OPTIMIZATION OF SPECTRAL EFFICIENCY USING PRECODING TECHNIQUES IN MULTI CELL MASSIVE MIMO

A Project report submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

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ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES

(UGC AUTONOMOUS)

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Sangivalasa, Bheemili Mandal, Visakhapatnam Dist. (A.P)

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CERTIFICATE

This is to certify that the project report entitled **"OPTIMIZATION OF SPECTRAL EFFICIENCY USING PRECODING TECHNIQUES IN MULTI CELL MASSIVE MIMO"** submitted by **G. Chandrakala (319126512146), R. Vishnu Surendra Reddy (319126512177), K. Mohan Sainarayana (319126512152), K. Namrata (320126512L22)** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Electronics & Communication Engineering of Anil Neerukonda Institute of technology and Sciences(A), Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

A proposed method for improving cellular networks' spectrum efficiency is MIMO. For multipath wireless communication, massive MIMO is a set of multiple input, multiple output technologies. It is a unique instance of multiuser MIMO that uses Massive Antennas as the surplus base station (BS) antennas. Coherent beam formation and the development of antenna arrays with hundreds or thousands of active components at base stations boost spectral efficiency. These systems should typically have an order of magnitude more antennas (M) than scheduled users (K), as the user's channels are likely to be nearly orthogonal when M/K is more than 10. Here, the relationship between M and other system parameters and the ideal number of scheduled users, K*, is examined.

In order to achieve this, novel SE expressions are developed that allow for effective system-level analysis with power control, flexible pilot reuse, and ad hoc user placements. While simulations are used to show what happens at final M, in various interference circumstances, with various pilot reuse factors, and for various processing systems, the value of K* in the large-M domain is determined in closed form. The receiver uses pilot signals to first estimate the channel coefficients between the transmitter and receiver before implementing the single cell MMSE. The received signal is then subjected to the MMSE filtering process to enhance its quality. The single cell MMSE method is extendable to multiple antennas, multiple cells, and many users, resulting in more advanced methods like multiuser detection and beamforming. M-MMSE consistently produces a larger sum SE when compared to S-MMSE and other precoding methods.

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LIST OF SYMBOLS

B	Bandwidth
D	Average cell density
f	Frequency
Bc	Coherence bandwidth
Tc	Coherence time
τc	Complex-valued samples
M	Antennas at base station
K	user equipment's in a cell
S	Transmission Symbols per Frame
w	Precoding vector
I	Interference term
β	Pilot reuse factor
μ	Propagation parameter

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MIMO	Multiple Input Multiple Output
BS	Base Station
UE	User Equipment
DL	Downlink
UL	Uplink
SE	Spectral Efficiency
FDD	Frequency Division Duplexing
TDD	Time Division Duplexing
SNR	Signal to Noise Ratio
ICI	Inter Carrier Interference
LS	Least-Square
S-MMSE	Single-Cell-Minimum-Mean-Square-Error
M-MMSE	Multi-Cell-Minimum-Mean-Square-Error
ZF	Zero Forcing
MRT	Maximal Ratio Transmission
RZF	Regularized Zero Forcing
PZF	Pilot Zero Forcing

CHAPTER 1

WIRELESS COMMUNICATIONS AND MASSIVE MIMO

1.1 Introduction

How people communicate has changed substantially as a result of the emergence of wireless communication technologies. A long time has passed since connected telephones, computers, and Internet connections were restricted to specific locales. Due to the development of satellite services, local area networks, and cellular wide area networks (based on the GSMI, UMTS2, and LTE3 standards), as well as local area networks based on various Wi-Fi standards IEEE 802.11 versions, these communications services are now wirelessly accessible almost everywhere on Earth. As with electricity, wireless networking has become a need in modern civilization, and as a result Technology promotes the creation of new services and applications. the revolution in streaming media, in which music and film are provided on demand over the Internet, has already taken place. A completely networked society with applications for augmented reality, connected houses and autos, and machine-to-machine communications has also begun to take shape. We will discover new cutting-edge Unpredictable wireless services currently available if we look ahead 15 years.

For many years, the volume of wireless voice and data transmissions has increased at an exponential rate. Since Guglielmo Marconi's first wireless transmissions in 1895, According to wireless researcher Martin Cooper, the number of voice and data connections has quadrupled every two and a half years. This pattern is known as Cooper's law. According to the Ericsson Mobility Report, mobile data traffic will grow more quickly than Cooper's law, with a compound annual growth rate of 42% from 2016 to 2022. We are transitioning into a networked culture where all electronic gadgets are connected to the Internet, and as video fidelity is constantly improving, new must-have services are likely to emerge, the demand for wireless data connectivity will undoubtedly continue to rise in the near future. How to advance present wireless communications technologies to fulfil the steadily rising demand and avert an impending data traffic congestion is a crucial challenge.

How to meet the escalating demands of service quality is a matter of equal importance. Just as they expect the power system to be reliable and always available, they will anticipate that wireless services will always and everywhere perform equally well. Industrial and university researchers must work tirelessly on new breakthrough wireless network technologies to keep up with an exponential traffic growth rate and concurrently provide universal connection. Technology known as Massive Multiple-Input Multiple-Output

(MIMO) is defined in this monograph along with the reasons why it is a promising way to handle several orders-of-magnitude4 more wireless data traffic than existing systems.

1.2 Cellular Networks

Based on radio, wireless communication uses electromagnetic (EM) waves to convey data from a transmitter to one or more receivers. As distance grows, less signal energy reaches the desired receiver because EM waves spread out and travel in all directions from the transmitter. In 1947, Bell Labs researchers proposed the theory that a cellular network topology is necessary to provide wireless services with a high enough received signal energy over a large coverage area. [3]. making use of a fixed-location base station, a component of network technology that permits wireless communication between a device and the network, this theory divides the coverage area into cells that function separately. Over the ensuing decades, the cellular idea was refined and examined before being used in actual practice. Unquestionably, the cellular concept was a significant advancement and has been the primary force behind the delivery of wireless services over the past 40 years. (Since the "first generation" of mobile phone systems emerged in the 1980s).

Definition 1.1: (Cellular networks). An assortment of base stations (BSS) and user equipment make up a cellular network. (UEs). Each UE is associated with a BS, which offers service to it. While UEs transmit data to their respective BSs are referred to as the uplink (UL), signals delivered from the BSs to their respective UEs are referred to as the downlink.

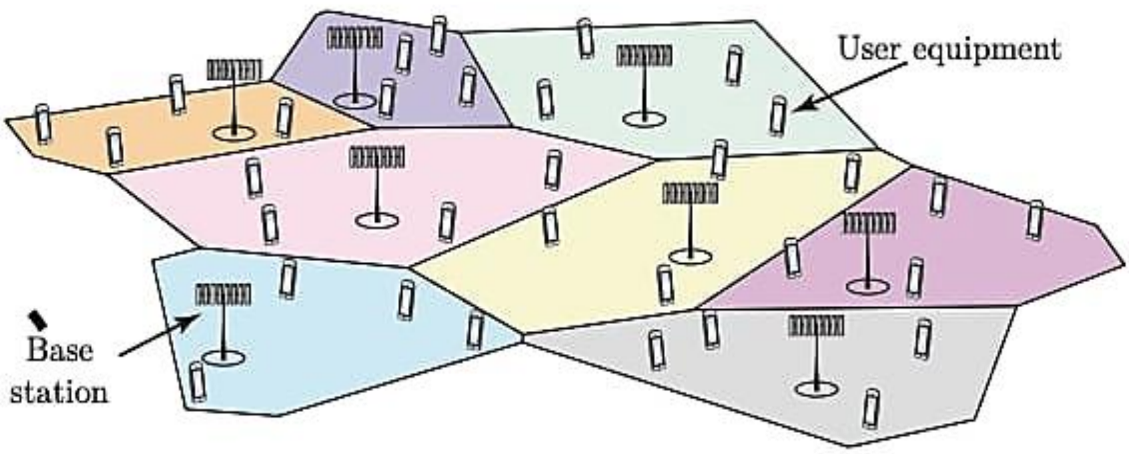

Fig 1.1: a basic cellular network in which each BS serves all UEs within a certain geographic region it serves. The region is designated as a "cell," and it is shown with a distinctive color.

Although wireless data transmissions increasingly predominate over wireless voice communications, cellular networks were initially built for wireless voice communications. The majority of cellular network traffic and the anticipated rise in traffic demand are both driven by video on-demand. The area throughput is therefore a very important performance indicator for both existing and emerging cellular networks. It is measured in bits per square kilometer, and the following high-level formula can be used to model it:

Area throughput (bit/s/km^2]=B[Hz].D[cells/ km^2] .SE [bit/s/Hz/cell] (1.1)

where Spectral Efficiency (SE) is the SE per cell, D is the average cell density, and B is the bandwidth. The SE is the quantity of data that can be carried over a bandwidth of one hertz (Hz) in a second.

In next cellular networks, higher area throughput will be achieved via these three factors that determine the area throughput must be increased. Based on (1.1), the volume of a rectangular box with sides B, D, and SE can be thought of as the area throughput. The possibility of a line-of-sight (LOS) channel between the transmitter and receiver (and between out-of-cell interferers and the reception) as well as the average propagation losses, among other factors, are influenced by the frequency band selection and cell density. These three elements are inextricably linked to one another. To get fundamental understanding, one can, however, examine these three elements independently as a first-order approximation. Consequently, there are three basic techniques to increase cellular networks' area throughput:

1. Give greater bandwidth;
2. Increase the number of BSS deployed to densify the network;
3. Boost the SE per cell

.1.3 Evolving Cellular Networks for Higher Area Throughput

Let us say, just for the sake of argument that we wanted to create a new cellular network that would have a 1000-fold increase in area throughput over current networks, thus resolving Qualcomm's "1000 data challenge." Note that assuming such a network can handle the three orders-of-magnitude increase in wireless data traffic that will occur over the next 15-20 years if the yearly traffic growth rate stays in the range of 41%-59%. How can we manage such a significant increase in traffic using the formula in (1.1)?

One alternative might be to multiply the bandwidth B by 1000. More than GHz of bandwidth is currently used by cellular networks collectively in the frequency spectrum below 6 GHz. The range and service dependability are physically constrained since the frequency spectrum is a shared global resource used by many different services and because it necessitates employing considerably higher frequency bands than in the past, this is physically impracticable. However, there are sizable bandwidths in the millimeter wavelength (mm Wave) bands (for instance, between 30 and 300 GHz) that can be utilized for close-range applications.

The change in coverage tiers has historically been dominated by increased cell density and increased bandwidth, which clarifies why we're getting close to a saturation point where future advancements become more difficult and expensive. However, it might be possible to significantly enhance the SE of cellular networks in the future.

Following the introduction of the early-1990s first-generation mobile network the mobile wireless communication system has through numerous stages of evolution in the recent years. Global need for more connections drove a rapid advancement in mobile communication standards to accommodate more users. Let's look at the stages of wireless communication technology development.

1.3.1 1G-First generation mobile communication system

In Tokyo in 1979, NTT, a subsidiary of Nippon Telegraph & Telephone, unveiled the first generation of mobile networks in Japan. Beginning in the 1980s, it gained popularity in the US, Finland, the UK, and Europe. This system, which made use of analogue transmissions, had a number of shortcomings due to technological limitations.

Key features (technology) of 1G system

• Bandwidth: 10 MHz (666 duplex channels with a bandwidth of 30 KHz)

• Frequency: 800 MHz and 900 MHz

• Technology: Analogue switching

• Modulation: Frequency Modulation (FM)

• Mode of service: voice only

• Access method: Frequency Division Multiple Access (FDMA)

Disadvantages of 1G system

- Voice quality issues brought on by interference
- Limited battery life
- Large-screen cell phones (not convenient to carry)
- Reduced security (calls could be decoded using an FM demodulator)
- A small user base and spotty cell coverage
- It was impossible to roam between similar systems.

1.3.2 2G - Second generation communication system GSM

A new digital wireless transmission technology known as the Global System for Mobile Communication was introduced with the second generation of mobile communication systems. (GSM). Later developments in wireless standards used GSM technology as their foundation. This standard may enable a maximum data rate of 14.4 to 64 kbps, which is adequate for SMS and email services.

The Qualcomm-developed Code Division Multiple Access (CDMA) system was also introduced and put into use about this time. In terms of spectral efficiency, user count, and data rate, CDMA outperforms GSM.

Key features of 2G system

- Switching to a digital system;
- possibility of SMS services
- It is possible to roam
- Voice transmission with encryption;
- First internet at a reduced data rate;
- Improved security

Disadvantages of 2G system

- Low data rates,
- limited mobility,
- fewer functionality on mobile devices,
- a small user base, and limited hardware capacity

2.5G and 2.75G system

in favor of an increased data rate. The launch and widespread use of the General Packet Radio Service (GPRS). Up to 171 kbps of data can be transmitted through GPRS. (maximum).

EDGE Enhanced Data G5M Evolution was developed to boost GSM network data speeds as well. Up to 473.6 kbps was supported by EDGE. (maximum). The introduction of CDMA2000, a further well-liked technology, allowed CDMA networks to accept larger data rates. This technology can deliver data rates of up to 384 kbps. (Maximum).

1.3.3 3G-Third generation communication system

Universal Mobile Terrestrial Telecommunication Systems (UMTS) marked the beginning of third-generation mobile communication. For the first time on mobile devices, video calling is supported by UMTS, which has a data rate of 384 kbps. Smart phones gained worldwide traction after the 3G mobile communication system was introduced. For smartphones, particular programs were created to handle multimedia chat, email, video calling, games, social media, and healthcare.

