FULL DUPLEX UPLINK COMMUNICATION EXPLOITING DISTRIBUTED ANTENNA SYSTEM FOR 5TH GENERATION CELLULAR NETWORK

This thesis paper is submitted to the department of “Electrical, Electronic and Communication Engineering (EECE)” of MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY (MIST) for partial fulfillment of the course “ EECE-400” for the degree of B.Sc. in Electrical ,Electronic and Communication Engineering.

Submitted By

Rubaiyat Sharmin Mimi	Student ID: 201416081
Syeda Rabeya	Student ID: 201416096
Ruhin Chowdhury	Student ID: 201416097

Supervised By

Dr. Md. Farhad Hossain

Associate Professor

Dept. of Electrical and Electronic Engineering

Bangladesh University of Engineering and Technology (BUET)

DEPARTMENT OF ELECTRICAL, ELECTRONIC AND COMMUNICATION ENGINEERING
MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY (MIST)
DHAKA 1216, BANGLADESH

DECLARATION

We certify that this undergraduate dissertation has not been accepted in any degree and is not under the submission for any degree or qualification – other than that of an undergraduate degree in BSc in Electrical, Electronics and Communication Engineering studied at the Military Institute of Science and Technology. We also declare that this work is the result of our own investigations, except where identified by references and free from plagiarism of the work of others.

Rubaiyat Sharmin Mimi	Sayeda Rabeya	Ruhin Chowdhury
Student ID: 201416081	Student ID: 201416096	Student ID: 201416097

Name of the Supervisor:

Dr. Md. Farhad Hossain

Associate Professor

Department of EEE, BUET

Dhaka-1205, Bangladesh

CERTIFICATION

This is to certify that the thesis titled ***FULL DUPLEX UPLINK COMMUNICATION EXPLOITING DISTRIBUTED ANTENNA SYSTEM FOR 5TH GENERATION CELLULAR NETWORK*** submitted to **MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY**, by Rubaiyat Sharmin Mimi (ID: 201416081), Sayeda Rabeya (ID: 201416096) and Ruhin Chowdhury (ID: 201416097), for the degree of **Bachelor of Science**, is a bona fide record of research work done by them under my supervision. The contents of this thesis have not been submitted to any other Institute or University for any degree or diploma.

Name of the Supervisor:

Dr. Md. Farhad Hossain

Associate Professor

Department of EEE, BUET

Dhaka-1205, Bangladesh

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ABSTRACT

Rapid growth of consumer demand for worldwide wireless communication has motivated the development of fifth generation mobile communication system which is 5G. It has encouraged higher frequency range with better service quality. For meeting the demand of increasing users, in-band full duplex communication has been proposed as a new scheme in 5G. Full duplex is significantly better than half duplex as it transmits and receives data signal simultaneously at the same frequency channel. But one of the major challenges in this technique is self-interference. In this content, we proposed a system model for uplink communication exploiting distributed antenna system to reduce self-interference to an extent and thus making the overall network performance better. The DAS proposed here is modified version of the conventional one. After comprehensive simulation of the proposed system, its performance is evaluated and compared with the existing DAS technology under different parameter setting and scenarios.

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LIST OF IMPORTANT ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
3GPP	Third Generation Partnership Project
5G	Fifth Generation
ADD	Any-Division Duplexing
BER	Bit Error Rate
BP	Breakpoint
BS	Base Station
BSC	Base Station Controller
BW	Bandwidth
CDF	Cumulative Distribution Function
COMP	Coordinated Multipoint
DAS	Distributed Antenna System
FD	Full Duplex
FDD	Frequency Division Duplex
FM	Frequency Modulation
GSM	Global System for Mobile Communications
HetNet	Heterogeneous Network
HLR	Home Location Register
ICI	Inter Cell Interference
iDAS	Indoor Distributed Antenna System

IMT-A	International Mobile Telecommunication Advanced
IOT	Internet of Things
ISD	International Subscriber Dialling
ITU	International Telecommunication Union
LOS	Line Of Sight
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MMWAVE	Millimeter Wave
MSC	Mobile Switching Centre
NLOS	Non Line Of Sight
oDAS	Outdoor Distributed Antenna System
PL	Path Loss
PSTN	Public Serviced Telephone Network
RAN	Radio Access Network
RF	Radio Frequency
RMa	Rural Macro
RX	Receiver
SF	Shadow Fading
SI	Self Interference
SIC	Self Interference Canceller
SINR	Signal to Interference Plus Noise Ratio

SNR	Signal to Noise Ratio
TX	Transmitter
UMa	Urban Macro
UMTS	Universal Mobile Telecommunication System
UT	User Terminal
UWB	Ultra Wide Band
VLR	Visitor Location Register
WLAN	Wireless Local Area Network
WWWW	World Wide Wireless Web

LIST OF SYMBOLS

d_{2D}	2D distance between BS and UT (or DAS)
d_{3D}	2D distance between BS and UT (or DAS)
d_{BP}	Breakpoint distance for RMa scenario
d'_{BP}	Breakpoint distance for UMa scenario
$f1$	Lower limits of required bandwidth
$f2$	Upper limits of required bandwidth
fc	Center frequency
h	Building height
h_{BS}	Base station height
h'_{BS}	Effective antenna height of the BS
h_E	Effective environment height
h_{UT}	UT (or DAS) height
h'_{UT}	Effective antenna heights of the UT (or DAS)
P_i	Self-interference power
P_l	Path loss
$PL_{RMa\text{-}LOS}$	Path-loss for RMa LOS scenario
$PL_{RMa\text{-}NLOS}$	Path-loss for RMa NLOS scenario
$PL_{UMa\text{-}LOS}$	Path-loss for UMa LOS scenario
$PL_{UMa\text{-}NLOS}$	Path-loss for UMa NLOS scenario
P_n	Thermal noise power
P_r	Received power
R	Resistive component of the impedance (or resistance)
T	Temperature in degrees Kelvin
V	integrated RMS voltage between frequencies f1 and f2
W	Average street width
X	Shadow fading
σ_{SF}	Variance

CHAPTER 1

INTRODUCTION

1.1 Introduction to 5G

In this era of advanced science, communication is one of the most important sectors in everyday life. Cellular network usage is increasing every day and to meet up with this demand, the network itself has to be developed faster and in a more efficient way. The previous four generations of cellular technology have each been a major paradigm shift. But the world needs even more sophisticated system. So 5^{th} generation communication will need to be a paradigm shift that includes very high carrier frequencies with massive bandwidths, extreme base station and device densities, and unprecedented numbers of antennas. One of the key technologies used in 5G is Full Duplex communication which will enable mobile operators to maximize the use of the limited frequency bandwidth they are given. But the biggest downside of FD is self-interference. There are numerous system models for SI cancellation with various techniques. But none of them works perfectly. In this thesis a modified distributed antenna system is introduced to reduce the SI in FD and the optimum location of das is also described.

1.2 Research Motivation

One of the biggest concerns in mobile cellular communication is frequency. Every operator has to use a different frequency band. But this frequency range is quite limited. In order to make most use out of this limited resource, we have to come up with advanced technologies. At first, FDMA was proposed. But it can’t utilize the bandwidth much because of band gaps and guard bands. Then came the technology of OFDM. Its rendition is better in many ways than FDMA, but fully orthogonal frequency channels are hard to realize in reality. For 5^{th} generation cellular communication, FD has been proposed, which utilizes simultaneous transmission and reception at the same frequency. But the major challenge regarding FD is Self-Interference. Many system models has been proposed for self-interference (SI) cancellation [40], [73], [74], and [75]. But whenever it has been tried to implement FD communication in hardware there has been so much noise due to SI that it seemed like the user was trying to hear the whisper of the other participant while screaming at the top of his lungs [72]. That is why, although FD is the major ground breaking technology proposed in 5G communication, it is indeed the biggest handicap in this network because of SI. If this barrier was removed and FD was implemented in regular communication networks, it would be a major breakthrough in communication technology. None of the system models proposed in this regard are full proof. Most of them are based on mathematical models which do not provide accurate results in reality [72], [75]. And only a few of those models used hardware approach. So to find a way to reduce this SI barrier and be able to implement FD in reality is the motivation behind this work.

1.3 Thesis Objective

The objective of this thesis is to reduce Self Interference in FD uplink Communication modifying the conventional DAS where the receiver is located at the center and the transmitters are located at optimum distance from the receiver.

1.4 Organization of this Thesis

Chapter 1 – It discusses the purpose and motivation behind this thesis.

Chapter 2 – This chapter, gives an overview of cellular network, 5G cellular network and its components which are used in this work such as full duplex, self-interference, Distributed antenna system.

Chapter 3 – In this chapter, proposed system model is explained along with the assumptions and performance analysis is shown under different scenarios.

Chapter 4 – In this chapter, results of this thesis were summarized are future works related to the proposed system model are discussed.

CHAPTER 2

OVERVIEW OF 5G CELLULAR NETWORK

2.1 Introduction

This chapter remains the basic fundamental concept of a cellular system .With the increasing applications for smart phones and with 3G and 4G networks being disposed and planned, cellular network technology are getting a lot of attention with next generation wireless communication 5G.This chapter includes the evolution of cellular system from 1G to 5G network and basic features of 5G technology. Furthermore, a detailed account of implementation of 5G network.

2.2 Basics of Cellular Network

The cellular network fulfils many requirements. It not only enables calls to be routed to and from the mobile phones but also enables calls to be maintained as the cell phone moves from one cell to another. It also enables other essential operations such as network accessing, billing, security and much more. To fulfil all these requirements the cellular network consists of many elements where each element has its own function to complete.

The antennas and the associated equipment, often located in a holder below, are often seen spread around the country, and especially at the side of highways and motorways. However, there is more to the network behind this, as the system needs to have elements of central control and it also needs to link with the Public Switching Telephone Network (PSTN) landline system to enable calls to be made to and from the wire based phones, or between networks.

Despite having different standards for the cellular networking system, the basic concepts are almost similar. A basic cellular system architecture consists of two network domains-an access network and a core network. They together form the cellular network infrastructure. An access network is a type of telecommunications network which connects subscribers to their immediate service provider. The core network is the central part of a telecommunications network that provides various services to customers who are connected by the access network. One of the main functions is to route telephone calls across the PSTN.

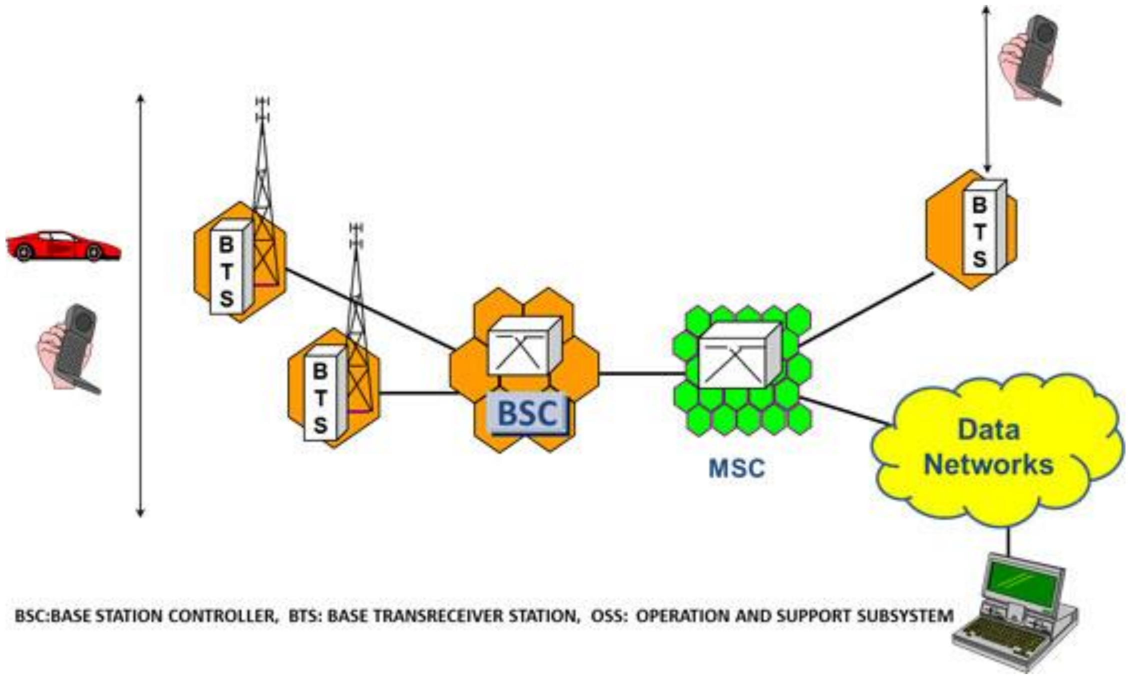

Fig 2. 1: Basic architecture of cellular network [62]

A cellular network provides wireless communications infrastructure to support mobile radio transceivers (cell phones) located throughout a geographical coverage area. This geographical area consists of many smaller coverage areas which are called cells.

The most obvious part of the cellular network is the base station. The mobile cell phones are supported by a stationary or fixed-location transceiver called a base station (BS). Base stations provide wireless communications coverage for cells that combine to make up a much larger coverage area consisting of all the BS.

Another unit acts as a base station to route calls to the destination called base station controller (BSC). The BSC coordinates with the mobile switching center (MSC) to interface with the landline-based PSTN, visitor location register (VLR), and home location register (HLR) to route the calls toward different base center controllers.

2.2.1 Single tier network or homogeneous network

A single tier network is also known as homogeneous network which is deployed by using a single type BS. Traditional cellular network are of this type utilizing only macro cells. Each macro cell can deliver coverage for large geographical area. The area ranges vary depending on the deployment areas which can be up to several kilometers. Usually, it depends on the number of user (e.g. smaller cell for urban areas and larger cell for rural areas as user is less there).

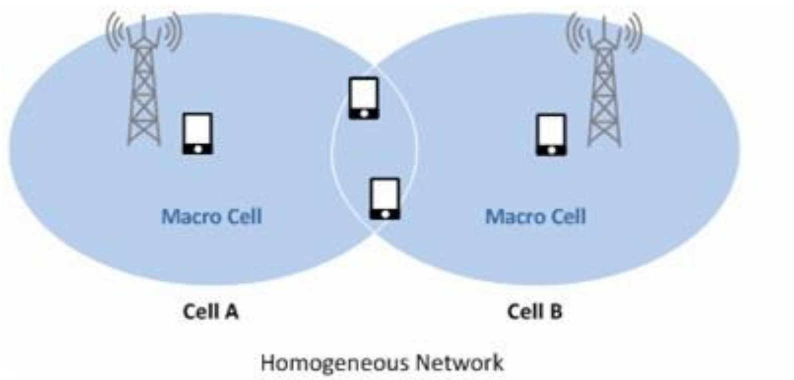

Fig 2. 2: A Single Tier or Homogeneous Network [63]

Poor indoor penetration and the presence of dead spot leading to reduced indoor coverage are two of the major limitation of homogeneous network [1]. Besides, as the users move to cell edges, there happened inter-cell interference which increases remarkably and causes drastic reduction in user throughput.

Again, due to the requirement of higher transmit power, edge users run out of power very quickly. Furthermore, the traffic demand is increasing rapidly, it is essential to install new base stations as adding further macro cells is not very much effective due to higher cost and the lack of attainable cell sites.

2.2.2 Multi–tier network or Heterogeneous network

With the rapid rise of traffic demand and for removing the drawbacks of conventional single tier network, next generation cellular network infrastructures, such as LTE-A, LTE-A PRO at 3GPP family, have adopted the concept of a multi-tier network. A multi-tier network, also known as heterogeneous network, is deployed using a mix of macro cells and small cells. Small cells include micro cells, Pico cells and femto cells which are overspread on macro cells for establishing multi-tier network [2].

