ANALYSIS OF GFDM AS AN EFFICIENT WAVEFORM FOR 5G NETWORKS

DISSERTATION-II

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By

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CERTIFICATE

This is to certify that the Dissertation-II entitled "**Analysis of GFDM as an Efficient Waveform for 5G Networks**" which is being submitted by ***Pawan Kumar*** in partial fulfillment of the requirement for the award of degree Masters of Technology in Electronics and Communication Engineering to Lovely Professional University, Jalandhar, Punjab is a record of the candidates own work carried out by her under my supervision. The matter embodied in this report is original and has not been submitted for the award of any other degree.

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DECLARATION

I, Pawan Kumar, student of M. Tech under the department of School of Electronics and Electrical Engineering of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation-II report is based on my own intensive research and is genuine.

This Dissertation-II does not, to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university or any other university without proper citation.

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ABSTRACT

In today's era the wireless communication is growing day by day with a tremendous rate. In the previous communication methods there were several shortcomings like the cost of the communication setup was more and many more. But with the advent of wireless communication we started to use the wired medium less for communication like we shifted from telephones to cell phones. Today the smart phones and mobile phones are getting developed day by day because of improvements in the traffic of mobile data. As far as the twenty first century is concerned the data rates and speed of mobile communication network is increasing day by day. Earlier Long Term Evolution (LTE) is the standard for the fourth generation cellular mobile communication systems. In order to increase the speed and capacity of mobile telephone network LTE is the last step towards fourth generation (4G).

GFDM is the waveform contender for the 5G technology. It is having a lot of advantages over the LTE based systems. GFDM outperforms the OFDM by providing low out of band emission. Along with this the spectral efficiency of the GFDM is better than that of OFDM. The GFDM also provides the best bandwidth utilization as it uses only one CP in it. The major thing that is required to add here is it also provides the low peak to average ratio (PAPR).

In the present report various aspects of wireless communication and along with that current technology that are being used are discussed. Along with this the various MIMO-GFDM diversity schemes such as maximum ratio combining and selection combining will be discussed. The separate analysis of AWGN channel with maximum ratio combining and selection combining is done along with the analysis of the Rayleigh channel with maximum ratio combining and selection combing in this. The BER of the pulse shaping filter such as Raise cosine (RC), Gaussian and Square Root Raised Cosine (SRRC) are also calculated.

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LIST OF ABBREVIATIONS

AMPS	Advance Mobile Phone Systems
BPSK	Binary Phase Shift Key
BER	Bit Error Rate
CDMA	Code Division Multiple Access
CP	Cyclic Prefix
CSI	Channel State Information
EDGE	Enhanced Data Rates for GSM Evolution
FFT	Fast Fourier Transform
FDD	Frequency Domain Duplexing
FDMA	Frequency Division Multiple Access
GSM	Global Service for Mobile
GPRS	General Packet Radio Service
HSDPA	High Speed Downlink Packet Access
IEEE	Institute of Electrical and Electronics Engineering
IFFT	Inverse Fast Fourier Transform
IMT-Advanced	International Mobile Telecommunications Advanced
ISI	Inter symbol Interference
ICI	Inter Carrier Interference
ITU-R	International Telecommunications Union-Radio
MRC	Maximal Ratio Combining
SC	Selection Combining
ML	Maximum Likelihood
MC	Multi-Carrier
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output

MU-MIMO	Multiple User Multiple Input Multiple Output
SU-MIMO	Single User Multiple Input Multiple Output
SISO	Single Input Single Output
SIMO	Single Input Multiple Output
STC	Space-Time Codes
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Key
QOSTBC	Quasi-orthogonal space time block coding
UMTS	Universal Mobile media transmission Systems

CHAPTER 1 INTRODUCTION

1.1 Wireless communication

In the 21st century wireless communication is the fastest growing field. People are more worried about the new technologies that are coming because it is making their life better. Our mobile phones have passed from the tremendous growth phases. We can compare the situation of our traditional cellular phones with the cell phones that we are using today [1]. Moreover the cell phones are used as an important tool for doing business. Also the wired systems are today replaced by the wireless systems in colleges, offices and home locations. We can clearly see the growth phase of the growth phase of the laptops which was started from the personal computers. In this chapter the various wireless systems, their origin and their applications in today's field will be discussed.

1.2 History of wireless communication

If we talk about the first wireless system then we can say that it was before the industrial phase time period when it was used [1]. In that case people used to communicate with each other via wireless channel using the techniques that uses mirrors, smoke, flares etc. The destination locations were in general building at the top of the hills and also adjoined to the roads so that the message can be further transmitted up to the longer distances. Then after some time period telegraph replace these systems. Telegraph network idea was given by the one of the known person of that time Samuel Morse in the year 1838. And after sometime it was further replaced by the telephone.

After the invention of the telephone network around 1895, an introductory transmission of radio signals from a distance of eighteen mile was started from a place called Wight isle for a tugboat. This is how our radio communication came into existence. Then modifications after modifications made us able to transmit the radio signal very effectively and fast up to the longer distances. These modified signal systems were having a significant quality of signal, less power consumption, smaller in size and most important these were too much costly that helped people to use them for their needs [2].

In the starting phase of wireless communication signals which were transmitted were analog in nature. But in today's scenario mostly we are using the digital signals. A radio which is digital in nature can do two different things-either it is going to send a continuous bit data or it do grouping of the bits by converting them into packets. The radio which do grouping of the bits into the packets is known as packet radio. This radio is differentiated by its transmission in the form of the bursts. The packet radio remains free until it is sending the packets.

The first network which was dependent on packet radio was ALOHANET. University of Hawaii in 1971 develops this. There were computer sites putted at the seven campuses which helped to make a connection with the central computer which as on Oahu with the radio transmission. The network structure used for it was the star topology. In this topology a hub was present at the center of the topology and any of the two terminal having computers connected to them can communicate with each other. The ALOHANET applied a certain set of rules for accessing the channel and also for the routing process in packet radio systems. The U.S. military was to a great degree keen on the mix of data in the form of packets and communicate radio intrinsic to ALOHANET.

In the entire seventh decade of twentieth century as well as in the beginning of eighth decade an USA defense agency popularly known at that time as DARPA provide good support for making such networks that use radio packets in better transmission of messages while fighting field. The hubs under such specially appointed remote systems is having capacity of programming itself inside the system and do not asking any guide from settled frameworks. Defense advanced research project agency interest in specially appointed systems crested in the mid 1980's; however the subsequent systems missed the mark regarding desires as far as speed and execution. These systems keep on being created for military utilize. Bundle radio systems likewise discovered business application in supporting wide-zone remote information administrations [2].

These administrations, presented in the mid 1990's, empower remote information get to (electronic mail counting, exchanging of files, and performing browsing on the web) in genuinely less rate, when requested for 20 Kbps. A solid demand of the given data services which are wireless and wide in area are not actually seen because they have the rate of data very low, cost is more, as well as there is absence of applications which are destroyer in nature [3]. In the ninth decade of the twentieth century the discussed services got vanished which were later on replaced through the abilities of wireless systems in case of data for local area networks as well as by others. In the other category the cellular telephone can be considered. Given presentation of wired Ethernet innovation in the 1970's guided numerous business organizations far away systems administration which were radio based. The information rate of Ethernet which was 10 Mbps far surpassed unspecified accessible radio which is utilized. The organizations do not bother if they are using wires in their offices for high speed. The empowerment of business advancement was done by the federal communication commission in 1985 by approving general usage of medical as well as industrial bands for the products of local area networks.

Industrial, scientific and medical bands were extremely alluring for the vendors of local area networks as it is not necessary for getting the license from federal communication commission for that band operation. In any case, remote local area networks frameworks couldn't meddle in respect to essential industrial, scientific and medical bands clients, that constrained these for the utilization of profile which is of low power as well as a ineffective messaging plan. In addition, the obstruction from essential clients inside this recurrence band was very high. Subsequently these underlying remote LANs had extremely poor execution regarding the rate of information as well as scope. The bad execution, when mix along the worries in regards to the safety and when institutionalization is absent, as well as huge price is concerned then it is brought about feeble deals. Few of these frameworks were really utilized for information organizing: those are consigned for the implementation of low technology i.e. controlling of stock [3]. Given present era of remote local area networks, in view with the group of 802.11 principles of the IEEE, results in good execution, in spite of the fact that the information rates are still moderately low (most extreme aggregate information rates of several megabits per second) together with small scope range (around 150 m) [4].

In today's scenario the Ethernets which are wired give information transfer speed (hundred megabits per second), in addition to the wired execution whole and remote local area networks are probably going in context with incrimination after some period in absence of extra range portion. Regardless of the enormous information rate contrasts, remote LANs are turning into the preferred Internet get to strategy in many homes, offices, and grounds situations because of their comfort and flexibility from wires. In any case, most remote LANs bolster applications, for example, electronic mail in addition to browsing on the web. And this is not transmission capacity escalated. Test for future remote local area networks can be for bolstering numerous clients all the while with data transmission serious and delay-obliged applications, for example, video. Go augmentation is additionally a basic objective for future remote LAN frameworks. By a wide margin the best utilization of remote systems administration has been the cell phone framework. When remote sending of voice in middle of New York and San Francisco first built up then that was the foundations of this framework started which started in 1915. In 1946 introduction of open administration of cell phone in 25 urban communities over the United States was done.

The above talked underlying frameworks utilized focal sender part for covering a whole cosmopolitan territory. The ineffective utilization for range of the radio combined to condition in regards to innovation of radio around then extremely constrained the framework limit: After the presentation in cell phone benefit thirty years later the framework of New York could just bolster five hundred forty three clients. An answer for this limit issue rose amid the fifth decade as well as sixth decade where scientists at Bell Laboratories of AT&T built up phone idea frameworks of cell phones misuse the way that the energy of a transmitted flag tumbles off with separation. In this manner, two clients can work on a similar recurrence at spatially-isolate areas with insignificant impedance between them [4]. This permits extremely efficient utilization of cell range so that an extensive number of clients can be obliged. The advancement of cell frameworks from starting idea to usage was frosty. In 1947 AT&T asked for range for cell benefit by the federal communication commission.

In the end 1960's this plan was near about its completion and in 1978 and in 1978 first filed test was conducted, in addition to that in 1982 federal communication commission conceded benefit approval. On that time a significant part with respect to earlier innovation was obsolete. Beginning simple cell framework conveyed in Chicago in 1983 was at that point soaked by 1984, and soon thereafter the FCC expanded the cell unearthly allotment from 40 MHz to 50 MHz The unstable development of the cell business overwhelmed practically everybody [5]. Truth be told by a AT&T promoting concentrate authorized prior to framework rise which anticipated about interest in mobiles should restrict specialists and the extremely wealthy. It was fundamentally deserted by AT&T for business of cellular networks around eight decade of twentieth century attention on systems of optic fiber, in the long run coming back to the business after its potential ended up noticeably evident. All through from the late 1980's, as an ever increasing number of urban areas ended up noticeably immersed with interest for cell benefit, the improvement of computerized cell innovation for expanded limit and better execution wound up noticeably fundamental. The cell frameworks of second generation, earlier conveyed between 1990, depended of computerized interchanges. The move from simple to computerized is directed from the upper limit of it.

In addition to it enhanced price, rate, and proficiency in terms of power for advanced equipment. However 2G cell frameworks at first gave chiefly voice benefits, these frameworks bit by bit developed to bolster information administrations, for example, email, Internet get to, and short informing. Sadly, the considerable market potential for phones prompted an expansion of second generation cell measures: three distinct principles for only United States, along with this in Europe and Japan there were incongruent different benchmarks. And way of distinctive urban areas includes diverse inconsistent guidelines forms meandering all through United States. Furthermore, entire sphere utilizing single authorities way for cell phones. In addition, a few nations have started benefit for third generation frameworks, for which there are additionally different contrary norms [1]. Geosynchronous satellites overwhelmed the two business and satellites of government frameworks on the sake of few years.

Geosynchronous satellites have huge scope territories, so less satellites (and dollars) are important to give wide-region or worldwide scope. Be that as it may, for satellite achieving requires lot energy, and proliferation deferral having regularity in extensiveness in application of postponement compelled as. The above discussed detriments brought on single move in direction of satellites of lower circle around 1990. In this the objective discussed is giving speech as well as information benefit focused along cell frameworks. In any case, the satellite portable terminals were considerably greater and high power devoured significantly. Also it price a great deal high as compared to present day PDAs that restricted its allure. Here the highest convincing component in frameworks was omnipresent overall scope, particularly in remote regions or underdeveloped nations with no landline or cell framework foundation. Shockingly, such places don't ordinarily have extensive request or the assets the compensation for satellite administration either. As cell frameworks turned out to be more boundless, it takes for maximum income of low earth orbit framework may has created for dense ranges. Low earth orbit satellite genuinely left market.

1.3 Evolution of wireless communication from 1G to 5G

The 1st generation (1G) cell frameworks in the U.S., called the Advance Mobile Phone Service (AMPS), utilized FDMA with 30 KHz FM-adjusted voice channels. The FCC at first assigned 40 MHz of range to this framework, which was expanded to 50 MHz not long after administration prologue to bolster more clients. Mobile communication and telephony were introduced by First generation [7]. This aggregate data transmission was partitioned into two 25 MHz groups, one for portable to-base station channels and the other for base station-to-versatile channels. The FCC isolated these channels into two sets that were allocated to two diverse specialist organizations in every city to empower rivalry. A comparable framework, the European Total Access Communication System (ETACS), rose in Europe.

AMPS were conveyed worldwide in the 1980's and remain the main cell benefit in some of these ranges, including some provincial parts of the U.S. A large number of the 1st generation cell frameworks in Europe were contrary, and the Europeans immediately joined on a uniform standard for second generation (2G) advanced frameworks called GSM. The GSM standard uses a blend of TDMA and moderate recurrence jumping with recurrence move keying for the voice tweak. Conversely, the gauges exercises in the U.S. encompassing the second generation of advanced cell incited a furious civil argument on range sharing procedures, bringing about a few contrary guidelines.

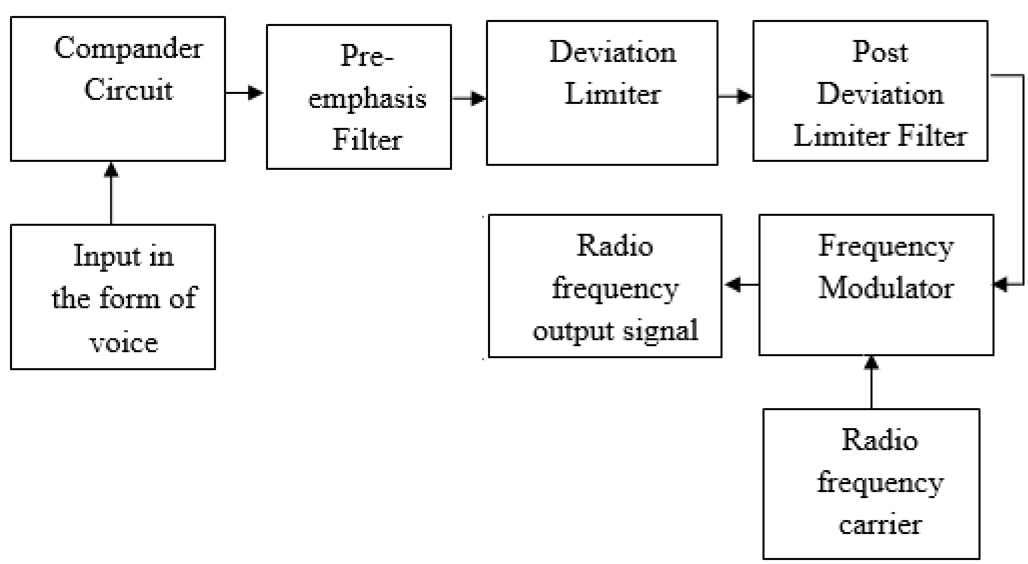

Fig. 1.1: Voice modulation process of AMPS

Specifically, there are two gauges in the 900 MHz cell recurrence band: IS-54, which utilizes a blend of TDMA and FDMA and stage move keyed balance, and IS-95, which utilizes coordinate arrangement CDMA with paired tweak and coding [6]. The range for computerized cell in the 2 GHz PCS recurrence band was unloaded, so specialist organizations could utilize a current standard or create restrictive frameworks for their bought range. The final product has been three distinctive computerized cell principles for this recurrence band: IS-136 (which is essentially the same as Seems to be 54 at a higher recurrence), IS-95, and the European GSM standard. The computerized cell standard in Japan is like IS-54 and IS-136 however in an alternate recurrence band and the GSM framework in Europe is at an alternate recurrence than the GSM frameworks in the U.S. This multiplication of inconsistent gauges in the U.S. what's more, universally makes it difficult to meander between frameworks across the country or internationally without a multi-mode telephone as well as numerous telephones (and telephone numbers).