Key features of 3G system

- Higher data rate

- Video calling
- Enhanced security, a greater number of users and coverage
- Mobile app support
- Multimedia message support
- Location tracking and maps
- Better web browsing
- TV streaming
- High quality 3D games

3.5G to 3.75 Systems

Another two network technology advancements—HSDPA, or HSUPA, also known as High-Speed Uplink Packet Access, and High-Speed Downlink Packet Access—are created and implemented to the 3G networks in order to increase data rate in the current 30 networks. The 375 system is an upgraded version of the 3G network with HSPA+ High Speed Packet Access. The 3.5G network can support data rates of up to 2 Mbps. Later, this system will develop into a 3.9G LTE system that is more potent. (Long Term Evolution).

The drawbacks of 3G technology

- High bandwidth requirements to handle faster data rates
- Compatibility with earlier generation 2G systems and frequency bands
- Expensive spectrum licenses
- Expensive infrastructure, equipment, and installation

1.3.4 4G-Fourth generation communication system

To replace the 3G networks, the IEEE developed the 4G systems. Fourth generation systems use LTE and LTE Advanced cellular technologies, which offer higher data rates and can handle more complex multimedia services. Additionally, it is backwards compatible with earlier versions, enabling the creation and upgrade of LTE and LTE Advanced networks simple.

The simultaneous transmission of speech and data is possible with the LTE system, dramatically increasing data rate. All services, including phone services, can be transmitted through IP packets. Carrier aggregation and complex modulation techniques boost the uplink and downlink capacity. WiMAX is one of the wireless transmission technologies that the 4G system uses to boost network speed and data rate.

Key features of 4G system

- Significantly increased data throughput of up to 1Gbps
- Improved security and mobility reduced latency for essential applications in the minion
- Video games and streaming in high definition.

- Volte Voice over LTE network (use IP packets for voice)

Drawbacks of 4G system

- High-end mobile handsets compatible with 4G technology are required, which is expensive
- Expensive hardware and infrastructure
- Expensive spectrum (most countries frequency bands are too expensive);
- Time-consuming wide rollout and upgrade

1.3.5 5G-Fifth generation communication system

The 5G network makes use of cutting-edge technologies to offer customers blazing-fast internet and multimedia experiences. Future LTE Advanced networks will be upgraded to become 5G networks. In initial deployments, the 5G network will function in standalone and non-standalone modes. both operating non-standalone. LTE and 5G-NR spectrum will be integrated. Control signaling will be linked to the LTE core network in a non-standalone mode.

The 5G technology will use unlicensed spectrum and millimeter waves to transmit data at a greater rate.

Key features of 5G technology

Low latency in milliseconds (important for mission-critical applications)

- Higher security and stable network
- Ultra-fast mobile internet up to 10Gbps
- Increases efficiency using technologies like tiny cells and beam shaping.
- Future improvements are offered by forward compatibility networks, which also provide cloud-based infrastructure that is easy to maintain and replace hardware and that is power-efficient.

Comparison of 1G to 5G technology

Table1.1 Comparison between different communication technologies

Generation	Speed	Technology	Key features
1G (1970-1980s)	14.4 Kbps	AMPS,NMT,TACS	Voice only services
2G (1990 to 2000)	9.6/14.4 Kbps	TDMA, CDMA	Voice and data services
2.5G to 2.75G (2001-2004)	171.2 Kbps 20-40 Kbps	GPRS	Mobile voice, data, and web services, as well as email and slow streaming.
3G (2004-2005)	3.1 Mbps 500-700 Kbps	CDMA2000 (1XRTT,EVDO) UMTS and EDGE	Voice, Data, Multimedia, Smart Phone App Support, Quicker Web Browsing, Video Calling, and TV Streaming.
3.5G (2006-2010)	14.4 Mbps 1-3 Mbps	HSPA	All 3G network services have increased speed and mobility.
4G (2010 onwards)	100-300 Mbps. 3-5 Mbps 100 Mbps (Wi-Fi)	WiMAX, LTE and Wi-Fi	High-speed, high-quality voice over IP, 3D gaming, HD video conferencing, global roaming, and HD multimedia streaming are all available.
5G (Expecting at the end of 2019)	1 to 10 Gbps	LTE advanced schemes, OMA, and NOMA	For mission-critical applications, IoT, security and surveillance, HD multimedia streaming, autonomous driving, and smart health care applications, there should be lightning-fast mobile internet and a low latency network.

1.4 INTRODUCTION TO MASSIVE MIMO SYSTEM

MIMO, or multiple input, stands for. Increased efficiency is achieved with multiple output radio antennas by using more transmitters and receivers. Perhaps more importantly, MIMO antennas enhance capacity without reducing spectrum since they can broadcast and receive signals over the same channel without the need for a turn-based system.

The base station antennas used in today's 4G and 5G networks typically have 12 antenna ports, which allow them to simultaneously broadcast information in all directions. As a result, current transceivers must wait their turns to transmit and receive data on the same frequency, which results in congestion.

MIMO, or multiple input and multiple output, is a radio technology used to boost the capacity of a radio link by utilizing multiple transmitting and receiving antennas to benefit from multipath propagation. Wireless communication technologies like HSPA+, IEEE 802.11ac, and IEEE 802.11n now include MIMO as a critical component. (Wi-Fi 4). (3G). WiMAX's long-term evolution (LTE). MIMO has more recently been employed for power line communication for three wire configurations as a part of the ITU G.hn standard and the Home Plug AV2 specification.

When it comes to wireless technology, the term "MIMO" used to refer to the usage of multiple antennas at the transmitter and receiver. The term "MIMO" as it is used now refers exclusively to a practical technique for simultaneously broadcasting and receiving multiple data signals over a single radio channel using multipath propagation. Orthogonal frequency division multiplexing (OFDM), which is used to encode the channels, is what gives rise to the increase in data capacity despite the interesting nature of the "multipath" phenomena. MIMO is fundamentally different from smart antenna technologies like diversity and beamforming, which were developed to enhance the performance of a single data transmission.

Modern wireless networks must incorporate MIMO systems, which have recently become quite popular due to their outstanding spectrum and energy productivity. Single input single output systems, which had a very low throughput and couldn't reliably service many clients, were the norm prior to the development of MIMO. Different new MIMO innovations, including as Organization MIMO, single-client MIMO (SU-MIMO), and multi-client MIMO, were developed to satisfy this significant client interest. However, these new advancements are also unable to satisfy the continuously growing demands. Over the past few years, wireless clients have grown significantly. These customers generate trillions of pieces of data that need to be handled productively and with better dependability.

Massive MIMO

Massive MIMO is the most intriguing development for 5G and beyond the wireless access era. Massive MIMO, which integrates hundreds, thousands, or more antennas at the base station and serves many clients simultaneously, is the advancement of modern MIMO systems used in existing wireless organizations. Massive MIMO's usage of extra antennas will assist concentrate energy into a smaller space, improving spectral efficiency and throughput.

Definition 1.2: (Massive MIMO), Massive MIMO base stations have a very large number of antenna elements installed in order to maximize spectrum and energy efficiency.

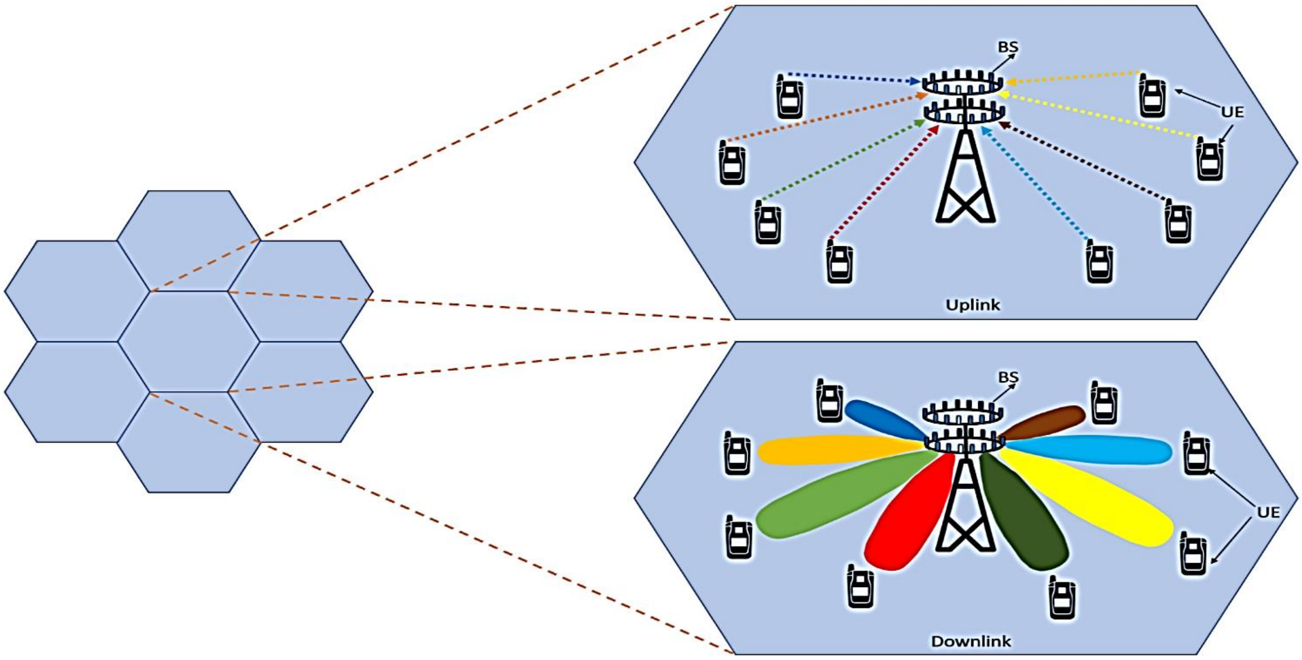

Fig 1.2 Massive MIMO Uplink and Downlink

thousands or even tens of thousands of antennas are frequently used in massive MIMO systems' single antenna arrays.

- By providing service to several UEs on the same time-frequency resources, it employs SDMA to multiply the multiplexing gain.
- It successfully reduces interference by having more BS antennas per cell than UEs. The BS must be adjusted so that the number of antennas increases if more UEs than anticipated are anticipated in a cell.
- It uses TDD mode to avoid relying on parametrizable channel models and to reduce the CSI acquisition overhead brought on using numerous antennas.

1.4.1 Advantages of Massive MIMO

Massive MIMO fundamentally enhances MU-MIMO's potential by adding more antennas, leading to significant increases in network performance. Thus, the 40 standard, LTE and LTE Advanced technologies, and 5G technologies have become some of the fundamental foundations of contemporary wireless cellular networks. A particular access point can direct the transmission and reception of electromagnetic signals to specified locations or targeted areas by placing a lot of antennas, which boosts throughput, capacity, and efficiency. Keep in mind that a Massive MIMO system also uses machine learning and an algorithm to coordinate the use of multiple antennas.

1.4.2 Increases Network Capacity

Massive MIMO boosts a wireless communication network's capacity in two different ways. First off, it permits the use of higher frequencies, such as those required by the Sub-6 5G specification. Second, Multi-user MIMO allows a cellular base station with Massive MIMO capacity to send and receive several data streams simultaneously from different users while sharing the same frequency resources.

It should be noted that network capacity is determined by the quantity or total amount of data a certain network can provide to its end-users, as well as by the maximum number of end-users that can be serviced based on an anticipated service level.

1.4.3 Enhances Network Coverage

Massive MIMO also has the benefit of great spectrum efficiency due to the coordination of numerous antennas with minimal computation and low power usage. Compared to fourth-generation networks, it enables ten times more spectral and network efficiency when employed in a 56 cellular network technology. Furthermore, it enhances the deep coverage of fourth-generation networks when used with 46 technologies.

The signals produced by next-generation cellular network technologies travel a short distance because they emit electromagnetic radiation with higher frequencies, or more specifically frequencies that fall between the upper limits of radio waves and the spectrum of microwaves. As a result, expanding network coverage is essential for current and emerging cellular technologies.

1.4.4 Complements Beamforming

Instead of broadcasting a signal in all directions, beamforming technology concentrates a signal in one direction, which allows for more direct communication between a transmitter and a receiver, more robust and dependable connectivity, and faster data transmission. This technology relies on sophisticated antenna technologies on both access points and end-user devices in order to function as a signal processing technique and traffic-signaling system.

A Massive MIMO system's numerous antennas enable three-dimensional beamforming, in which a single beam of electromagnetic radiation carrying a signal travel in both vertical and horizontal directions. Data transmission speeds are increased further, reaching people in elevated locations like buildings and moving vehicles.

1.4.5 Enables Next-Gen Technologies

Massive MIMO is a crucial part of the 5G network. As an illustration, the Sub-6 5G specification permits the use of frequencies in the sub-6 GHz band. Additionally, according to the mm Wave 5G specification, this technology improves electromagnetic radiation dispersion, enables genuine multi-user wireless communication within a specified area, and extends frequency reach to increase network coverage.

1.4.6 Disadvantages of Massive MIMO

The expense involved in implementing and deploying Massive MIMO is one of its main drawbacks. In comparison to conventional base station units and antenna technologies, the systems are considerably more extensive. Additionally, the assembly and installation of multiple antenna systems for cellular networks is more difficult and time-consuming due to their more complicated design.

Additionally, frequency division duplexing, or FDD, produces feedback overhead. When a receiver transmits feedback signals to a transmitter, this phenomenon occurs. The overhead increases further as the antenna elements are increased. Time-division duplex, often known as TDD, is hence a better choice for Massive MIMO implementation.