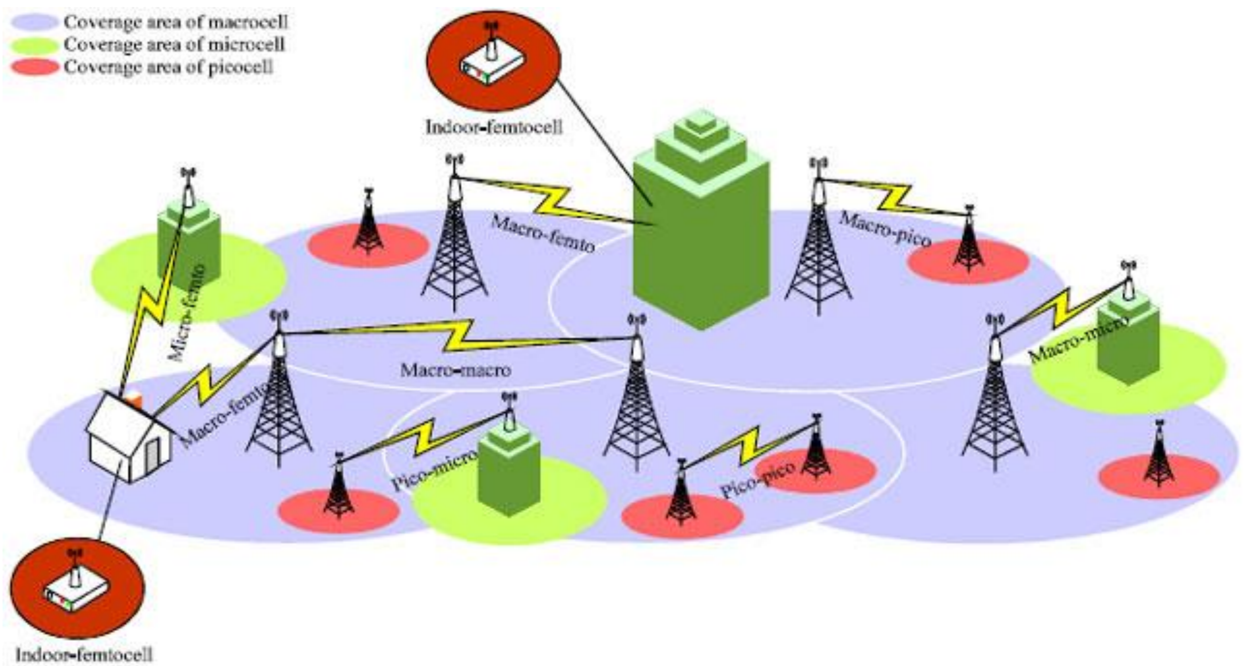

Fig 2. 3: Multi-tier cellular network including macro cell, microcell, pico cell and femto cell [64]

A multi-tier network has a huge potential in improving network coverage, capacity, and energy efficiency with fast and flexible installation. Many researchers also refer to a multi-tier network as a heterogeneous network though it has a broader meaning including cell sizes, technologies, services, frequency bands and user terminals.

2.2.3 Cellular network technology evolution

In the last few years, mobile communication has experienced a remarkable change due to fast reforming from 1G to 5G technology. The mobile wireless Generation (G) generally refers to a change in the features of the system, speed, technology, frequency, data capacity, latency etc. Each generation have some standards, different capacities, new techniques and new features which differentiate it from the previous one.

The first generation (1G) mobile wireless communication network was analog type used for voice call only. The second generation (2G) is a digital technology and supports text messaging. The third generation (3G) mobile technology provided higher data transmission rate, increased capacity and provides multimedia support. The fourth generation (4G) integrates 3G with fixed internet to support wireless mobile internet, which is an evolution to mobile technology and it overcame the limitations of 3G. It also increased the bandwidth and reduced the cost of resources. 5G stands for 5^{th} Generation Mobile technology and is going to be a new revolution in mobile market which will change the means to use cell phones within very high bandwidth. User never experienced ever before such high value technology which includes all type of advance features and 5G technology will be most powerful and in huge demand in near future [3].

Fifth Generation which has started from late 2010s and a target was taken that it will be implemented within 2020. Facilities that might be seen with 5G technology includes far better levels of connectivity and coverage. The main focus of 5G will be on World Wide Wireless Web (WWWW). It is a complete wireless communication with fewer limitations.

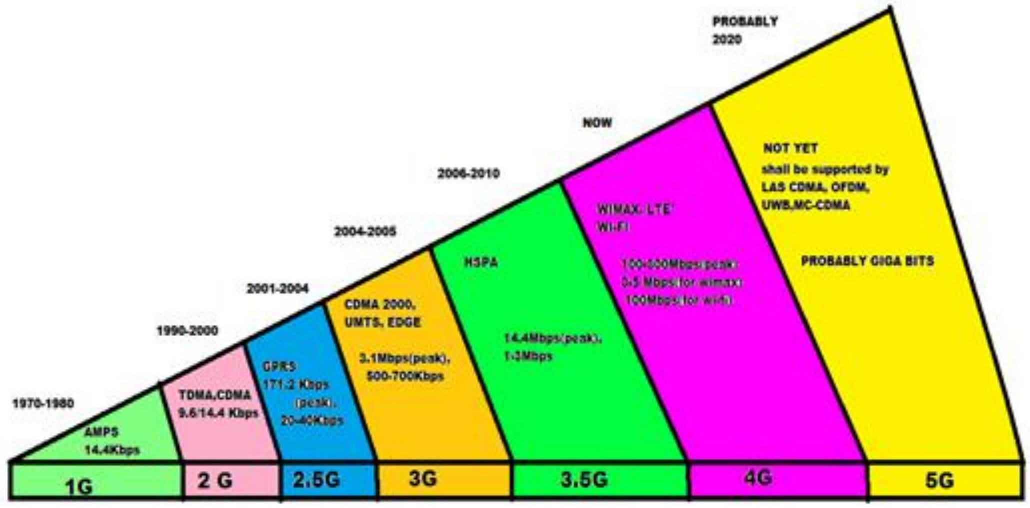

Fig 2. 4: Cellular Network evolution from 1G to 5G [65]

This reform is due to requirement of service compatible transmission technology and very high increase in telecom customers. Generation refers change in nature of service compatible transmission technology and new frequency bands. In 1980 the mobile cellular era had started, and since then mobile communications have undergone reconcilable changes and experienced massive growth and it will be continued till the implementation of next generation wireless communication with better features and tremendous experience.

Table 2. 1: Evolution of cellular network from 1G to 5G [4] [5]

Technology	1G	2G	3G	4G	5G
Start	1970-80	1990-2004	2004-2010	NOW	Probably by 2020
Data Bandwidth	2kbps	64kbps	2Mbps	1Gbps	>1Gbps
Technology	Analog	Digital	CDMA-2000, UMTS, EDGE	WI-MAX, WI-FI, LTE	WWWW, LTE-A
Core network	PSTN	PSTN	Packet N/W	Internet	Internet
Multiplexing	FDMA	TDMA/CDMA	CDMA	CDMA	CDMA
Switching	Circuit	Circuit/packet	packet	All packet	All packet
Primary Service	Analog Phone Calls	Digital Phone Calls and Messaging	Phone calls, Messaging, Data	All-IP Service (including Voice Messages)	High speed, High capacity and provide large broadcasting of data in Gbps
Key differentiator	Mobility	Secure, Mass Adoption	Better Internet experience	Faster Broadband Internet, Lower Latency	Better coverage and no dropped calls, much lower latency, Better performance
Weakness	Poor spectral efficiency, major security issue	Limited data rates, difficult to support demand for internet and email	Real performance fail to match type, failure of WAP for internet access	Battery use is more, Required complicated and expensive hardware	Research is under process

2.2.4 Mobile network in 5G era

Over the last couple of decades, the society has observed gradual evolution of mobile wireless communications towards second, third and fourth generation wireless networks [4]. Now it's time for embracing 5G mobile network to address new opportunities and challenges [4], [5], [6]. Its prime concern is to build a single powerful mobile network that meets the demands of a super connected world and industry development with high capacity, coverage and less latency [6] of a wide range of service.5G's main focus is to enable WWWW. Its capabilities can be summarize as:

1. Powerful network capability to meet divergent requirements for capacity, coverage, and latency of a wide range of services.
2. An agile and flexible network architecture to improve the efficiency of multi-service connections.
3. Intelligent network management to provide efficient network O and M and optimization of diversified service experience.

There are many existing and ongoing campaign efforts worldwide targeting 5G channel measurements and modeling. LTE Advanced Pro (LTE-A Pro, also known as 3.5G, 3.5G Pro, 3.9G, Pre-5G, 5G Project, and so on) is a marker of the 3GPP release 13 and 14, which is a natural evolution of Long Term Evolution (LTE) with speed up to Gbit/s level which incorporated numerous new technologies that would be used in 5G standard including 256QAM, Massive MIMO, LTE-Unlicensed, LTE IOT. 5G also include FD system [6], METIS2020 [7], COST2100/COST [8], IC1004 [9], mm Wave [10], NIST 5G mmWave Channel Model Alliance [11], MiWEBA [12], mm Magic [13].Research is under process and it will be continued until implementation.

2.2.5 Specifications for 5G

For achieving 5G technology, new schemes and methods of connection will be required as one of the main drawbacks of previous generations is lack of coverage, dropped calls and low performance at cell edges [3].

According to **Next Generation Mobile Network Alliance** [71], 5G requirements have been set. Facilities that might be seen with 5G technology includes far better levels of connectivity and coverage [4], [5], [6]. Typical parameters for a 5G standard may include:

Table 2. 2: Suggested 5G Wireless Performance [71]

PARAMETER	**SUGGESTED PERFORMANCE**
Network capacity	10 000 times capacity of current network
Peak data rate	10 Gbps
Cell edge data rate	100 Mbps
Latency	<1ms

These are some of the ideas being put forwards for a 5G standard, but they are not accepted by any official bodies yet.

2.2.6 Research opportunity in 5G

There are several key areas that are being investigated by research organizations. These include:

1. **Millimeter-Wave technologies**: For 5G, frequencies of above 50GHz are being considered and this will present some real challenges in terms of the circuit design, the technology, and also the way the system is used as these frequencies do not travel as far and are absorbed almost completely by obstacles. Using frequencies much higher in the frequency spectrum opens up more spectrum and also provides the possibility of having much wider channel bandwidth - possibly 1 to 2 GHz. However this poses new challenges

for handset development where maximum frequencies of around 2 GHz and bandwidths of 10 - 20 MHz are currently in use [10].

2. **Duplex methods**: There are several forms of duplex that are being considered. Currently systems use either frequency division duplex (FDD) or time division duplex (TDD). The wireless research community aspires to conceive full duplex operation by supporting concurrent transmission and reception in a single time/frequency channel for the sake of improving the attainable spectral efficiency by a factor of two as compared to the family of conventional half duplex wireless systems [14]. This scheme for 5G would enable high frequency range expanding resource allocation on the same channel.
3. **Future PHY / MAC:** The new physical layer and MAC presents many new interesting possibilities in a number of areas One key area of interest is that of the new waveforms that may be seen [15], OFDM including GFDM, Generalized Frequency Division Multiplexing, as well as FBMC (Filter Bank Multi-Carrier), UFMC (Universal Filtered Multicarrier). Each has its own advantages and limitations and it is possible that adaptive schemes may be employed, utilizing different waveforms adaptively for the 5G mobile systems as the requirements dictate. This provides considerably more flexibility for 5G mobile communications [15].
4. **Modulation:** Whilst PSK and QAM have provided excellent performance in terms of spectral efficiency, resilience and capacity, the major drawback is that of high peak to average power ratio. Modulation schemes like APSK could provide advantages in some circumstances.
5. **Massive MIMO**: Although MIMO is being used in many applications from LTE to Wi-Fi etc. the number of antennas is fairly limited - Using microwave frequencies opens up the possibility of using many tens of antennas on a single equipment becomes a real possibility because of the antenna sizes and spacing’s in terms of a wavelength [16].

In dense networks, reducing the size of cells provides a much more overall effective use of the available spectrum. Techniques to ensure that small cells in the macro-network are deployed as femtocells can operate satisfactorily as required.

2.2.7 New added fields in 5G

There are many new concepts that are being investigated and developed for the new 5th generation mobile system. Some of these include:

1. **Pervasive networks:** This technology which is being considered for 5G cellular systems is where a user can concurrently be connected to several wireless access technologies and seamlessly move between them.
2. **Group cooperative relay:** This is a technique that is being considered to make the high data rates available over a wider area of the cell. Currently data rates fall towards the cell edge where interference levels are higher and signal levels are lower.
3. **Cognitive radio technology**: If cognitive radio technology is used for 5th generation cellular systems, then it would enable the user equipment / handset to look at the radio landscape in which it is located and choose the optimum radio access network, modulation scheme and other parameters to configure itself to gain the best connection and optimum performance [17].
4. **Wireless mesh networking and dynamic ad-hoc networking**: With the variety of different access schemes it will be possible to link to others nearby to provide ad-hoc wireless networks for much speedier data flows.
5. **Smart antennas**: Another major element of any 5G cellular system will be that of smart antennas. Using these it will be possible to alter the beam direction to enable more direct communications and limit interference and increase overall cell capacity.

There are many new techniques and technologies that will be used in the new 5G cellular or mobile telecommunications system. These new 5G technologies are still being developed and the overall standards have not yet be defined. However as the required technologies develop, they will be incorporated into the new system which will be defined by the standards bodies over the coming years.

2.2.8 5G multiple access schemes

There are several candidate systems that are being considered as the 5G multiple access scheme. They include a variety of different ideas.

1. **Orthogonal frequency division multiple access, OFDMA:** OFDMA has been widely used and very successful for 4G and could be used as a 5G multiple access scheme. However it does require the use of OFDM and requiring orthogonally between carriers and the use of a cyclic prefix has some drawbacks. As a result other multiple access schemes are being investigated.
2. **Sparse Code Multiple Access, SCMA**: SCMA is another idea being considered as a 5G multiple access scheme and it is effectively a combination of OFDMA and CDMA. Normally with OFDMA a carrier or carriers is allocated to a given user. However if each carrier has a spreading code added to it, then it would be able to transmit data to or from multiple users. This technique has been developed to use what are termed sparse code and in this way significant numbers of users can be added while maintaining the spectral efficiency levels.
3. **Non-orthogonal multiple access, NOMA:** NOMA is one of the techniques being considered as a 5G multiple access scheme. NOMA superposes multiple users in the power domain, using cancellation techniques to remove the more powerful signal. NOMA could use orthogonal frequency division multiple access, OFDMA or the discrete Fourier transform, DFT-spread OFDM.

There are several multiple access schemes that could be used with 5G. The one or ones used will be chosen as a result of the standardization process which is currently ongoing.

2.3 Distributed Antenna System

A distributed antenna system, also known as DAS in short, is a network of geographically separated antenna nodes that are connected to a common source through a transport or communication medium in order to provide wireless communication service in a specific area.

2.3.1 Configuration of DAS

Traditional antenna system for a single area is made up of a single antenna radiating at high power. Distributed antenna system replaces that single antenna with multiple low power antennas to cover that same area. In DAS, antenna modules are geographically distributed to reduce access distance instead of centralizing at a location. Each distributed antenna module is connected to a home base station (or central unit) via dedicated wires, fiber optics, or an exclusive RF link. [19] At the head-end of the DAS, service providers typically locate base stations to provide the cellular signal. A main hub takes that signal, convert it to a digital signal, and distributes it to other hubs and radio. At the antenna, this signal is converted from digital to RF and RF to digital.

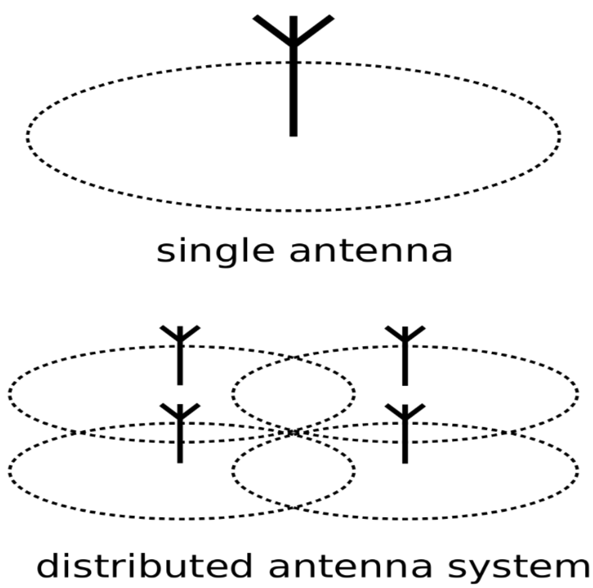

Fig 2. 5: Distributed Antenna System Architecture [19]

2.3.2 Types of DAS

Based on the geographical characteristics, DAS can be of two types – Indoor distributed antenna system (iDAS) and outdoor distributed antenna system (oDAS). iDAS is used inside buildings where there is a large number of users e.g. commercial buildings, shopping malls, apartment complexes etc. [18].

