB for ZF Detector, MMSE Detector, NEUMANN Series and GUASS SEIDEL for (Nt=50 Nr=300)

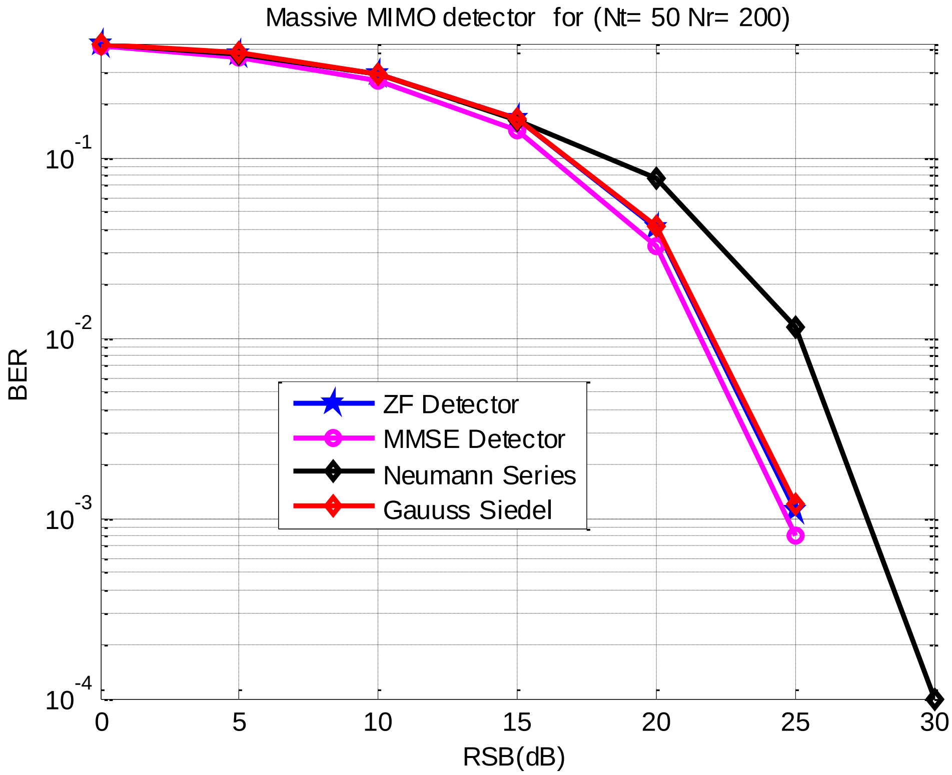

Figure 23- BER Performance Against RSB of ZF Detector, MMSE Detector, NEUMANN Series and GUASS SEIDEL for (Nt=50, Nr=200)