Hardware components must fit into a smaller space since several antennas are placed in a base station's designated region. Advanced components that can give their desired degree of performance despite being smaller than their larger counterparts are required for a sizable system with various inputs and outputs. Keep in mind that employing a lot of antennas is only one aspect of massive MIMO. In addition to frequency management signal processing techniques, data transfer, and artificial intelligence, the entire system also functions using machine learning and artificial intelligence. To do this, sophisticated processing algorithms are needed, which raises the price and difficulty of designing, implementing, and deploying a whole system.

1.4.7 Spatial Multiplexing and Spatial Diversity

Modern antenna systems in 4G LTE and 3G NR networks utilize the radio communication techniques of spatial multiplexing and spatial diversity. These two methods each have a crucial but distinct function in MIMO (Multiple Input Multiple Output) antenna systems.

Definition 1.3: (Spatial Diversity). By transmitting numerous copies of the same radio signal across several antennas, the MIMO technique known as spatial diversity lowers the risk of signal fading. By using several antennas at the transmitter or receiver to broadcast multiple copies of the same signal, spatial diversity increases the quality of radio signal links. The duplicates of the signal can then be used to rebuild the original signal, allowing the antennas to overcome the effects of multipath fading.

Diversity is not a novel concept in mobile communications; it has been used for a long time to lessen the negative impacts of signal fading. A radio signal (such as a mobile signal) can go by a number of different routes from the cellular base station to the receiver of a mobile phone, depending on the obstructions in its path. A few examples of obstructions are buildings, trees, poles, mountains, etc. The ability of an antenna system to produce redundant network resources for the signal to minimize the overall impact of signal fading is known as diversity in radio communications. It simply means making more copies of the signal so that scattered signals can be picked up in parts and pieces and used to reconstruct the original signal. When the signal encounters any obstructions, it can get scattered and become weak or "fade" by the time it reaches the receiver.

Theoretically, solutions for frequency, duration, and spatial variety can take at least three different forms. Frequency diversity calls for many frequency channels that transmit various iterations or duplicates of the same signal. By using distinct time-slots, time diversity achieves the same result by sending multiple copies of the signal at various times. However, MIMO antenna systems use a sort of diversity known as space diversity, sometimes known as spatial diversity. MIMO systems allow for spatial diversity by using several antennas at the transmitter and receiver that communicate (transmit or receive) a different version of the same signal. In essence, these are perfect replicas of the first signal. The receiver can collect all the different signal versions and reconstruct the signal when used at the receiving end to lessen the impact of signal fading. In 4G LTE and 5G NR networks, MIMO systems, which use multiple antennas at the transmitter and receiver, are an essential part of the network architecture.

Definition 1.4 (Spatial Multiplexing) Spatial multiplexing is a MIMO technique that increases data speeds by transmitting the data payload across spatially separated antennas in different streams. By allowing the total data payload to be sent to a user device in the form of numerous data streams that carry discrete pieces of the overall information, spatial multiplexing enhances data speeds. One user device or many user devices may be the target of the data streams.

Spatial multiplexing, commonly referred to as space division multiplexing (SDM), is a multiplexing technique used by MIMO antenna systems. It is an essential part of MIMO and the primary argument in favor of its use in 50 NR and 4G LTE networks. A transmitter or receiver may employ a number of spatially multiplexed antennas that are angularly separated from one another. Between the transmitter and receiver, these antennas serve as separate channels for broadcasting and receiving data (such as a WhatsApp message). Using the same frequency and temporal resources, they can send and receive many different data streams. Multiple data streams from a MIMO system can be sent simultaneously to one or more user devices for communication. When the data payload is sent in a number of concurrent streams, the data rate for a user device rises. Massive MIMO, a more advanced variation of MIMO used by 5G NR networks, consists of tens or even hundreds of antenna elements packed into a single antenna panel.

Massive MIMO can simultaneously give better data speeds to multiple user devices because of the sheer number of antenna elements and the ability to accommodate multiple users. In order to increase data speeds while preserving signal quality, MIMO systems in 4G LTE and 5G NR networks employ both spatial multiplexing and spatial diversity. By transmitting different versions or copies of the same signal over many antennas, the spatial diversity technique used in MIMO enables users to combat the harmful effects of multipath signal fading. By broadcasting and receiving several data streams across distinct spatially-separated antennas, spatial multiplexing, on the other hand, increases the achievable data rates for end users.

1.4.8 Importance of channel in wireless communication

A channel is a type of conduit or medium that is used to convey data or an information signal from one transmitter or receiver to another. In wireless communication, the channel is crucial because it has the potential to deteriorate the information signal by introducing multipath fading and Doppler effects. (If channel is mobile) A crucial requirement for designing a wireless communication system is accurate channel knowledge. a path for communication that connects to a multiplexing or physical transmission medium, such as a radio channel or a physical transmission medium like a cable.

An information signal is transmitted across a channel from one or more senders to one or more receivers. A channel's ability to transfer data is often determined by its bandwidth in Hz or its data rate in bits per second.

Wireless networks cannot be used widely since bandwidth is a finite resource utilized by several organizations. Path loss, interference, obstruction, and other transmission barriers can all affect wireless channels. These variables limit the wireless transmission's range and dependability. The mobility of the transmitter and receiver as well as the environment can have an impact on how much these factors affect broadcast.

CHAPTER 2

LITERATURE SURVEY

In high mobility and low mobility scenarios, the Fifth Generation (5G) specifications call for data rates of 1 Gbps and 10 Gbps, respectively, as well as spectral efficiency of 15–30 bps/Hz and a reduction in latency of less than 1 millisecond (ms). One of the 5G standard's potential technologies that offers a significant increase in spectral efficiency is massive multiple-input and multiple-output (Massive MIMO). The primary focus of this work is the uplink scenario spectral efficiency in a Massive MIMO simulation network based on the long-term evolution (LTE) document of 5G.Through the use of a 5G Massive MIMO network simulation, this paper investigates the spectral efficiency metric. The study then determined the key constraint factors, including the number of user antennas (K), the number of base station antennas (M), transmission power (P), channel bandwidth (B), and coherence (C).

Researchers Jehangir Arshad, Abdul Rehman, Ateeq Ur Rehman, and Rehmat Ullah looked at a huge The area throughput of the system is ultimately improved by the MIMO system's ability to increase SE in each cell.Since area throughput is a function of the average cell density (D), the available bandwidth (B), and the SE, we are seeking to discover suitable values for these factors to maximise area throughput. Similar to this, a In order to attain a higher transmit power and antenna array gain, the SE augmentation model was developed. Along with incident angles of intended and interfering users, the proposed model takes into account inter-user interference from surrounding cells. Furthermore, simulation results show that the proposed model may be implemented in real-time scenarios, with maximum SEs of 12.79 bits/s/Hz for LoS scenarios and 12.69 bits/s/Hz for NLoS scenarios, respectively. The indicated results further support the SE augmentation since, when using the Uniform Linear Array (ULA) architecture, the SE augmentation is a linear function of transmit power and array gain.The research's findings guarantee effective information transmission in networks of the future.

When using 28 GHz frequency bands for downlink wideband MIMO transmission, Pooja Nuti, Elyes Balti, and Brian L. Evans looked into the co-design of multielement RIS phase shifts and per-subcarrier power allocation matrices. They made three contributions to the development of RIS-aided links: (1) Pathloss and blockage modeling,as well as the construction of a uniform rectangular array (URA), are used to improve system modelling. The gradient ascent co-design algorithm is designed, as well as the suggested algorithm's asymptotic (Big O) complexity analysis and runtime complexity assessment.

Aymen Omri1, Mazen O. Hasna1, and Mohammed Nafie introduced a new metric, effective area spectral efficiency, to measure the spectral efficiency as well as the spatial characteristics of point-to-point transmission systems and decode and forward (DF) relaying communications networks with interference management. (EASE). For each transmission method, we obtain a closed-form expression for the maximum transmission range in a Rayleigh fading environment. Using the maximum transmission range, we define and calculate the average impacted area and the average ergodic capacity. We next introduce the EASE equation to quantify the spatial spectrum utilisation efficiency. The source relay communication index, a freshly developed DF relaying measurement, serves as the foundation for the EASE metric. (SRCndx).SRCndx provides information on the necessity of using relaying communications and is used to assess the feasibility of communication between a source and a relay for specified transmission parameters in a given setting.We demonstrate the EASE metric's ability to offer a fresh viewpoint on the design of wireless transmissions, particularly the process of choosing the transmission power, using mathematical analysis and numerical examples.

In a Time Division Duplex (TDD) architecture, Ali M. A. and E.A. Jasmin examined various approaches to improving the spectral efficiency (SE) of a huge MIMO. Through simulation, the system's performance is assessed under a variety of real-world restrictions and settings, including a constrained coherence block length, a large number of base station (BS) antennas, and a high number of active users. Zero forcing (ZF) and maximum ratio combing are two more linear precoding techniques that are used to compare the SE performance. (MRC). According to simulation studies, a huge MIMO with hundreds of BS antennas can easily achieve very high spectral efficiency increases.

The authors concentrate on increasing the spectrum efficiency by applying several meta-heuristic optimisation algorithms, such as convex optimisation solver, White shark optimisation (WSO), and particle swarm optimization, to these constraint parameters. (PSO). In general, the results indicate a 1–10% improvement in the parameter as compared to other study publications. The greatest value attained is 49.84 bps/Hz, which is three times higher, according to the 3GPP and International Telecommunication Union (ITU) release document. One crucial performance metric for wireless communication systems is spectral efficiency estimation. However, the Rayleigh channel multipath fading model and Massive MIMO need to be taken into account while formulating the mathematical functions for spectral efficiency.

This study makes use of the exhaustive work done by Bjornson et al., who supplied the mathematical analysis of the Massive MIMO network. There are various methods of receiver combining, such as minimum mean square error (MMSE), zero-forcing (ZF), regularised ZF (RZF), and maximal ratio combining. (MRC). In this instance, the simulation network just uses the multi cell MMSE (M-MMSE) equations as they are from the literature. This study examined various methods for enhancing spectral efficiency, which were not previously addressed in research articles. Inter- and intra-cell interference, the number of base station antennas, and receiver combining techniques are the key optimisation constraints in a conventional Massive MIMO network. However, the data presented in this article provides a greater understanding of other factors, such as the base station antennas, transmission power, user count, and pilot time interval. This optimisation was put through a convex optimisation solver to yield the highest spectral efficiency result from the research publications that have been published thus far.

Through the use of meta-heuristic optimisation procedures that significantly affect spectral efficiency with the identification the author's contribution to this study mainly focuses on high impact characteristics that are responsible for this quantum increase. In order to understand how B, Tau_C, and P affected the advancement of the spectral efficiency parameter, nature-inspired WSO and PSO were also employed to achieve this. Tu is the uplink data time and Tc is the coherence time when a flat fading Rayleigh multipath fading channel is taken into account. In the equation, Tu=Tc-Tp-Td, where Td stands for downlink data and Tp for pilot time. The goal is to cut down on pilot time Tp if uplink data time Tu is taken into account. This is the rationale behind why the constraint parameter for increasing spectral efficiency is optimal pilot time.

In order to increase the spectrum efficiency parameter, Finding and analysing high impact parameters that affect spectral efficiency is the author's contribution to this research. This is done by using optimisation techniques such convex optimisation solver, WSO, and PSO metaheuristic algorithms. In order to raise the total wireless connectivity parameters—such as data throughput, received signal quality, latency, and interference—spectral efficiency must be maximised. This study demonstrates that the convex optimizer solver can achieve spectrum efficiency of 49.84 bps/Z, It is roughly three times the spectral efficiency criterion outlined in the 5G LTE release document by the 3GPP consortium, IMT-2020, and ITU.

When evaluating huge MIMO networks, spectral efficiency (SE) is a crucial metric. The goal of this study is to improve huge MIMO networks without cells in terms of SE and power control. Both uplink and downlink transmission are covered in the study.The writers' main interests were in studying the spectrum resource and making the most use of its bands.They researched current spectrum sharing (SS) technologies for the advancement of 5G. Additionally, a thorough analysis of cognitive radio technology in SS linked to 5G was conducted.

The authors suggested a brand-new analytical approach for evaluating the performance of huge MIMO networks without green cells. Numerical data show that using the proposed analytical framework in cell-free massive MIMO networks significantly increases spectral efficiency. The authors looked at a hybrid time-division duplex massive MIMO system that uses beamforming technology. The performance of a huge MIMO deployment scenario based on time division duplex was assessed by the authors in one of the Turkish commercial sites. A huge MIMO system based on time-division duplex has higher throughput and SE than a

MIMO deployment based on frequency division duplex. The authors suggested a low-complexity, dictionary-constrained hybrid precoding and combining approach for millimetre-wave massive MIMO systems. For the SE maximisation problem, the suggested approach takes into account a decoupled optimisation strategy between the RF and baseband domains.

The real-time array calibration (ERAC) technique was suggested by the authors. Fast-moving cars were successfully positioned accurately. The tested receiver's ERAC technique performance is better than that of the conventional single point positioning receiver when dealing with multipath interference. In order for MIMO communication systems to guarantee the delivery of confidential and secure information, the authors suggested a novel practical technique called the spatial spectrum method that could efficiently detect and locate the eavesdropper. The speed of multi-cell large MIMO systems is slowed down by pilot contamination (PC).