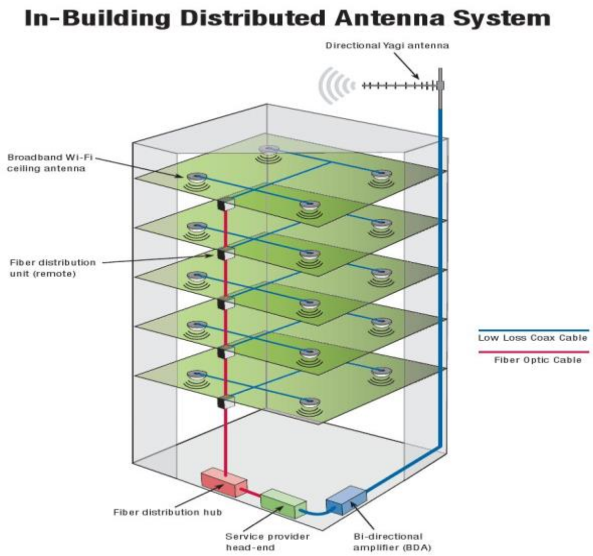

Fig 2. 6: Structure of iDAS [69]

oDAS is used outdoors, for both line-of-sight and non-line-of-sight communication. It is a larger scale version of iDAS.

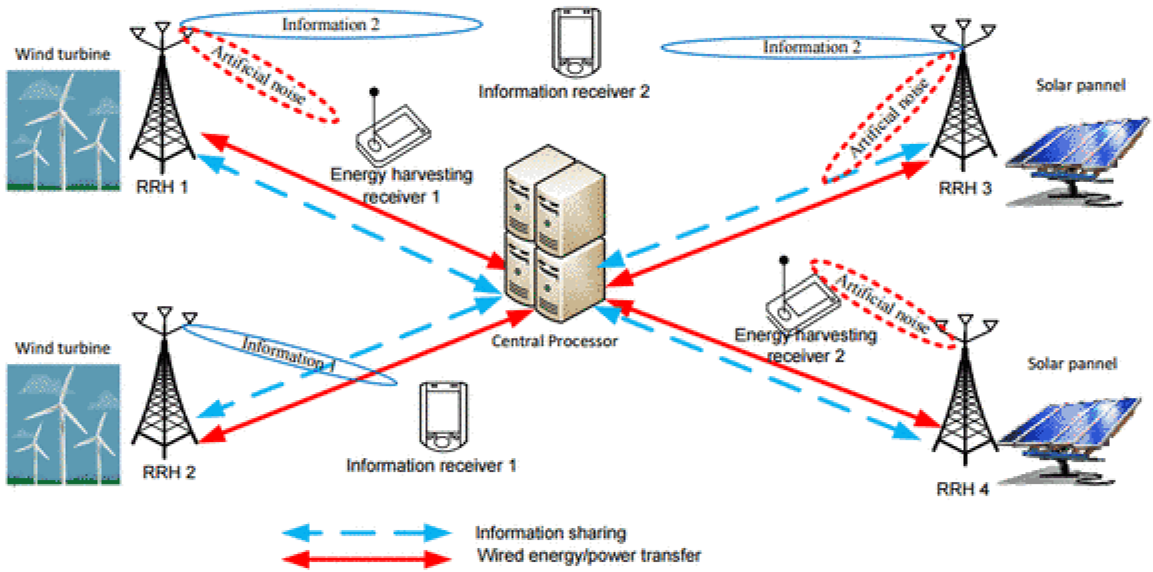

Fig 2. 7: Structure of oDAS [70]

Distributed antenna system can be classified into two categories based on the components used in the system. These two types are – active das and passive das.

Passive DAS systems generally consist of passive components like coaxial cable, splitters, and diplexers to distribute signal. They use bi-directional amplifiers to rebroadcast signal from the macro cellular network using a donor signal on the roof.

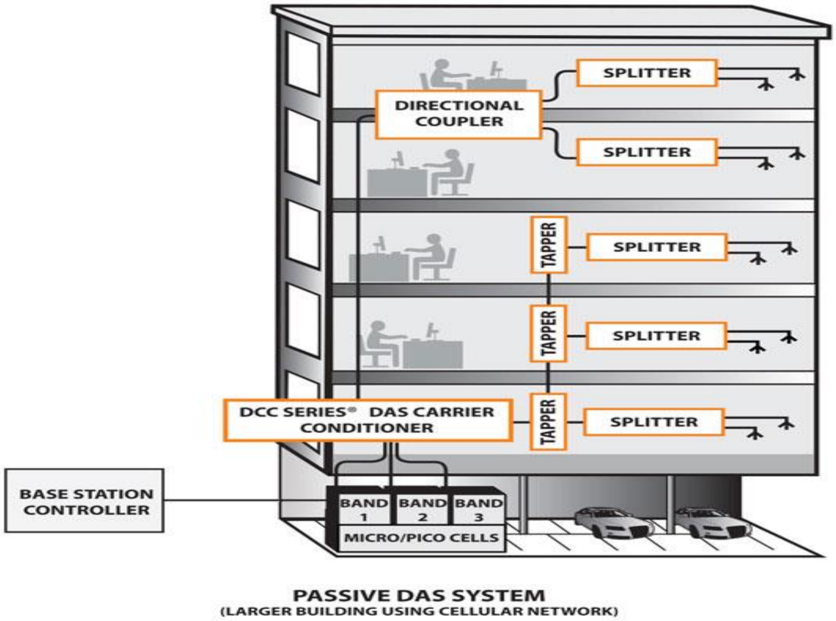

Fig 2. 8: Structure of Passive DAS [67]

In Active DAS, the components require a power source to operate. An active DAS system utilizes fiber optic cables to connect with remote nodes. All the antennas are powered separately.

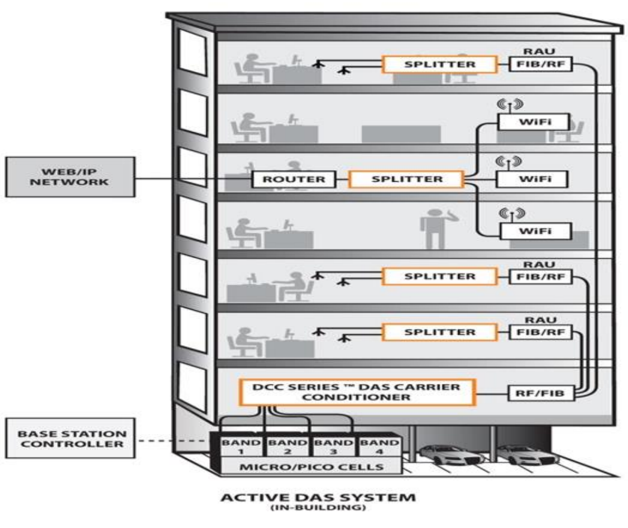

Fig 2. 9: Structure of Active DAS [68]

There are limitations of passive DAS solutions. Because they use coaxial cable to distribute signal, signal loss is higher than with active DAS. The further away the antennas are from the amplifier, the higher the signal loss. The signal loss results in lower downlink output power. These restrictions mean that the maximum coverage area for a passive DAS system is typically around 500,000 sq. ft.

But the advantages of passive DAS solutions are considerable. In particular, they are considerably cheaper than active DAS. Because they typically rebroadcast the macro network's signal, there is less need for carrier approval and coordination.

When additional capacity is needed, an active DAS system is used. The equipment used in an active DAS are extremely expensive. This is one of the main drawbacks to an active DAS system

The other big inconvenience of active DAS is that every installation must be approved by the cell phone carriers affected. This is an FCC regulation, because the carriers own the cellular frequencies [20].

Hybrid DAS is another option. A hybrid system works a lot like an active DAS. Hybrid DAS uses fiber for a portion distribution of signal, but relies on passive coaxial cable for much of the signal distribution. Hybrid systems can be a good solution for medium-sized spaces, or unusual signal problems. Multiple passive systems can be linked by fiber cable to a remote amplifier unit.

A hybrid system still has many of the same drawbacks as active DAS. It is still very expensive and, because it because it involves using signal provided by the carriers themselves, it still needs carrier approval and involvement.

2.3.3 Advantages of DAS

- If a given area is covered by many distributed antenna elements rather than a single antenna, then the total radiated power is reduced by approximately a factor $N^{1-n/2}$ and the power per antenna is reduced by a factor $N^{n/2}$ where a simple power-law path-loss model with path-loss exponent n is assumed.

- DAS provides increase in capacity of cellular communication tower by having multiple antennas for single or multiple bands.
- The total area covered could be extended for a fixed limit of effective radiated power, which may be important to ensure concession with safety border on radiation into the human body.
- In DAS technology, cell towers have provision to add antennas as per requirements in the future. Hence increase in user traffic can be managed very easily.
- It helps improving the speed of communication using MIMO/Beam-forming techniques.
- Individual antennas do not need to be as high as a single antenna for the equivalent coverage
- A single antenna leaves out a lot of coverage holes, this problem can be solved with distributed antennas.
- As the distance between a mobile user and the cellular signal grows, the quality of the cellular signal begins to degrade; however, by strategically placing distributed antennas at targeted locations where there's more users, it can be ensured that mobile users are always within close proximity to a strong and fast signal.

2.3.4 Downsides of DAS technology

1. **Cost:** When discussing DAS network implementation, the most significant drawback is DAS networks are more expensive. The price difference stems from the need to use fiber-optic cables to connect each radio head to a central hub, the development of the hub itself, and the placement of the cellular base stations. As such, the implementation of a DAS network for all the necessary equipment is expensive and time consuming, along with the tuning and optimization that will be required afterward.

2. **Backhaul:** Routing backhaul is another major concern of distributed antenna systems. Because each of the nodes used to broadcast the cellular signal requires routed fiber-optic cables, the installation process can easily become problematic. This process can potentially

create issues with cable management, as keeping the fiber-optic lines out of sight will require that the cables be carefully routed through the walls and other important structures of the facility. If this process is not conducted properly, the routing of these cables can cause serious harm to the structural integrity of the facility, making it unsafe and hazardous.

3. **Upgradeability:** DAS communication networks are harder to upgrade. As new technology becomes available, it is more difficult to upgrade an existing DAS network than it is to upgrade a single antenna network. A single antenna network can be upgraded over the air without the need for a technician visiting the cell site. DAS network upgrades require the replacement of the base station and modifications being made to the nodes themselves, which makes the upgrade process significantly more difficult.

2.4 Full duplex

The full duplex concept for 5G technology is to transmit and receive signals simultaneously using the same frequency band for both uplink and downlink i.e. the same channel. With the increasing number of traffic now a days the communication devices operating in half-duplex, which waste the resources by utilizing either time-division or frequency-division, will not be able to provide us usable frequency bands in the near future. On the other hand the full duplex (FD) system which can simultaneously transmit and receive signals over the same frequency band, will be able to double the capacity compared to the half-duplex system. This will help in the evolution of cellular technology with limited spectrum. This system can be used to utilize the limited resources and improve spectral efficiency and the performance of cellular communication network.

2.4.1 Advantages of FD system

1. **Doubling the capacity**: 5G full duplex uses a single channel i.e. only one channel is used as transceiver from and to the base station which is more effective than using the FDD or a TDD scheme. This results in the utilization of full transmission time in both ways.
2. **Fading**: As full duplex uses the same frequency band for the same channel, the fading characteristics will be similar for both uplink and downlink. But in the case of FDD, fading differs for both channel which creates difficulties. As the fading characteristics are similar, the cancellation techniques will be similar for both uplink and downlink.
3. **Filtering**: Since 5G full duplex uses a single channel, the numbers of filters (so that transmitted signal do not enter the receiver) required at the receiver will be less than that of FDD scheme. More the number of filters more the loss and more the degradation of performance.
4. **Novel relay solutions:** The techniques used for 5G FD on a single channel enable the simultaneous re-use of spectrum resources in backhaul as well as the main user access can allow for almost instantaneous retransmission and high throughput mesh operation for HetNet. [32]

5. **Enhanced interference coordination:** 5G full duplex reduce the air interface delays due to simultaneous reception of feedback information while data transmitted. It is also possible to use and provide much tighter time or phase synchronization for CoMP.
6. **Spectrum virtualization:** Full duplex is the extreme case of completely overlapped two channels. It can act as a software controlled duplexer simplifying and reducing the cost of supporting multiple fragmented frequencies, effectively enabling radios to exploit fragmented spectrum.
7. **Any-division duplexing (ADD):** the distinction between TDD and FDD is eliminated by SIC. TDD an obsolete duplexing method is replaced by in-band full duplex, while FDD greatly benefits from the configurability of SIC, becoming adaptive and capable of flexible carrier aggregation.

2.4.2 Self-Interference (SI)

There coincides an enormous disadvantage in full duplex system, a loopback interference from the transmission-end [24] known as Self Interference.

Due to the transmission and reception of signals over the same frequency band there exists an interference. The receiver will receive the transmitted signal from the UT along with the transmitted signal of transmitter. This transmitted signal coming from the transmitter end is unwanted and will thus result in self-interference (SI). This causes power leakage and reduce the potential gain of the overall system [25], [26]. Furthermore FD doubles the interference leading to inter-cell interference (ICI) [24].

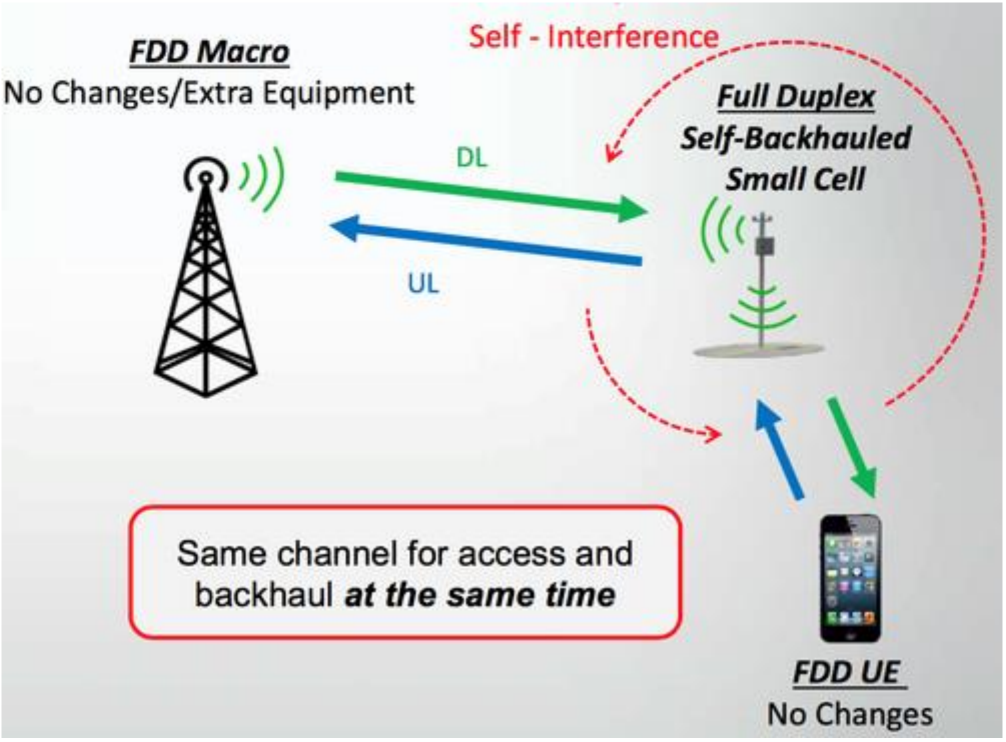

Fig 2. 10: Self Interference in FD [66]

2.4.3 Self-interference cancellation (SIC)

To minimize SI in the FD system, various methods have been proposed known as self-interference cancellation. Studies [27], [28] shows that the amount of SIC is in fact a random variable that depends on the random wireless fading channel, and the amount passive and active interference cancellation.