The greater part of the second generation computerized cell guidelines have been upgraded to bolster high rate bundle information administrations. GSM frameworks give information rates of up to 100 Kbps by totaling all timeslots together for a solitary client [7]. This upgrade is called GPRS. A more key improvement, Enhanced Data Services for GSM Evolution (EDGE), additionally builds information rates utilizing an abnormal state tweak arrange consolidated with FEC coding. This adjustment is touchier to blurring impacts, and EDGE utilizes versatile strategies to relieve this issue. Specifically, EDGE defines six distinctive regulation and coding mixes, each enhanced to an alternate estimation of got SNR. SNR is measured at the recipient and encouraged back to the transmitter, and the best balance and coding blend for this SNR esteem is utilized.

The IS-54 and IS-136 frameworks right now give information rates of 40-60 Kbps by accumulating vacancies and utilizing abnormal state balance. This development of the IS-136 standard is called IS-136HS (rapid). The IS-95 frameworks bolster higher information utilizing a period division procedure called high information rate (HDR). The third generation (3G) cell frameworks depend on a wideband CDMA standard created inside the support of the International Telecommunications Union (ITU). The standard, at first called International Mobile Telecommunications 2000 (IMT-2000), gives diverse information rates relying upon portability and area, from 384 Kbps for person on foot use to 144 Kbps for vehicular use to 2 Mbps for indoor office utilize. The 3G standard is contradictory with 2G frameworks, so specialist organizations must put resources into another foundation before they can give 3G benefits. The 1st 3G framework was conveyed in Japan. One reason that 3G administrations turned out 1stin Japan is the procedure of 3G range portion, which in Japan was granted without much in advance cost. The 3G range in both Europe and the U.S. is apportioned in view of selling, in this manner requiring a gigantic beginning speculation for any organization wishing to give 3G benefit. European organizations all things considered paid more than 100 billion dollars in their 3G range barters.

There has been much contention over the 3G sell off process in Europe, with organizations charging that the way of the bartering brought on colossal overbidding and that it will be exceptionally difficult if not difficult to harvest a profit on this range. A couple of the organizations have officially chosen to discount their interest in 3G range and not seek after framework build out. Actually 3G frameworks have not developed as foreseen in Europe, and it creates the impression that information upgrades to 2G frameworks may suffice to fulfill client requests [8]. Nonetheless, the 2G range in Europe is extremely packed, so clients will either in the long run move to 3G or controls will change so that 3G transfer speed can be utilized for 2G administrations (which are not right now permitted in Europe). 3G improvement in the U.S. has lingered a long ways behind that of Europe. The accessible 3G range in the U.S. is just about a large portion of that accessible in Europe. Because of wrangling about which parts of the range will be utilized, the 3G unearthly sales in the U.S. have not yet occurred. Be that as it may, the U.S. allows the 1G and 2G range to be utilized for 3G, and this flexibility may permit a slower rollout and speculation than the more prohibitive 3G necessities in Europe. It creates the impression that deferring 3G in the U.S. will permit U.S. specialist organizations to gain from the mix-ups and achievements in Europe and Japan.

1.3.1 First generation communication systems

In remote media transmission innovation first generation system is known as 1G which was presented in 1980. The primary distinction between then existing frameworks and 1G was imagine of cell innovation and subsequently it is otherwise called First era of simple cell phone. In 1G or First era of remote media transmission innovation the system contains numerous cells (Land region was isolated into little segments, every part is known as cell, a cell is secured by a radio system with one handset) thus same recurrence can be reused commonly which brings about extraordinary range use and in this manner expanded the framework limit i.e. huge number of clients could be obliged effectively. Utilization of cell framework in 1G or First era of remote media transmission innovation brought about extraordinary range use.

The First era of remote media transmission innovation utilized simple transmission methods which were fundamentally utilized for transmitting voice signals. 1G or original of remote media transmission innovation likewise comprise of different models among which most famous were Advance Mobile Phone Service (AMPS), Nordic Mobile Telephone (NMT), Total Access Communication System (TACS). The greater part of the gauges in 1G utilizes recurrence adjustment systems for voice signs and all the handover choices were taken at the Base Stations (BS). The range inside cell was separated into number of channels and each call is assigned a devoted combine of channels. Information transmission between the wire some portion of association and PSTN (Packet Switched Telephone Network) was done utilizing parcel exchanged system [6].

1.3.2 Second generation communication systems

2G (or 2-G) is short for second-era remote phone innovation. Second-era 2G cell telecom systems were industrially propelled on the GSM standard in Finland by Radiolinja (now some portion of Elisa Oyj) in 1991. Three essential advantages of 2G systems over their antecedents were that telephone discussions were carefully encoded; 2G frameworks were fundamentally more productive on the range taking into account far more noteworthy cell phone infiltration levels; and 2G presented information administrations for versatile, beginning with SMS instant messages. 2G advances empowered the different cell phone systems to give the administrations, for example, instant messages, picture messages, and MMS (interactive media messages). All instant messages sent more than 2G are carefully scrambled; taking into account the move of information such that exclusive the expected beneficiary can get and read it. After 2G was propelled, the past cell phone frameworks were retroactively named 1G. While radio flags on 1G system are simple, radio flags on 2G systems are computerized [7]. Both frameworks utilize advanced motioning to associate the radio towers (which tune in to the handsets) to whatever remains of the phone framework. 2G has been superseded by more current advancements, for example, 2.5G, 2.75G, 3G, and 4G; notwithstanding, 2G systems are as yet utilized as a part of most parts of the world.

1.3.3 Third generation communication systems

Versatile and remote systems have encountered phenomenal development as of late. It was initially followed up on the one hand by the arrangement of a few progressive eras of media communications organizes for the most part devoted to communication [second era (2G), GSM] and more situated toward mixed media (3G, UMTS). Then again, remote Local Access Networks (LANs) have attacked regular day to day existences through driving measures, for example, Wi-Fi and Bluetooth. In addition, the normal development of remote correspondence frameworks is generally arranged now to consider the QoS. It is intrinsic in answers for telecom administrators (GSM, UMTS), however just stayed negligible in the main remote system arrangements (Wi-Fi or Bluetooth) for which it essentially offers starting arrangements that work for undemanding clients.

This is no longer satisfactory; hence, these days all the new models consolidate components to guarantee the QoS to specific streams or potentially certain clients. The 3G frameworks upheld new innovations contrasting with 2G frameworks, for example, Wideband Code Division Multiple Access (WCDMA) since it is the extensively picked 3G air interface [6]. In any case, 3G can't be viewed as a solitary extraordinary standard since it is really an arrangement of models working all together, for example, UMTS and HSPA+. In this way, the inescapable innovations that depend on two parallel spine foundations, one comprising of circuit-exchanged (CS) hubs and one of parcel situated hubs, are additionally talked about in the accompanying area.

- **UMTS**

UMTS is a versatile framework with a downlink most extreme speed of 384 kbps and an uplink greatest speed of 128 kbps. It is the successor of GSM, in view of the 2G systems, offering just telephone calls and little measures of information by means of MMS administration. Truth be told, the UMTS, which speaks to a noteworthy 3G remote innovation, offers remote Internet administrations at an overall scale, amplifying the extent of the 2G remote systems from straightforward voice communication to complex information applications including voice over Internet protocol (IP), videoconferencing over IP, web perusing, media administrations, and rapid information exchange. In this manner, once the 3G framework cleared the market in 2003, it offered bigger information sums, for example, recordings and a higher scope of greatly propelled administrations, which permitted the new pervasive innovation to defeat past ones. A variation of the UMTS Time Division Duplex (TDD), called Time Division Synchronous Code Division Multiple Access (TD-SCDMA), is likewise institutionalized by the 3GPP. The innovation works on a data transfer capacity of 1.28 MHz, and is principally conveyed in China.

- **HSPA+**

HSPA innovation development, monetarily known as 3G+, was acquainted with cure the cutoff points of the Release 99. In this manner, HSPA is really the amalgamation of two portable communication conventions: High speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA) that grow and improve the current WCDMA conventions' execution. These advancements have been characterized by the 3GPP Release 5 (2002) and Release 6 (2005) with the Enhanced Dedicated Channel (E-DCH), otherwise called HSUPA. In institutionalization discussions, WCDMA has developed as the most broadly received 3G air interface innovation for portable correspondences.

Since the initial 1999 arrival of the WCDMA-based widespread earthbound radio get to organize (UTRAN), new elements have been included, for example, fast HSDPA in Release 5 and HSUPA in Release 6. Inactivity can be characterized when all is said in done as the reaction time taken by the framework to a client ask for, and is a key figure the view of client's information administrations. In 2007, another component of HSPA+ in the 3GPPP Release 7 presented interestingly the Multiple-Input Multiple-Output (MIMO) strategy, which permits the utilization of up to two radio wires: one for transmission and the other for gathering, otherwise called 2 × 2 MIMO for downlink (DL) transmission. Discharge 11 was presented in 2013 by including the 4 × 4 MIMO for the DL and 2 × 2 MIMO for the uplink (UL).

The principle development of HSPA concerns the entry from an exchanging circuit on the radio interface, where radio assets are saved for every User Equipment (UE) for the call term, to a bundle where the base station chooses powerfully the assets sharing between dynamic UEs. The dynamic asset designation is performed by the planning capacity, depending specifically on the momentary nature of the radio channel of every UE, its QoS imperatives, and the general framework productivity. Consequently, PS enhances the utilization of radio assets for information administrations. The extraordinary 3G abilities change was flawlessly self-evident; be that as it may, analysts did not quit redesigning the current correspondence frameworks to adapt to the enormous request. Accordingly, 4G portable systems were presented and are talked about in the accompanying area.

Table 1.1: Comparison of 3G and 4G system

Parameters	**3G System**	**4G System**
Data rate	Max. 2 Mbps	Max. 20 Mbps or can exceed than that
Accessing Technique	Wideband CDMA	OFDM
Forward Error Correction	Turbo codes	Concatenated codes
Switching	Circuit switching/Packet Switching	Packet Switching
Mobile top Speed	200 kmph	200 kmph
Frequency Range	1.8-2.5 GHz	2-8 GHz
Bandwidth	5-20 MHz	5-20 MHz

1.3.4 Fourth generation communication systems

To fulfill the regularly expanding interest for portable broadband correspondences, the International Mobile Telecommunications-Advanced (IMT-A) norms have been endorsed by the International Telecommunications Union (ITU) in November 2010 and the 4G remote correspondence frameworks are right now being sent overall . The colossal thriving of the Internet and its associated administrations prompted clients' and industrialists desires to pine for bigger transfer speeds and quicker correspondences.

1.3.5 Fifth generation communication systems

While LTE organization is advancing at a quick pace, the term 5G has been a significant enthusiasm for both scientists and industrialists and is in the long run going to overwhelm the market around the world. It might sound untimely to as of now begin talking about the up and coming 5G since the LTE-A has not been conveyed yet. Be that as it may, the development of client prerequisites has been gigantic amid the previous couple of years that constrained researchers to examine more research endeavors so as to think of quicker and more propelled innovation that is the 5G, which will be the following stride in the NGN. Sending the all-inclusive ultra-broadband system foundation requires particular perspectives.

The reality of the matter is that the LTE Rel-8, which is for the most part sent in a macro cell/microcell format, gives enhanced framework limit and scope, high pinnacle information rates, low dormancy, diminished working expenses, multiantenna bolster, adaptable transfer speed operation, and consistent coordination with existing frameworks. However, the LTE-A strikingly overhauls the current LTE Rel-8 utilizing more extensive move correspondence data transfer capacities, better scope, and higher throughput prompting an exceeding expectations client encounter. Besides, LTE-A frameworks target bolster for DL crest ghostly productivity of 30 bits/s/Hz and UL top phantom proficiency of 15 bits/s/Hz, and support for roughly 1.5× enhanced cell normal and cell edge ghastly effectiveness over Rel-8 and Rel-9 principles. They likewise utilized various radio wires called MIMO information transmission in the PHY layer on both the transmitter and the recipient sides [3].

This radio component is a key empowering agent system that gives quick remote information administrations, which upgrades the overall efficiency [6]. They additionally included bearer accumulation method in this rendition of discharge that empowers clients to download information from expanded sources at the same time, which engages them with higher paces. Consequently, the radio side is indicated by the LTE and the center side is described by the System Architecture Evolution (SAE). The SAE as a piece of the 3GPP movement concentrates on the CN of a versatile system, while the adjustments in the RAN [PHY and Medium Access Control (MAC) layers] are taken care of in the LTE extend, which concentrates on the RAN. Those two tasks delivered as a yield the E-UTRAN and the EPC, which is the CN characterized as a piece of the SAE extend. It can give consistent handovers and high information rates. On one hand, the E-UTRAN is made out of a few eNodeBs. The eNodeB is outfitted with two planes: the Control Plane that is in charge of Radio Resources Control (RRC), which is charged of lower layers' design and the User Plane arranged between the eNodeB and the UE. It comprises of the ensuing sub layers, which are MAC, Packet Data Convergence Protocol (PDCP), and Packet Radio Link Control (RLC). The RRC is charged of settling on Handover Decisions in light of the distinctive estimation reports of the UE and controlling these reports. It likewise is in charge of paging and communicates methods, all versatility capacities, and radio carrier control, while each of the second layer's sub layers has its own capacity. For example, the MAC sub layer is in charge of transporting configuration determination and for movement volume estimation. The PHY layer exchanges physical channels to MAC that vehicles it as sensible channels to the RLC layer [3]. The PDCP exists on both control plane and client plane.

It assumes responsibility of unscrambling procedure and the figuring procedure in both sides. Notwithstanding, it just deals with the uprightness insurance for control plane and the exchange of its information. It offers header pressure. Handover Management, Macro diversity and Encryption and Radio channel coding, IP header pressure and encryption of client information streams, RRM, Location Management, Measurement and estimation detailing arrangement for versatility and planning, and Traffic Management are included in the radio get to conventions in the E-UTRAN get to stratum.

These are functionalities that are included in the E-UTRAN. Then again, the EPC is made out of a Mobility Management Element (MME), a Serving Gateway (SGw), a Packet Data Network (PDN) Gateway (PGw), and a PCRF. It empowers capacities, for example, offering access to outside IP systems. At the point when the client shifts starting with one cell then onto the next, it is primordial that the EPC supplies an easily ceaseless portability at the third layer through different get to advancements, for example, Wi-MAX and Wireless Local Area Network (WLAN). It is likewise characterized in RFC 6459 as a development of the 3GPP GPRS framework portrayed by a higher-information rate, bring down inertness, bundle upgraded framework that backings numerous RATs. The EPS licenses various versatility convention utilization as per the utilized get to innovation. That is the reason, from the client through the radio system through the EPC toward a goal IP organize, that entire end-to-end engineering is the EPS.

It is imperative to note that lone eNodeB frame the E-UTRAN. The MME, the Home Subscriber Server (HSS), the SGw, and the PGw all together shape the EPC that is consolidated to E-UTRAN to make an EPS. As appeared in Fig. 6.6, the LTE convention stack is made out of four fundamental segments, which are the UE, eNodeB, SGw, and PGw. The PGw is the portal of the CN, though the SGw works as the door for the EPC.