To minimise the effects of PC in huge MIMO systems and increase system spectral efficiency, the authors suggested a combination pilot allocation and pilot sequences optimisation technique. Both SE and EE power regulation are optimised for cell-free massive MIMO networks in this paper. Both uplink and downlink transmission are considered in the study. By reducing the symbol error rate, the authors jointly optimise the precoder and RIS phase shifts. In this article, the authors suggest using an alternating optimisation (AO) method to adjust the power distribution matrix and RIS phase shifts in both narrowband and wideband MIMO systems. A MIMO-OFDM system's channels can be estimated by the authors first present a workable transmission protocol. They next suggest an AO method to optimise the RIS phase shifts and power distribution matrix. In order to address the issue of mutual coupling in a SISO-OFDM environment, The authors recommend a straightforward method for channel estimate and RIS setup that incorporates binary RIS phase shifts and reflection amplitudes that are realistic.

The authors of this article demonstrate how spatial-frequency water falling outperforms one-dimensional water filling in both the frequency and spatial domains when frequency-selective MIMO systems are used and CSI is available at the transmitter. In this study, To increase SE in each cell, which improves the system's area throughput, we considered a large MIMO system. Since area throughput is a function of the average cell density (D), the available bandwidth (B), and the SE, we are seeking to discover suitable values for these factors to maximise area throughput. Along with incident angles of intended and interfering users, the proposed model takes into account inter-user interference from surrounding cells. By attaining maximum SE of 12.79 bits per second per Hz for line of sight (LOS) situations and 12.69 bits per second per Hz for non-line of sight (NLOS) scenarios, respectively, simulation results further demonstrate the proposed model's suitability for real-time settings.

The authors have developed a novel technique to improve the bit-error-rate (BER) performance of iterative detection and decoding (IDD) schemes using Low-Density Parity Check (LDPC) codes. Recent times have seen the deployment of a novel family of protograph LDPC codes also known as Root-Protograph (RPLDPC) codes. Due to their quasi-cyclic nature, the given codes can achieve high speed encoding and decoding. In Block-Fading (BF) setups, it can also attain performance that is close to the outage limit. The authors' single cell scenario, which ignores the interference from other cells, results in a maximum attainable value of approximately 8.5 bits/s/Hz. Comparing the proposed SE augmentation method to existing work, there is an increase of about 25%. In order to demonstrate how and why massive MIMO technology is a more effective way to handle increased data traffic than current wireless technology, this article examines the technology. The major goal of this study is to select appropriate B, D, and SE values in order to increase area throughput at 1000x.

Area Throughput = D*B*SE Bits/s/km2 = Hz. cells/km2.bit/s/Hz/cell (2.1)

In upcoming mobile networks, SE optimisation is the technique for area throughput optimisation. It is mostly important for BSs that cannot rely on network densification and do not utilise the mm-Wave spectrum. Our understanding is that the research papers that have been published so far on 5G Massive MIMO simulation networks benchmark this spectral efficiency as the greatest value attained. Now, this simulator moves through the MRC, P-ZF, ZF, and R-ZF to see if an improved outcome is possible. Variations in transmission power P, the number of base station antennas M, and the number of user antennas K are made according to the pilot reuse factor. (beta). The typical quantity of data per complex-valued sample that an encoding/decoding system may reliably transmit over the targeted channel is known as SE. As is clear from this definition, the SE is a deterministic number that can be represented in terms of bits per complex-valued sample.

Since there are B samples per second, a bit per second per Hertz, or bit/s Hz, is a unit identical to the SE. The SE, which will be defined below, can be thought of as the average number of bits/Hz over the realisations of fading channels, which change over time. The SE of a channel between a UE and a BS, also known as the SE of the UE, is frequently taken into consideration in this monograph. The information rate [bits], which is determined by dividing the SE by the bandwidth B, is a related statistic. Additionally, we frequently take into account the aggregate SE of the channels from all of the UEs in a cell to the corresponding BS, which is expressed in bits/Hz/cell. A cell's SE can be increased by increasing transmit power, adding BS antennas, or servicing more UEs per cell.

Any of these techniques, whether used directly (by increasing transmit power) or inadvertently, effectively increase the PC of the network. (by utilising more hardware). The network offers connection over a specific area and transfers data to and from UEs. The ability to access the network from any location at any time is included in the price that users pay in addition to the delivered bit rate. A cellular network's performance can be evaluated in a number of different ways, each of which influences the metrics in a unique way, making it more difficult to grade than it might initially appear. One of the most widely used definitions of the SE of a cellular network, which borrows from the definition of SE, states that "the SE of a wireless communication system is the number of bits that can be reliably transmitted per complex-valued."

The SE can also be described as "total information transferred in a second using a bandwidth of one hertz (Hz)". The use of bandwidth and BSs that are strategically arranged utilising innovative multiplexing and modulation techniques equates to SE optimisation. The physical layer's role in enhancing SE is crucially influenced by modulation and channel coding. In essence, higher SE can be obtained by using a low-code rate with high SNR and a higher-order modulation approach. Another aspect of SE augmentation in large MIMO systems and antenna array components is mutual coupling. As mutual coupling rises, the system's efficiency has a negative impact on the antenna properties. The SE rises with increased SNR (or transmit power), but the beneficial impact moves the system into an interference-limited zone, where the SE falls.

This study examines the non-convex problem of joint data and pilot power optimisation for optimum sum spectral efficiency (SE) in multi-cell Massive MIMO systems. In order to find a stationary point in polynomial time, we first suggest a new optimisation procedure that is motivated by the weighted minimal mean square error (MMSE) approach. Green communication metrics are a major barrier to high data rate transmission in Wireless Sensor Networks. (WSNs). Therefore, one intriguing design criterion for such systems is a single measure that guarantees a successful balance between the energy efficiency (EE) and the spectrum efficiency (SE). This research focuses on EE-SE trade-off optimisation in Wireless Underground Sensor Networks (WUSNs), where node power supply is crucial and signals must pass through a difficult lossy soil medium. We propose to apply the Salp Swarm method, a powerful new metaheuristic optimisation method, to optimise the source and relay powers needed for each packet transmission. (SSA). As a result, the ideal source and relay transmission powers are discovered, which maximise the EE-SE trade-off under the restrictions of the maximum permitted transmission powers and the beginning battery capacity.

Three WUSN channels' features are described in detail by the authors:

(1) Passage from underground to underground (UG2UG),

(2) Conduit connecting the ground and the air (UG2AG) and

(3) Conduit connecting the surface to the ground (AG2UG).

Additionally, authors in WUSNs, which harvest RF energy from an aboveground access point for subsurface sensors, attempt to maximise throughput. These studies encourage us to investigate the trade-off EE-SE optimisation in WUSNs in order to improve resource allocation and increase the lifespan of these networks.

The Gravitational Search Algorithm (GSA) is used to increase the energy efficiency of WSNs. In, writers use a novel version of GSA to calculate the ideal cluster size and identify the best cluster leaders to maximise effective energy usage.

CHAPTER 3

SPECTRAL EFFICIENCY AND OPTIMIZATION

The information rate that can be transferred over a specific bandwidth in a particular communication system is known as spectrum efficiency, spectrum efficiency, or bandwidth efficiency. It evaluates how successfully a finite frequency spectrum is used by the physical layer protocol and, occasionally, the media access control. (the channel access protocol).

3.1 Importance of Spectral Efficiency

Spectral efficiency is a concept that is frequently brought up when discussing radio communications. When contrasting two wireless systems, having an understanding of it is useful. For instance, you might compare two systems that each consume 80 MHz of spectrum, but the quantity of useful data that each system can convey may differ significantly. One explanation for the discrepancy could be because different technologies operate more or less efficiently than one another.

The term "spectral efficiency" refers to the quantity of data that can be delivered over a specific bandwidth. It can be applied to evaluate how well two different systems use the same frequency. This is significant given that spectrum is frequently restrictive;Only a limited number of frequencies are accessible for broadcast. Therefore, throughput can be enhanced by utilising the spectrum in a way that maximises the capacity or throughput available. The unit of measurement for spectral efficiency is bits per second per hertz (bps/Hz).

A straightforward formula is used to determine spectral efficiency:

Spectral efficiency = (Capacity in bps) / (bandwidth in KHZ) (3.1)

As an example, the computation in Tarana G1 for a single sector (Base Node) would seem as follows:

30 bps/Hz = (2400 Gbps) / (80 MHz)

One of the numerous benefits of G1 is its extremely high spectral efficiency, which is 30 bps/Hz. Even the most ground-breaking technology will be less helpful without excellent spectral efficiency.

Of course, there are alternatives to G1. Let's examine a Wi-Fi setup as a contrast. We'll utilise an 802.11ac 22:2 MIMO setup for our example. The maximum PHY data rate with an 80 MHz-wide channel is 867 Mbps.

10.8 bps/Hz = (867 Mbps) / (80 MHz)

This indicates that G1 has a data transmission efficiency that is around three times that of Wi-Fi. If you are an operator who profits from each unique piece of information supplied, this is a big game changer.one analogy for spectral efficiency is that of cars. Even if the engines in two of your automobiles are the same, one of them may be tuned much better than the other. The slower (lower horsepower) car can be distinguished from the faster one using horsepower. Similar ideas can be applied to spectral efficiency. Information can be transferred using any communications technology, although some are significantly faster and better at it. This is why spectral efficiency is a crucial factor in determining how well wireless radios work. The entire subscriber experience, throughput, and speeds might be impacted by every duplicate transfer or reduced data rate. Retransmissions, which can result in excessive delays and jitter, are particularly dangerous for applications like online gaming or video conferencing.

Interference is another factor that can cause spectral efficiency to vary between various solutions. Transmissions are jumbled by interference, which necessitates retransmission of the same data. The amount of interference may require repeated transmissions of the same data before it is effectively delivered. As a result, a link's total capacity declines as more time is spent transmitting fewer bits of information.

G1's spectral efficiency is so excellent because of the way it manages many factors that can impair performance, like interference. Asynchronous burst interference cancellation (ABIC), one of the technologies we've previously discussed, is made to cancel out interference even when the payload is being transmitted. As a result, subscribers will receive a crisp, clear signal with little jitter and latency.

3.2 System spectral efficiency or area spectral efficiency

Digital wireless networks' system spectrum efficiency or area spectral efficiency is typically represented as (bit/s)/Hz per square metre, (bit/s)/Hz per cell, or (bit/s)/Hz per site. It measures the number of concurrent users or services that can be offered within a specific geographic radio frequency range. For instance, it might be defined as the maximum aggregated throughput (or goodput), which is the total number of system users divided by the channel bandwidth, the covered region, or the number of base station sites.The utilisation of multiple access strategies, radio resource management approaches, and single-user transmission techniques all have an impact on this measure. The management of dynamic radio resources can significantly enhance it. If it is defined as a measure of the greatest goodput, retransmissions brought on by co-channel interference and collisions are excluded. The higher-layer protocol overhead and media access control sublayer are often ignored. The system spectral efficiency of a cellular network can alternatively be expressed in terms of the maximum number of simultaneous phone calls per area unit over a 1 MHz frequency spectrum, as measured in E/MHz per cell, E/MHz per sector, E/MHz per site, or (E/MHz)/m2.The source coding (data compression) strategy has an impact on this measure as well. It can also be applied to analogue cellular networks. Poor system spectral efficiency does not always equate to an ineffective encoding technique when measured in (bit/s)/Hz for the link. Consider CDMA spread spectrum, which is not a particularly spectral-efficient encoding method when considering a single channel or single user. However, due to the ability to "layer" numerous channels on the same frequency band, the overall spectrum utilisation for a multi-channel CDMA system can be fairly high. Optimal fixed or dynamic channel allocation, power control, link flexibility, and diversity schemes are just a few examples of radio resource management techniques that can boost spectral efficiency. Justice and system spectral efficiency are both gauged by the fairly shared spectral efficiency.

3.3 The Three Factors of Superior Spectral Efficiency

According to Figure 1, three transmission parameters affect spectral efficiency: the number of raw bits per symbol, overhead efficiency, and the amount of spectrum "wasted" because of the necessary intervals between wavelengths. In the subsequent blog, I'll go into more detail about these three elements, highlighting the optical engine and line system characteristics that permit higher spectrum efficiency, before briefly describing how Shannon's law is beginning to constrain spectral efficiency advancements.

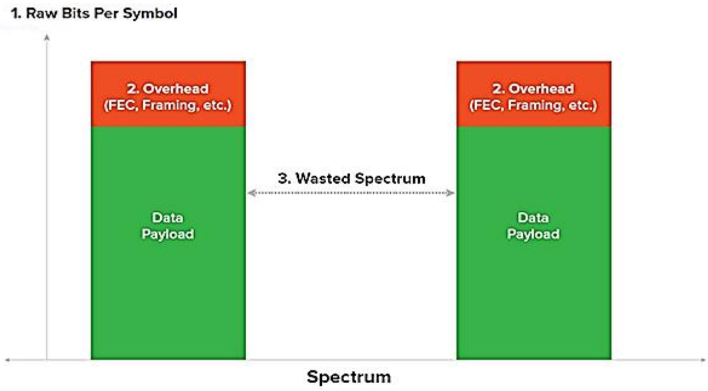

Fig 3.1: The three factors that determine spectral efficiency

Factor 1: More Raw Bits per Symbol

Getting additional bits per symbol for a specific set of reach conditions is the first element that permits greater spectral efficiency. This boils down to higher-order modulation at closer ranges. Advanced optical engine features include Nyquist subcarriers, a high modem signal-to-noise ratio, and long-codeword probabilistic constellation shaping (LC-PCS) enable more bits per symbol for a particular range of reach conditions. (SNR). By combining LC-PCS and Nyquist subcarriers, dynamic bandwidth allocation (DBA) increases the overall amount of bits per symbol for the wavelength by enabling additional bits per symbol on the inner subcarriers. Two wavelengths can share FEC gain using SD-FEC gain sharing, increasing the number of raw bits per symbol on the second, more challenging wavelength. For a specific set of reach circumstances, effective forward error correction (FEC) can also increase the number of bits per symbol.