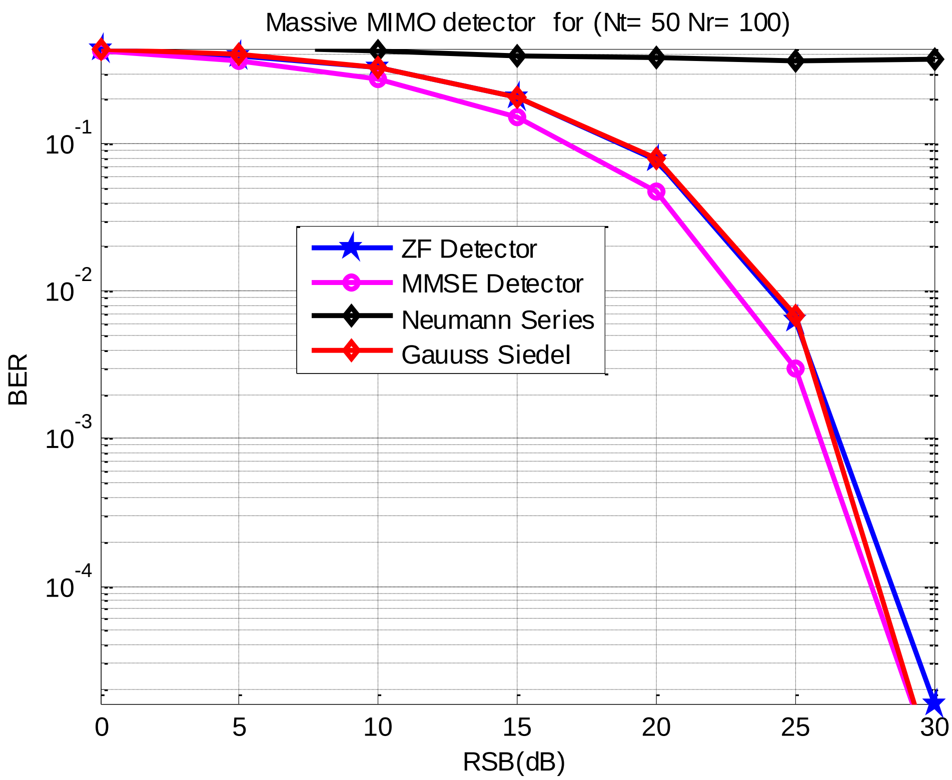

Figure 24- BER Performance Against RSB of ZF Detector, MMSE Detector, NEUMANN Series and GUASS SEIDEL for (Nt=50, Nr=100)

The Figures 22, 23 and 24 gave comparison between different performance of ZF detector, MMSE detector, NEUMANN series and GUASS SEIDEL. The results show that the BER and SNR are inversely proportional. Another remark that the NEUMANN series is very sensitive to the low report $Nr\ /Nt$, contrary to the GUASS SEIDEL method. This case because NEUMANN series is based on approximation not exactly as that of GUASS SEIDEL.

3.5: CONCLUSION

In this chapter, we have seen different simulations of Massive MIMO detectors based on approximated inverse matrix channel. We have presented the superior performance of NEUMANN series and GUASS SEIDEL when the received antenna number Nr is enormous and they have a similar performance with the classical detector ZF and MMSE but with low complexity. We remarked that Neumann series method need high report $Nr\ /Nt$ to approximate to the performance of the classical detectors ZF or MMSE.

GENERAL CONCLUSION

GENERAL CONCLUSION

5Generation or 5G is a new generation of mobile network. It is also known as a global wireless standard after 1G, 2G, 3G, and 4G networks. 5G enables a new kind of network, applications, softwares and other services, which are designed to connect virtually everyone and everything together including machines, objects, and devices such as: computers, mobile-phones, houses, cars …etc.

5G wireless technology is meant to distribute advanced multi-Gbps peak data speeds, ultra low latency, more dependability, enormous network capability, increased availability, and a more uniform user experience to more users. Higher performance and improved efficiency empower new user experiences and connects new industries.

In this research, we intended to explore the quality of this modern generation of algorithms on the wireless communications systems. To realize this objective, we implemented the Massive MIMO technique to have deep results especially, when we increase the number of antennas we observe the impact of these latter on the complexity of detectors as ZF and MMSE. To have a gist understanding of the antenna's influence, we utilized an algorithm to calculate the inverse of massive MIMO channel with an approximate method (not a direct method as ZF, MMSE) like NUEMANN series and GAUSS SEIDEL method

This study demonstrated that the more iterations of approximated inverse algorithms we have, the best result of inverse channel is achieved.

Other main remark that we observe that the NEUMANN series is very sensitive to the low report $Nr\ /Nt$, contrary to the GUASS SEIDEL method. This is because NEUMANN series is based on approximation not exactly as that of GUASS SEIDEL.

LIST OF FIGURES

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[1] A Closer Look at Massive MIMO. [(accessed on 20 January 2020)]; Available online: https://business.sprint.com/blog/massive-mimo.