1.4 Orthogonal Frequency Division Multiplexing (OFDM)

There are a lot of wireless and telecommunications standards that are used in current scenarios of wireless communication. Orthogonal Frequency Division Multiplexing (OFDM) is the latest wireless standard that is current in use. This technology is selected for the cellular telecommunication standard LTE/LTE-A. Along with this it is also adopted for the arena of Wi-Fi for the standards like 802.11n, 802.11a, 802.11ac and many more. This is also adopted by the WiMAX. The broadcast standards also utilize OFDM in them ranging from DAB digital radio to digital video broadcast standards. This can also be implemented for other broadcast systems along with digital radio model. Being more complex compared to the previous forms of signal format, OFDM provides some new advantages related to data transmission.

1.4.1 Concept of OFDM

OFDM is regarded as a modulation scheme in which multiple subcarriers are used. The signals of OFDM are composed of a large number of closes by spaced modulated carriers. The modulation of voice and data with the carrier signal results into the spreading of the sidebands. And the receiver requires the whole signal in order to demodulate it. It became easy for the receiver to separate the signals with the help of filter when they are equally spaced. Along with it the receiver signals must have guard band between them [1]. It is not the scenario with the OFDM. The subcarriers that are wanted can be received without interference even though there exists the overlapping of sidebands because these are orthogonal in nature with respect to each other.

The condition for that is the carrier spacing should be equal to the reciprocal of the symbol period. In order to analyze the working of OFDM, it is mandatory to consider the specifications of receiver. Each signal is transformed down to DC by this receiver which works as a bank of demodulators. In order to regenerate the signal the final signal is combined with the symbol period.

The other carriers are also demodulated by this demodulator. The subcarriers will have whole number of cycles under the symbol period and their overall contribution will add to zero. This is because the spacing of the carrier is equal to the inverse of the period of symbol. In conclusion there will not be any contribution of interference between the subcarriers.

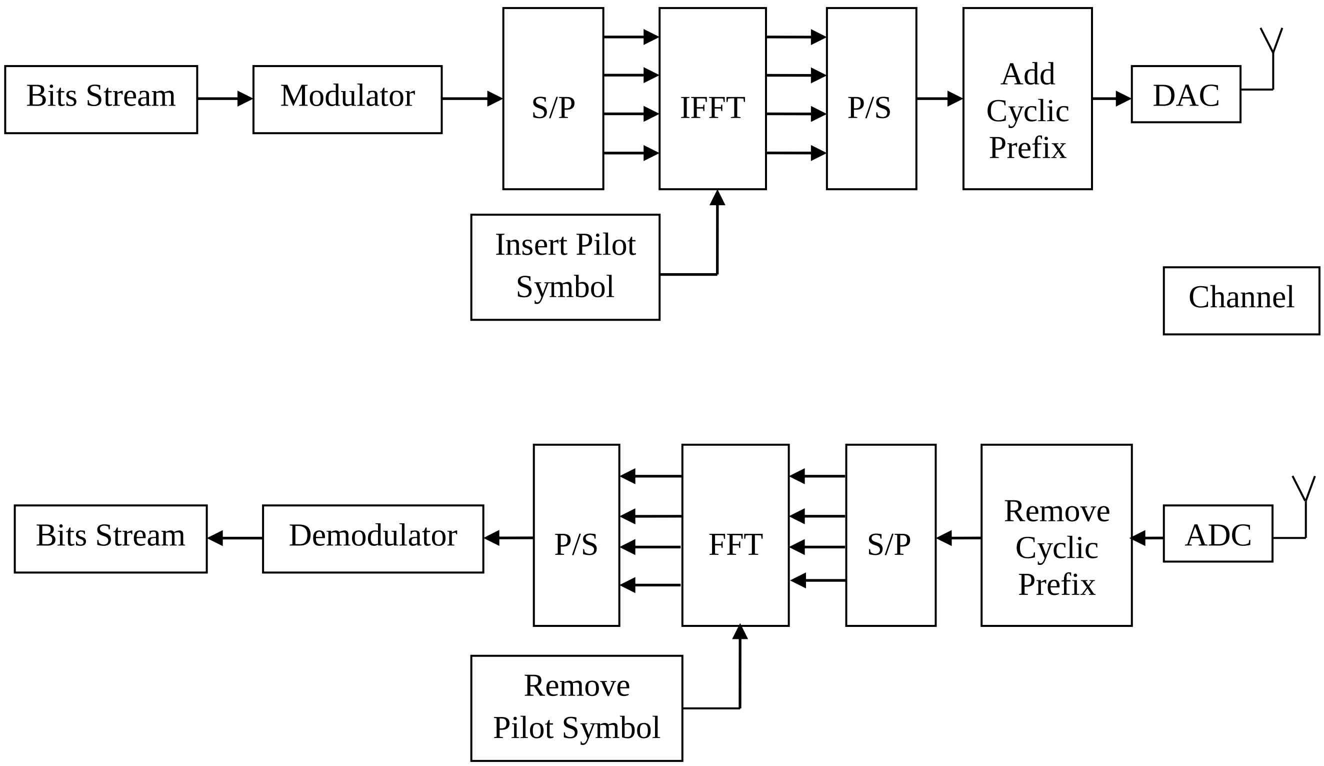

Fig.1.2: Block diagram of OFDM transceiver

There is a condition for the OFDM systems that the transmitter and receiver should be linear in nature. If this condition is not satisfied then it will lead to the interference among the subcarriers. This may exist due to the inter-modulation distortion [2]. Here the unwanted signals are introduced that can cause interference and deteriorate the orthogonality of the transmission. In OFDM the data that is transmitted get spread along the carriers of the signal in which each carrier is taking part of the payload. Due to this the data rate of OFDM gets reduced. Lower is the data less critical will be the interference from the reflections. It is obtained by adding guard band under the system. It makes sure that when the message signal is stable only then data is sampled and along with that there is no such new delayed signal arrived that can vary the phase as well as the timing of the signal.

OFDM has further a lot of advantages due to the distribution of data across a huge number of subcarriers. The nulls that are generated by the interference and multipath effects give impact on only a little number of subcarriers [3]. The rest of the subcarriers are received quite efficiently. There are a lot of error coding techniques can be used in the OFDM. They add further data to the transmitted signal of the OFDM. It enables us to reconstruct the data at the receiver side that was corrupted due to the previous processing.

- **Implementation using FFT and IFFT**

The OFDM systems use the FFT at the sender side and IFFT at the receiver side which makes the implementation of OFDM modulator and demodulator quite simpler and efficient. Mathematically the time that is required to calculate the FFT and IFFT should be less than the time of each symbol. The FFT size varies linearly with respect to the computational demand. That means a double size FFT will need the double amount of time [4].

1.4.2 Advantages of OFDM

The OFDM is implemented in a lot of wireless applications due to the below given advantages which are as follows:

- **Immune to frequency selective fading**

Among the advantages of the OFDM, one of the advantages is that OFDM systems are more resistant to the frequency selective fading as compared to the single carrier systems. This is because that the overall channel is divided into multiple narrowband signals and the fading affect the narrowband signals individually as flat fading sub-channels [2].

- **Flexibility towards interference**

In OFDM, the interference that is encountered on the channel may be band limited. And by this approach it will not leaves impact on all the sub-channels. As a result of that the data will not be lost.

- **Spectral efficiency**

When the close spaced overlapping subcarriers are used in the OFDM, then it makes the best use of the available spectrum. So the spectral efficiency is quite significant.

- **Flexibility towards Inter symbol Interference (ISI)**

The OFDM systems are very much flexible towards the Inter symbol Interference (ISI) and inter frame interference. This is achieved because of the low data rates over each of the sub-channel of the OFDM system.

- **Flexibility towards the effects of narrow-bands**

Sometimes due the presence of frequency selectivity as well as due to the presence of the narrow band interference the symbols may get lost. With the help of the efficient channel coding and interleaving techniques we can recover the lost signals. So as a result of that not all the data will be lost.

- **Easier equalization of channel**

In the earlier present CDMA systems the complexity of the channel equalization that was implemented over the whole channel, was quite high which later became a issue for that. In OFDM, multiple sub-channels were used that makes the equalization quite simpler as compared to the previous one.

1.4.3 Disadvantages of OFDM

While the OFDM systems are most commonly used today but there exists certain disadvantages of it. Those problems or issues can be disastrous in terms of the performance [3]. The disadvantages of OFDM shows that it further needs some modifications in order to eradicate those problems. The current scenario’s waveform contenders are proving that they can solve those issues of the OFDM. The OFDM disadvantages were as follows:

- **Large PAPR**

OFDM systems have large values of peak to average power ratio. It puts its impact on the efficiency of the RF amplifiers as the amplifiers that are expected should be linear. This means that with the high efficiency level the amplifiers cannot be operated [5].

- **Sensitivity toward the carrier offsets and drifts**

The OFDM systems are more sensitive towards the carrier frequency offsets and drifts. In comparison to the OFDM, the single carrier systems are less sensitive towards the carrier offsets and drifts.

1.4.4 Variants of OFDM

There are a lot of variants that are available in the technical literature of the OFDM. All of these follow the basic format of OFDM and are explained as follows:

- **Coded Orthogonal frequency division multiplexing (COFDM)**

The coded orthogonal frequency division multiplexing is the technique in which one more thing is added to the OFDM systems and that is the error correction coding. Error correction codes are used in COFDM.

- **Orthogonal frequency division multiple access (OFDMA)**

Orthogonal frequency division multiple access is the technique that is used to give multiple access capability to the applications like cellular communications while using the orthogonal frequency division multiplexing techniques.

- **Vector OFDM (VOFDM)**

MIMO technology was introduced to the conventional OFDM to obtain vector OFDM. CISCO systems are developing the vector OFDM. The term MIMO basically stands for Multiple Input Multiple Output and it uses the concept of multiple antennas for transmitting and receiving signals in order to utilize the multipath effects for the enhancement of reception of the signal and to increase the speed of the transmission.

- **Wideband OFDM (WOFDM)**

Wideband OFDM uses the concept of spacing between the channels which is that much large enough that any kind of the error in between the transmitter and receiver cannot affect the performance. Wi-Fi system is having such kind of technique used in it.

- **Flash OFDM**

Flash OFDM was developed by the Flarion. This was that form of OFDM which was fast hopped. The concept of several tones and fast hoping was used to spread the message signal over the band of spectrum. All the above discussed forms of the OFDM use the identical basic concept that was based on the usage of closely spaced orthogonal carriers which were carrying the low data rate signals.

1.4.5 LTE

In media transmission, Long-Term Evolution (LTE) is a standard for rapid remote correspondence for cell phones and information terminals, in view of the GSM/EDGE and UMTS/HSPA advancements. It expands the limit and speed utilizing an alternate radio interface together with center system changes. LTE which stands for Long Term Evolution is a standard in the field of wireless communication having high data rate and low latency. LTE increases the capacity as well as the data rate of the network by using the new modulation techniques based on GSM/EDGE and UMTS/HSPA networks [2]. It is specified in the Release 8 document series of 3rd Generation Partnership Project (3GPP) and some enhancement of it is described in Release 9. On 14 December 2009, TeliaSonera launched the first publically available LTE service between its two Scandinavian capitals Oslo (Norway) and Stockholm (Sweden). Despite the fact that LTE referred in the 3GPP's Release 8 and 9 documents is commonly known as 4G wireless service, it does not satisfy the requirements that were putted in front by ITU-R organization.

LTE is the redesign way for transporters with both GSM/UMTS systems and CDMA2000 systems. The diverse LTE frequencies and groups utilized as a part of various nations imply that lone multi-band telephones can utilize LTE in all nations where it is bolstered. The prerequisites were initially put forward by the ITU-R association in the IMT Advanced particular. Be that as it may, because of advertising weights and the huge headways that WiMAX, Evolved High Speed Packet Access and LTE convey to the first 3G innovations, ITU later chose that LTE together with the previously mentioned advances can be called 4G technologies. The LTE Advanced standard formally fulfills the ITU-R necessities to be viewed as IMT-Advanced.

To separate LTE Advanced and WiMAX-Advanced from current 4G innovations, ITU has characterized them as "Genuine 4G". The LTE determination gives downlink crest rates of 300 Mbps, uplink crest rates of 75 Mbps and QoS arrangements allowing an exchange idleness of less than 5 ms in the radio get to organize. LTE can oversee quick moving mobiles and backings multi-cast and communicate streams. LTE bolsters versatile transporter transfer speeds, from 1.4 MHz to 20 MHz and backings both Frequency division duplexing (FDD) and time-division duplexing (TDD). The IP-based system engineering, called the Evolved Packet Core (EPC) intended to supplant the GPRS Core Network, underpins consistent handovers for both voice and information to cell towers with more established system innovation, for example, GSM, UMTS and CDMA2000.

The less difficult design brings about lower working expenses (for instance, every E-UTRA cell will bolster up to four times the information and voice limit upheld by HSPA). We shifted from third generation to the fourth generation systems. Long Term Evolution (LTE) has become the best fit standard after the first release of the 3rdgeneration partnership project in December 2008. As needs be, LTE systems have seen fast development since 2009 when just two systems were at first propelled [3]. The number immediately extended throughout the following couple of years, presently achieving 89 organizes crosswise over 45 nations. From the clients side, the number of worldwide LTE supporters is probably going to surge more than five-overlay to achieve somewhere in the range of 50 million in 2012 from 9 million in 2011,and is required to surpass 560 million in 2016. 3GPP has been taking a shot at further advancement of the LTE, which is alluded to as LTE Advanced, to build up a genuine 4G standard. The LTE Advanced is focused to fulfill or even outperforms every one of the necessities of universal portable broadcast communications Advanced (IMT-Advanced) which is an official definition of 4G made by worldwide media transmission union (ITU) in 2008 [4]. These necessities incorporate pinnacle information rates, top ghastly efficiency, cell phantom efficiency, and adaptable data transmission. There are a ton of specialized difficulties for effective institutionalization of the LTE Advanced that meets the ITU necessities and backings in reverse similarity with the LTE.

The basic architecture of LTE is composed of enhanced nodeBs (eNBs), Mobility Management Entities (MMEs) and Serving Gateways (S-GW). The interface that is used for showing the eNBs is X2 interface, while at the core these are adjoined to the entities (MMEs and S-GWs) with the help of S1 interface. When compared with its predecessor (UMTS Terrestrial Access Network (UTRAN)), LTE was simple network configurations. The other name given to LTE is EUTRAN. All the decisions and considerations are handled by eNBs and the core network related concentrations in LTE are taken care of in the core. We get substantial performance improvement because of the functional split [6]. The boundaries between the two control stratums and network management are further identified by the split in which eNBs handles the most part of Access Stratum (AS) and several other entities of the core handles Non-Access Stratum.The accompanying are the key useful network components in the LTE design:

- **Evolved Node B (eNB)**

eNodeB is that part of the LTE which manages air interface and performs radio administration of resources. It Provides radio asset administration capacities, for example, IP header compression, client information encryption. The radio interface given by eNodeB can be shared by a few administrators by having separate MME, SGW and PDN Gateway.

- **Serving Gateway (SGW)**

It deals with between eNodeB handovers and User Equipment (UE) portability between 3GPP systems. It fills in as the versatility grapple for the client plane. It is in charge of steering/sending information bundles between the eNodeB& PDN Gateway.

- **Packet Data Network Gateway (PDN GW)**

It gives the UE availability to the outer information systems, for example, Internet. It fills in as the stay point for intra-3GPP system versatility, and in addition portability in the vicinity of 3GPP and non-3GPP systems. It deals with Policy and Charging Enforcement Function (PCEF), which incorporates Quality of Service (QoS).

- **Mobility Management Entity (MME)**

It works in the Control plane and gives capacities, for example, overseeing session states, confirmation, versatility with 3GPP 2G/3G hubs, and meandering. It oversees versatility, UE personalities and security parameters.