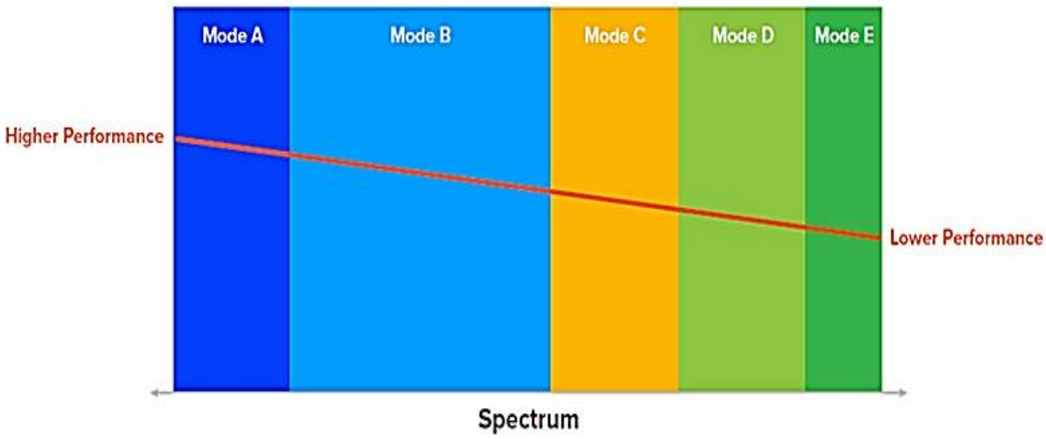

Fig 3.2: Multiple modes required to optimize for each part of the spectrum in a submarine fibre

Superior spectral efficiency can also be achieved with high degrees of optical engine programmability in terms of baud rate and modulation (bits per symbol), particularly on undersea fibres where performance changes with tilt, ripple, dispersion, and nonlinearities, as shown in Figure 2. For instance, there are now more than 200 baud rate and modulation bit combinations supported by the ICE6-powered CHM6 transponder for the GX G42 Compact Modular Platform. The need to align to practical bandwidth increments (such as 50 Gb/s or 100 Gb/s) makes the combination of modulation and baud rate programmability particularly advantageous, even though in principle PCS alone can theoretically give the requisite performance granularity.

A super-Gaussian PCS distribution, which results in less volatility in the power levels of the symbols and thus smaller nonlinear impairments, is another element that can maximise spectral efficiency in subsea networks. For dispersion-uncompensated large-effective-area fibres that frequently run at high power levels, super-Gaussian is hence ideal. Specialized 4D and 8D multi-dimensional modulation formats can be crucial for increasing spectral efficiency for vintage dispersion-managed subsea cables.

Super-Gaussian PCS distribution, which leads in less volatility in the power levels of the symbols and, thus, reduced nonlinear impairments, is another element that can enhance spectral efficiency in subsea networks. Since dispersion-uncompensated large-effective-area fibres frequently run at high power levels, super-Gaussian is the optimal distribution for these fibres. Sophisticated 4D and 8D multi-dimensional modulation schemes can be essential for increasing spectral efficiency for vintage dispersion-managed subsea cables.

Factor 2: Higher Overhead Efficiency

Higher overhead efficiency, which quantifies the percentage of raw bits used for data payload compared to overhead for a given number of symbols broadcast, is the second factor that increases spectral efficiency. One feature necessary for great overhead efficiency is effective FEC with a high net coding gain. The Ethernet framing mode of ICE6 is another illustration of how overhead efficiency can be increased. It has lower framing overhead for Ethernet client traffic than OTN framing modes that can accommodate both Ethernet and OTN type clients. With PCS-64QAM actually sending 12 bits per symbol and the distribution matcher's bits-to-symbols mapping functioning as overhead, probabilistic constellation shaping is likewise a type of overhead. Optimal balance of FEC and PCS overhead and gain is one future approach for overhead optimization.

Factor 3: Minimized Spectral Waste

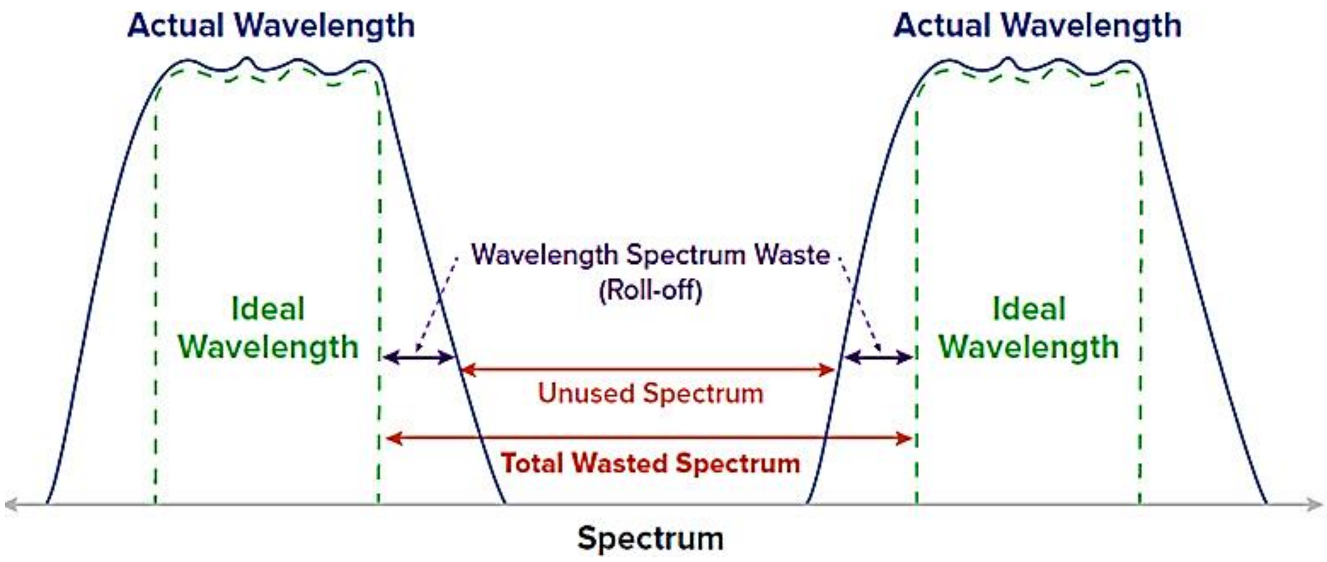

Fig 3.3: Wasted spectrum

The ability to pack wavelengths closely together, or to put it another way, limiting the spectrum that is wasted between wavelengths, as illustrated in Figure 3, is the third component that contributes to higher spectral efficiency. Having a single high-baud-rate wavelength rather than several low-baud-rate wavelengths occupying the same spectrum, which necessitates an inter-wavelength gap between each wavelength, is one technique to lessen the wasted spectrum. Using super-channels, which group numerous different wavelengths into a single block of spectrum, is another method for reducing waste. As seen on the right of Figure 4, another method is to produce wavelengths with a sharper roll-off or a squarer frequency-domain shape. By allowing wavelengths to be crammed closer together, a sharper roll-off lowers spectrum waste. A shared wave locker is the final optical engine feature that can help reduce spectral waste. By allowing the lasers of two or more wavelengths to drift together, for instance in response to temperature changes, less guard band is needed to support uncorrelated frequency shifts.

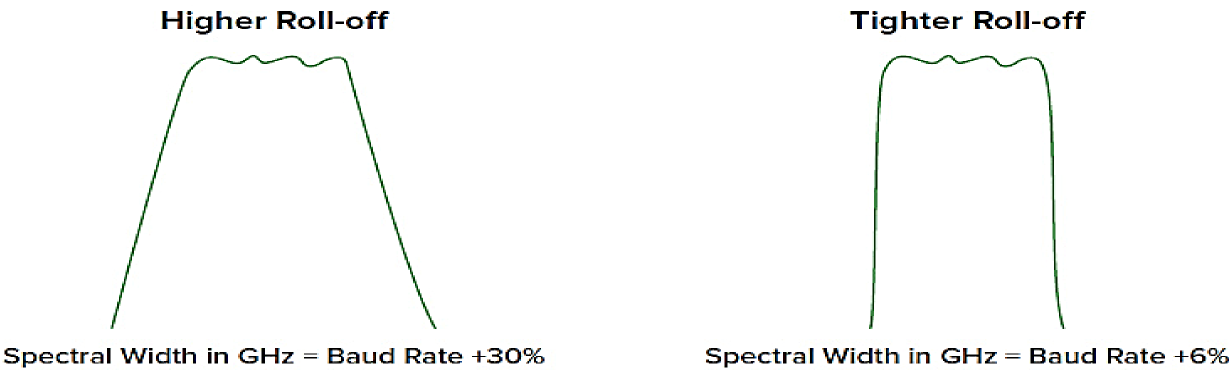

Fig 3.4: Tighter roll-off enables closer wavelength packing

Together with these optical engine characteristics, reducing spectral waste also calls for flexible-grid ROADMs with fine-grained control over each channel's width and centre frequency.

3.4 Spectral Efficiency Limitations

Shannon, a mathematician, electrical engineer, and information theorist who was employed at Bell Labs at the time, created what is now known as Shannon's law, also known as the Shannon-Hartley theorem, in a 1948 paper. This law/theorem limits the amount of data that can be transmitted via a channel with a particular bandwidth and noise level. Modern high-performance embedded optical engines, like Infinera's ICE6, are typically 1 to 2 dB from the Shannon limit, implying that any spectral efficiency improvements in the future are probably going to be small.

Papers mentioning the "nonlinear Shannon limit," which offers a lower limitation based on nonlinear penalties and is obtained through simulations, are occasionally included in the proceedings of optical conferences. The (linear) Shannon limit and the genuine, as of yet unidentified, upper limit, which would be a function of both linear and nonlinear penalties, cannot be beaten by new nonlinear mitigation approaches.

In conclusion, improving spectral efficiency necessitates both advances in optical engines and line systems that can reduce spectral waste and increase the number of bits per symbol. Other capacity-boosting techniques, such as adding new spectrum bands to existing fibres and space-division multiplexing (SDM), which can be accomplished with more fibres per subsea cable or new multi-core or multi-mode fibres in terrestrial networks, are likely to become more important. This is because modern optical engines are getting close to the (linear) Shannon limit for spectral efficiency.

Achievable uplink Spectral Efficiency

Uplink and downlink are parts of a complete link because it consists of two earth stations and a satellite. Communication from a satellite to the ground is referred to as downlink, and communication from the ground to a satellite is referred to as uplink. The communication is referred to as two-way when an uplink is received by the spacecraft at the same time that a downlink is received by Earth. Upload refers to communication that simply involves an uplink. One-way communication is defined as communication that only occurs downlink.

The received UL signal $\mathbf{y}_j \in \mathbb{C}^M$ at BS j in a frame is modelled,

$$yj = \sum_{k=1}^{K} \sum_{l} \sqrt{plk} * hjlk * xlk + nj \tag{3.2}$$

Where p_{lk}=UL transmit power

h_{jlk}=channel response between BS and UE

x_{lk}=symbol transmitted by UE

n_j=additive noise

When codewords cover both the Rayleigh fading and random locations of the interfering UEs, we are able to calculate the feasible SE for any UE.

We assume the pilot reuse factor, indicated by the integer β = B/K, to be an integer for the sake of notational simplicity. The cells in L are divided into one disjoint subset in order to use the same K pilot sequences inside a set while utilising different pilots in different sets. Non-universal pilot reuse means exactly what we say it does. As a lower bound on the ergodic capacity, which is unknown for general multi-cell networks, the ergodic attainable SE for any UE in cell j is used. Similar bounds are discovered as a result of the bounding approach's interaction with Rayleigh fading, which leads its predictions to fall inside the logarithm while the user positions are averaged at the outside. To calculate these expectations, we must first characterise the receive combining. Passive and active interference rejection are both used in massive MIMO combining techniques.

3.5 Optimizing SE for Different Interference Levels

We simulate the spectral efficiency in each given hexagonal grid cell while accounting for any non-negligible interference. However, they must be at least 0.14r away from the serving Base stations for the User Equipment's (UEs) to be located anywhere in the cells (this makes the analysis independent of r).Because the Spectral Efficiency (SE) equations for the Uplink and Downlink are identical, with the exception of the fractions (ul) and (dl), we compute the sum of these spectral efficiencies and note that it can be freely distributed between the Uplink (ul) and Downlink (dl).

Both directions employ the same linear processing strategies. The simulations take into account MR, ZF, P-ZF, and RZF combining, and all outcomes are calculated using closed-form formulas for various parameter configurations. Using Matlab, the simulations were carried out.

3.5.1 Zero Forcing (ZF):

A multiple antenna transmitter in a multi-user Massive MIMO system is able to totally reduce multi-user interference thanks to the zero forcing (ZF) method of spatial signal processing.