Method for cancellation of self-interference:

1. Analog cancellation:

Different analog methods [32], [33], [34] are included for cancellation of self- interference like time-domain (TD) cancellation algorithms in single-input single-output (SISO) and multiple-input multiple-output (MIMO) based techniques, antenna cancellation, pre-coding/decoding, block deionization, optimal Eigen beam forming and analog filter type etc. All the type has limited advantage to suppress self-interference.

2. Digital cancellation:

There are many sophisticated techniques to design digital cancellation filters like utilizing post-filters or *adaptive* linear filtering [29]. Almost common method is using normalized least mean square (NLMS) algorithm for OFDM (orthogonal frequency division multiplexer) signals designing a self-interference canceler filter for full duplex software-defined radio [30], [31]. Again, electrical balance duplexer and dual-polarized antenna is proposed to achieve a tunable SIC characteristics [37].

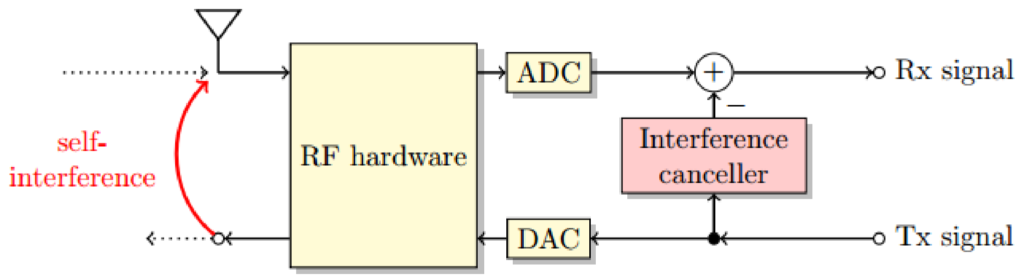

Fig 2. 11: Self-interference cancellation by digital filter [30]

3. Passive SI suppression:

Passive SI suppression [34], [35] is defined as the signal power attenuation imposed by the path loss due to the physical separation between transmit and receive antennas of the same device. Typical passive SI suppression techniques include:

a. **Directional SI suppression:** In this technique, the main radiation lobes of the transmit/receive antennas of an FD device have minimal intersection, enabling the SI to be partially suppressed prior to the receiver's RF front-end [32], [34], [35].
b. **Antenna separation and SI cancellation**: Increasing the path loss between the transmit/receive antennas constitutes an effective approach to attenuate the SI power, in this method, a higher antenna separation implies better SI suppression performance. When relying on antenna separation, the natural isolation may also exploit the surrounding buildings or the beneficial inclusion of a shielding plate, provided that strict restrictions imposed on the device size [32], [33], [34], [35].

4. Mixed-Domain Based DSIC:

The M-DSIC scheme is shown in Fig. 2.11. The information signal, generated by the encoder, is converted to analog form by the DAC and then up-converted to radio frequency by the transmit radio for channel transmission. Through the leakage path of the circulator, the transmitted signal couples into the receive chain. In the front of the receive chain, the received signal subtracts the output of the analog SI reconstruction circuit to cancel the strong SI, targeting to avoid saturating the receive chain. Then the resulting signal is down-converted by the receive radio and fed to the M-DSIC stage, at which the down-converted signal subtracts the analog version of the output of the digital SI reconstruction module to clean out the SI left by the ASIC stage. Finally the ADC samples the desired user signal and feeds the sample points to the decoder.

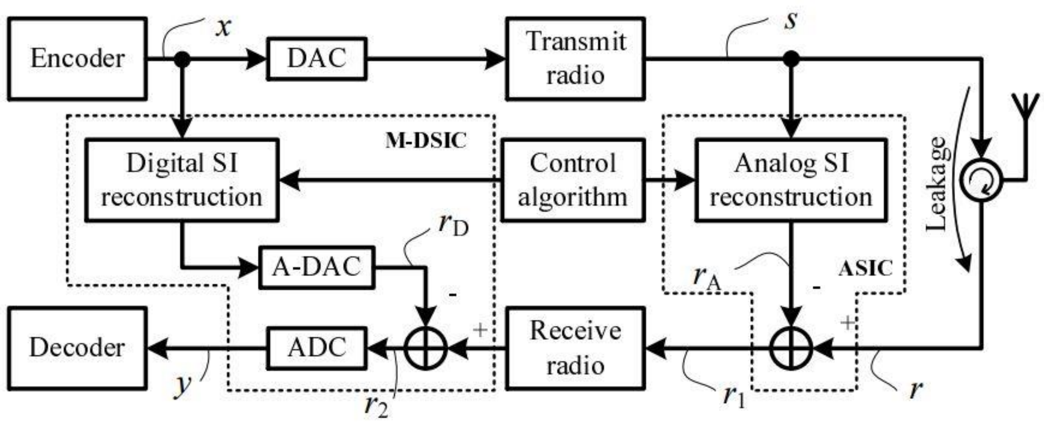

Fig 2. 12: MDSIC scheme [39]

5. Multi Tap delays

A common technique for RF self-interference cancellation in shared antenna architectures is to use a multi-tap RF filter with fixed delay lines and tunable gains. The delays (in the range of 400ps to 1.4 ns) are permanently tuned to the strongest self-interference paths through the antenna. An RF cancellation of about 60 dB is reported (in conjunction with a circulator) [39].

6. Mixed cancellation scheme

The wideband interference spreading across the transmitter TX and receiver RX band and the frequency space in between will be pursued by an analog cancellation filter, with coefficients to be optimized digitally. That is why it is a mixed cancellation scheme. The reference signal for this echo cancellation process will be taken from the output of the power amplifier (PA) to avoid the impact of the transmit chain impairments on the cancellation quality [40].

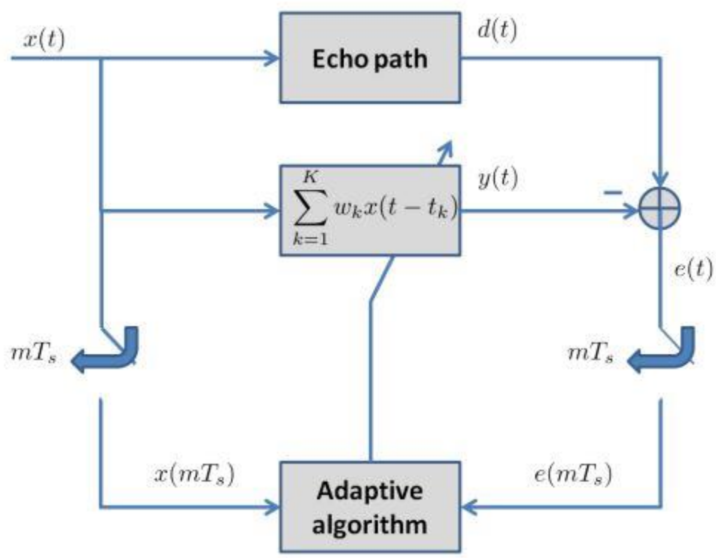

Fig 2. 13: Mixed Cancellation Scheme [40]

2.5 3GPP Path-Loss Model

The 3GPP model is for the channel model(s) for frequencies above 6 GHz up to 100GHz. As 5th Generation cellular communication system supports higher frequency bands (greater than 3GHz), this model is useful in our calculation.

2.5.1 3GPP technique on 5G era:

The 3GPP refers as the 3rd generation partnership project which unites different telecommunication company to gives standard and stable environment for the development of cellular network. Its main function is to provide a complete cellular system specifications like radio and non-radio access, security, service capabilities, quality of service and interworking with WI-FI networks.

Since the first release, the 3GPP technology was about Global System for Mobile Communication (GSM) and Universal Mobile Telecommunication System (UMTS) (which is related to 3G standard). After several number of enhancements in subsequent releases LTE STANDARD have been introduced at 3GPP release 8. Improvements to the standard that enabled LTE to meet the International Mobile Telecommunication Advanced (IMT-A) specifications were attained in release 10 which is included as LTE-Advanced. Some of the enhancements such as the use of small cells known as microcells, femto cells are visualized to be the basis of fifth generation (5G) wireless networks. Thus, LTE and LTE-Advanced have crossed the "generational boundary" offering the next generation(s) of capabilities.

LTE-Advanced Pro is the next to LTE-Advanced which describes what has been achieved with the completion of Release 13. LTE-Advanced Pro is 3GPP's stepping stone to 5G systems narrated at release 14 [41].

2.5.2 Path loss model in 3GPP technology: 3GPP TR 38.900 V14.3.1 (2.017-07) [42]

3GPP has researched on high frequencies above 6GHz up to 100GHz [42] which covers the identification of the expectation of existing information on high frequencies e.g. channel models, spectrum allotment, path loss models on different scenario and so on. At 3GPP TSG RAN (radio access network) #69 meeting the Study Item Description on "Study on channel model for frequency spectrum above 6 GHz" was approved [42]. This study item is documented at 3GPP TR 38.900 V14.3.1 (2.017-07) and the channel model(s) for frequencies above 6 GHz up to 100 GHz. We are considering the channel path loss model from this technical report documents. The result is observed not always consistent with earlier channel models for <6 GHz.

2.5.3 Requirements for 3GPP channel modelling

The requirements for >6 GHz channel modelling for 3GPP are as follows [42]:

- Channel model SI is taken into account for the outcome of RAN-level discussion in the '5G' requirement study item.
- This model considers the complexity of Description, Generating channel coefficients, development complexity and Simulation time.
- This model supports frequency range up to 100 GHz.
- The critical path of this model for the SI is 6 – 100 GHz.
- It deals with mm-Wave propagation aspects for example, blocking and atmosphere attenuation.
- The model is consistent in space, time and frequency
- This model also supports large channel bandwidths (up to 10% of carrier frequency)
- This model is to cover a range of coupling loss taking current cell sizes into account. It should be noted that to validate investigation of the applicability of the 5G system for higher frequency bands this model is proposed.
- It is modified for UT mobility.
- The speed of mobile can be up to 500 km/h.
- This also supports large antenna arrays.

2.5.4 Requirements for 3GPP path-loss model.

The path loss model is applicable for different scenario at Line of Sight (LOS) and Non Line of Sight (NLOS) having log normal shadow fading with some basic criteria like BS height, distance between BS and UT and so on [42].

- The path-loss model supports urban microcell street canyon, urban macro cell, indoor office, and rural macro cell.
- Supported bandwidth is up to 10% of the fc but not larger than 2GHz.
- Supports mobility of one end of the link.
- Supports spatial consistency by correlation of LOS/NLOS state.
- It supports large array which is based on far field assumption and stationary channel over the size of the array.

2.5.5 Path-loss parameters

The 3GPP model discusses the path-loss scenarios for Urban Macro (UMa) indoor and outdoor Rural Macro (RMa) and for Urban Micro (UMi-street canyon) . But as our proposed model is only for outdoor scenarios we are going to discuss the parameters for UMa outdoor and RMa scenarios only.

Table 2. 3: Parameters for UMa scenarios [42]

Parameters		**UMa**
Cell layout		Hexagonal grid, 19 macro sites, 3 sectors per site (ISD = 500m)
BS antenna height h_{BS}		25m
UT location	Outdoor/indoor	Outdoor and indoor
	LOS/NLOS	LOS and NLOS
	Height h_{UT}	Same as 3D-UMa in TR36.873 [43]
Indoor UT ratio		80%
UT mobility (horizontal plane only)		3km/h
Min. BS - UT distance (2.D)		35m
UT distribution (horizontal)		Uniform

Table 2. 4: Parameters for RMa scenarios [42]

Parameters	RMa
Carrier Frequency	Up to 7Ghz
BS height h_{BS}	35m
Layout	Hexagonal grid, 19 Macro sites, 3sectors per site, ISD = 1732m or 5000m
UT height h_{UT}	1.5m
UT distribution	Uniform
Indoor/Outdoor	50% indoor and 50% in car
LOS/NLOS	LOS and NLOS
Min BS- UT distance(2.D)	35m

2.5.6 Equations for 3GPP path-loss model

In 3GPP technology, the distance between BS and UT, two dimensional and three dimensional both the distance are calculated and it is in meters [42].

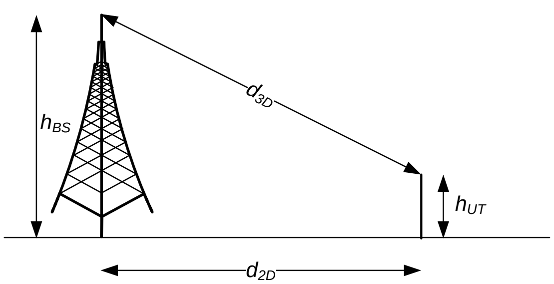

Fig 2. 14: d_{2D} and d_{3D} for outdoor UTs

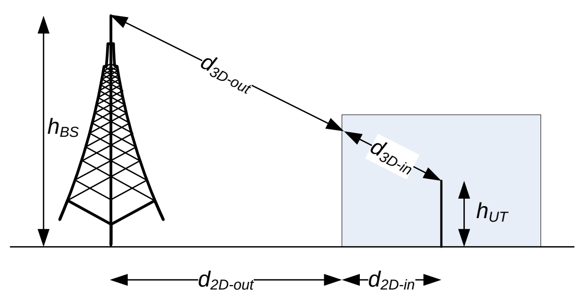

Fig 2. 15: $d_{2D\text{-}out}$, $d_{3D\text{-}out}$, $d_{3D\text{-}in}$ for indoor UTs [42]

Here, h_{BS} is denoted for base station height and h_{UT} is for UT. Mathematically,

$$d_{3D\text{-}OUT} + d_{3D\text{-}IN} = \sqrt{(d_{2D\text{-}OUT} + d_{2D\text{-}IN})^2 + (h_{BS} - h_{UT})^2} \quad (2.1)$$

$$d_{3D} = \sqrt{(d_{2D\text{-}IN})^2 + (h_{BS} - h_{UT})^2} \quad (2.2)$$

This two equation describes the total 3D distance. This is equal to the root of together square of total 2D distance and square of the difference between base station height and user terminal height. Where eq (2.1) is for indoor and outdoor and eq (2.2) is for outdoor only from Fig 2.14 (used in our proposed system model).

The path-loss model equations for LOS and NLOS for UMa and RMa outdoor along with all the parameters are described below:

PATH-LOSS EQUATION FOR UMa :

1. **FOR LOS:**

   Considering the peak to peak distance between BS and UT is d_{3D} in meters, the linear distance between BS and UT is d_{2D} in meters, base station height h_{BS} = 25m, UT height (h_{UT}) within the range($1.5 \leq h_{UT} \leq 22.5$m) , Breakpoint distance is d'_{BP} in meters, and the path-loss, $PL_{UMa\text{-}LOS}$, for UMa LOS scenarios is given by:

$$PL_{UMa\text{-}LOS} = PL_1 \quad \text{for } (10\text{m} \leq d_{2D} \leq d'_{BP}) \tag{2.3}$$

$$PL_{UMa\text{-}LOS} = PL_2 \quad \text{for } (d'_{BP} \leq d_{2D} \leq 5\text{km}) \tag{2.4}$$

Where,

$$PL_1 = 32.4 + 20\log_{10}(d_{3D}) + 20\log_{10}(fc) \tag{2.5}$$

$$PL_2 = 32.4 + 40\log_{10}(d_{3D}) + 20\log_{10}(fc) - 10\log_{10}((d'_{BP})^2 + (h_{BS} - h_{UT})^2) \tag{2.6}$$

$$d'_{BP} = 4\, h'_{BS} h'_{UT}\, fc/c \tag{2.7}$$

Here, the speed of light, $c = 3.0\times10^8$ m/s

Center frequency is fc in Hz

The effective antenna heights at the BS (in meters), $h'_{BS} = h_{BS} - h_E$

The effective antenna heights at the UT (in meters), $h'_{UT} = h_{UT} - h_E$

The effective environment height, h_E = 1m (for UMa)

The variance, σ_{SF} = 4 for shadow fading.