There is a considerable measure of specialized difficulties for effective institutionalization of the LTE Advanced that meets the ITU prerequisites and backings in reverse similarity with the LTE. The key elements of the LTE Advanced differentiated from the LTE incorporate support for more extensive transfer speed, enhanced uplink execution, better vitality efficiency, progressed multi radio wire innovation, propelled impedance administration, and self-sorting out system [5]. As needs be, from the point of view of physical (PHY) and medium get to control (MAC) layers, multihop hand-off, multicell multi-input multi-yield (MIMO), and transporter conglomeration and savvy impedance administration are testing regions to be investigated. Arrange viewpoints to be considered are heterogeneous systems (HetNets), femto cell improvement, and self-sorting out systems. The point of this uncommon issue is assembling late unique accomplishments and improvements of empowering advances for PHY, MAC, and system layers of the LTE Advanced.

1.5 Generalized Frequency Division Multiplexing (GFDM)

In the today's scenario the fifth generation (5G) of cellular communication systems is expected to handle of a lot of things depending on the expectation of the users. It will need very less latency for the tactile internet, a loose synchronization for the Internet of Things (IoT), reliability, efficient and robust high throughput in order to communicate via bit pipe communication, large coverage area and a dynamic allocation of spectrum with the low value of out of bad emission. The main concept that distinguishes GFDM from OFDM is that the subcarriers that are used in GFDM are not orthogonal in nature [6]. So it is not required that they must full fill the need the orthogonality principle.

Earlier because of the need of orthogonality in the OFDM we cannot stretch the systems after a certain level in term of performance parameters variations. The major change in GFDM is that the Cyclic Prefix (CP) is not added to every subcarrier which was earlier consuming a lot of bandwidth. So in spite of that it is added only to the resultant message signal and then transferred to the next stage of communication system. While transmitting the message signals, firstly we perform the modulation of the message signals and then it is transferred to the next stage. The modulation processes that can be used in the GFDM are QPSK, QAM and OQAM. The process of implementation of GFDM using OQAM is a little bit different from the QAM and QPSK. For the OQAM modulation, the whole working is divided into two parts. These are pre-processing block and post-processing block. In the pre-processing block the whole processing is done earlier that include complex to real conversion for the even cases and odd cases and later on the convolution of that is done with the other signal [7].

Cyclic prefix is that portion of the block diagram of the GFDM where we are adding some part of a message generally ¼ of the message bits to the front portion of the message bits. This prefix is added in order to avoid the interference between the adjacent channels. In GFDM in spite of adding cyclic prefix to every subcarrier we add only one cyclic prefix to the combination of sub carriers. We obtain the same bits that we sent at the receiver. The demodulations which can be preferred in case of GFDM are QAM, QPSK and OQAM. The pre-processing and post processing also plays a significant role while implementing the GFDM demodulation.

The reasons behind the selection of GFDM for the implementation of 5G includes it attractive properties. The main attraction of GFDM is that while addressing the limitations of the OFDM, it also preserves most of the advantageous properties of it. For carrier aggregation, OFDM was having high out of band emission [8]. GFDM replaces it by reducing the out of band emission of the message signals. The bandwidth efficiency of it can be clearly seen by the usage of only one CP in its transmitter while transmitting the signals.

1.5.1 Guard symbol in GFDM

OOB was the major drawback of the OFDM. OOB emission of the GFDM can be reduced if there is smooth transition between the blocks of GFDM. If the signal is having circularity in the time domain then it presents a solution to decrease the sudden change in the blocks of the GFDM. The guard symbol is introduced in between the GFDM blocks by erasing the first sub-symbol. And there will be the orientation of signal edges towards zero corresponding to that. This will make the transitions between the GFDM blocks smooth. This whole process is named as guard-symbol GFDM (GS-GFDM). Later on the addition of CP again makes the transition between the blocks hard. We can avoid this problem too by making the last sub symbol equal to zero [9].

1.5.2 OQAM

Generally, GFDM is a non-orthogonal waveform but it can be made orthogonal by using pulse shaping filters like Dirichlet pulse. It can also be done by making use of the combination of GFDM and OQAM. OQAM can be regarded as two independent Gabor expansions in which the input symbol is limited to be either real only or only the imaginary part which achieves the orthogonality condition instead of the direct modulation of the symbol input in the form of in-phase and quadrature-phase (Q).

When bandwidth is limited up to two subcarriers for square root nyquist prototype filter then the I input part produces the real interference among the adjacent subcarriers and Q input part introduces only imaginary interference. The flexibility of the waveform can be improved by using the pulse shaping filters which have arbitrary length, overlapping factor and considers OQAM. A substitute which uses the shorter pulses in time is being proposed and also known as frequency shift-OQAM (FS-OQAM).

1.6 Multiple Input Multiple Output (MIMO)

A new technology that is referred nowadays in many applications related to the radio communication is the Multiple Input Multiple Output (MIMO). Wi-Fi, LTE and many other applications are using new MIMO techniques in order to provide the increase in the capacity of the link along with the spectral efficiency. The implementation of MIMO is under the development from the past several years. For this we require such new technologies which will help in implementation of it. The starting work of the MIMO was focused on spatial diversity.

Earlier the MIMO was used for limiting the degrading of the signal due to the effect of multipath propagation. But later on the multipath propagation became the advantage of the system by assuming the additional paths of the signals as additional channels which can carry additional data in it. The signal which is affected by the fading will have the impact of fading on its Signal to Noise Ratio (SNR) [26]. In other word it will affect the error rate in the digital transmission of the data. Diversity is the technique in which multiple versions of the signal are obtained. If the signal path is affecting these signals in a different way than the probability in terms of how much they are affected can be reduced comparatively. The stabilization to a link is provided by the diversity scheme. Diversity also modifies the performance and also reduces the error rate.

1.6.1 Different modes of diversity

There a lot of diversity modes which are available for MIMO and also provide a lot of advantages:

- **Frequency Diversity**

The concept of different frequencies is used in the frequency diversity. This can be achieved by the usage of the various differing channels and the technologies like orthogonal frequency division multiplexing or spread spectrum.

- **Time Diversity**

With the help of different time slots and channel coding a message is transmitted in the time diversity. The message transmission is done at the different interval of time.

- **Space Diversity**

Space diversity is assumed as the basis technique of the multiple input and multiple output. In order to get the advantage of the different radio paths that are present in different terrestrial surroundings this concept uses the antenna that are placed at different positions.

1.6.2 Spatial multiplexing in MIMO

Among the advantages of the MIMO spatial multiplexing, one of the advantage is that it provides additional data capacity. This is achieved in MIMO by the usage of multiple paths and efficiently using them for carrying data by assuming them as additional channels. In the field of science there are certain boundaries beyond which we cannot go. This also holds true for the maximum data transmission capacity in the channel [27]. While transmitting the data the maximum amount of it that can be transferred is restricted by the physical boundaries of the Shannon law. It is named after the name of the person who formulated it. This law is represented as:

$$C = W * log_2\left(1 + \frac{S}{N}\right) \quad (1.1)$$

Where C = Capacity of channel in bits per second

W = Bandwidth in Hertz

S/N = Signal to Noise ratio

From the above equation it is clear that there exists a ultimate limit of the capacity of the channel. When this limit is reached, the capacity is limited by the signal to noise ratio of the message signal.

1.7 Objective of the study

- **Performance improvement**

As the previous used waveform contenders are not capable of providing lesser BER , out of band emission and PAPR, we require a waveform contender that will be able to eradicate the above said problems. GFDM is a capable waveform contender in the race of implementing 5G technology.

- **Integration of GFDM with MIMO**

The GFDM can be integrated with the MIMO technology in order to provide higher data rates and better efficiency. It is necessary to integrate MIMO and GFDM because years after years the data rate requirement of the users is increasing and we require an approach that can handle the scenario.

- **Analysis of GFDM using different filters**

When different filters are applied to GFDM then it can achieve different BER with respect to the signal to noise ratio. The filters that can be selected for the GFDM analysis are RC, SRRC and Gaussian filters, Dirichlet, Xia, Flipped hyperbolic secant and Flipped inverse hyperbolic secant.

1.8 Chapters outline

- Chapter 1 presents the basic view of the wireless technology. It also discussed about the basic introduction of OFDM, GFDM and MIMO systems.
- Chapter 2 presents the Literature survey of the various journals, books and conference papers with respect to GFDM, OFDM and MIMO systems.
- Chapter 3 presents the description of GFDM in detail right from its need to the block diagram description of it.
- Chapter 4 presents the description of MIMO and the various schemes used in it.
- Chapter 5 presents the simulation results of the GFDM integration with MIMO under different channels.

2.1 OFDM

Long Soo Cho et al. [1] tells that in order to communicate with the single carrier transmission we require nyquist bandwidth in order to get the symbol transferred per unit time. These systems have the frequency selectivity issue and it can be eradicated with the usage of multiple carriers for the data transmission. It should be taken into account that the frequency non selectivity of sub channel affects the equalizer that is used in it. If the narrow band channel is frequency non-selective then the equalizer will be less complex. OFDM transmitter maps the messages with the help of PSK and QAM. The guard intervals in case of OFDM can be implemented by two different methods. First one is the usage of zeroes for padding in between the data and the second one is the Cyclic Prefix (CP). If there is any interference obtained between the symbols CP will try to recover the message which the zero pad cannot do.

Shengli Zhou et al. [2] described zero padded Orthogonal Frequency Division Multiplexing (ZP-OFDM) for the illustration of results. CP-OFDM can also be referred for the representation for the better performance of OFDM. It is brought to our notice that while communication is done under water the guard interval can be very long. And that may consume more transmission power in case of CP-OFDM. In ZP-OFDM, it not only saves the transmission power but also decreases the duty cycle of the practical transducer. Along with that when derivations for both are done it was found that the derivation of ZP-OFDM was simpler compared to the CP-OFDM. When windows are incorporated in OFDM, ZP-OFDM found it quite convenient but CP-OFDM does not. The uncoded OFDM was having worse performance under different fading channels.

Being a combination of a large number of modulated signals OFDM signal may show the high instantaneous peak signal by taking average signal level into consideration. L. Hanzo et al. [3] says that after this the high amplitude variations are noticed under the traversal of time domain signal from the small instantaneous power representation to the large power representation. This may leads to the high value of out of band radiation. The OOB emission can be prevented by not letting the power amplifiers to reach up to their saturation state. Therefore these operate along with the so called back-off. This creates the "head room" for the peaks of the signal. As a result the risk of the amplifier saturation and out of band emission (OOB) gets less.

Stefan H. Muller et al. [4] proposed a flexible and distortion free technique for OFDM that is eradicating redundancy that was present in it. This technique may enhance the complexity of the OFDM. It is brought to our notice that the results of PAR reduction obtained from the performed histogram are not good as compared to those which are theoretically found. When the 4-DPSK is implemented in alliance with PTS-OFDM along with the subcarriers, it is found that redundancy is R_{ap}=2(V-1) which was independently of W. V is depicting the number of sub blocks used in PTS and W is depicting the admitted angles for b_{μ}^{v} which must not be quite high.

E. Del Re et al. [5] compared the OFDM with the direct sequence code division multiple access (DS-CDMA). DS-CDMA is a competent technique in the wireless communication under which every bit of the signal that is needed to be transmitted over the channel is multiplied for the pseudo noise sequence. This pseudo noise sequence's fundamental element which is known as chip is quite short as compared with the information bits. The direct sequence code division multiple access systems provide the better performance as compared to the OFDM. In the proposed system a non-negligible portion of the noise power is focused in narrow band interference. As a result of that under the small values of SNR we obtain better performance.

2.2 GFDM

In the paper of Arman Farhang et al. [6] discussed that Generalized Frequency Division Multiplexing is taken into consideration when we talk about the new candidate waveforms of fifth generation (5G) communication systems. This decision is taken on the basis of several facts that prove GFDM can replace the previous OFDM communication systems. Cyclic prefix is one the reason for GFDM in place of OFDM. GFDM is using only one cyclic prefix to the aggregation of the symbols whereas in case of OFDM the CP is added to every subcarrier. GFDM is more bandwidth efficient because of this approach. There is a transceiver proposed which uses the FFT at the transmitter side and IFFT at the receiver side. With the help of DFT and IDFT matrices we can reduce the computational complexity. The new less complex receiver structure for Zero Forcing (ZF), Matched Filter (MF) And Minimum Mean Square Error (MMSE) receivers is also proposed. A table is given while calculating the complexity of computations which shows that the mathematical complex multiplications required in the earlier proposed transmitter are more as compared to the new proposed transmitter. Similar number of complex multiplications are calculated for GFDM receiver in the form of tabulation and compared with the earlier approached techniques. The complexity is less in the new approach. The comparison of results is also given graphically which proves that results obtained have lower computation cost.

The progression in our new technologies should not be abrupt. It is not desirable for the users as well as for the manufacturers. The reason for that is they need to change their systems completely in order to fulfill that progression. In the earlier used technologies because of the presence of clock compatibility in between WCDMA and LTE, the manufacturers were able to build less expensive and multi standard devices. GFDM is the waveform which can be selected for the 5G communication network. Ivan Gasper et al. [7] described that it is able to implement the Long Term Evolution (LTE) master clock for the 5G PHY layer. Along with that the time - frequency structure of the nowadays cellular systems can also be implemented on it. There are two separate paths that are followed for the coexistence of 4G and 5G waveforms. In order to improve the flexibility of the GFDM an approach of positioning subcarriers is also introduced. While implementing two of its approaches for the paper the first approach shows that GFDM signal is best fitted in the LTE grid while configuring it. This reduces the latency of the GFDM by the factor of 15. The second approach shows that the latency of signaling in 5G may be smaller by the current LTE systems. This can be 10 times smaller than it. The second approach is used for the coexistence of 4G and 5G signals.

Zahra Sharifian et al. [8] discussed that circular pulse shaping is used in GFDM in order to make the system compatible with the new applications of 5G networks like Machine To Machine communications (M2M) and Internet of Things (IoT). Like other systems suffer from the problem of high Peak to Average Power (PAPR), GFDM also suffers from this problem. With the help of iterative expansion a polynomial based companding technique can be used. The GFDM transmitter can be regarded as a synthesis filter bank which uses circular filtering while implementation of it. From the simulations it can be analyzed that in case of OFDM the PAPR value is little less as compared to GFDM. The reason is that the GFDM signal is the addition of exponential terms that is limited with the main lobe of Raised Cosine (RC) filter and OFDM is the addition of exponential terms that are limited with a rectangular window. After analysis we reached at a conclusion that PAPR reduction ability of GFDM are inversely proportional to each other.

In order to get a multiplexing technique that should be potent enough opposite to the frequency selective channels, the combination of generalized frequency division multiplexing and Walsh Hadamard transform (WHT) is used as per Nicola Michailow et al. [9] opinions. This is proved by comparing the bit error rate of the GFDM with the WHT-GFDM under the frequency selective channels. The main target of WHT is not to replace the existing coding rather than this it is targeted to enhance the trustworthiness of the burst transmission in frequency selective channels. Along with these advantages it also provides the low out of band radiation. The receiver is supposed to be MMSE receiver. At one side when the FSC's are less in number, it does not improve the system performance and there is that much noise enhancement provided by the frequency domain equalizer that can be neglected. And at the other side results proves that at low SNR value MMSE receiver can effectively reduce the noise enhancement and also do betterment of BER performance at high SNR value.

The robustness of GFDM against the fading multipath environment can be increased by the application of space-time coding at the transmitter side under the minimal level complexity at the receiver. Maximilan Matthe et al. [10] implemented the Alamouti-STC for GFDM along with a Maximum Ratio Combining receiver (MRC). The application is supposed to be straight forward because in FBMC/OQAM due to Offset Quadrature Amplitude Modulation (OQAM) modulation the difficulty was increased. The up sampling of the signals is done after the serial to parallel conversion of modulated signal and then filtering of that signal is done. Later on it is applied with the Fast Fourier Transform (FFT). At the low value of SNR, the effective use of cyclic prefix makes the STC-GFDM a little better than STC-OFDM.