Zero Forcing (also known as "null steering") is a spatial signal processing method that allows a multiple antenna transmitter to completely eliminate multi-user interference in a multi-user Massive MIMO system.

$$SE\_ZF\ (n, k, j, m) = k*(1-B/S\ (m))*\log2\ (1+SINR\_ZF) \qquad (3.3)$$

Where;

k=scheduled users

B=pilot length

m=array of antennas

3.5.2 Maximal Ratio Combining (MRC):

As part of a transmit beamforming technique, MR transmission employs multiple antennas for both transmission and reception. Wireless communication systems use the MRC technique, also known as maximum ratio combining, to boost a signal's signal-to-noise ratio (SNR). It combines multiple received signals from various antennas with different phases and amplitudes in order to enhance the quality of the signal received. By merging the signals that are received from numerous antennas, MRC maximizes the ratio of the power of the received signal to the power of the noise. Combining the weighted average of the received signals into a single output signal. The weights are chosen to improve the signal-to-noise ratio.

The value of MRC resides in its capacity to reduce multipath interference and fading effects that occur in wireless communication channels. Signal attenuation, phase shifting, and time delays brought on by fading and multipath interference can lead to signal distortion, worse signal quality, and greater error rates.

MRC can improve the efficiency and dependability of wireless communication systems by reducing the effects of fading and interference, raising the SNR, and boosting signal strength. It is widely used in modern wireless communication systems, such as cellular networks, satellite communications, and wireless local area networks. (WLANs).

$$SE\_MR\ (n, k, j, m) = k*(1-B/S\ (m))*\log2\ (1+SINR\_MR) \qquad (3.4)$$

3.5.3 Regularized Zero-Forcing (RZF):

An efficient linear precoding method for single-cell communication networks is RZF. The improved version of a zero forcing detector is called regularised zero forcing. The ZF approach limits the useable signal by sending beams with some deviation rather than directly to the users. The next change corrects the beams, enables some user-to-user interference, and dramatically boosts payload. It makes sense that the suggested precoding strategy would maximise signal power and avoid reported inter-user interference.

Using regularised Zero-Forcing (RZF) precoding, whose regularisation parameter $\lambda > 0$ depends on noise level and average path-losses, one might lessen the drawbacks of these methods. For each antenna number, M, we maximise the spectral efficiency in respect to the K number of User Equipments (UEs) and the pilot reuse factor (which defines B =β K).

In wireless communication systems, regularised zero-forcing (RZF), a linear precoding technique, is used to reduce the impact of interference between various communication channels. It entails multiplying the data to be broadcast by a matrix that accounts for the system's noise and channel response. The zero-forcing (ZF) method is improved by RZF by include a regularisation term, which aids in stabilising system performance. The transmitted data is multiplied by the inverse of the channel matrix in traditional zero-forcing (ZF). This approach, however, can amplify system noise, which might impair overall performance. RZF, on the other hand, employs a regularisation term to balance the trade-off between noise amplification and interference cancellation. The regularisation process enhances.

RZF's significance originates from its capacity to deliver improved performance in wireless communication systems. By lowering interference and raising channel capacity, RZF can contribute to the system's spectral efficiency. Additionally, it can adapt to various transmission conditions and is more resilient to changes in the channel. Cellular networks, wireless local area networks, and satellite communication systems have all made extensive use of RZF.

SE_RZF (n, k, j, m) =k*(1-B/S (m))*log2 (1+SINR_RZF) (3.5)

3.5.4 Pilot Zero-Forcing (PZF):

Pilot zero forcing (PZF) is a technique used in wireless communication systems to lessen the effects of channel interference and improve the quality of the received signal. The method entails estimating the channel response using a known pilot signal, and then processing the received signal through an equaliser to eliminate interference and retrieve the broadcast signal. The equaliser coefficients used in PZF are selected to make the received signal at the pilot sites equal to zero. As a result, the interference at those points is essentially eliminated, and the channel response may be estimated more precisely. The equaliser can be used to eliminate interference at all other sites after the channel has been estimated, enhancing the received signal's overall quality.

PZF is crucial in multi-antenna systems because interference from several antennas can be significant in these systems. The interference can be significantly minimised by using a known pilot signal and applying PZF, leading to better system performance and higher data rates. Overall, pilot zero forcing is a useful method for reducing interference and enhancing wireless signal quality, especially in multi-antenna systems.

$$SE\_PZF (n, k, j, m) = k*(1-B/S (m))*\log2 (1+SINR\_PZF) \qquad (3.6)$$

Considerations:

We used S = 400 for the coherence block length. (e.g., 2ms coherence time and 200 kHz coherence bandwidth). Set the pathloss exponent to k= 3.7 and the SNR to $\rho/\sigma 2$ = 5 dB.

We take into account three intercellular interference situations, each with a different level of severity:

1) Average case: averaging across constant UE positions throughout all cells.

2) Best case: At the cell edge that is farthest from BS j, all UEs in the other cells are. (for each j).

3) Worst case: The cell edge nearest to BS j is where all UEs in the other cells are. (for each j).

By using 106 UE positions in each cell during Monte-Carlo simulations, the parameters' corresponding values were calculated. Because the optimal UE locations in the interfering cells vary depending on which cell they are in, the best-case scenario is unduly optimistic. It does, however, provide a ceiling on what may be accomplished by cell-level coordination of scheduling. The worst-case scenario is unduly gloomy since no one UE can be simultaneously located in a place that is the worst in relation to all other cells. The average situation—where the averaging is brought about by UE mobility, scheduling, and random pilot sequence switching among the UEs in each cell—is arguably the most useful in real-world applications. The best and worst models have considerably varied attainable SEs (per cell).

Under the best case intercell interference, ZF achieves substantially higher SEs than MR because there is a significant potential advantage from mitigating intra-cell interference. In the best scenario, P-ZF is equivalent to ZF, but it performs better in the worst situation due to its ability to actively decrease intercellular interference. The optimised SEs for MR, ZF, and P-ZF in the realistic average scenario are rather similar, especially in the realistic range of $10 \leq M \leq 200$ antennas. The biggest disparities always show up when there are a lot of antennas. (notice the logarithmic M-scales). It was demonstrated that M = 105 is necessary to approach the asymptotic limit, and that many more antennas are needed in the best case of interference. It is obvious that the asymptotic bounds.

The fundamental distinction between MR, ZF, and P-ZF is not in the values of the optimised SE but in the method by which they are attained, i.e., the number of UEs K* and pilot reuse factor β. Because the channels get more orthogonal with M, the usual behaviour is that a larger M predicts a higher K*and a smaller. The reuse factor is an integer, thus when changes, K* does not change constantly; smaller permits greater K*, and vice versa. Compared to the other approaches, MR schedules the most UEs and changes to a lesser reuse factor at fewer antennas. P-ZF, on the other hand, favours large reuse factors and schedules the fewest UEs so that it can suppress more inter-cell interference.

$K = S/2\beta$ becomes the optimal number of UEs as $M \rightarrow \infty$.

$K^* \rightarrow 67$ in the average case (where $\beta = 3$)

$K^* \rightarrow 200$ in the best case (where $\beta = 1$)

$K^* \rightarrow 50$ in the worst case (where $\beta = 4$)

High per cell SEs are achieved by scheduling many UEs for simultaneous transmission.

P-ZF gives the highest performance per UE.

MR gives the lowest performance per UE.

MR schedules the large number of UEs.

P-ZF schedules smaller number of UEs.

ZF processing is often the best choice in terms of per cell SE as P-ZF is only needed in some special cases to suppress strong interference suppression.

We also study about M-MMSE and S-MMSE, M-MMSE stands for Multi-cell minimum mean squared error.

S-MMSE stands for single-cell minimum mean square error.

CHAPTER 4

Proposed method to optimize spectral efficiency

4.1 S-MMSE introduction

The single cell minimum mean squared error (MMSE) technique is used in wireless communication to reduce interference and enhance signal quality in a single cell of a cellular network. The MMSE is a linear filter that reduces the mean squared error between the signals that are being sent and received while accounting for channel noise and interference.

The receiver uses pilot signals to first estimate the channel coefficients between the transmitter and receiver before implementing the single cell MMSE. The received signal is then subjected to the MMSE filtering process to enhance its quality. The single cell MMSE method is extendable to multiple antennas, multiple cells, and many users, resulting in more advanced methods like multiuser detection and beamforming.

Single cell minimal mean squared error is referred to as S-MMSE. A single cell approach is used. This plan is employed to boost spectral efficiency gain. The S-MMSE detector only employs the K estimated channel directions from the serving cell. Directions from different cells are handled as random noise. The Minimum Mean Squared Error estimator has a specific definition.

If BS j only estimates the channels from its own UEs, the single-cell minimal mean-squared error (S-MMSE) combining strategy is what we obtain. The S-MMSE scheme and the M-MMSE scheme are equivalent when there is a single isolated cell. Its capacity to attenuate interference from interfering UEs in other cells is significantly worse and it is generally distinct from other UEs. Because a few strong interfering UEs from other cells may be placed close to the cell edge and produce interference on par with that of the intra-cell UEs, this could have a large detrimental impact.

The Single Cell Minimum Mean Square Error (SC-MMSE) is a technique used in communication systems for signal detection in a wireless communication channel. A signal is distorted as it is delivered across a wireless channel due to a variety of variables including noise, interference, and fading. The SC-MMSE approach is used to get rid of or lessen these distortions and improve the receiver's signal quality. Using a per-cell approach, the SC-MMSE technique treats each wireless network cell as a separate communication channel. To assess the channel properties and determine the best receiver filter coefficients for each cell, statistical approaches are used.

The value of SC-MMSE is found in its capacity to enhance wireless communication networks' overall system performance and signal-to-noise ratio (SNR). SC-MMSE offers more dependable and effective communication between devices by minimising the effects of noise and interference, which is crucial in many applications like mobile communications, wireless sensor networks, and the Internet of Things. (IoT).

Additionally, SC-MMSE is computationally effective, making it appropriate for application in real-world wireless systems that need real-time processing. In comparison to other detection methods, it also offers a reasonable balance between performance and complexity. Overall, the SC-MMSE technique is a crucial tool for communication engineers and researchers and helps to increase the dependability and effectiveness of wireless communication systems.

4.2 M-MMSE introduction

Multi-user multiple-input multiple-output (MU-MIMO) communication has seen a substantial increase in interest in recent years. By placing several users on the same time-frequency resource, multiple antennas can be used to focus signals on intended receivers, reduce interference, and ultimately increase system throughput.

An forthcoming 5G technique called massive MU-MIMO scales MU-MIMO up by orders of magnitude. The plan is to use a base station (BS) array with 100 or more antennas to simultaneously serve tens of customers in each cell. Since phase-coherent processing offers a comparable array gain, It is also possible to significantly reduce the broadcast power for both the uplink and the downlink. Matching filtering (MF), zero-forcing (ZF), and minimum mean square error (MMSE) processing are the most often utilised processing methods in uplink reception and downlink transmission. The BS ignores or only considers users in other cells based on their long-term statistics and only uses the instantaneous realisations of the channels to its own intra-cell users for creating the precoders/detectors. This is an important characteristic of these systems. Because of this, MF, ZF, and S-MMSE are categorised as single-cell schemes. Massive MIMO resolves the channel estimation issue by employing time-division duplex (TDD) mode and just uplink pilots for channel estimation. More antennas can be added without affecting the pilot overhead since the pilot overhead scales linearly with the number of users rather than the number of BS antennas.

M-MMSE reduces background noise and intracellular interference while boosting the necessary signal. In comparison to traditional single-cell designs, it offers substantial Spectral Efficiency increases. The most popular processing techniques used in uplink reception and downlink transmission are matched filtering (MF), zero-forcing (ZF), and minimum mean square error (MMSE) processing. A larger β results in a better channel estimate, less pilot contamination, and an improvement in the system's spectral efficiency. A larger β also denotes more M-MMSE detector estimated channel directions that are accessible, allowing for greater inter-cell interference suppression. For the range of values taken into consideration, the possible sum SE rises with.

This is because a larger results in less pilot contamination, which helps to improve the accuracy of channel estimation and, as a result, increases the possible SE. Additionally, when designing the M-MMSE scheme, a larger provides more estimated channel directions, leading to a higher inter-cell interference suppression. At least for $\beta \leq 7$, the possible sum SE grows monotonically as increases. A multi-cell MMSE detector has the ability to actively reduce noise, some inter-cell interference, and intra-cell interference.

4.2.1 BENEFITS OF M-MMSE

During the uplink phase, the average effective channel gain between users and the BSs that are supplying it is constant. This is a simple but effective approach that avoids near-far blockage and, to some extent, guarantees a constant user experience in the uplink. To achieve the same downlink SE at each user as in the uplink, the transmit power is selected for downlink payload data transmission. In comparison to S-MMSE, our proposed M-MMSE consistently produces a higher sum SE.

As β and/or K rise, the benefit becomes more significant. For K=10 and K=30, respectively, the SEs of M-MMSE for β=3 and M=200 are 30% and 42% higher than those of S-MMSE. For K=10 and K=30, the advantages rise to 42% and 82%, respectively, for β=7 It promises incredibly promising sum SE gains over S-MMSE and other single-cell approaches by actively reducing both intra-cell and inter-cell interference. Our M-MMSE significantly outperforms the S-MMSE in terms of SE gain, and the advantage grows as β and K go up. The MMSE is more accurate and works with a variety of S/N ratio-expressed channel state circumstances. The M-MMSE detector outperforms S-MMSE because inter-cell channel estimations get better over time.

4.2.2 Uplink M-MMSE detector

We consider a synchronous, multi-cell massive MIMO cellular network. Each cell is given an index within the L-cell set, where |L| is the cardinality. The BS in each cell of each coherence block, which includes an antenna array with M antennas, serves K single-antenna clients. We will determine the best M-MMSE detector based on the estimates after calculating the uplink channel before broadcasting the uplink payload data. We use different symbols for the pilot and the payload data in order to enable different power control tactics. The uplink SINR has a generalised Rayleigh quotient as its form. To optimise this instantaneous SINR for a particular channel, a novel M-MMSE detector could be developed.