2. **FOR NLOS:**

   Keeping the parameters unchanged, the path-loss for UMa NLOS scenarios, $PL_{UMa\text{-}NLOS}$ is given by:

$PL_{UMa\text{-}NLOS} = max(PL_{UMa\text{-}LOS}, PL'_{UMa\text{-}NLOS})$ for ($10m \le d_{2D} \le 5km$) (2.8)

Where,

$PL'_{UMa\text{-}NLOS} = 13.54 + 39.08log_{10}(d_{3D}) + 20log_{10}(fc) - 0.6(h_{UT} - 1.5)$ (2.9)

For the above case the variance, $\sigma_{SF} = 6$ for shadow fading.

PATH-LOSS EQUATION FOR RMa :

1. **FOR LOS:**

   Considering base station height (h_{BS}) within the range ($10m \le h_{BS} \le 150m$), User terminal (UT) height (h_{UT}) within the range ($1m \le h_{UT} \le 10m$), Breakpoint distance is d_{BP} in meters, Average building height (h) within the range ($5m \le h \le 50m$) and Average street width, W within an applicable range of ($5m \le W \le 50m$) and other parameters same as for UMa, the equation of path-loss for RMa LOS scenarios, $PL_{RMa\text{-}LOS}$ is:

   $PL_{RMa\text{-}LOS} = PL_1$ for ($10m \le d_{2D} \le d_{BP}$) (2.10)

   $PL_{RMa\text{-}LOS} = PL_2$ for ($d_{BP} \le d_{2D} \le 5km$ and $\sigma_{SF} = 6$) (2.11)

Where,

$$PL_1 = 20log_{10}(4\pi d_{3D}fc/3) + min(0.03h^{1.72},10)log_{10}(d_{3D}) - min(0.044h^{1.72},14.77) + 0.002log_{10}(h)d_{3D} \quad (2.12)$$

And the value of variance (σ_{SF}) becomes 4 for shadow fading.

$PL_2 = PL_1(d_{BP}) + 40log_{10}(d_{3D}/d_{BP})$ *(2.13)*

$d_{BP} = 2\pi\, h_{BS}\, h_{UT}\, f_c/c$ (2.14)

c is the propagation velocity in free space (m/s) and fc is center frequency in Hz.

And the value of variance (σ_{SF}) becomes 6 for shadow fading.

2. FOR NLOS:

The parameters and ranges are similar to LOS. The equation for NLOS RMa scenarios, $PL_{RMa\text{-}NLOS}$ is:

$$PL_{RMa\text{-}NLOS} = max\,(PL_{RMa\text{-}LOS}, PL'_{RMa\text{-}NLOS}) \quad \text{for } (10\text{m} \leq d_{2D} \leq 5\text{km}) \tag{2.15}$$

Where,

$$\begin{aligned} PL'_{RMa\text{-}NLOS} = {} & 161.04 - 7.1log_{10}(W) + 7.5log1_{10}(h) - (2.4.37 - 3.7(h/h_{BS})^2)log_{10}(h_{BS}) \\ & +(43.42 - 3.1log_{10}(h_{BS}))(log_{10}(d_{3D}) - 3) + 20log_{10}(fc) \\ & - (3.2(log_{10}(11.75h_{UT}))^2 - 4.97) \end{aligned} \tag{2.16}$$

And the value of variance (σ_{SF}) becomes 8 for shadow fading.

2.6 Thermal Noise

Thermal noise is also known as Johnson-Nyquist noise, Johnson noise, or Nyquist noise. This noise gained its various names because this noise was first detected and measured by John B. Johnson in 1926, and later explained by Harry Nyquist.

This electrical or radio frequency (RF) noise is generated as a result of thermal agitation of the charge carriers which are usually electrons within an electrical conductor. This thermal noise actually occurs regardless of the applied voltage because the charge carriers vibrate not as a result of the voltage but of the temperature. This vibration is dependent upon the temperature. The higher the temperature, the higher the agitation and hence the higher thermal noise level.

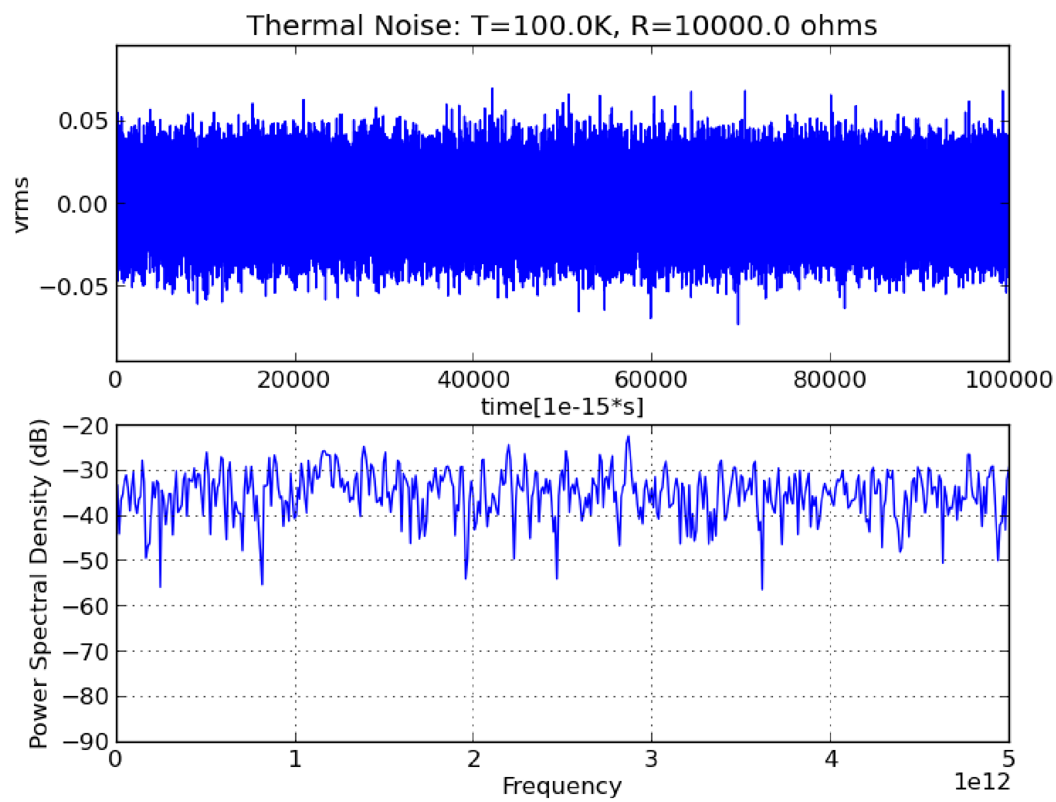

Fig 2. 16: Thermal noise [46]

Thermal noise is effectively white noise meaning that the power spectral density is nearly constant throughout the frequency spectrum. When limited to a finite bandwidth, thermal noise has a nearly Gaussian amplitude distribution [44]. The noise power is proportional to the bandwidth. It is therefore possible to define a generalized equation for the noise voltage within a given bandwidth. The generic, statistical physical derivation of this noise is called the fluctuation-dissipation theorem, where generalized impedance or generalized susceptibility is used to characterize the medium. The equation is as follows:

$$V^2 = 4\,k\,R\,T \int (f1)(f2)df$$

Or, $$V^2 = 4\,k\,R\,T \int (f1)(f2)df \text{ [45]} \tag{2.17}$$

Where:

V = integrated RMS voltage between frequencies f1 and f2

R = resistive component of the impedance (or resistance) Ω

T = temperature in degrees Kelvin

$f1$ and $f2$ = lower and upper limits of required bandwidth

For most cases the resistive component of the impedance will remain constant over the required bandwidth. The simplified thermal noise equation is as follows:

$$V^2 = 4\,k\,T\,R\,B \tag{2.18}$$

Where:

B = bandwidth in Hz

The equation for power is given by:

$$P_n\,[Watts] = V^2/R = 4\,k\,T\,B \tag{2.19}$$

As only half of the source voltage drops across the resistor, the resulting noise power (P_n) can be written as:

$$P_n[Watts] = k\,T\,B \tag{2.20}$$

We can further write the above eq(2.4) in dBm:

$$P_n[dBm] = 10log_{10}(kT \times 10^3) + 10log_{10}(B) \tag{2.21}$$

This equation can be approximated for room temperature (T = 300 K) as:

$$P_n[dBm] = -174 + 10\log_{10}(B) \tag{2.22}$$

$$P_n[Watts] = 10^{(P_n/10)} \times 10^{(-3)} \tag{2.23}$$

Table 2. 5: Noise Power for Different Bandwidth

Bandwidth	**Thermal noise power**	**Notes**
1 Hz	−174 dBm	
10 Hz	−164 dBm	
100 Hz	−154 dBm	
1 kHz	−144 dBm	
10 kHz	−134 dBm	FM channel of 2-way radio
100 kHz	−124 dBm	
180 kHz	−121.45 dBm	One LTE resource block
200 kHz	−121 dBm	GSM channel
1 MHz	−114 dBm	Bluetooth channel
2 MHz	−111 dBm	Commercial GPS channel
3.84 MHz	−108 dBm	UMTS channel
6 MHz	−106 dBm	Analog television channel
20 MHz	−101 dBm	WLAN 802.11 channel

40 MHz	−98 dBm	WLAN 802.11n 40 MHz channel
80 MHz	−95 dBm	WLAN 802.11ac 80 MHz channel
160 MHz	−92 dBm	WLAN 802.11ac 160 MHz channel
1 GHz	−84 dBm	Ultra wide band (UWB) channel

Thermal noise, like other forms of noise, is random in nature. It is not possible to predict the waveform and therefore it is not possible to reduce the effects by cancellation or other similar techniques. Thermal noise is always present in electronic circuits and it is one of the major sources of noise.

In RF circuits, it is often a critical parameter, especially for front end receiver circuits where it is key design parameters. To reduce this noise, we have to reduce either temperature or the number of resistors. Both the options are not plausible.

2.7 Shadow Fading (SF)

If there are any objects (such buildings or trees) along the path of the signal, some part of the transmitted signal is lost through absorption, reflection, scattering, and diffraction. This effect is called shadowing. Shadowing describes the random variation about the distant-dependent large-scale path loss model, and is caused by the received signal power fluctuation due to objects obstructing the propagation path between transmitter and receiver. These fluctuations are experienced on local-mean powers, that is, short-term averages to remove fluctuations due to multipath fading. This is shadow fading effect. This result describes the ranges of path loss values by that one might expect using a distant-dependent path loss model, without having knowledge of the site-specific details of an environment.

When a signal is transmitted from transmitter *TX*, then the transmitted signal is received by the receiver *RX*, the signal strength for the same distance from the *TX* and *RX* is different for different locations depending upon the environmental variation.

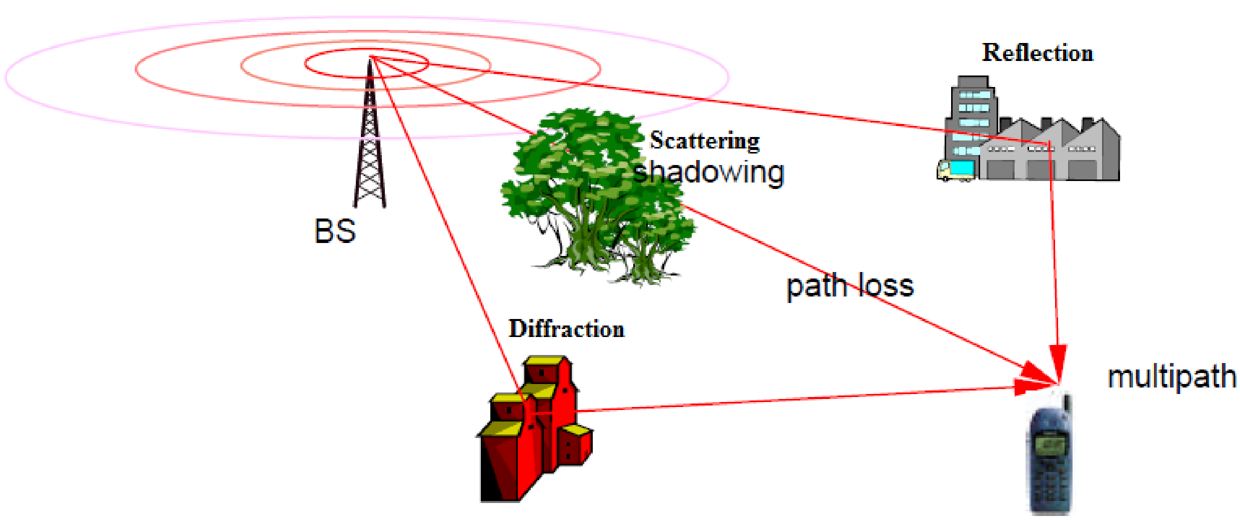

Fig 2. 17: Path loss with shadow fading between TX and RX [52]

In order to determine the shadow fading characteristics, distribution of X is a significant matter which is accurately represented as a log-normal distribution about the distant-dependent mean path loss whose logarithm is normally distributed (zero mean and difference variance for particular location) as shown in [47],[48].

Mathematically,

$$f(X;\mu,\sigma^2) = \frac{1}{X\sigma\sqrt{2\pi}}\exp\left(-\frac{(logX-\mu)^2}{2\sigma^2}\right) \quad (2.24)$$

Fig 2. 18: Shadow fading effect on RX signal power over distance [47].

Here, μ, σ^2 mean and variance of the distribution respectively [47].In general, the random variable $\chi\sigma$ is a zero mean Gaussian random variable, with standard deviation σ_{SF} (in dB). Standard deviation for outdoor location ranging from 4dB to 13dB [49]. Thus, an accurate distant-dependent path loss model that treats path loss as a random variable due to variations of attenuation and shadowing in a channel may be given by:

$$P_L(d)\,[dB] = P'_L(d) + X\sigma$$

$$= P'_L(d_0) + 10\gamma\,\log(d/d_0) + X\sigma \quad (2.25)$$

Here, $X\sigma$ represents the random shadowing effects. where $PL(d)$ is the path loss due to attenuation and the standard deviation σ_{SF} (in dB) is due to shadowing about the distant-dependent mean from *TX* to *RX* or vice versa [47], [48], [50]. In lognormal shadow fading case, lognormal distribution describes the multiplication of large number of random attenuating factors. Despite the fact that the lognormal is the most studied and universally accepted distribution to model shadow fading, many studies show that measurement pdfs have close fit for lognormal pdf but do not have a perfect fit [48], [50], [51] .

2.8 Signal to Interference plus Noise Ratio (SINR)

Signal-To-Interference-Plus-Noise Ratio (SINR), a term specially used in Telecommunication, is a physical model on the availability and quality of connections in a wireless communication network and a measurement of theoretical upper bounds on channel capacity.

SINR is defined as the power of the desired signal divided by the sum of the interference power and the noise power. If the noise power is zero, then the SINR reduces to the signal-to-interference ratio (SIR). Similarly interference power being zero gives signal-to-noise ratio (SNR).

$$\text{SINR} = \text{Signal} / (\text{Interference} + \text{Noise})$$

In our thesis paper SINR calculation is given by

$$\text{SINR} = \text{Received power} / (\text{Self-interference Power} + \text{thermal noise power})$$

The calculation of SINR in dB is given by,

$$SINR\ [dB] = 10 * \log_{10} (SINR) \tag{2.26}$$

SINR is a crucial parameter. For receivers having high demand for sensitivity and anti-interference of devices. With the increase of users the interference increases and effects the SINR of the communication network. Besides, as the base stations use the same frequency, there is an impact on different stations [54].

SINR diagrams is one of the fundamental point to understand how wireless network works, and it is important in the development of suitable algorithms for such networks, analogous perhaps to the role played by Voronoi diagrams in the study of proximity queries and in computational geometry [55].

SINR is dependent on the distance between the TX and RX or the TX and UT or the RX and UT. With the increase in distance there is an increase in path loss thus it decreases the value of SINR.