Maximilian Matthe et al.[11] bring to our notice that the usage of pulse shaping per subcarrier can reduce the Out Of Band (OOB) radiation in GFDM. Along with it this shaping also produces non-orthogonal waveforms. The circular pulse shaping filter used in GFDM are Raised Cosine (RC), Root Raised Cosine (RRC), Xia pulse and Gaussian pulse and Dirichlet pulse. The OOB suppression of GFDM is 11 decibels. In other words it is 39 decibels higher than OFDM under the circumstances when we are using zero or one guard symbols and also one guard carrier too. When the number of guard carriers are increased from 1 to 6, the GFDM shows out of band emission suppression which is 50 decibels high as compared to the OFDM systems when only one guard symbol is used. The var (I) of the used pulse shaping filter is directly associated with the BER of the Generalized Frequency Division Multiplexing (GFDM) systems. Gaussian pulse is the pulse which gives the highest values of variance that is relatively independent of its alpha value. This is nearly equal to 0.2. If the dirichlet pulse is used it can make the systems orthogonal and we can reach up to the BER level of OFDM system under the presence of additive white Gaussian noise channel (AWGN).

Rohit Datta et al. [12] claim that sensing performance of GFDM based cognitive radio receiver is good and quite significant. There is a block diagram presented that shows the functioning of energy detector. After the demodulation of the obtained data from transmitter, the data block is allowed to pass through a square law device. There are two types of cognitive radios systems present. One is the synchronous receiver and other one is the asynchronous receiver. While considering the asynchronous systems, ROC curves are drawn for the GFDM as well as OFDM. And the results proved that the sensing ROC performance is better in the GFDM, when the GFDM transmission of the messages is sensed by the GFDM receiver. The performance of OFDM based sensor using conventional ROC gives worse performance compared to GFDM sensor. GFDM do betterment of the ROC characteristics of the traditional OFDM systems.

Ahmad RezazadehReyhani et al. [13] says that with the help of successive interference cancellation we can get performance of GFDM equal to that of the OFDM. GFDM has a restriction in terms of total number of symbols per data pack. GFDM gets a high error floor in terms of BER when the numbers of packets used have even values. When small constellation sizes are used, GFDM and C-FBMC obtains the OFDM equivalent BER performance. But at further stage, when the constellation size is increased, there exists spacing between the curves of GFDM and OFDM BER. And the performance of OFDM will be same as that of C-FBMC and it is analyzed that the computational complexity of C-FBMC is simpler than that of GFDM.

Maximilian Matthe et al. [14] showed the equivalence of finite discrete critically sampled Gabor expansion with the recent considered waveform contender of 5G i.e. Generalized Frequency division Multiplexing (GFDM). Due to the non existence of the Zero Forced (ZF) receiver we cannot provide Noise Enhancement Factor (NEF) for the even values of complex valued samples. Proves that the value of noise enhancement factor ascend with the increase in the value of complex valued samples. The ZF receiver needs to cancel more ICI and ISI as per the traditional way of approaching the high values of complex valued samples and roll off factors. This leads to the noise amplification but with the wider opening as well as the dense sampling of continuous time Zak transform in the transmitter filter, the values that are contained in Discrete Zak Transform (DZT) leads to zero and this will constitute the high values of the DZT of the dual window. Because of this the dual norm of window is enhanced and also the noise enhancement factor is increased.

Ayesha Ijaz et al. [15] told that although we are using OFDM for last several years but is having a lot of flaws. There are many other candidate waveforms for the 5G technology. Filtered orthogonal frequency division multiplexing, Widowed orthogonal frequency division multiplexing, FBMC, UFMC and GFDM are some of them. As far as PAPR is concerned GFDM shows moderate PAPR for SC-FDE and for the rest of cases it is high. GFDM and UFMC provides short burst traffic which is not present in the rest of waveforms. And the complexity is low in the OFDM as compared to other waveforms. When the different Machine to Machine Communication (M2M) schemes are considered, then the analysis proves that PAPR of FOFDM is high and that of WOFDM is similar. The time frequency efficiency for FOFDM is similar and low for WOFDM and high for GFDM. GFDM, FOFDM and FBMC show the moderate computational complexity and for the WOFDM it is similar and is high for the UFMC case.

Zhipeng Zhong et al. [16] described that by using the combination of GFDM and the time reversal space time coding in order to cancel the decrease of the error performance that existed earlier due to the presence of frequency selective channels. The bit error rate (BER) that is obtained in Multiple Input Multiple Output Generalized Frequency Division Multiplexing (MIMO-GFDM) is significant as compared to the Single Input Single Output Generalized Frequency Division Multiplexing (SISO-GFDM). The usage of matched filter maximizes the Signal to Noise Ratio (SNR) in GFDM at the sample point. For calculating the BER performance of MIMO-GFDM and SISO-GFDM Minimum Mean Square Error (MMSE) method is selected at the receiver and the reason for that is its good performance. If the condition of orthogonality is not required in GFDM, then it consumes less power. As a result of that they remained power can be saved.

Matt Carrick et al. [17] proposed a new Frequency Shift Filter (FRESH) in order to exploit the time varied spectral redundancy. This type of filter helps in creating such multicarrier waveforms that are reliable and resistant to the frequency selective fading. The suggested structure of the filter can mix up with the spectrum which is assumed to be redundant in order to provide signal processing gain and also acts as fractionally spaced equalizers. This complete scenario can be implemented on the preexisting waveforms and also can be used along with the signaling techniques.

OFDM and GFDM are the waveforms in which we can analyze the impact of Timing Offset (TO), Carrier Frequency Offset (CFO) and phase noise. Byungju Lim et al. [18] provided the signal to interference ratio (SIR) analysis for the four classified cases of the TO. Along with these a receiver filter is presented that is optimized in order to maximize the SIR under CFO in additive white Gaussian noise channels. The SIR of GFDM is degraded slowly as compared to the OFDM because of its robustness against the timing offsets. The conventional GFDM is more sensitive in terms of CFO as compared to the OFDM. This conventional GFDM is outperformed by the new proposed GFDM. The reason for that is the filter that is used here is robust.

A. Kumar et al. [19] described that the main characteristic of the GFDM is its low out of band emission. The previous earlier generation cellular systems were optimized to provide high rates of data as well as a trustworthy coverage to the mobile user. GFDM is the multi branch multicarrier filter bank approach in which pulse shaping is provided in time domain to every subcarrier. The impact of “Better than Nyquist” pulse shaping filter with respect to the symbol error rate (SER) performance of GFDM is evaluated. The receiver that is considered in this case is zero forced receivers. The transmission is specified with 16-QAM modulation over the additive white Gaussian noise. Moreover, the better time-frequency localization can be obtained with the usage of wavelets in the pulse shaping filters using the Meyer auxiliary function. Results of this approach shows that superior SER performance can be achieved using this approach.

Arman Farhang et al. [20] tell that the Zero Forced (ZF) receiver is proposed by them is 4 times more complex than the previously used OFDM receiver under the presence of multipath channel. This statement is provided on the basis of analysis results that are discussed. The performance of the new zero forced (ZF) and MMSE solutions are investigated in AWGN. The modulation preferred in this case is 64-QAM modulation. In order to make the modulation matrix sparse and hence reduce the burden of computations. DFT and IDFT are used in the transmitter in order to reduce the computations burden and to make the modulation matrix sparse. The block diagonalization of matrices is used in the design of MF, ZF and MMSE demodulators. This also helps in the matrix inversion and multiplication operations complexity reduction. Later on, the closed form expressions of ZF and MMSE filters of receiver are formulated.

With the presence of covariance structure the CP based maximum likelihood (ML) blind synchronization is complicated in GFDM because of the non-orthogonal pulse shaping it possesses the time varying signal power and some weak self-induced interference. Fo-Sen Wang et al. [21] shown that the simulated results of GFDM are very close to that of OFDM. The common pulses that are preferred for the ISI free transmission such as Root Raised Cosine (RRC), Raised Cosine (RC) and Xia (with smaller value of roll offs) does not suffer that much because of such structures. The simulated results shows that the self inter symbol interference do not seem to be a serious issue in cyclic prefix based blind synchronization.

Sylvain Traverso [22] presented the design of square root nyquist filter which is having low group delay and fast and high decaying stop band attenuation. The square root nyquist filter was naturally used in single carrier transmission. Moreover, there are several multicarrier waveforms that also uses square root nyquist filter. The operations that are performed at the transmitter and receiver are dependent directly on the impulse response of the filter. The key requirement for the square root nyquist filter is high Stop Band Attenuation (SBA). The reason is that the spectral confinement constraints and linearity get more crucial in order to restrict the quantity of OOB spectrum leakage.

David W. Lin et al. [23] tells that GFDM pulse shaper matrix is singular under some configurations. At different space dimensions, GFDM pulse shaper matrix may have unequal magnitude gains. The GFDM pulse shaper matrix decomposition can be done on the basis of Fourier transform. The pulse shaper matrix nullity upper bound is obtained. As far as this kind of nullity is concerned if it is singular it is equal to one. The transmitter capacity of GFDM is affected when its filter bank does not have full rank under some certain conditions. It happens when the GFDM symbols have even number of sub symbols and corresponding to that the number of subcarriers will be even. There will be certain symmetry in the prototype filter as a result of that.

Shahab Ehanfar et al. [24] says that GFDM can provide flexibility in terms of large number of requirements. It provides low latency and coarse synchronization. GFDM received signal is composed of data, pilots and noises. By utilizing the traditional technique of channel estimation, further challenges are encountered in the design of GFDM receiver. The different pilot patterns will have non-negligible impact on the resulted interference term if in a single GFDM multiple pilots per subcarrier are used. GFDM takes the advantage of clear pilot observation when the performance of it is compared with the OFDM. The Genie-Aided (GA) receivers can be compared for OFDM and GFDM in which the information about the ISI is known at the receiver side. The performance obtained by GFDM - multiple pilot (GFDM-MP) case is better than the GFDM-One Pilot (GFDM-OP) case because GFDM MP provides better rejection of the interference.

Ghaith Al-Juboori et al. [25] tells that the new waveform supposed to be implemented on 5G should have a smooth transition from the old technology to the new technology. It is analyzed from the results that the PER performance get worse when higher were the correlation values. This is due to the fact that the theoretical capacity of the channel is reduced by the spatial correlation between the transmitter and receivers antennas. Along with this the high values of spatial correlation are reduced because of the difference between GFDM and OFDM in the high values of MCS modes. In other words, GFDM is less sensitive to spatial correlation effects at large values of MCS modes. The packet error rate (PER) and throughput of GFDM provides comparable results along with the certain additional advantages like reduced out of band emission. This can be a key factor in a lot of 5G implementation applications like IoT and Machine to Machine (M2M) communication.

2.3 MIMO GFDM

Nicola Michallow et al. [26] tells that Space Time Coding (STC) can be used along with the Generalised Frequency Division Multiplexing (GFDM) while transmitting and receiving data in order to achieve diversity. With the advancement in the electronics we will be able to manage the complexity of the GFDM. In order to develop the GFDM proof of receiver structure customizable Field Programmable Gate Array (FPGA) is used. In Generalised Frequency Division Multiplexing the increase in noise can be ignored winder the usage of Raised Cosine (RC) filter with the value of roll of factor equal to 0.1. In this case, the SER curves of the GFDM and OFDM matches. But in the case when the RC filter with the roll factor equal to 0.9 is used the GFDM SER is quite badly affected. In order to avoid the prohibitive loss of performance, the pulse shape of prototype filter must be properly chosen.

Ghaith Al-Jaborri et al. [27] took the concept of spatial multiplexing into consideration for the performance evaluation of MIMO-GFDM. The performance of a UE under the real urban channel is also presented with the help of channel model. The K-factor and delay spread for the UE are 0.42 µsec and -9.8 dB respectively. As far as low modulation order are concerned (low MCS) the performance of the GFDM and OFDM is very near to them. But when the higher modulation orders are considered the GFDM is outperformed by the OFDM performance. At the high value of Signal to Noise Ratio (SNR), the maximum difference between them is approximately 1 dB. This is because GFDM subcarrier is composed of M samples. Therefore the effect of one sample can be seen on M samples while in OFDM, one subcarrier affects only one sample. Moreover the situation gets worse when the modulation order is increased.

The National Instruments USRP-R10 proves that the complexity of the new waveforms can be handled by the today's generation technology. The Space Time Code (STC) can be used in non-orthogonal modulation techniques like GFDM. When it required implementing STC in frequency domain the TR-STC-GFDM is used. A known preamble is pre-pended beyond the data block implementation of the space time code in order to obtain the channel estimation and synchronization. Martin Dannenberg et al. [28] has shown that the out of band levels of GFDM are quite less as compared to OFDM because the spectrum analyzer sensitivity, RF impairment and non linearties are not taken into consideration.

Jayanta Datta et al. [29] tells that self inter carrier interference is generated because of the non-orthogonal carriers of GFDM. Later on when MIMO is implemented due to the presence of inter antenna interference the bit error rate of GFDM is also affected. In order to eradicate that problem the concept of spatial multiplexing is used in which for separate information symbols different active transmit antenna index are selected in the mapping table that is actually user defined. The processing is done in such a way that each symbol is sent by the antenna which is in active state for the particular symbol at that time as per the mapping table. On comparison between the V-blast GFDM and spatial modulation based GFDM it was found that the BER performance of spatial modulation based GFDM is better than the V-blast GDFM with the transmitter-IC precoded.

Shahab Ehsanfar et al. [30] described the insertion of pilot symbols for MIMO-GFDM channel estimation. It is claimed specifically that the MIMO-OFDM are outperformed by the MIMO-GFDM. The pilots are orthogonal in nature in IFPI as a result of that the performance of the channel estimation becomes similar to that of the OFDM system. If we consider the normal GFDM system it will suffer from non-negligible interference and has a huge error floor at high SNR regions. If we apply channel estimation to the GFDM, then significant gain is achieved as compared to the normal GFDM. Along with it, if we compare OFDM and IFPI GFDM, the performance loss of non-orthogonal waveform, GFDM is negligible as compared to the OFDM systems.

2.4 FILTERS USED IN GFDM

The matched filter when used at the receiver it try to maximize the SNR. But in practice of maximizing we actually introduce self-interference at receiver under the usage of non-orthogonal pulses. Non-orthogonal pulses are the pulses which do not obey the orthogonality principle. OFDM uses the optimal pulse shape i.e. rectangular pulse shape respective to the additive white Gaussian noise. Shwetal K. Antapurkar et al. [31] told that under the doubly dispersive fading channels, GFDM is assumed to adapt channel dependent pulse shapes dynamically which are also optimal in nature. The various pulse shaping filters for GFDM like Root Raise Cosine (RRC), Raised Cosine (RC), Gaussian pulse and dirichlet pulse shaping filter.

Atul Kumar et al. [32] proposed the advanced nyquist pulse shaping filters that were brought to our notice under the context of single carrier modulation schemes in order to diminish their variation with the timing error of symbol because of higher eye opening as well as the smaller maximum distortion. The properties of GFDM are affected by the choice of pulse shaping filter. While implementing nyquist filters in digital communication it is separated into two parts. At the transmitter, a square root nyquist filter is used and also at the receiver, a square root nyquist filter is used. Afterwards the squares of frequency coefficients satisfy the symmetry condition. In order to achieve better time frequency localization and flexibility in design the concept of wavelet is used. Along with the RC, RRC, flipped hyperbolic secant and flipped inverse hyperbolic secant are used as pulse shaping filters in GFDM. While comparing all these filters we came to know that flipped inverse hyperbolic secant is the optimal filter as compared to the RRC and flipped hyperbolic secant. In the latter stage when we apply the Meyer auxiliary function to the flipped inverse hyperbolic secant it gives results in the form of high SER as compared to a condition without Meyer.

Remote gadgets have been exponentially and clearly developing; in this way, critical client's interest for new information concentrated administrations has been amazingly expanding. However, the predominant 2G/3G systems were not intended to adapt to this blast in information utilization. Albeit adequate for some uses, their plan confines their potential for the requirements of tomorrow's prospective ideas, for example, Smart Cities and IoT. These genuine advances are as of now battling with the blasting needs since it is no longer proficient to totally adapt to the guaranteeing request. Thus, 3GPP as of late discharged the discharge 8 (Rel-8), which can be considered as separating line between both 3G and 4G.