The S-MMSE detector only employs the K estimated channel directions from the serving cell and treats directions from other cells as uncorrelated noise, it is vital to note. While B > K, our M-MMSE detector actively suppresses some inter-cell interference since it uses all of the estimated directions for B that are currently known. Our detector can therefore effectively optimise the SINR, even while S-MMSE can only do so in single-cell settings. The M-MMSE technique might be seen of as a coordinated beamforming scheme, even though we underline that there is no signalling between the BSs because BS j can directly estimate the channels from the uplink pilots. Additionally, BS collaboration is not necessarily required because the uplink control channel can be used to receive the long-term channel statistics (such as the channel attenuation and the pilot allocation) of all users to each BS. Therefore, the M-MMSE method is totally scalable. Our M-MMSE detector is more versatile and comprehensive.

First off, our method enables any pilot reuse approach and power regulation, making it possible to conduct an analysis based on a more flexible and realistic network configuration. Non-universal pilot reuse in massive MIMO is a reliable technique for lowering pilot contamination and obtaining high spectral efficiency. Additionally, as will be demonstrated later, the MMMSE outperforms the S-MMSE by a significant margin when using larger pilot reuse factors. Additionally, the uplink detector is built on the erroneous premise that the BS knows the perfect CSI, whereas our detector takes into account faulty channel estimation. As a result, practical systems are capable of achieving the performance advantages afforded by our detector. Complex multiplications are necessary for the M-MMSE detectors in a cell to calculate. This is more effective than the S-MMSE detector, which is necessary after a K-dimensional matrix inversion. When K is modest or moderate, the complexity increase is not a serious worry because M >> K is usually assumed in large MIMO systems. This is especially true given how quickly computing efficiency of digital hardware is rising.

4.2.3 Downlink M-MMSE precoder

A novel multi-cell MMSE precoder is suggested to be used with massive MIMO systems. With k users per cell and B orthogonal pilot sequences available, a multi-cell network with B=βK and β≥1 as the network-wide pilot reuse factor is examined. Contrary to conventional single-cell precoding, which only employs the K intra-cell channel estimates, the proposed multi-cell MMSE precoder utilises all B channel directions that can be locally calculated at a base station. So that the transmission spatially suppresses both the intra- and inter-cell interference.

The uplink SEs can be reached in the downlink if the downlink transmit power is properly selected and each downlink precoder is a scaled counterpart of the accompanying uplink detector, according to a recent uplink-downlink duality for massive MIMO systems. The M-MMSE detector is the most sophisticated uplink technique, thus we employ the same technology for downlink precoding. The downlink M-MMSE precoder is constructed.The MMMSE precoder can minimise intra-cell interference and also lessen the interference caused to other cells by making use of all the available estimated directions. As a result, our precoder is predicted to have a higher SINR than traditional single-cell precoders, at least if the right power management is used.

By utilising all of the channel directions that may be locally determined at a BS, the proposed multi-cell MMSE precoder may actively reduce interference caused to nearby cells in addition to reducing intra-cell interference. Numerical studies show that the recommended precoder can obtain a considerable total SE gain over the single-cell MMSE precoder, and the gain gets increasingly significant as k grows.

Unlike the multi-cell ZF precoder, whose performance significantly degrades for larger k, our M-MMSE precoder delivers a strong and consistent performance even for very big K.

4.3 Comparison of different combining schemes

The lessened computational complexity is the main advantage of utilising a combining technique other than the "optimal" M-MMSE. For all combining systems, complexity rises with the number of UEs and BSs antennas. Clearly, M-MMSE and S-MMSE have the highest levels of complexity. Since S-MMSE reduces complexity by 10% to 50% over M-MMSE and does not employ inter-cell channel estimates in the calculation.

S-MMSE scheme offers SE that is lower than M-MMSE but 5%–10% greater than RZF and ZF. S-MMSE, RZF, and ZF produce similar SE for all f, with f = 2 producing the largest SE. Precoding options include M-MMSE, S-MMSE, RZF, ZF, and MR. Similar to their UL counterparts, these precoding schemes exhibit similar behaviour. For any number of antennas, M-MMSE offers the maximum SE.

The SE provided by S-MMSE, RZF, and ZF is nearly identical, with the exception that ZF has robustness difficulties for M < 20 antennas. For both schemes and both value sets, the CP (circuit power) grows as M. M-MMSE requires the largest CP, followed by S-MMSE. Regarding Value Set 1 (Fixed power: PFIX=10W, Power for BS LO: PLO=0.2W, Power per BS antennas: PBS=0.4 W, Power per UE: PUE =0.2W). Due to the lack of inter-cell channel estimates, S-MMSE lowers the CP by 0.5% to 25%.

But bear in mind that the SE of M-MMSE is higher than that of S-MMSE. Quantitatively, for M = 100 and K = 10, M-MMSE requires 48.16 dBm (65.48 W) of CP, whereas S-MMSE only requires 47.5 dBm (56.35 W), which is a 14% reduction. The aforementioned figures indicate that the CP increase with M-MMSE is countered by the 10% higher SE with M-MMSE in both UL and DL. For Value set 2 (Fixed power: PFIX=5W, Power for BS LO: PLO=0.1W, Power per BS antennas: PBS=0.2 W, and Power per UE: PUE =0.1W), the CP required by M-MMSE is just 0.1%–7% higher than with S-MMSE. The main cause of this is the improved processing performance.

For Value set 1:

In comparison to S-MMSE, the M-MMSE requires CP that is 8% to 100% greater. This CP boost drops to between 2% and 25% CP.

For Value set 2:

It's interesting to note that when throughput increases, RZF and ZF often behave as M-MMSE and S-MMSE, respectively.

This occurs because a bigger number of antennas results in a higher CP the higher the throughput. The SE advantage of employing M-MMSE and S-MMSE is offset by the CP growth, which happens more quickly with M-MMSE and S-MMSE than with RZF and ZF.

CHAPTER 5

RESULTS

5.1 SE Optimization for Various Interference Levels

We simulate the SE while taking into consideration any non-negligible interference in any hexagonal grid cell. The UEs can be situated anywhere in the cells, but they must be at least 0.14r away from the serving BS. (this makes the analysis independent of r). Since the preceding SE formulations are the same for the UL and DL with the exception of the fractions ζ(ul) and ζ(dl), we simulate the sum of these SEs and see that it can be arbitrarily divided between the UL and DL. Both directions employ the same linear processing strategies. All results are computed using the preceding closed-form equations for various parameter combinations, and the simulations account for MR, ZF, and P-ZF precoding/combining. Matlab was used to run the simulations. By examining the range of all plausible integer values, We optimise the SE for each antenna number, M, taking into account the pilot reuse factor β and the number of UEs K (which determine B = βK). The pathloss exponent is chosen as = 3.7, the SNR is set to ρ/σ2= 5 dB, and the coherence block length is set at S = 400 (2 ms coherence time and 200 kHz coherence bandwidth).

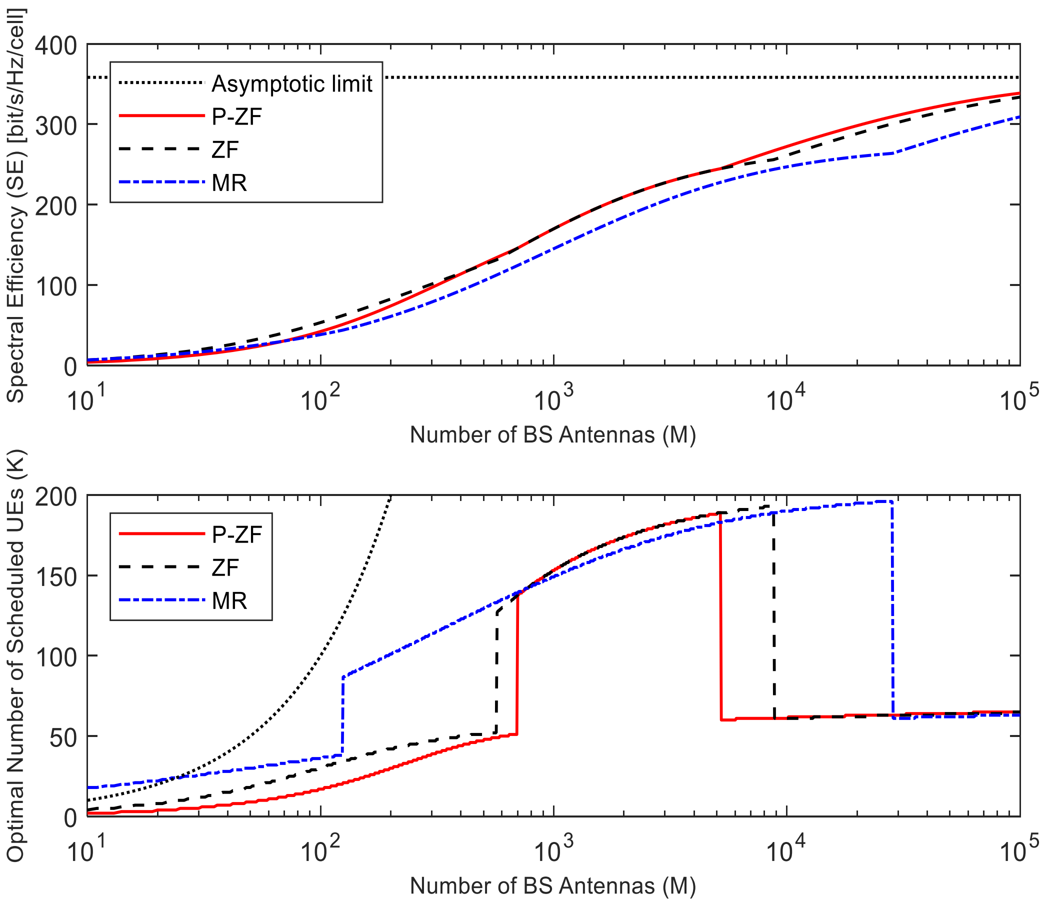

Fig: 5.1 Simulation of an improved SE with average inter-cell interference as a function of M.

We take into account three intercellular interference situations, each with a different level of severity:

1. Average case: taking an average over the same sites of UE in every cell.

2) Best case: All UEs in the other cells are at the cell edge nearest to BS j. (for each j).

3) Worst case: cellular edge nearest to BS j is where all UEs in the other cells are. (for each j).

Using Monte-Carlo simulations with 106 UE sites in each cell, the related values of the parameters μ^((1))j1 and μ^((2)) j1were calculated. Since the ideal UE placements in the interfering cells vary depending on which cell they are in, the bestcase scenario is unduly optimistic. It does, however, provide a ceiling on what may be accomplished by cell-level coordination of scheduling. The worst-case scenario is unduly gloomy since no one UE can be simultaneously located in a place that is the worst in relation to all other cells. The average situation, where the scheduling, UE mobility, and random switching of pilot sequences among the UEs in each cell result in the averaging, is probably the most applicable in practise. Figures 5.1, 5.2, and 5.3 illustrate the results for the average case, the best case, and the worst situation, respectively. The appropriate K* is shown, as well as the optimised SE.

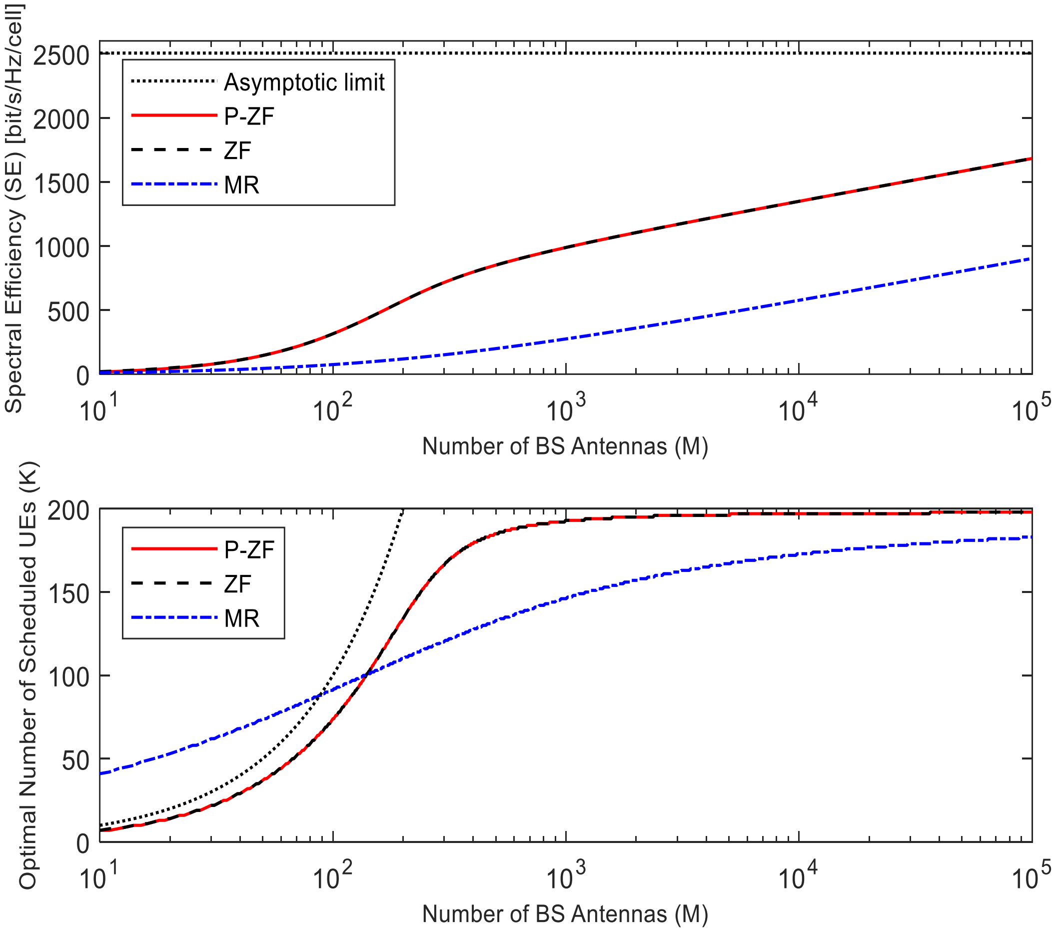

Fig 5.2: Simulation of optimized SE, as a function of M, with best-case inter-cell interference.