[2] Rusek F., Persson D., Lau B.K., Larsson E.G., Marzetta T.L., Edfors O., Tufvesson F. Scaling up MIMO: Opportunities and Challenges With Very Large Arrays. IEEE Signal Process. Mag. 2013;30:40–60. doi: 10.1109/MSP.2011.2178495. [CrossRef] [Google Scholar]

[3] Larsson E.G., Tufvesson F., Edfors O., Marzetta T.L. Massive MIMO for Next Generation Wireless Systems. IEEE Commun. Mag. 2014;52:186–195. doi: 10.1109/MCOM.2014.6736761. [CrossRef] [Google Scholar]

[4] Marzetta T.L. Massive MIMO: An Introduction. Bell Labs Tech. J. 2015;20:11–22. doi: 10.15325/BLTJ.2015.2407793. [CrossRef] [Google Scholar]

[5] Wu X., Beaulieu N.C., Liu D. On Favorable Propagation in Massive MIMO Systems and Different Antenna Configurations. IEEE Access. 2017;5:5578–5593. doi: 10.1109/ACCESS.2017.2695007. [CrossRef] [Google Scholar]

[6] BASTIEN, Evolution of mobiles communication, BASTIENBONNARD, article, 2020

[7] HUANG, H., PAPADIAS, C. B., VENKATESAN, S. MIMO Communication for cellular Networks. Springer Science & Business Media, 2011.

[8] Xiang, Wei, Kan Zheng, and XUEMIN Sherman Shen, eds. 5G mobile communications. Springer, 2016.

[9] AMTA, 5G Connecting the Community, 5G&EMF Explained AMTA, article, 23 Aug 2019

[10] BISOGNIN, Aimeric. Évaluation de technologies organiques faibles pertes et d'impression plastique 3D afin de contribuer au développement de solutions antennaires innovantes dans la bande 60 GHz–140GHz.University Nice Sophia Antipolis, 2015.

[11] ETTIENE Sicard, 5G integration with 4G, _From_4G_to_5G _Trends in Physical layer integration, publication, April 2014.

[12] MMWAVE.2019 [en ligne]. http://www.efort.com/r_tutoriels/5G_EFORT.pdf

[13] 5G system .2019 [en ligne]. http://www.efort.com/r_tutoriels/5G_EFORT.pdf

[14] DACI KAOUTER ; DOU WARDA, Etude de massive MIMO pour la 5G. Université ECHAHIDE Hamma Lakhdar El-Oued ,2019.

[15] MAX EDY, Weaknesses of the future 5G network, news/5g-is-the-future-of-wireless-but-it-has-weaknesses, news, 8 August 2019.

[16] Molisch A.F., Ratnam V.V., Han S., Li Z., Nguyen S.L., Li L., Haneda K. Hybrid Beamforming for Massive MIMO: A Survey. IEEE Commun. Mag. 2017;55:134–141. doi: 10.1109/MCOM.2017.1600400. [CrossRef] [Google Scholar]

[17] Yang B., Yu Z., Lan J., Zhang R., Zhou J., Hong W. Digital Beamforming-Based Massive MIMO Transceiver for 5G Millimeter-Wave Communications. IEEE Trans. Microw. Theory Tech. 2018;66:3403–3418. doi: 10.1109/TMTT.2018.2829702. [CrossRef] [Google Scholar]

[18] CHALLITA, Frédéric, MARTINEZ-INGLES, Maria-Teresa, LIÉNARD, Martine, et al. Line-of-Sight Massive MIMO Channel Characteristics in an Indoor Scenario at 94 GHz. IEEE Access, 2018, vol. 6, p. 62361-62370.

[19] Fatema N., Hua G., Xiang Y., Peng D., Natgunanathan I. Massive MIMO Linear Precoding: A Survey. IEEE Syst. J. 2018;12:3920–3931. doi: 10.1109/JSYST.2017.2776401. [CrossRef] [Google Scholar]

[20] Costa M. Writing on dirty paper (Corresp.) IEEE Trans. Inf. Theory. 1983;29:439–441. doi: 10.1109/TIT.1983.1056659. [CrossRef] [Google Scholar]