Really, the LTE arrange, which is the successor to the UMTS portable radio standard, is one of the ubiquitous ideas in versatile industry composed so as to meet the necessities of genuine 4G framework as characterized by the ITU. Its presentation addresses the exponential development of portable information traffic, which is multiplied in the previous couple of years in worldwide normal. 4G frameworks guarantee to offer not just IP-based administrations, higher speed and better limit additionally essential than adapt to the Scalability challenge [6], which is fundamentally characterized as the capacity to deal with extending clients' number and administrations' assortment. In addition, one of the fundamental objectives of the 4G prerequisites is satisfying a wonderful QoS keeping in mind the end goal to have the capacity to facilitate between the different HetNets.

Subsequently, the 3GPPP LTE, otherwise called 3.9G, has as of now been acquainted with the market as the 4G. It is first rate in the accompanying segment alongside its successor LTE-A. Media transmission industry has seen an impressive cost diminishment contrasting with its first development, which drove customers to expect better execution versus a perceptible charges decrease. In the quickly changing remote correspondences field, specialists have as of late created one of the current media communications measures, which is LTE, keeping in mind the end goal to enhance information rates and reduction handover inertness. The sending of 4G versatile broadband frameworks in view of the 3GPP LTE radio get to innovation is currently progressing on an expansive scale.

In this way, keeping in mind the end goal to effectively fulfill raising clients' needs, the LTE radio get to innovation never stopped unfurling and step by step developing. In 2010, the development of LTE was for the most part introduced by the event of the 3GPP Release 10 (Rel-10), known as LTE-A, which is really a change of Rel-8 and discharge 9 (Rel-9) models. Smooth move to the 4G is proficient by giving administrations utilizing the advancements created for 4G and a similar recurrence groups with respect to 3G. Be that as it may, not at all like UMTS, LTE includes two systems of duplex information transmission: the Frequency Division Duplex (FDD) and TDD. These two portable correspondence advancements depend on various recurrence groups and can total and to grow the limit of data transmission completely.

On one hand, the FDD utilizes two unmistakable transporters: One for transmitting and one for accepting information, which gives greater ability to LTE systems. Then again, TDD utilizes a solitary recurrence to transmit information non concurrently to total to use their individual abilities. In all cases, both procedures depend on various frequencies for the administrator that endeavors both. Not at all like CS administrations, can LTE bolster parcel exchanged administrations. In addition, the LTE design changed since all Radio Network Controller (RNC) capacities have been moved to eNodeB, otherwise called the Evolved–Universal Terrestrial Radio Access Network (EUTRAN) hub B; it no longer had a focal radio controller hub.

These modifications in the Radio Access Network (RAN) system layout are in a general sense created by the basic necessity of providing clients with greater adaptability as far as postponement and phantom proficiency. Developed Packet Core (EPC) is the CN, all-IP–based parcel. Not at all like the 2G and 3G systems where the CS space and PS are obviously recognized in the CN, has the new system just had bundle area called EPC. All Services will be offered over IP including those previously gave by the circuit space, for example, voice, video communication, Short Messaging Service (SMS), and all communication administrations. In addition, the EPC can collaborate with the untimely 2G/3G systems and CDMA2000 in the event of portability. It is conceivable to course movement from the EPC to the LTE get to, CDMA2000, 2G, and 3G and hence guarantee the handover between these get to innovations to give consistent interchanges in a heterogeneous situation. The EPC bolsters Default conveyor as well as devoted bearers.

As an issue of a reality, the Evolved Packet System (EPS) is really institutionalized by the 3GPP institutionalization association and has a few capacities, for example, organize get to control, portability administration, bundle directing and exchange, and radio asset administration (RRM) capacities.

Table 3.1: Comparison of various technologies

S.No.	Parameters	Wi-Fi	LTE	HSDPA	UMTS
1	Multiple Access DL	OFDMA	OFDMA	CDMA/TDMA	DS-CDMA/TDMA
2	Multiple Access UL	OFDMA	SC-FDMA	CDMA/TDMA	CDMA/TDMA
3	Duplexing	TDD	FDD/TDD	FDD	FDD/TDD
4	Channel Bandwidth	Scalable (3.5, 5, 7, 8.75, 10 MHz)	Scalable 1.4, 3, 5, 10, 15, 20 MHz	5 MHz	5 MHz
5	Frame Length	5 millisecond	1 millisecond	2 millisecond	10 millisecond
6	Max MIMO	2	4	2	1
7	Modulation	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 8PSK

The essential part of the PCRF is to give benefit control without experiencing the UE and to progressively deal with the information sessions, which is the primary distinction of the LTE design contrasted with the past ones. Battery life is a standout amongst the most essential parameters to consider on the grounds that it is more effective to utilize mobiles that devour the minimum conceivable measure of battery power. Shockingly, it is obligatory to utilize a transmission mode described with a consistent power level, which can't be offered by the Orthogonal Frequency Division Multiplexing Access (OFDMA) method. Accordingly, the Single Carrier Frequency Division Multiple Access (SC-FDMA) procedure is utilized since it can decrease control utilization of the terminal and in this way adds to the expansion in battery life. For the DL of the LTE radio connections, for which there is a lower vitality requirement, the OFDMA system is fundamentally utilized on the grounds that it permits—for the same ghastly width—higher piece rate.

Along these lines, so as to achieve the distinctive prerequisites, for example, a greatest phantom proficiency, negligible defer need, and speedier information rates, the scientists disposed of the WCDMA system to utilize the OFDMA that precisely fits the LTE's specific necessities in empowering multiuser access by assigning diverse subcarriers to different clients, improving range adaptability, on the radio side, in this way redesigning the pinnacle rates on the DL and discrete Fourier change (DFT)- spread OFDM additionally recognized as SC-FDMA on the UL.

3.1 Generalized Frequency Division Multiplexing (GFDM)

Generalized Frequency Division Multiplexing (GFDM) is the recently proposed technique that has many attractive properties. Among all the advantages, it is having an advantage that it preserves the advantages of the OFDM while removing the limitations of it. For the past several years, OFDM was the choice of technology in the case of wireless as well as wired system. The introduction of 5G in wireless communication has led to the need of new signaling schemes with the efficient time as well as frequency containment as compared to the OFDM [10].The GFDM transmit signal can be represented by the below given expression:

$$X(n) = \sum_{m=0}^{M-1} \sum_{k=0}^{N-1} d[m] g[(n - mN) mod\ M * N] e^{j2\pi kn/N} \quad (3.1)$$

Where, d[m] = QAM modulated data stream

n = 0, …….., M*N -1

M = symbols that are added during CP insertions

M*N = length of samples

3.1.1 Concept of orthogonality

Thoughtfully the OFDM systems are the special case of FDM but there is another constraint that is here all the subcarriers are orthogonal to each other. While selecting the subcarrier frequencies it is taken care that all the all the sub carriers should be orthogonal among themselves.

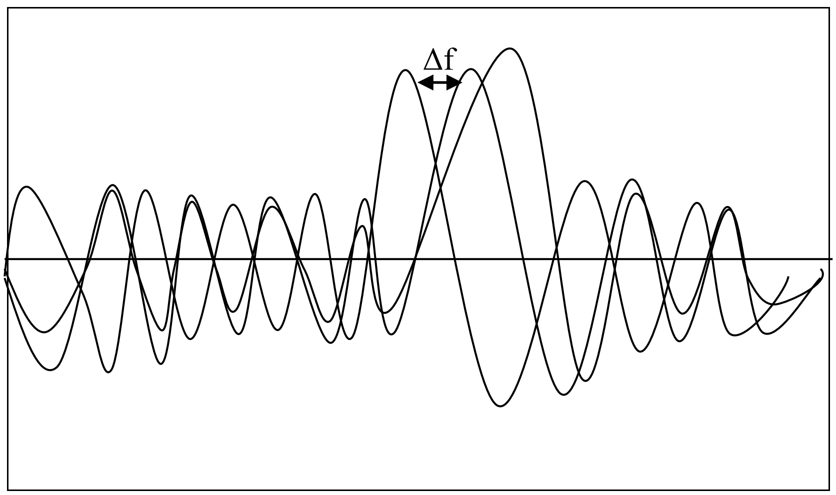

Fig. 3.1: Orthogonality principle

That mean the concept of cross talk between the sub channels is eradicated and the guard band between the carriers is not required [11]. It actually simplifies the design of the transmitter and receiver unlike the traditional frequency division multiplexing an individual filter is not required for the sub-channel. For the orthogonality it is required that the spacing of the subcarrier is:

$$\Delta f = \frac{k}{T} \tag{3.2}$$

where k = positive integer

T = useful symbol duration

We obtain high spectral efficiency because of the orthogonality under the condition in which total symbol rate is nearly equal to the nyquist rate of the equivalent baseband signal [12]. The overall spectrum of the OFDM is generally white that provides it benign interference properties that are electromagnetic in nature with respect to the co-channel users.

3.1.2 W-GFDM

A timing window can be used for smoothing the transition between the GFDM blocks. This method is referred as windowed-GFDM (W-GFDM). A cyclic suffix (CS) with length $N_{CS}=N_W$, where N_W the length of the time window transition and a cyclic prefix (CP) with length $N_{CP}=N_{CH}+N_W$ where N_{CH} is the length of channel impulse response are added in the blocks of GFDM. Basically CS is only a copy of first N_{CS} samples in GFDM up to its end.

The definition of time window is given as:

$$W\ (n) = \begin{cases} Wrise[n] & 0 \le n < Nw \\ 1 & Nw \le n \le Ncp + N \\ Wfall[n] & Ncp + N < n < Ncp + N + Nw \end{cases} \qquad (3.3)$$

where $W_{rise}[n]$ = ramp up segment of time window

$W_{fall}[n]$ = ramp down segment of time window

3.1.3 Precoding using WHT

Among the challenges for the low latency scenarios, one challenge is to achieve reliability in the single shot transmission under the frequency selective channels. For the above discussed case, the probability of error of the small packet that are received should be low because the systems which require low latency will not allow the retransmission of packages. The robustness of the GFDM can be increased by using the WHT [13]. As far as this approach is concerned what we want is the spreading of the data symbols over the subcarriers. This is because if the data symbols get spread then they can be efficiently and correctly recovered at the receiver side even when severe attenuation is encountered on subsets of subcarriers.

3.1.4 Gabor transform in GFDM

Consider a signal,‘s’ for better understanding of the general axioms of the multicarrier modulation. The exact information about the behavior of the signal is revealed when the time domain representation s (t) of the signal is looked upon. This type of depiction of the signal does not contain any kind of frequency component under such positions. If we compare it with the traditional Fourier transform then we analyze that Fourier transform gives us the exact information about the frequency components. Moreover the short time Fourier transform is used to give the information that is time localized with respect to the frequency components of that signal while considering the Fourier transform of the signal in multiplication with time window [14]. Since the frequency and time sampling is kept independent, STFT is seen as highly redundant.

In 1947, Dennis Gabor proposed a method to show the message signal as the mixture of Gaussian functions which are assumed to be linear and these are shifted in frequency and time with respect to the positions of the grid given as:

$$s(t) = \sum_{k \varepsilon Z} \sum_{m \varepsilon Z} a * g(t - m\Delta T) exp(j2\pi \Delta F k t) \quad (3.4)$$

Where ΔT = Grid distance in time

ΔF = Grid distance in frequency

g(t) = Gaussian bell function

The Gaussian functions were selected by the Gabor because of its synchronal localization in frequency and time in order to describe the local behavior of the signal correctly. The original signal can be distinguished by the ‘a’ coefficients multiplied by the Gaussian functions making the base of the time –frequency analysis [15]. The non-unique expansions are implied for the oversampled densities $\rho>1$. The expansion coefficients exists only for certain signals with the $\rho<1$. The expansion is novel and present only for certain windows at the critical densities $\rho=1$.

3.1.5 Synchronization

By permitting adaptation of traditional OFDM for estimating carrier frequency offset (CFO) and symbol time offset the synchronization in GFDM is achieved. But another factor that should be considered for the GFDM is low OOB emission. When straight forward proposal of a separated preamble is used in the algorithms that were given to the OFDM, we can achieve one shot synchronization. Along with this, the above given concept can be used in the GFDM by using windowed preamble for the best distinction between the data and training sequence to get low OOB emission or via adding training sequence as midamble. This can also be referred by the pseudo circular preamble approach. The exploration of robust coarse autocorrelation metrics is done by the successive transmission of same signals. The sub symbols that are configured to take the same pseudo-noise sequence data helps in the achievement of the above said case.

3.2 Block diagram of GFDM

The block diagram of GFDM can be assumed as a synthesis filter bank with the circular filtering present in it. The working of various blocks used in the transmitter as well as receiver is given as:

3.2.1 Modulated signal

The first step in the GFDM transmitter is that the stream at a very high data rate $d=[d_0^T, \ldots\ldots\ldots\ldots, d_{N-1}^T]^T$ which is composed of the QAM modulated symbols is divided into a low rate sub-stream whose rate is N times smaller than that of d. Here M is the number of data symbols that are taken over every band of subcarrier which is given by:

$$dkT = \left[dk[0], \ldots\ldots\ldots\ldots\ldots\ldots\ldots, dk[M-1]\right] \quad (3.5)$$

To order to place it differently, d_k^T is sent over mth time slot and kth subcarrier [16]. Generally we can use the QAM, QPSK and OQAM in the block diagram of GFDM. These are explained as:

- *QAM*

QAM which stands for Quadrature Amplitude Modulation is that modulation technique which is used to modulate the message signal onto the carrier signal in the radio communication. It is having several advantages over the previous modulation techniques like PSK although some types of message modulation technique works along with each other. QAM have the property in which two of the message signals are shifted from each other by the phase of 90 which is making them apart. The result output is made up of the duo amplitude as well as the phase variations. As it is having the variation in terms of amplitude as well as in terms of phase, it is assumed as the combination of both the amplitude modulation as well as phase modulation. Earlier in case of amplitude modulation, the straight amplitude modulated signal (double sideband with the suppressed carrier) was occupying the double bandwidth as compared to the modulating signal. This was leading to the problem of wastage of the frequency spectrum [17]. The balancing was done in such a way that two independent double side band suppressed carrier signals were placed into the same spectrum in the form of one simple double sideband suppressed carrier signal. When QAM is used in the radio communication for the digital transmission the system is able to carry high data rates as compared to the traditional amplitude and phase modulated techniques.

Table 3.2: Comparison of different modulation schemes

Modulation	**Bits Per Symbol**	**Error Margin**		**Complexity**
OOK	1	1/2	0.5	Low
BPSK	1	1	1	Medium
QPSK	2	$1/\sqrt{2}$	0.071	Medium
16QAM	4	$\sqrt{2}/6$	0.23	High
64QAM	6	$\sqrt{2}/14$	0.1	High

In QAM, there is a square grid arrangement of the constellation point in which the horizontal and vertical spacing are same. QAM uses the number of points equal to the power of 2 i.e. 4, 16, 64 etc. While using the higher modulation formats in which more points are used at the constellation, more number of bits can be transmitted per symbol. As the points are close to each other, so it is more susceptible to noise and data errors.

The QAM constellation is a square normally. The various forms of it are 16QAM, 64QAM and 256 QAM. The higher order of the QAM is only used when we have a quite significant Signal to Noise Ratio (SNR). 16QAM is the lowest order of QAM. This is because the 2QAM is basically the BPSK and 4QAM is QPSK [18]. The 8QAM is not that much used because the performance of the error rate of 8QAM is identical with the 16QAM. It is about 0.5 dB better and having the data rate of three quarters as compared to the 16QAM. These are the simulated results that arise from the rectangular constellation rather than the square shape of the constellation.

- *OQAM*

Generally, GFDM is a non-orthogonal waveform but it can be made orthogonal by using pulse shaping filters like dirichlet pulse. It can also be done by making use of the combination of GFDM and OQAM. OQAM can be regarded as two independent Gabor expansions in which the input symbol is limited to be either real only or only the imaginary part which achieves the orthogonality condition instead of the direct modulation of the symbol input in the form of in-phase and quadrature-phase (Q). When bandwidth is limited up to two subcarriers for square root nyquist prototype filter then the I input part produces the real interference among the adjacent subcarriers and Q input part introduces only imaginary interference. The flexibility of the waveform can be improved by using the pulse shaping filters which have arbitrary length, overlapping factor and considers OQAM. A substitute which uses the shorter pulses in time is being proposed and also known as frequency shift-OQAM (FS-OQAM).