The two other situations and the best-case interference have considerably different possible SEs (per cell). This demonstrates that conclusions from massive MIMO single-cell analysis are frequently inapplicable to multi-cell scenarios. (and vice versa). Under the best scenario intercell interference, ZF produces significantly greater SEs than MR. In the best scenario, P-ZF is comparable to ZF. The optimised SEs for MR, ZF, and P-ZF in the realistic average scenario are rather similar, especially in the realistically, $10 \leq M \leq 200$ antennas can be used .The biggest disparities always show up when there are a lot of antennas. (notice the logarithmic M-scales). In order to approach the asymptotic limit, M =10^5 is at least necessary, and best case interference calls for numerous additional antennas. It is not recommended to utilise the asymptotic bounds as performance indicators because convergence requires an excessive number of antennas.

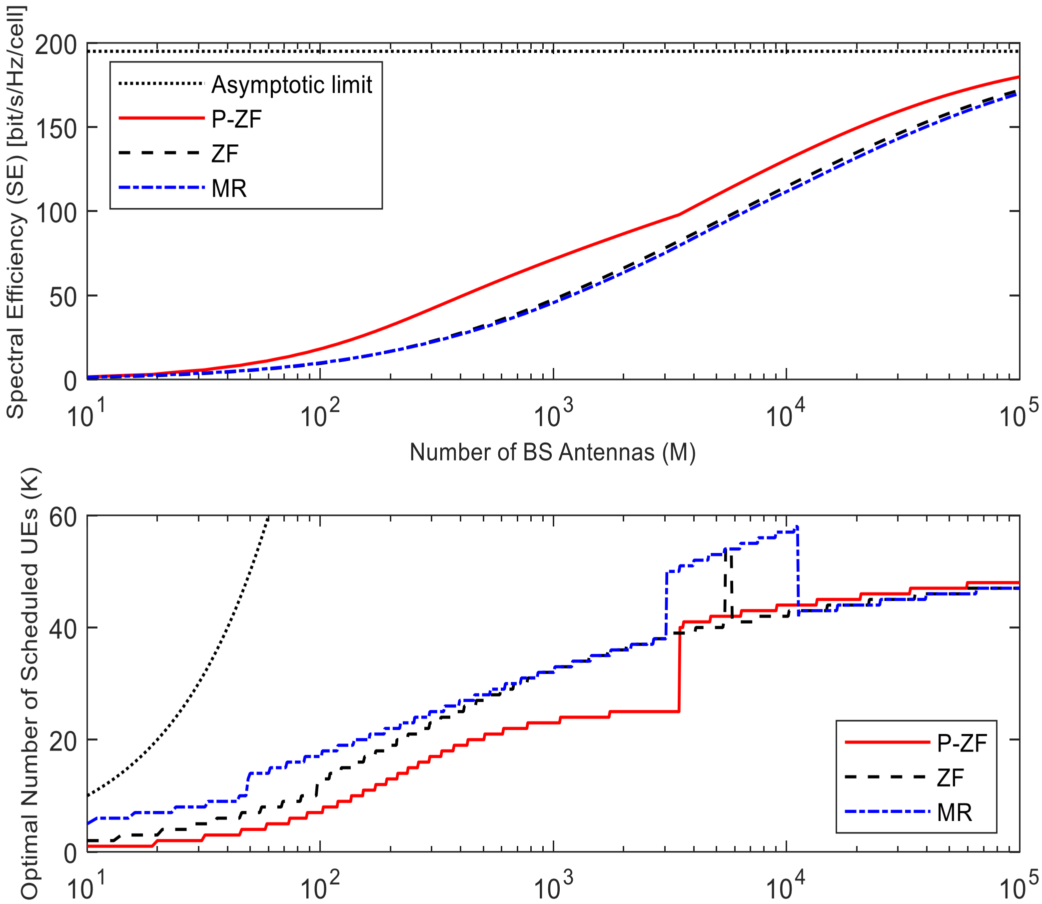

Fig 5.3: Simulation of the best-case inter-cell interference with an optimised SE as a function of M.

In the best scenario, P-ZF is equivalent to ZF, but it performs better in the worst situation due to its ability to actively decrease intercellular interference. A greater M generally results in a because the channels grow more orthogonal as M rises, there is a smaller β and a higher K*(UE'S).The reuse factor is an integer, thus when β changes, K*(UE'S) does not change continuously; smaller β permits bigger K*(UE'S), and vice versa. In order to suppress more inter-cell interference, P-ZF schedules the fewest UEs and prefers large reuse factors, whereas MR schedules the most UEs and switches to a smaller reuse factor at fewer antennas than the other schemes.

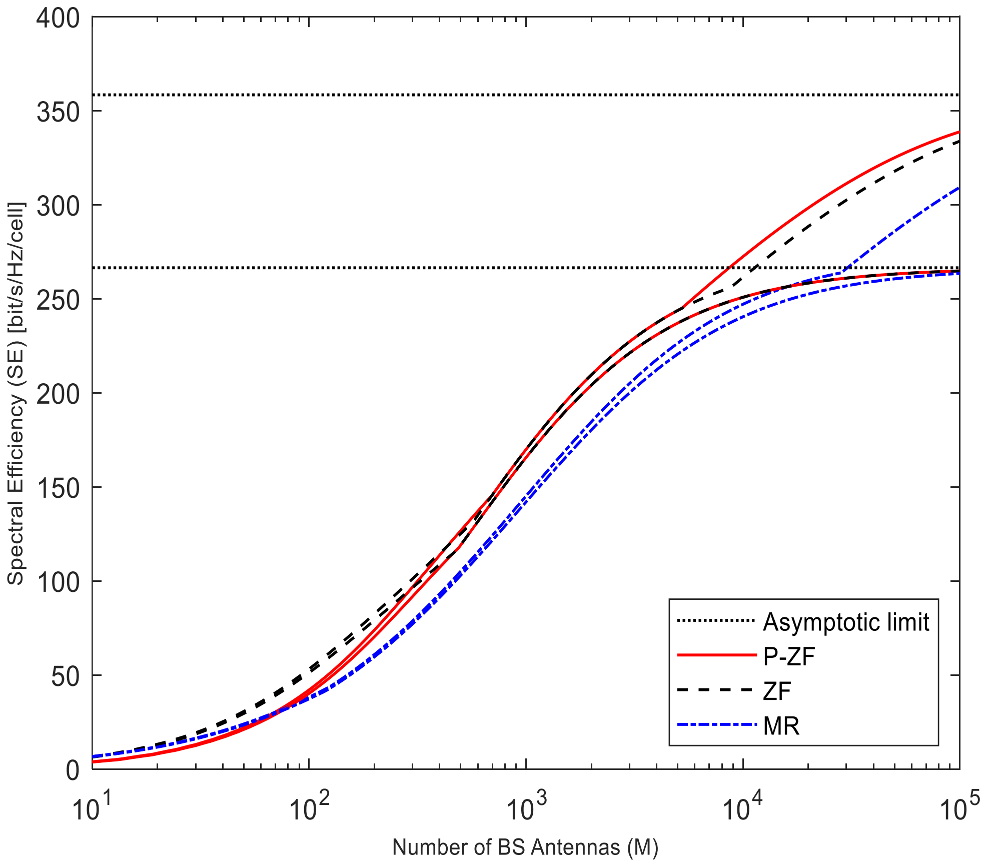

Fig 5.4: With or without hardware impairment, optimised per-cell SE

This graph displays the average inter-cell interference's per-cell SE. This graph displays outcomes for excellent hardware with €= 0 (as in Fig. 5.1(a)) and for hardware impairments with €= 0.1, a significant EVM number in these circumstances. It's interesting that there isn't much of a change in SE for M<5000. This is largely because at the optimised operating points, the SE per UE isn't very large, and the distortion noise thus only poses a modest constraint. Due to the differences between the asymptotic limitations for perfect and imperfect hardware, the difference is significant for greater numbers of antennas.We come to the conclusion that practical large MIMO systems that have been enhanced for high SE appear to be mostly unaffected by hardware deficiencies.

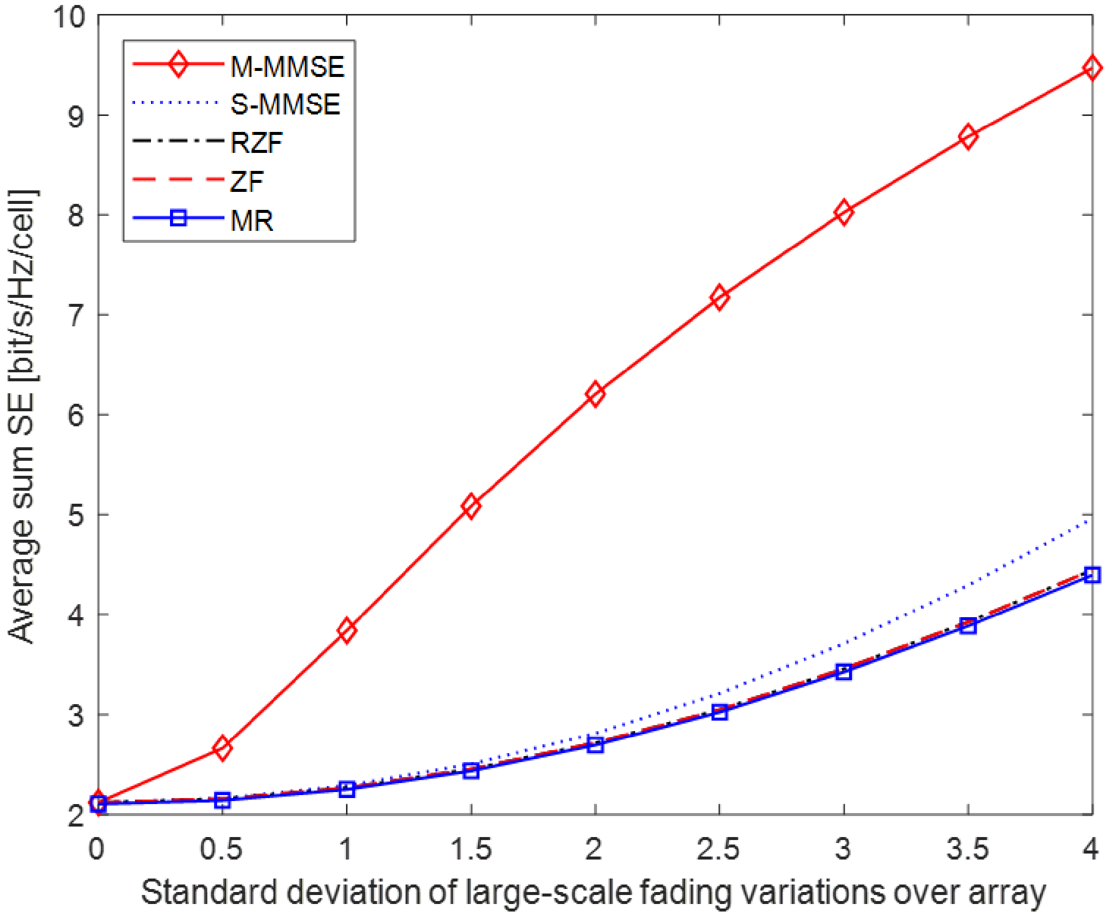

Fig 5.5: Average UL sum SE as a function of standard deviation of large-scale fading variations over array for different combining scheme

Our M-MMSE significantly outperforms the S-MMSE in terms of SE gain, and the advantage grow as β and K go up.

For K = 10 and K = 30, the SE of M-MMSE is 28% and 56% bigger than that of S-MMSE for β= 4 and M = 200.

At least for β ≤7, the possible sum SE grows monotonically as increases.

The suggested multi-cell MMSE outperforms the single-cell MMSE, according to numerical results, which are highly encouraging.

Conclusion

The research's main objective is to use precoding techniques to boost spectral efficiency (SE) in multi-cell Massive MIMO networks. In order to increase spectral efficiency, base stations that use massive MIMO have a very high number of antenna components installed on them. Single antenna arrays in huge MIMO systems are usually composed of tens, hundreds, or even thousands of antennas.In section 1.4, we looked at the huge MIMO system model for both uplink and downlink.

By this it concludes that precoding could increase spectral effectiveness. Later, we looked at a variety of precoding methods, including M-MMSE, S-MMSE, R-ZF, ZF, P-ZF, and MR. In the beginning, we looked at how spectral efficiency changed for MR, ZF, and P-ZF under the best, average, and worst cases of interference due to an increase in BS antennas (M).Later, we looked examined how SE varied when using various combining strategies with various pilot reuse factors. A technique with lower computational complexity and higher spectrum efficiency is what we require. Therefore, the M-MMSE combining technique, It is the best choice because it has a low computational complexity and a good spectrum efficiency.

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