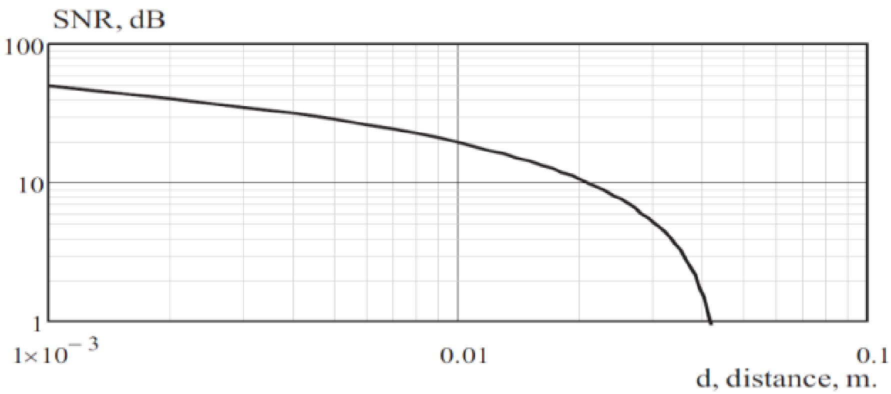

Fig 2. 19: SNR Verses Distance [56]

2.9 Shannon's Capacity

Shannon's Mathematical Theory of Communication [57], [58], [59] can be characterized as the limit of a single-user channel, regarding the shared data between the information and yield of the channel. Additionally, Shannon demonstrated that this limit measures up to the most extreme rate at which solid correspondence can be performed, without any requirements on encoding or decoder unpredictability and delay.

Channel limit is the greatest data rate that can be transmitted over a correspondent channel where to accomplish subjectively little bit error rate (BER) [60]. Before Shannon hypothesis, it was thought that with the expanding of data rate, the error rate increases to a great deal. Specially, it is required to decrease the data transmitting rate to decrease BER. In any case, Shannon's theorem demonstrates that is not right. If the channel reaches its maximum rate, which is known as channel limit, it is difficult to stay away from error probability. On the off chance that data rate isn't greater than channel limit, by adding intelligent skills, it can be possible to get small error probability. In other words, Shannon proved that the mutual information of the channel maximizing over all possible input distributions is equal to the capacity of a large class of single-user time-invariant channels [61]. Shannon capacity is defined as the maximum error free data rate that a channel can support [54].

Shannon-Hartley theorem:

$$C = B * log2\ (1+S/N) \tag{2.27}$$

Here, C = maximum capacity of the channel in bits/second (Shannon's capacity limit)

B = the bandwidth of the channel (Hz)

S = the signal power (Watts)

N = the noise power (Watts)

S/N = Signal to Noise Ratio (SNR). In our calculation we have taken the SINR of the signal.

To transmit an errorless information over a channel, the maximum rate is thus limited by 3 factors: bandwidth, signal level, and noise level.

Shannon capacity theory is one of the most important concepts in wireless communication system. From the Shannon capacity transmitted information rate should be C or lower than C with the smallest error zero with intelligent system coding. But, for transmission rate higher than *C* it is more likely impossible to transmit errorless information. Shannon's theory is also base of spread spectrum techniques.

From the above equation for the channel capacity:

1. Bandwidth limits the information symbol rate that can be sent over the specific channel.
2. The SNR ratio limits the information that can be squeezed in per transmitted symbols. With the increase in SNR transmitted symbols becomes less noisy.
3. The SNR and the allocated bandwidth have to be interchanged for increasing the information rate.
4. The SNR becomes infinite as noise becomes zero and so information rate will be infinite over a small bandwidth.

However, with an increase in bandwidth the noise power also increases. Thus the channel capacity cannot become infinite even though the bandwidth tends to zero.

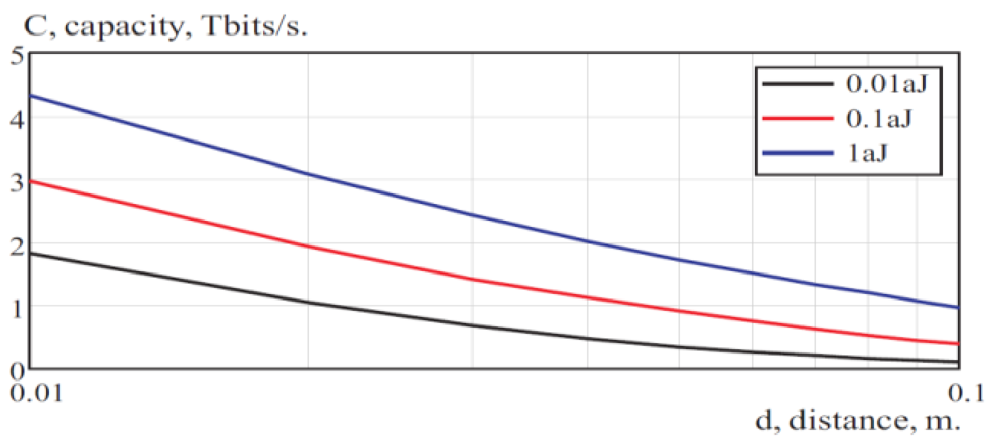

Fig 2. 20: Channel Capacity with different energy from signal of interest [54]

CHAPTER 3

SYSTEM MODEL AND PERFORMANCE ANALYSIS

Our system model describes a modified version of Distributed Antenna System (DAS) for implementation of 5G technology minimizing the SI.

3.1 Assumptions

- The considered cell is a macro cell in a homogenous cellular network.
- The wireless communication is based on the FD system, i.e. same frequency band is used for both transmission and reception simultaneously.
- Inter-cell interference was ignored.
- Different cells use different frequencies which are orthogonal to each other resulting in zero inter-cell interference.
- Proposed model is for uplink cellular communication.
- A user can be connected to only one DAS and the BS at a time.

3.2 Proposed System Model

Our model is based on In-band FD system for uplink communication using DAS. The equations of chapter 2 (2.5.6) are used for path-loss calculations which are based on 3GPP model. The proposed system model exploits a macro cell in a Homogenous Network consisting of a receiver approximately at the center and multiple transmitters. The proposed cell is defined by the coverage area of the receiver along with the transmitters which are within the receiver's perimeter.

Since full duplex method is used to transmit and receive signals simultaneously using the same frequency band, there exists Self Interference which is one of the major concerns in this model. The closer the transmitters and receiver are, the more SI there will be. Therefore we propose to separate transmitter and receiver entirely to reduce SI considerably. We used a single receiver at the center of the cell. The transmitters are distributed within the coverage area of the receiver. Transmitters will only transmit signals and receiver only receives signals. Every transmitter and receiver works individually not as transceiver. In our calculation only a single user is placed randomly in the cell at a time. This is our proposed Distributed Antenna System model which is a modified take on the traditional system mentioned above. Fig 3.1

UT connects to the receiver and the nearest transmitter. The receiver receives signal from the UT and the transmitter transmits signal to the UT, individually.

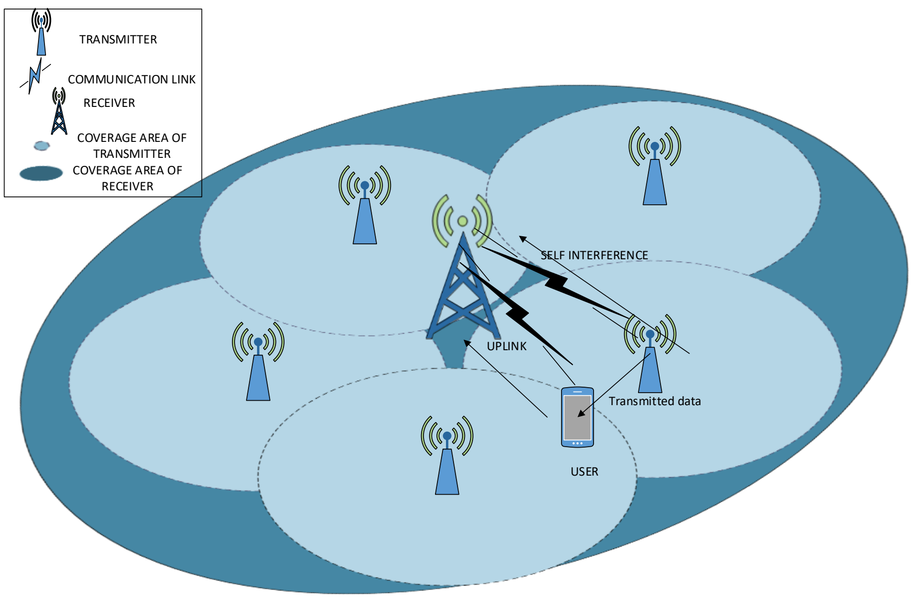

Fig 3. 1: Full duplex uplink exploiting DAS

For a traditional Distributed Antenna system in case of implementing FD, interference degrades the SINR output resulting in a far worse signal strength and crosstalk. In this model all the nodes work as transceivers. During a phone call, UT sends and receives signal from the same node resulting in major SI. Since same frequency is used for transmission and reception simultaneously, the receiver of DAS will receive the received signal of User Terminal (UT) as well as a portion of the transmitted signal as self-interference shown in Fig 3.2. Eventually, this self-interference will also occur between the transmitter and receiver of the UT.

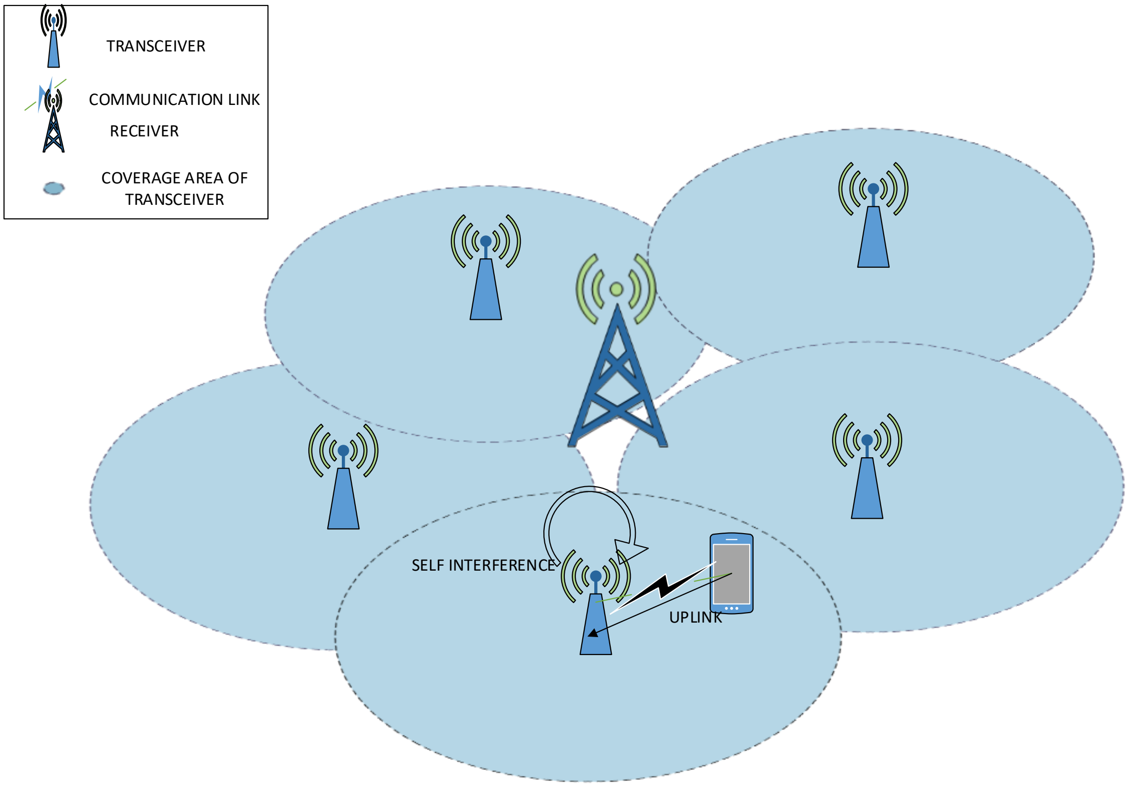

Fig 3. 2: Full duplex uplink exploiting Traditional DAS

3.3 Received Power and SINR Calculation

The received power is calculated from the equation below:

$$Pr = Pt - Pl + X \tag{3. 1}$$

Where, $Pr = Received\ power$ [dB]
$Pl = Path\ loss$ [dB]
X = Shadow fading [dB]

Our calculation is based on two cases:

1. <u>Calculation of received power from the UT for uplink :</u>

$$Pr = Pt\,(\mathrm{UT}) - Pl\,(\mathrm{UT}) + X \quad (3.2)$$

$$Pr(W) = 10^{(Pr/10)} \quad (3.3)$$

P_t(UT) is the transmitted power from the UT to the receiver in the center and P_l (UT) is the path-loss from the UT to receiver. X is the value of Shadow-fading explained in chapter 2 (2.7). All the units of eq 3.1 are in dB. $P_r(W)$ is the received power taken in Watts for calculation from eq (3.2).

2. <u>Calculation of received SI power from the DAS (transmitter):</u>

   The SI power is received from the transmitter connected to UT shown in the Fig.3.2

   This power deteriorates the performance of the system. According to our model the SI power can be calculated:

$$Pi = Pt\,(\mathrm{DAS}) - Pl\,(\mathrm{DAS}) + X \quad (3.4)$$

$$P_i(W) = 10^{(\,Pi/10)} \quad (3.5)$$

P_i is the SI power received from the DAS where P_t (DAS) is the transmitted power coming from a certain DAS. P_l (DAS) is the path-loss from the DAS to the receiver. All the units in eq (3.4) are in dB. $Pi(W)$ is the received SI power taken in Watts for calculation from eq (3.5).

For traditional DAS system the SI power is calculated:

$$P_i\,(\text{traditional das}) = P_t\,(\mathrm{DAS}) \quad (3.6)$$

$$\mathrm{SINR} = Pr/\,(P_i + P_n) \quad (3.7)$$

Here P_n is the thermal noise power in Watts explained in eq (2.22) and eq (2.23) earlier in Chapter 2 (2.6). The bandwidth for noise power is selected from the Table 2.5 for one resource block in LTE. This is the SINR calculation for our proposed model.

$$\mathrm{SINR} = Pr\,/\,(P_i + P_n) = Pr/(P_t + P_n) \quad (3.8)$$

Eq (3.8) is used for calculating the SINR of a transceiver in traditional DAS system.

The SINR calculated in dB is taken from eq (2.26).

3.4 Performance Analysis and Result Discussion

To get the results from simulation the approximate cell radius taken for most of the simulation was 4km where the BS is always at the center and the number of DAS is 5. The distributed antennas are at 2.67 km from the BS. The optimum frequency range for 5G can be described by 3GPP path-loss model (6-100GHz). The equations are used for calculating path-loss between BS-UT and BS-DAS. The results are based on the parameters of Table (2.3 and 2.4).

3.4.1 SINR performance varying frequency for UMa (LOS)

The following Fig 3.3 shows the graphical plot of Cumulative Distribution Function (CDF) of SINR varying frequency for users taken for LOS. Performance develops as frequency goes higher.

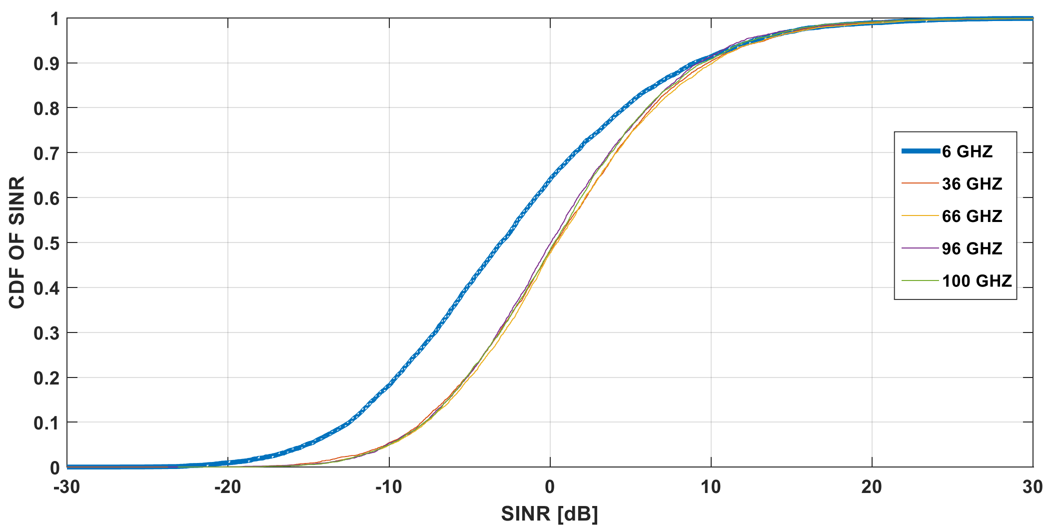

Fig 3. 3: SINR performance varying frequency (Proposed DAS system for users at LOS)

3.4.2 Average SINR varying frequency for UMa scenarios (NLOS)

This Fig 3.4 shows the plot of average SINR varying frequency for NLOS in UMa scenarios. The lowest frequency used, shows the best output.