- *QPSK*

Quadrature phase shift keying is a technique in which two information bits are modulated at once by selecting one carrier phase shift state out of the four carrier phase shift states. Let T_{sym} be the symbol duration and s(t) be the QPSK signal which is given as:

$$s(t) = Acos[2\pi fct + \theta n], \quad 0 \le t \le Tsym, n = 1,2,3 \tag{3.6}$$

Where the phase of the signal is given by:

$$\theta_n=(2n-1) \tag{3.7}$$

The four possible initial phases of the signal are given as: $\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4}$.

Also, the above equation can be written as:

$$s(t) = A\, cos\theta n cos(2\pi fct) – A\, sin\theta n\, sin(2\pi fct) \; = sni\phi i(t) + snq\phi q(t) \qquad (3.8)$$

Where ϕ_i (t),ϕ_q (t) = orthogonal basis function

s_{ni} = in phase signaling point

s_{nq} = quadrature signaling point

3.2.2 Oversampling

In next step we are going to consider either upsampling or the oversampling for the operations on the signals. Mathematically both of these do the same operations. In oversampling the sampling of the signal with a sampling frequency higher than the Nyquist rate is done [19]. While upsampling is the process of the conversion of the rate of messages from the considered rate to the other arbitrary rate. It is proved that the perfect reconstruction of the signal of band limited signal can be done if it is sampled equal to the nyquist rate or above than that.

Mathematically, the nyquist rate is given as the twice of the maximum frequency of the signal given as:

$$Nyquist\ rate \; = \; 2 * maximum\ frequency\ of\ the\ signal \qquad (3.9)$$

The advantages of the oversampling are given as:

- *Improvement in the resolution*

Oversampling helps in the improvement of resolution. It helps us in order to get cheap and higher resolution A/D and D/A conversion. For example, in order to get a 24- bit converter, it will be convenient to use a 20-bit converter which may run at 256 times the desired sampling rate. While combining the 256 successive samples which are 20 bit it can enhance the SNR by the factor of 16 at voltage level with efficient addition of 4 bits in the resolution. It will produce one sample with the 24 bit resolution. The dynamic range got increased by the $\log_2(N)$ bits when oversampling with a factor of N is done. This is because for the sum there will exists N times as many values. The value of SNR increases by sqrt (N). In nutshell, the amplitude is increased by sqrt(N) because of uncorrelated noise. The sqrt (N) value also increases the SNR.

- *Reduction of noise*

Oversampling also reduces the noise content in the signals. When the uncorrelated noise is considered with several samples of the same quantity and is added with each sample then the noise power get reduced by a factor of 1/N. There are several kind of analog to digital converters which are also called as delta sigma converters that produce more quantization noise in disproportion at the top part of the output spectrum. With the help of these converters a less noise is obtained at the output.

- *Ease of realization of anti-aliasing filter*

It makes the realization of the anti-aliasing filter much easier. If oversampling is not used then it became very difficult for us to get sharp cutoff while implementing the filters in order to maximize the usage of available bandwidth despite exceeding the given nyquist limit. The design constraints of the anti-aliasing filter can be relaxed by increasing the bandwidth of the sampled signal. Once this type of sampling is done then the signals can be filtered digitally and later on it can be down sampled to a particular desired frequency. The digital filters are considered here for the implementation as compared to the analog filters because it is easier to implement the digital signals. It also helps in avoiding the aliasing and the phase distortion by loosening the performance requirements of the anti-aliasing filter.

3.2.3 Circular convolution

The convolution that is performed in between the two vectors is of two types. First one is the linear convolution and second one is the circular convolution. Linear convolution is calculated basically for the aperiodic sequences over the all the related values of n from - ∞ to ∞ [20]. In contrast to that the circular convolution is taken between the two periodic sequences having period N which is varying from 0 to N-1. Let us consider h[n] be the impulse response of the given LTI system and x[n] be the input vector.

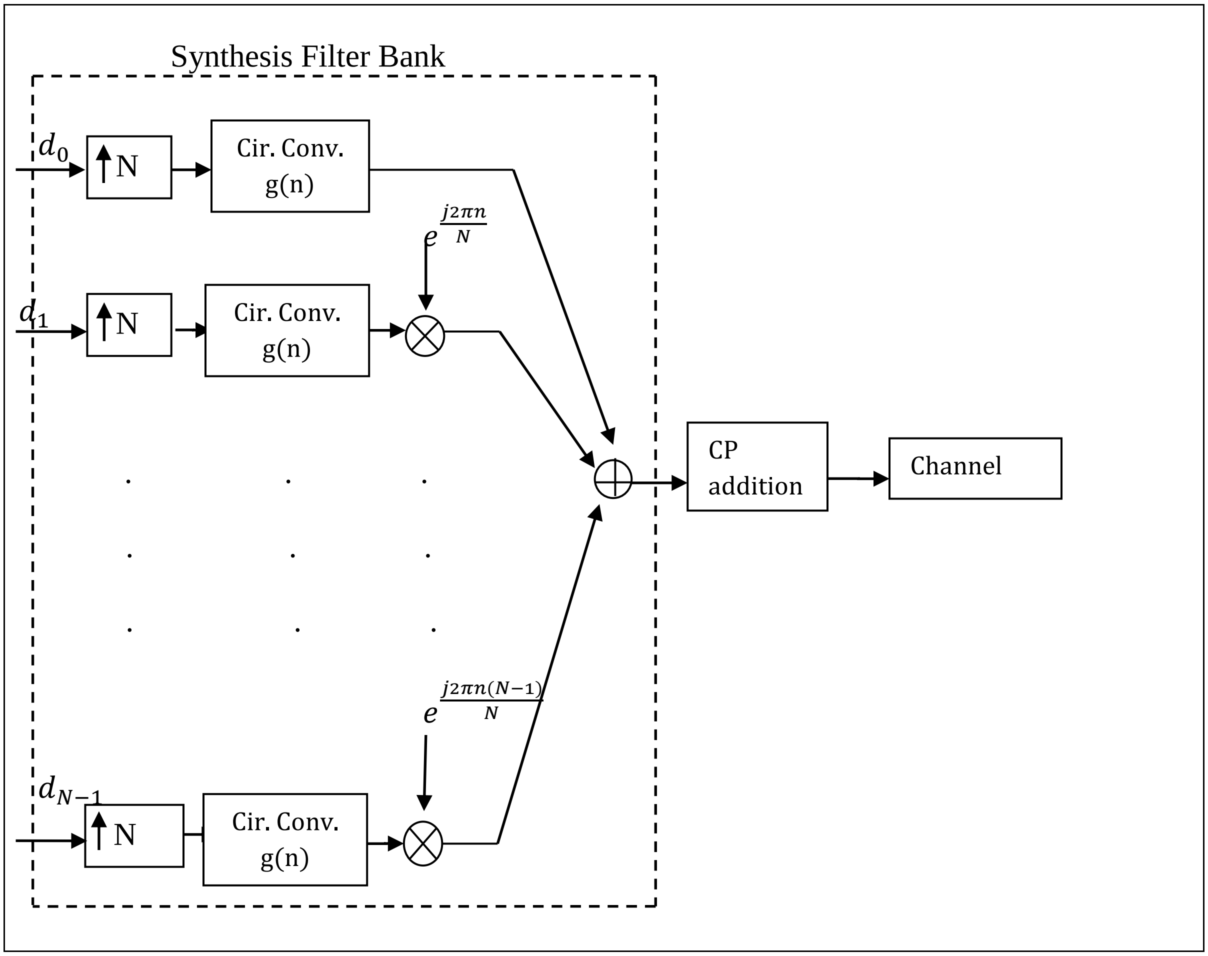

Fig.3.2: Representation of GFDM transmitter

Then, we can compute its response or output y[n] as:

$$y[n] = \sum_{-\infty}^{\infty} x[k]h[n-k] = \sum_{-\infty}^{\infty} h[k]x[n-k] \quad (3.10)$$

Where h[n] = the impulse response of the given LTI system

x[n] = the input vector

y[n] = the input vector

This expression represents the linear convolution. For the calculation of the circular convolution we multiply the IFFT of the considered two, after performing the FFT of the padded input vectors. The circular convolution is implemented with the help of pulse shaping filters in the GFDM. The filters that are used for the GFDM are Root raised cosine (RRC),Flipped-hyperbolic secant (Fsech), Xia pulse, Gaussian pulse, Dirichlet pulse.

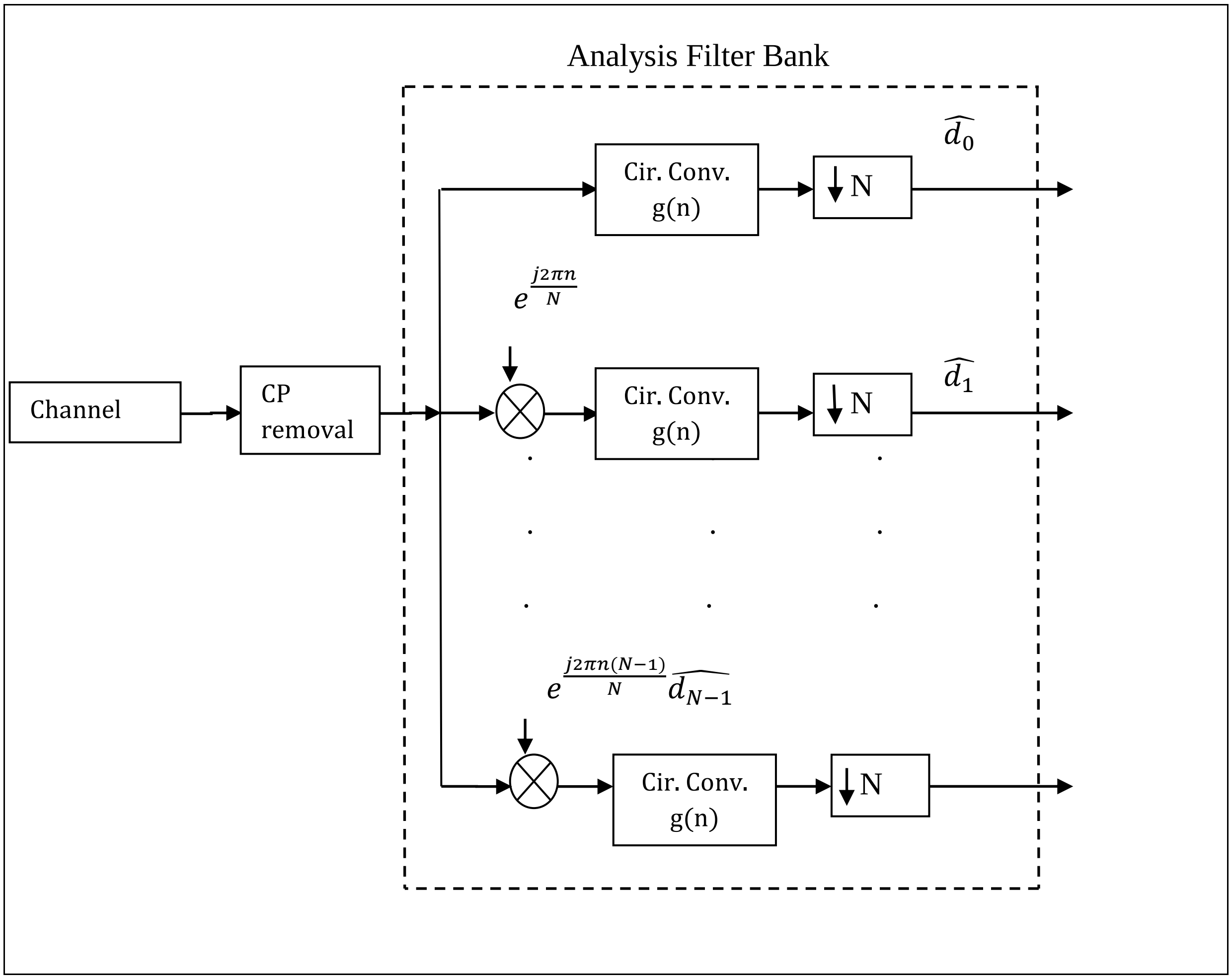

Fig.3.3: Representation of GFDM receiver

They can we implemented by using the complete algorithms or with the help of inbuilt function in MATLAB. Matched filter are used at the receiver end in order to reduce the effect of noise for additive white Gaussian noise. Another main reason for using matched filter in case of receiver stage is that the complexity of this filter is very less. By using the complex cancellation method for interference the performance of MF can become latterly close to a system which is orthogonal [21]. The filtration of every subcarrier is done individually corresponding to this filter. After that the subcarriers whose filtering is done are sampled with respect to the symbol slot for the detection of symbols of the data.

3.2.4 Cyclic prefix insertion

Cyclic prefix is that portion of the block diagram of the GFDM where we are adding some part of a message generally ¼ of the message bits to the front portion of the message bits. This prefix is added in order to avoid the interference between the adjacent channels. In GFDM in spite of adding cyclic prefix to every subcarrier we add only one cyclic prefix to the combination of subcarriers [9].

Cyclic Prefix	Payload

Fig.3.4: Cyclic prefix addition to the payload

The characteristics of the cyclic prefix are as follows:

- *Size of CP with respect to symbol time*

Symbol time is the time that is given by the difference of end value of a signal time period to the initial value of the signal period. CP is basically the 10-15 % of the symbol time.

- *Size of CP with respect to symbol Delay spread*

In order to get effective results from the CP it should be greater than that of the delay spread. If the delay spread value got increased as compared to the signal time then it will leads to interference.

- *Effect of interference on length*

The presence of the interference and guard band level affects the length of the CP. If the delay spread value got increased as compared to the signal time then it will leads to interference. More is the interference more will be the length of the CP.

- *Mitigation of inter symbol interference*

Cyclic prefix mitigates any of the inter symbol interference that may present in the system. This inter symbol interference may exist due to non-orthogonality of the subcarriers.

- *Preservence of orthogonality*

CP may preserve the orthogonality of the subcarriers. Orthogonality is the condition when in a single time period two or more signal can be transmitted. This is made possible by sending signal in such a way that at one time one signal will be having maximum value and at the same time other will be having minimum value of the amplitude.

- *Mitigation of frequency offset problems*

Frequency offsets are the major problems in the communication systems. CP can mitigate the problems that may arise due to the frequency offsets and this will affect the performance of the system.

3.2.5 Decoded stream

In this block the decoding of the bits is done. In other words we obtain the same bits that we sent at the modulator. The demodulation which is preferred in case of GFDM is OQAM, QAM and QPSK. The preprocessing and post processing also plays a significant role while implementing the GFDM demodulation in case of OQAM demodulation. The linear receivers are further classified into three of its types which are as follows:

- *Matched filter Receiver*

Matched filter Receiver (MF) is the receiver that is used to having an matrix that is used to maximize the signal to the noise ratio per individual subcarrier. This type of receiver can introduce self-interference in the system because there is a possibility that the filtered signal may not be orthogonal at the transmitter side [22].

- *Zero Forcing Receiver*

Zero Forcing Receiver(ZF) can be represented in the form of matrix that will further increase the noise power to cancel out the self-interference.

➢ *Linear Minimum Mean Square Error*

Linear Minimum Mean Square Error (MMSE) helps in the balancing of the self-interference. It also helps in the balancing of the noise enhancement [22]. It outperforms the ZF and MF at the price of the increased complexity. This is because of the necessary approximation of the noise variation.