[21] Cao F., Dao N.C.-D. Receive Beamformer Design for MMSE multiuser Tomlinson-Harashima precoding. IEEE Commun. Lett. 2011;15:293–295. doi: 10.1109/LCOMM.2011.011311.101477. [CrossRef] [Google Scholar]

[22] Zu K., de Lamare R.C. Multi-branch THP design for MU-MIMO systems: Theory and Algorithms. IEEE Trans. Commun. 2014;62:939–951. doi: 10.1109/TCOMM.2014.012514.130241. [CrossRef] [Google Scholar]

[23] Boccardi F., Caire G. The pSphere Encoder: Peak-Power Reduction by Lattice precoding for the MIMO Gaussian broadcast channel. IEEE Trans. Commun. 2006;54:2085–2091. doi: 10.1109/TCOMM.2006.881396. [CrossRef] [Google Scholar]

[24] Gao X., Edfors O., Rusek F., Tufvesson F. Linear pre-coding performance in measured very-large MIMO channels; Proceedings of the 2011 IEEE Vehicular Technology Conference (VTC Fall); San Francisco, CA, USA. 5–8 September 2011; pp. 1–5. [Google Scholar]

[25] Shi S., Schubert M. MMSE transmit optimization for multi-user multi-antenna systems; Proceedings of the 30th IEEE International Conference on Acoustics, Speech, and Signal Processing; Philadelphia, PA, USA. 23 March 2005; pp. 409–412. [Google Scholar]

[26] Bahrami H.R., Le-Ngoc T. Maximum Ratio Combining Precoding for Multi-Antenna Relay Systems; Proceedings of the 2008 IEEE International Conference on Communications (ICC'08); Beijing, China. 19–23 May 2008; pp. 820–824. [Google Scholar]

[27] Park C.S., Byun Y.S., Bokiye A.M., Lee Y.H. Complexity reduced zero-forcing beamforming in massive MIMO systems; Proceedings of the 2014 Information Theory and Applications Workshop (ITA 2014); San Diego, CA, USA. 9–14 February 2014; Piscataway, NJ, USA: IEEE; 2014. pp. 1–5. [Google Scholar]

[28] Crâmariu V., Arvinte M., Enescu A., Ciochină S. Waterfilling power allocation applied in block-diagonalization Multi-User MIMO precoding technique; Proceedings of the 2016 12th IEEE International Symposium on Electronics and Telecommunications (ISETC); Timisoara, Romania. 27–28 October 2016; pp. 91–94. [Google Scholar]

[29] Mukubwa E., Sokoya O.A., Ilcev D.S. Comparison and analysis of massive MIMO linear precoding schemes in the downlink; Proceedings of the 2017 IEEE AFRICON; Cape Town, South Africa. 18–20 September 2017; pp. 187–191. [Google Scholar]

[30] Colon D.L., Gregorio F.H., Cousseau J. Linear precoding in multi-user massive MIMO systems with imperfect channel state information; Proceedings of the 2015 XVI Workshop on Information Processing and Control (RPIC); Cordoba, Argentina. 6–9 October 2015; pp. 1–6. [Google Scholar]

[**31**] ROZE, Antoine. *Massive MIMO, une approche angulaire pour les futurs systèmes multi-utilisateurs aux longueurs d'onde millimétriques*. Diss. INSA de Rennes, 2016.

[32] Mahmoud A. ALBREEM, Mohammed H. ALSHARIF, Sung Hwan Kim, Why massive MIMO, publication, Published: 21 February 2020.

[33] The Role of Massive MIMO in 5G. Michael Wang. 23 OCT 2018 [Enligne]. https://medium.com/@miccowang/the-role-of-massive-mimo-in-5g-c362e790ef61 [consulté le 03 Avril 2019

[**34**] ABOUD, Ahmad. Interference mitigation in 5G mobile networks: Uplink pilot contamination in TDD massive MIMO scheme. DISS. Limoges, 2017.

[35] HAJRI, Salah Eddine. (Thèse de doctorat 2018). L'amélioration des performances des systèmes sans fil 5G par groupements adaptatifs des utilisateurs. University Paris-Saclay.