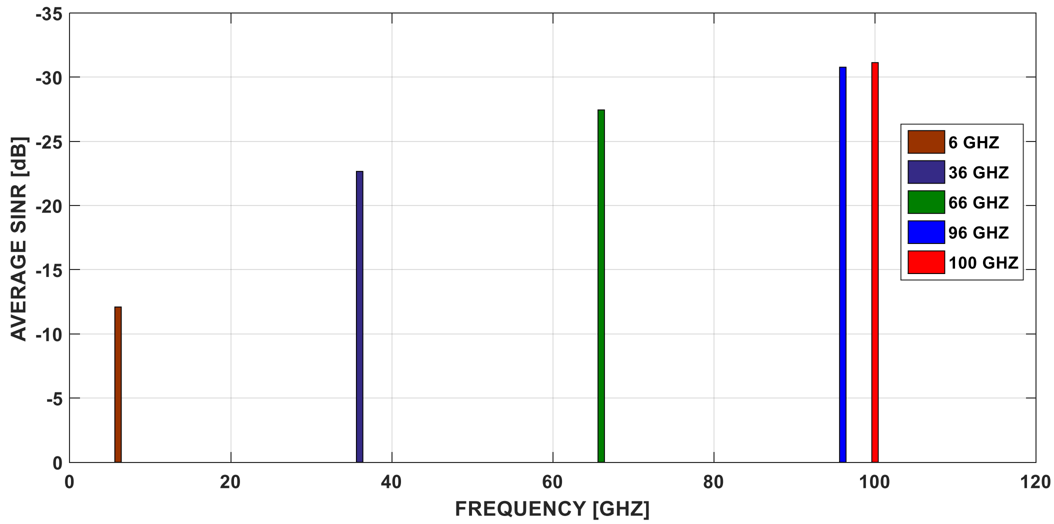

Fig 3. 4: Average SINR varying frequency (Proposed DAS system for LOS).

3.4.3 SINR performance varying UT transmitted power for UMa scenarios (NLOS)

The increase in transmitted power of UT shown in Fig 3.5 raises the performance of the system for a fixed distance and frequency.

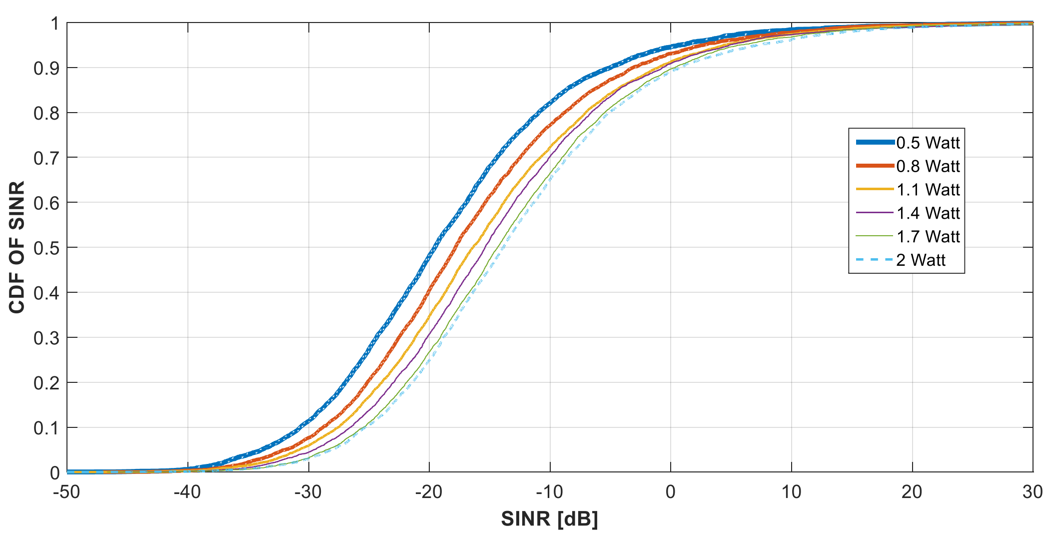

Fig 3. 5: SINR Performance Varying User Transmitted Power

3.4.4 Throughput varying frequency for UMa scenarios (LOS)

The following Figure shows a comparison among the throughputs of urban macro cell scenarios (LOS) while frequency was varied. It can be seen that throughput becomes invariant after 26 GHz. And For 6GHz, throughput is better than the rest.

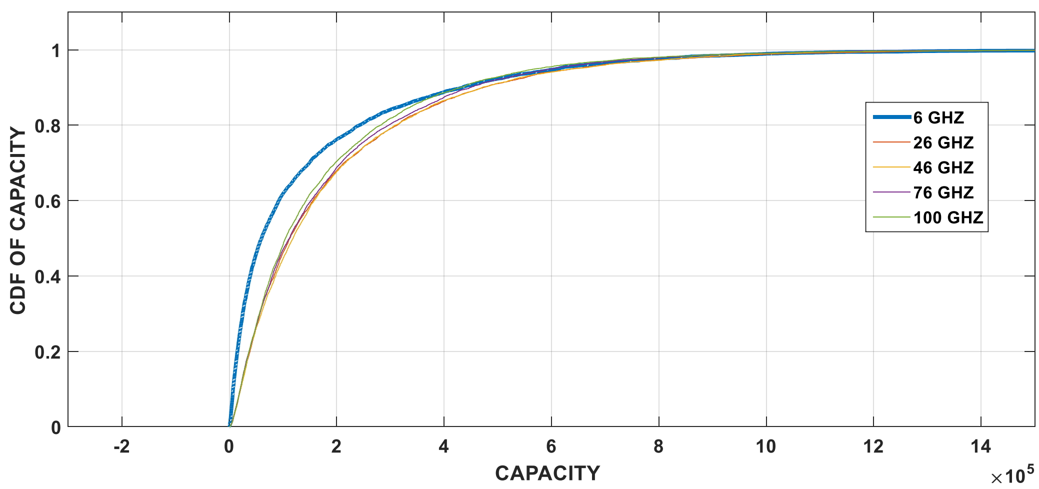

Fig 3. 6: Throughput varying frequency (UMa LOS)

3.4.5 Throughput varying frequency for UMa scenarios (NLOS)

The following Figure shows a comparison among the throughputs of urban macro cell scenarios (NLOS) while frequency was varied. The result seems quite different from the LOS scenario. In this case the performance is enhanced with the increase of frequency.

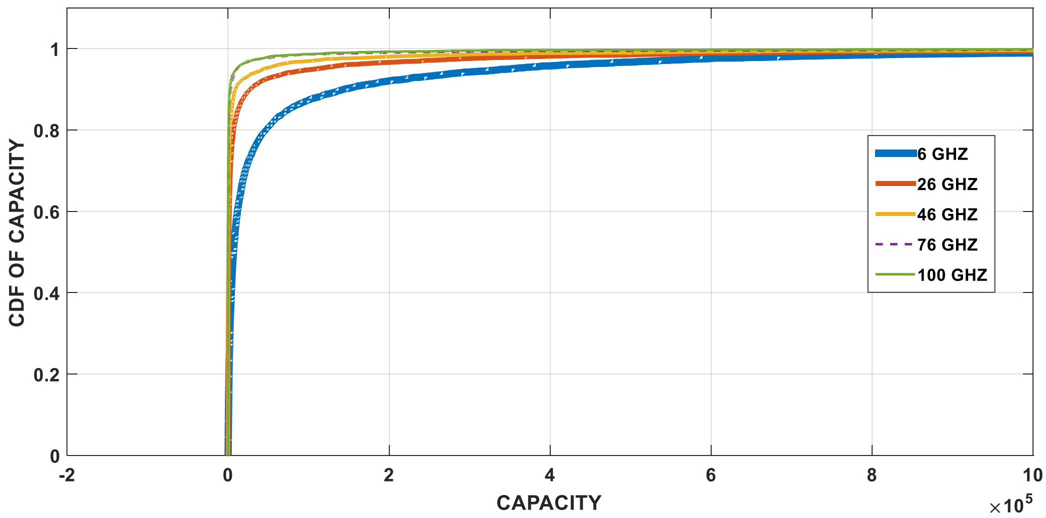

Fig 3. 7: Throughput varying frequency (NLOS)

3.4.6 Throughput varying distance of DAS for UMa scenarios (LOS)

The following Figure shows a comparison among the throughputs of urban macro cell scenarios (LOS) while distance of DAS from the receiver was varied. Performance is best when distributed antennas are positioned at a distance of 500m from the receiver. The output degrades with the increase of distance.

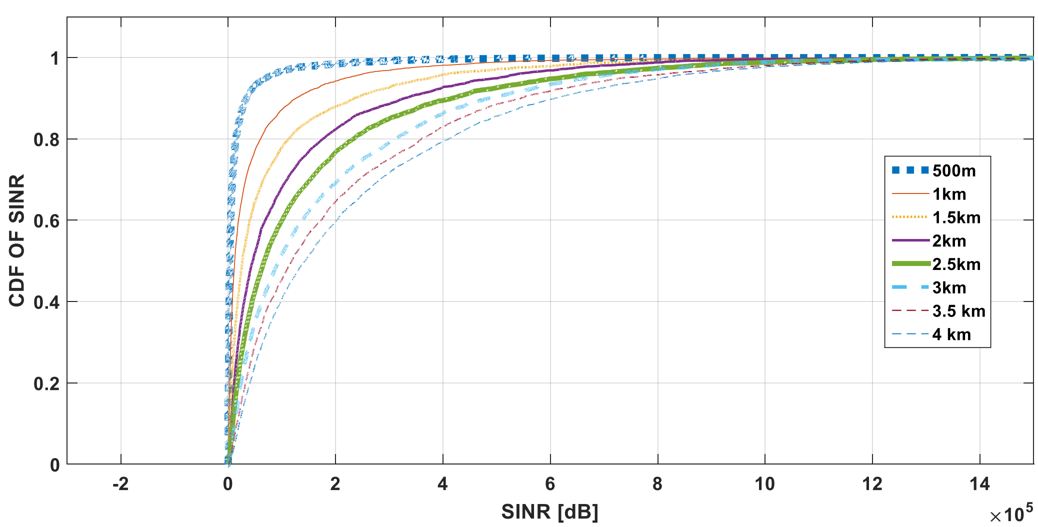

Fig 3. 8: Throughput varying distance of DAS for UMa scenarios (LOS)

3.4.7 Throughput varying distance of DAS for RMa scenarios (NLOS)

The following Figure shows a comparison among the throughputs of urban macro cell scenarios (NLOS) while distance of DAS from the receiver was varied. Performance is best when distributed antennas are positioned at a distance of 500m from the receiver. The output degrades with the increase of distance.

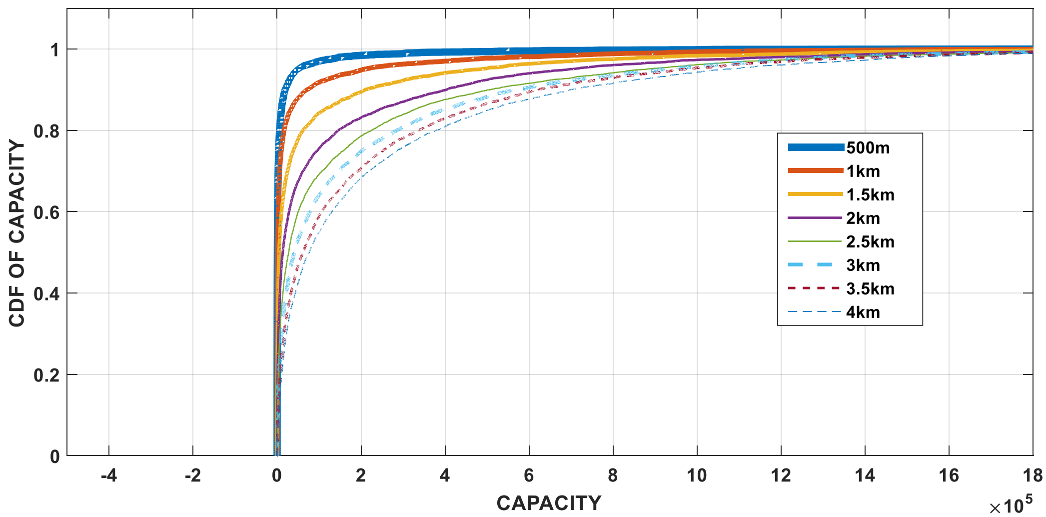

Fig 3. 9: Throughput varying distance of DAS for RMa scenarios (NLOS)

3.4.8 SINR performance varying number of DAS

Simulation was ran varying the number of DAS while keeping the cell radius, frequency, and distance of DAS intact. From the following figures, it can be seen in Fig 3.10 and Fig 3.11 that, the number of das is not effecting our proposed model that much.

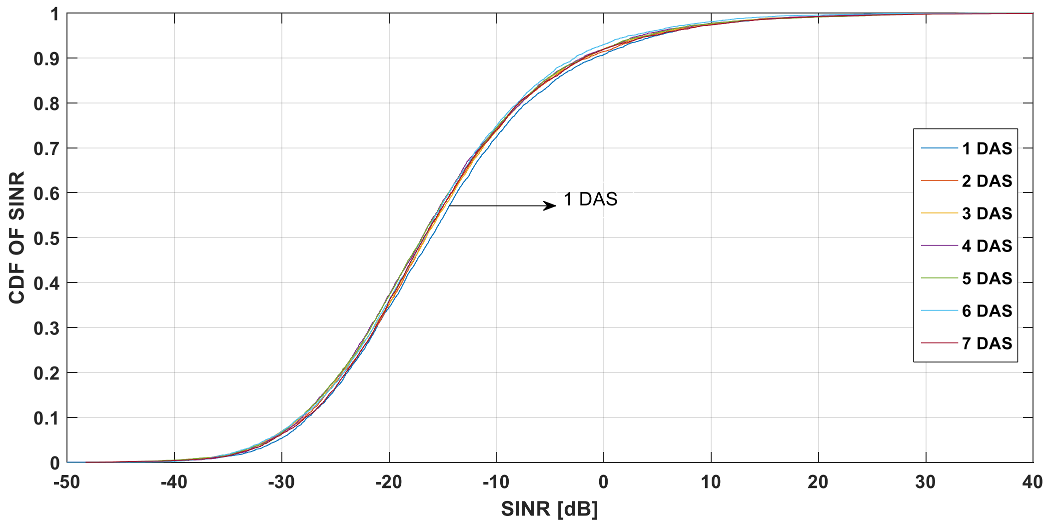

Fig 3. 10: SINR performance varying number of DAS (NLOS UMa)

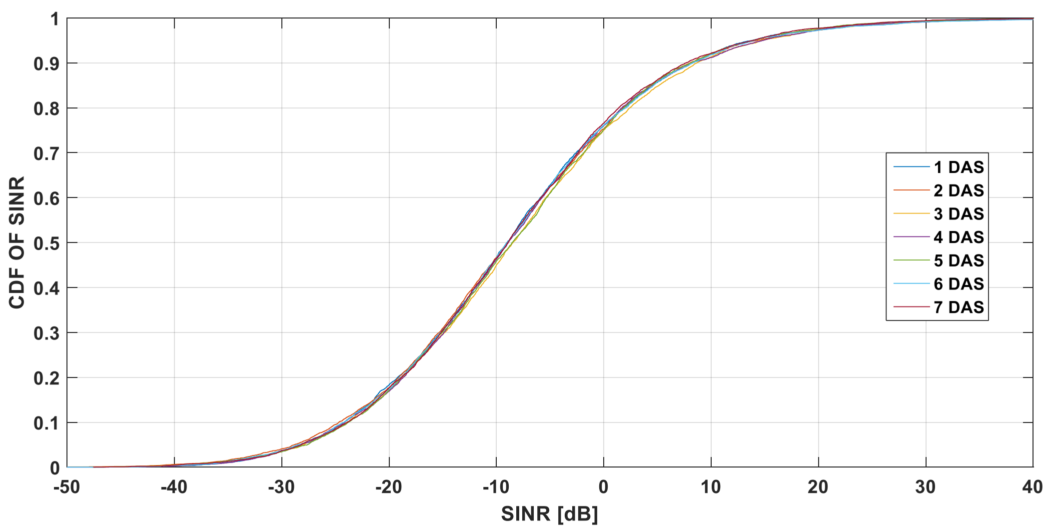

Fig 3. 11: SINR performance varying number of DAS (NLOS RMa)

3.5 Optimum Position of DAS

When the DAS are closest to the BS performance degrades the most due to SI. Gradual increase in distance improves the quality of system. Although the path-loss increases with the distance, the impact of path-loss is comparatively lesser than SI. So it can be concluded that SI is the dominating parameter.

3.5.1 SINR performance varying distance of DAS from receiver for 7GHz NLOS UMa scenario

The following Figure shows a comparison among the SINR of urban macro cell scenarios (NLOS) at 7GHz fixed frequency while distance of DAS from the receiver was varied. Performance is best when distributed antennas are positioned at the furthest distance from the receiver as SI reduces with the increase in distance. The output degrades with the decrease of distance. Thus the optimum location of DAS is between 3.5 and 4km within the cell radius.

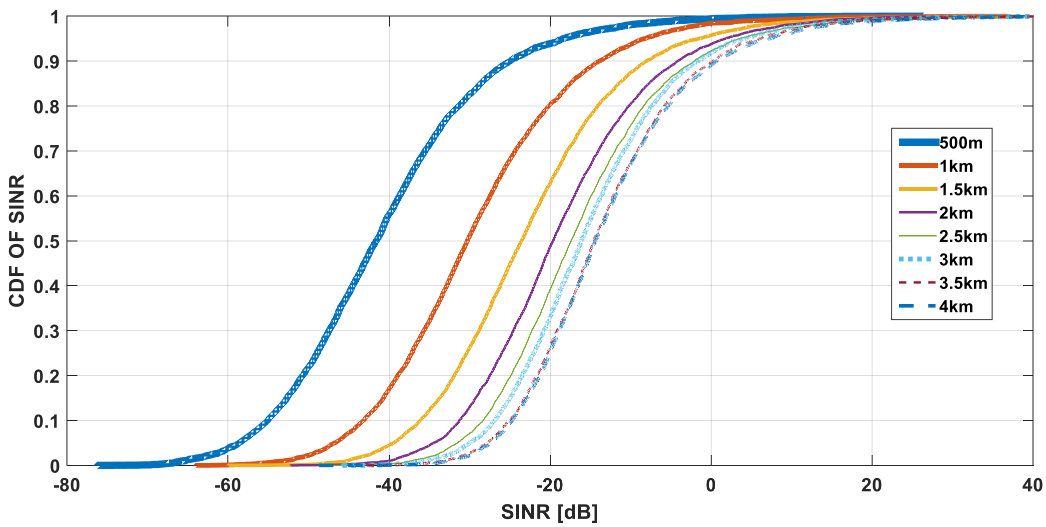

Fig 3. 12: SINR performance varying distance of DAS from receiver for 7GHz NLOS UMa scenario.

3.5.2 SINR performance varying distance of DAS from receiver for 7GHz NLOS RMa scenario

The following Figure shows a comparison among the SINR of rural macro cell scenarios (NLOS) at 7GHz fixed frequency while distance of DAS from the receiver was varied. Performance is best when distributed antennas are positioned at the furthest distance from the receiver as SI reduces with the increase in distance. The output degrades with the decrease of distance. Thus the optimum location of DAS is between 3.5 and 4km within the cell radius.

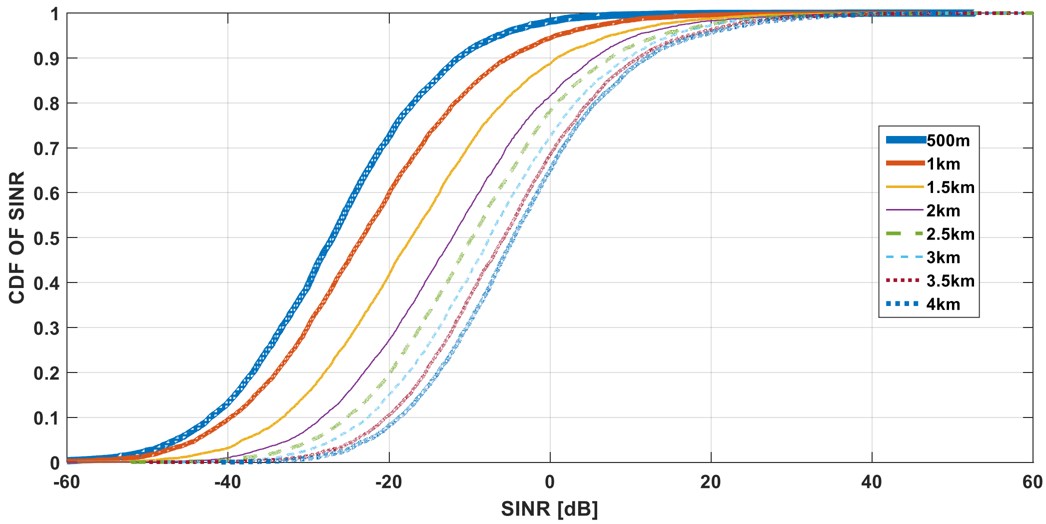

Fig 3. 13: SINR performance varying distance of DAS from receiver for 7GHz NLOS RMa scenario

3.6 Comparison between Proposed Model and Traditional DAS

For the traditional DAS system, as every DAS works as a transceiver, a huge amount of SI is present. Thus the SINR becomes worse using FD.

3.6.1 SINR performance varying frequency for UMa (NLOS)

Simulation was run for conventional DAS and proposed model for UMa NLOS scenario with same parameters. From the following two figures, it can be concluded that our proposed shows 6 times better SINR than conventional DAS.

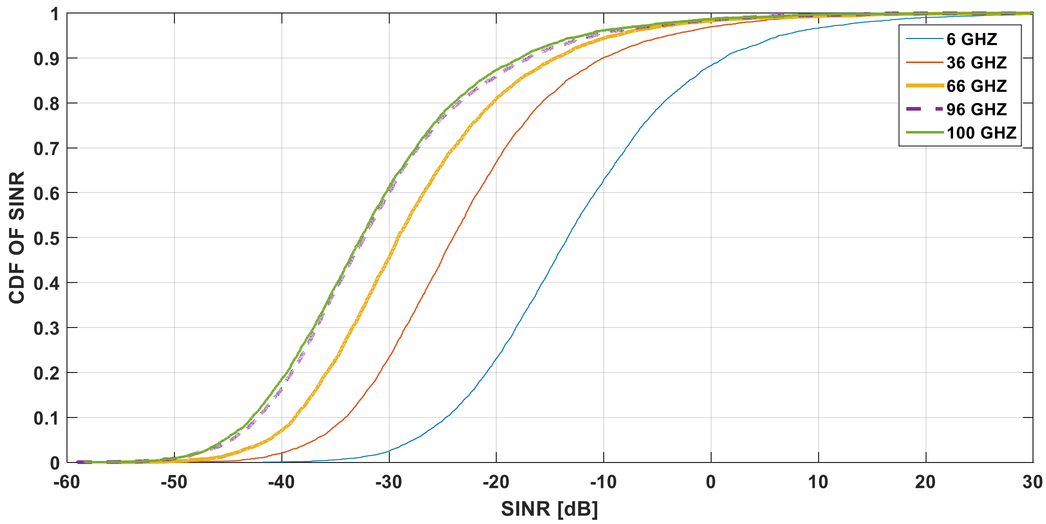

Fig 3. 14: SINR performance varying frequency (Proposed DAS system for users at NLOS)

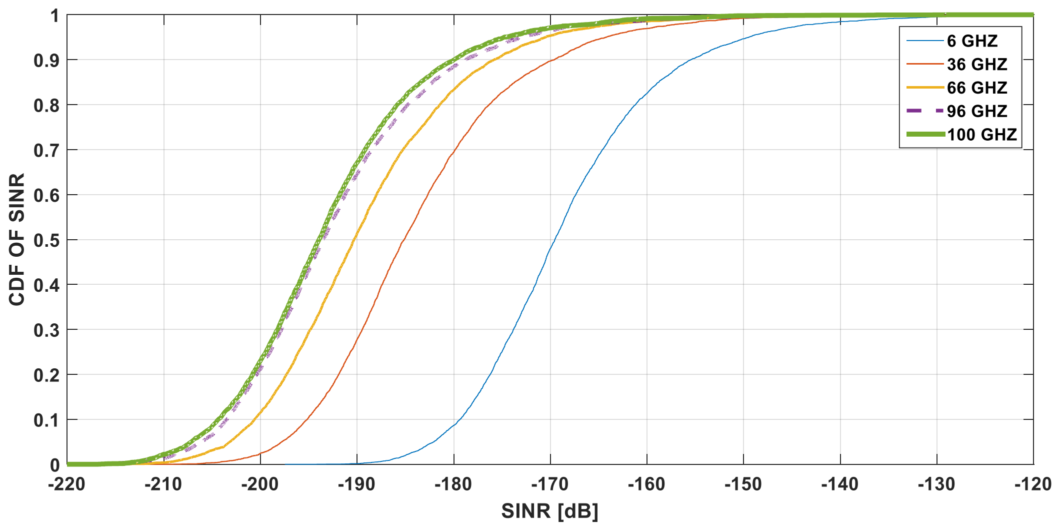

Fig 3. 15: SINR performance varying frequency (Traditional DAS system for UMa NLOS)

3.6.2 SINR performance for 7GHz frequency for RMa (LOS and NLOS)

Simulation was run for conventional DAS and proposed model for RMa NLOS scenario with same parameters. From the following two figures, it can be concluded that our proposed shows 6 times better SINR than conventional DAS. The situation is quite similar to the Uma scenario.

From the 3GPP path-loss model the frequency range for RMa is 7GHz.

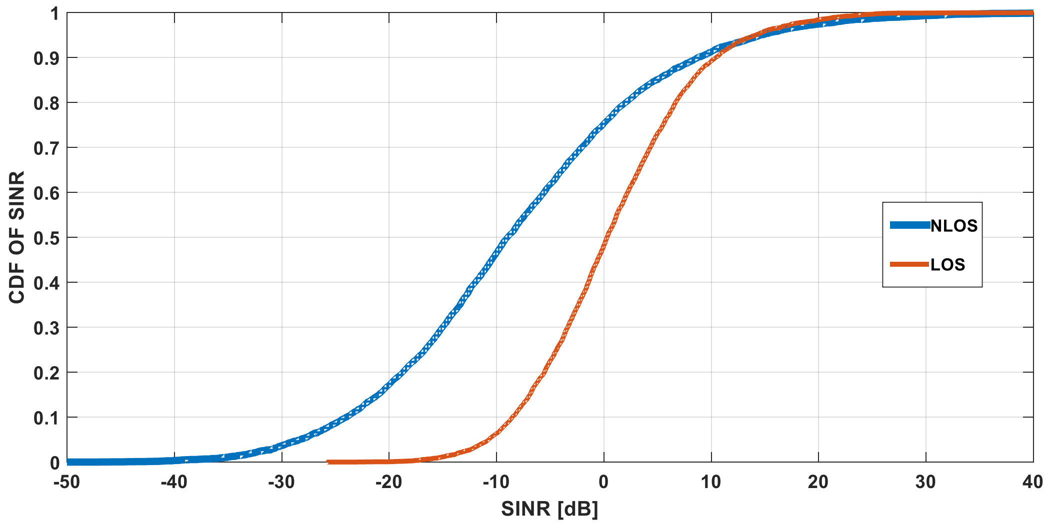

Fig 3. 16: SINR performance for 7GHz frequency (Proposed DAS system for RMa for LOS and NLOS)

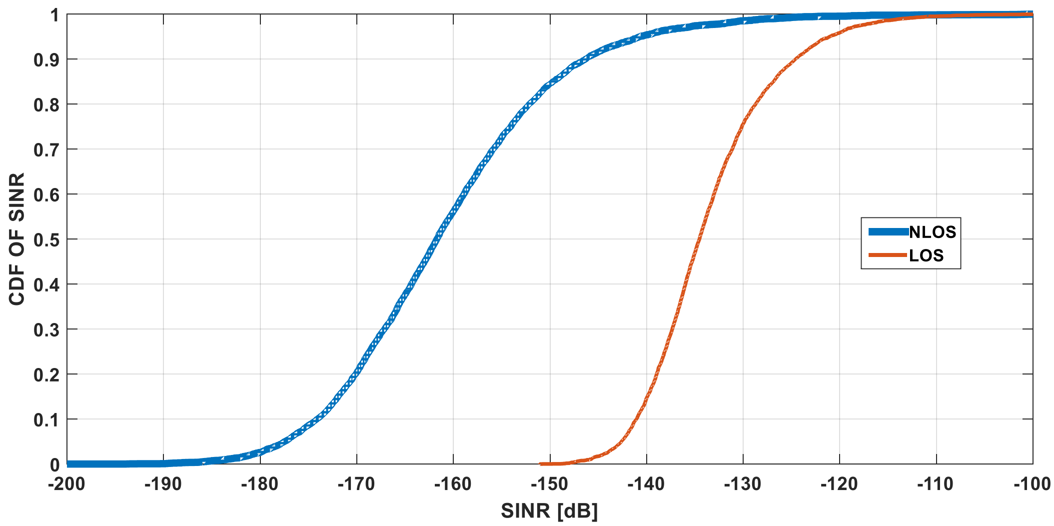

Fig 3. 17: SINR performance FOR 7GHz frequency (Traditional DAS system for RMa LOS and NLOS)

CHAPTER 4

CONCLUSION AND FUTURE WORKS

4.1 Conclusion

In order to cope up with the fast growing usage of cell phones, cellular network has to be expanded worldwide. Number of users are increasing day by day. And to meet with their demands with a limited resource, cellular network has to develop issues regarding coverage and frequency bandwidth.

To fulfill this growing demand, this thesis is proposed. The system model presented in this thesis comprises of two technologies – Full Duplex communication and Distributed Antenna System. Simulation was ran for different case scenarios and various parameters were changed to see their impact on the network. The findings are summarized below

- After investigation, we found that, for traditional DAS (where the nodes perform as transceiver), the SINR was quite bad due to a huge amount of SI. But for the proposed DAS (with the same parameters), the SINR was much better in comparison.
- The performance of SINR as well as throughput of this 5^{th} generation communication network in NLOS scenario is better when a lower frequency is used. The performance becomes saturated after a certain frequency. But in LOS scenario, output is better when frequency is higher.
- When DAS is closest to the receiver, the overall system performance is the worst. Gradual increase in distance enhances the output of the system.

4.2 Future Works

- **Downlink Communication:** This research is for uplink communication. It can be extended for downlink communication.
- **ICI:** This system model ignored Inter cell interference. Further research can be done to reduce ICI.
- **Positioning of DAS:** From this system model we can further research the optimum location of distributed antennas to cope up with the call traffic.
- **Number of DAS:** From this system model we can further research the optimum number of DAS based on traffic density.
- **Indoor DAS:** From this system model we can further research indoor DAS cellular communication.
- **Heterogeneous Network:** This system model is for homogenous communication network. This research can be extended for heterogeneous network.
- **CoMP Transmission and Reception:** This research can be further extended for Co-ordinated multipoint transmission and reception that enable dynamic coordination or transmission and reception with multiple geographically separated distributed antennas.

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