3.3 Pulse shaping filters used in GFDM

3.3.1 Root raised cosine (RRC)

Root raised cosine (RRC) is that category of the pulse shaping filter that is well defined by the square root raised cosine (SRRC) and raised cosine (RC) functions in the time domain along with the roll off factor equal to α [11]. The expression for the RRC filters is as follows:

$$\mathrm{grc}(t) = \begin{cases} 1, & |t| \leq \frac{(1-\alpha)T}{2} \\ \frac{1}{2}\left[1 + \cos\left(\pi \mathrm{P_{rc}}(t)\right)\right], & \frac{(1-\alpha)T}{2} < |t| \leq \frac{(1+\alpha)T}{2} \\ 0, & otherwise \end{cases} \tag{3.11}$$

where $P_{rc}(t)$ = inner argument of the cosine

$$\mathrm{P_{rc}}(t) = \left(\frac{|t| - \frac{(1-\alpha)T}{2}}{\alpha T}\right) \tag{3.12}$$

The inner argument of the cosine should be modified by the introduction of Meyer auxiliary function as:

$$\mathrm{P_{rc}}(t) = v\left(\frac{|t| - \frac{(1-\alpha)T}{2}}{\alpha T}\right) \tag{3.13}$$

The definition of the RRC is given as:

$$G_{rrc}(t) = \sqrt{g_{rc}(t)} \tag{3.14}$$

In other word when we perform the square root of the raised cosine (RC) then the square root raised cosine (SRRC) is obtained [32].

3.3.2 Flipped-hyperbolic secant (Fsech)

The expression for the flipped hyperbolic secant is given as:

$$g(t)=\begin{cases} 1, & |t| \leq \frac{(1-\alpha)T}{2} \\ [1-\operatorname{sech}(\rho * p_1\ (t))], & \frac{(1-\alpha)T}{2} < |t| \leq \frac{T}{2} \\ \operatorname{sech}(\rho * p_2(t))), & \frac{T}{2} < |t| \leq \frac{(1+\alpha)T}{2} \\ 0, & \frac{(1+\alpha)T}{2} < |t| \end{cases} \tag{3.15}$$

Where sech = hyperbolic secant function

$\rho = \ln(\sqrt{3}+2)/\alpha * \frac{T}{2}$

p_1 (t), p2 (t) = inner arguments of the hyperbolic function

$$p_1(\mathrm{t}) = \frac{(1+\alpha)T}{2}) - |t|) \tag{3.16}$$

and

$$p_2(\mathrm{t}) = (|t| - (\frac{(1-\alpha)T}{2})) \tag{3.17}$$

Let us consider the Meyer auxiliary function υ(x) which is introduced in the above equation. Then after that the modified equation with the inner arguments of the hyperbolic secant function p_1 (t) and p_2 (t) will be given as:

$$p_1(\mathrm{t}) \ = v((\frac{(1+\alpha)T}{2}) - |t|) \tag{3.18}$$

and

$$p_2(\mathrm{t}) \ = \ v((\ (|t| - (\frac{(1-\alpha)T}{2})) \tag{3.19}$$

3.3.3 Flipped- inverse hyperbolic secant (Farcsech)

When the independent frequency variable is interchanged with the time variable then we got the time domain expression if Farcsech is obtained [34]. This expression is given as:

$$g(t)=\begin{cases} 1, & |t| \leq \frac{(1-\alpha)T}{2} \\ [arc\text{sech}((1/\rho) * p_1 * (t)))], & \frac{(1-\alpha)T}{2} < |t| \leq \frac{T}{2} \\ [1 - arc\,\text{sech}\left(\left(\frac{1}{\rho}\right) * p_2(t)\right)], & \frac{T}{2} < |t| \leq \frac{(1+\alpha)T}{2} \\ 0, & \frac{(1+\alpha)T}{2} < |t| \end{cases} \tag{3.20}$$

where arcsech = inverse hyperbolic secant function

$\rho = \ln(\sqrt{3} + 2)/\alpha * \frac{T}{2}$,

p_1 and p_2 = inner arguments of the inverse hyperbolic function

$$p_1(t) = ((|t| - \frac{(1-\alpha)T}{2})) \tag{3.21}$$

and

$$p_2(t)=((\frac{(1+\alpha)T}{2} - |t|)) \tag{3.22}$$

Let us consider the Meyer auxiliary function v(x) which is introduced in the above equation. Then after that the modified equation with the inner arguments of the inverse hyperbolic secant function P_1 (t) and P_2 (t) will be given as:

$$p_1(t) = v((\frac{(1+\alpha)T}{2} - |t|)) \tag{3.23}$$

and

$$p_2(t) = v((|t| - \frac{(1-\alpha)T}{2})) \tag{3.24}$$

3.3.4 Xia pulse

The Xia pulse shaping filter is the filter that is implemented by using two orders of it. In this 1st and 4th order of the Xia are considered for the analysis which is mathematically given as:

The first order Xia is as follows:

$$G_{xia}[f] = \frac{1}{2}\left[1 - e^{-j\pi lin\alpha\left(\frac{f}{M}\right)sign(f)}\right] \tag{3.25}$$

And, the 4th order of Xia is as follows:

$$G_{xia4}[f] = \frac{1}{2}\left[1 - e^{-j\pi p^4 lin\alpha\left(\frac{f}{M}\right)sign(f)}\right] \tag{3.26}$$

3.3.5 Gaussian pulse

When the truncation of the sampled version of the continuous time impulse response of Gaussian filter is done then we obtain the FIR Gaussian filter and is shown as the below given expression:

$$h(t) = \left(\frac{\sqrt{\pi}}{a} e^{\frac{-(\pi t)^2}{a^2}}\right) \tag{3.27}$$

The parameter ‘a’ is related to 3db bandwidth symbol time product ($B*T_s$) of Gaussian filter.

$$a = \frac{1}{BT_s}\sqrt{\frac{\log 2}{2}} \tag{3.28}$$

3.3.6 Dirichlet pulse

Dirichlet pulse shaping filter is regarded as the special case of the Xia pulse when the roll off approaches to zero. It is generally a perfect rectangular function that may be represented in the frequency domain with the width of M frequency bins. These bins are basically located near the DC bin in order to get the time domain response as dirichlet response [35]. This is the pulse shaping filter which actually helps in making the subcarriers orthogonal. This is mathematically represented as:

$$[g_f]_l = \sqrt{K} \sum_{k=0}^{M-1} \delta_{lk}, \quad l = 0, 1, \dots \dots \dots \dots \dots .., \mathrm{D} - 1 \qquad (3.29)$$

3.4 Advantages of GFDM

- **Low OOB**

GFDM is having the low out of band emission as compared to OFDM. Its low out of band radiation approximately equal to -35 dB.

- **Specific subcarrier allocation**

If we talk about GFDM it is having specific subcarrier allocation in it. Every subcarrier is individually processed by the blocks of the GFDM.

- **Low PAPR**

The PAPR of GFDM is quite efficient as compared to the OFDM. The GFDM systems have low PAPR value as compared to OFDM.

- **Less length of CP**

The cyclic Prefix Length of GFDM is less because only one cyclic prefix is added to the various subcarriers. In OFDM we were adding the CP to every subcarrier which as a result was consuming more bandwidth.

3.5 Disadvantages of GFDM

- **Complex design**

The design of the GFDM receiver is quite complex as compared to the OFDM. In this we implementing circular filtering for the purpose of the filtering in which we need to firstly calculate two different FFT and after that we are doing IFFT at the transmitter side.

- **Requirement of matched filter**

In GFDM, there is a requirement of matched filters in order to remove the consecutive inter carrier interference. At the transmitter side we use pulse shaping filter and at the receiver side, matched filter is used to remove the unwanted content.

- **Requirement of OQAM to replace matched filter**

Alternating to the matched filter usage, it is required that we must use OQAM in GFDM which makes the implementation of the MIMO very difficult.

- **Time offset estimation**

In GFDM, there is a requirement of the symbol time offset (STO) estimation.

- **Frequency offset estimation**

In GFDM, there is a requirement the carrier frequency offset (CFO) estimation.

- **Requirement of higher order filtering and tail biting**

GFDM needs high order filtering and tail biting in order to suppress the inter symbol interference.

- **Requirement of successive interference cancellation**

In order to cancel the inter subcarrier interference pre-cancellation or successive interference cancelation is required that is still present after the filtering.

4.1 Introduction

MIMO is defined as multiple-input multiple output. In which multiple number of antennas are used at transmitter side and at receiver side. MIMO, remains for numerous information and various yield and output, is a procedure where diverse gathering contraptions are used at both the transmission and the collector for expand the connection unwavering quality, the ghastly proficiency, or both. MIMO has the capacity to interact with various antennas at a same time which are 2x2, 3x3, 4x4 .This idea has been around for a long time yet its utilization in remote gauges is later. This is likely due to some extent to the way that OFDM (orthogonal recurrence division multiplexing), which encourages the usage of MIMO, is presently normally utilized as a part of today's remote measures. MIMO methods are utilized today in advances like Wi-Fi and LTE, and new strategies are under review for future benchmarks like LTE Advanced. The primary element of MIMO frameworks is space-time preparing. Space-Time Codes (STCs) are the codes intended for the utilization in MIMO frameworks [21]. In STCs, signs are coded in both transient and spatial areas. Here we use encoder at the transmitter side and decoder at the receiver side.

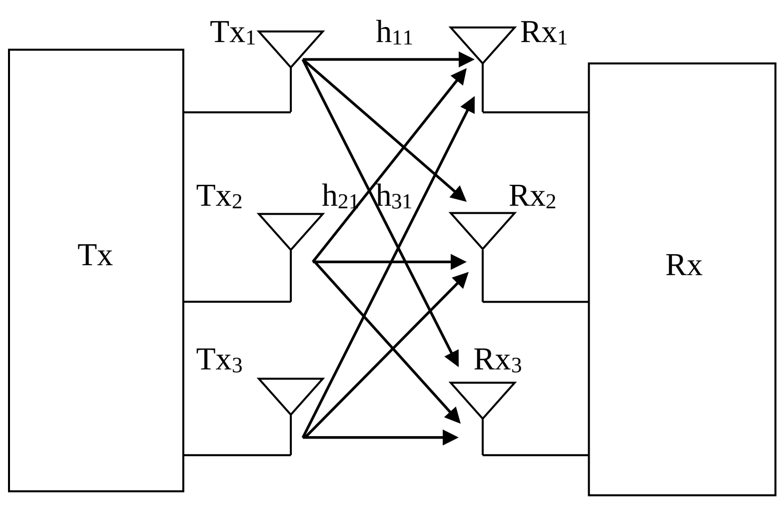

Fig. 4.1: Basic diagram of MIMO

Here h_{mn} represents the impulse channels. An m represents the transmitter impulse channels and n represents receiver impulse channels.

4.2 History

MIMO is frequently followed back to 1970s research papers concerning multi-station advanced transmission frameworks and impedance (crosstalk) between wire matches in a link package: AR Kaye and DA George (1970), Branderburg and Wyner (1974), and W. van Etten (1975, 1976). Despite the fact that these are not instances of abusing multipath expansion to send different information streams, a bit of the logical strategies for overseeing regular deterrent exhibited accommodating to MIMO change [21]. In the mid-1980s Jack Salz at Bell Laboratories made this investigation a walk further, inspecting multi-customer structures working over "generally cross-coupled direct frameworks with included substance uproar sources, for instance, time-division multiplexing and dually-stimulated radio frameworks.

Strategies were delivered to improve the execution of cell radio frameworks and enable more mighty repeat reuse in the mid-1990s. Space-division different access (SDMA) uses directional or splendid radio wires to confer on a comparative repeat with customers in different zones inside extent of a comparative base station. A SDMA structure was proposed by Richard Roy and Bjorn Ottersten, investigators at ArrayComm, in 1991.Their US patent (No. 5515378 issued in 1996[8]) portrays a strategy for expanding limit utilizing "a variety of getting receiving wires at the base station" with a "majority of remote clients”.

4.2.1 Standards and commercialization

MIMO advancement has been regulated for remote LANs, 3G mobile phone frameworks, and 4G wirelesses composes and is by in wide business use. Greg Raleigh and V. K. Jones built up Airgo Networks in 2001 to make MIMO-OFDM chipsets for remote LANs. The Institute of Electrical and Electronics Engineers (IEEE) influenced an errand to gather in late 2003 to develop a remote LAN standard passing on no under 100 Mbit/s of customer data throughput. There were two significant fighting suggestions: TGn Sync was supported by associations including Intel and Philips, and WWiSE was reinforced by associations including Air go Networks, Broadcom, and Texas Instruments. The two social affairs agreed that the 802.11n standard would be established on MIMO-OFDM with 20 MHz and 40 MHz channel options. TGn Sync, WWiSE, and a third suggestion (MITMOT, maintained by Motorola and Mitsubishi) were united to make what was known as the Joint Proposal. In 2004, Air go turned into the primary organization to dispatch

MIMO-OFDM products. Qualcomm procured Air go Networks in late 2006.The last 802.11n standard bolstered accelerates to 600 Mbps (utilizing four concurrent information streams) and was distributed in late 2009.

Surendra Babu Mandava and Arogya swami Paulraj set up moved toward becoming Communications in 2004 to convey MIMO-OFDM chipsets for Wi-MAX. The association was secured by Broadcom in 2010. Wi-MAX was delivered as a differentiating choice to cell rules relies upon the 802.16e standard, and uses MIMO-OFDM to pass on quicken to 138 Mbit/s. The further created 802.16m standard engages download quickens to 1 Gbit/s. A the country over Wi-MAX sort out was worked in the United States by Clear wire, a reinforcement of Sprint-Nextel, covering 130 million motivations behind embodiment (PoP) by mid-2012. Run in this way pronounced plans to pass on LTE (the telephone 4G guidelines) covering [11] urban groups by mid-2013 and to shut down its Wi-MAX organize before the complete of 2015.

The underlying 4G cell standard was proposed by NTT Docomo in 2004. Long haul headway (LTE) relies upon MIMO-OFDM and continues being created by the third Generation Partnership Project (3GPP). LTE decides downlink rates up to 300 Mbit/s, uplink rates up to 75 Mbit/s, and nature of organization parameters, for instance, low idleness. LTE Advanced incorporates reinforce for picocells, femtocells, and multi-transporter channels up to 100 MHz wide. LTE has been gotten a handle on by both GSM/UMTS and CDMA administrators.

The principle LTE organizations were pushed in Oslo and Stockholm by TeliaSonera in 2009. Organization is most dynamic in the United States, where each of the four Tier 1 overseers has or is working the country over LTE frameworks. There are starting at now more than 360 LTE sorts out in 123 countries operational with around 373 million affiliations (contraptions).

4.3 Types of MIMO

MIMO has two types:

- Single user-MIMO
- Multiuser-MIMO

These are explained below:

4.3.1 Single user-MIMO (SU-MIMO)

For a single user equipment data rate is to increase is called single user-MIMO.

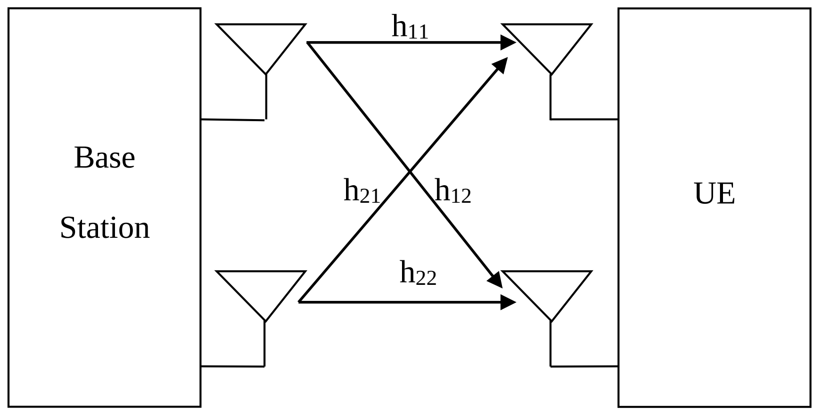

Fig. 4.2: SU-MIMO

4.3.2 Multiple user-MIMO (MU-MIMO)

When an individual streams are given to multiple users, it is called MU-MIMO. It is used in uplink due to complexity on user equipment can be kept a minimum by using only single transmit antenna. It is also called collaborative-MIMO.

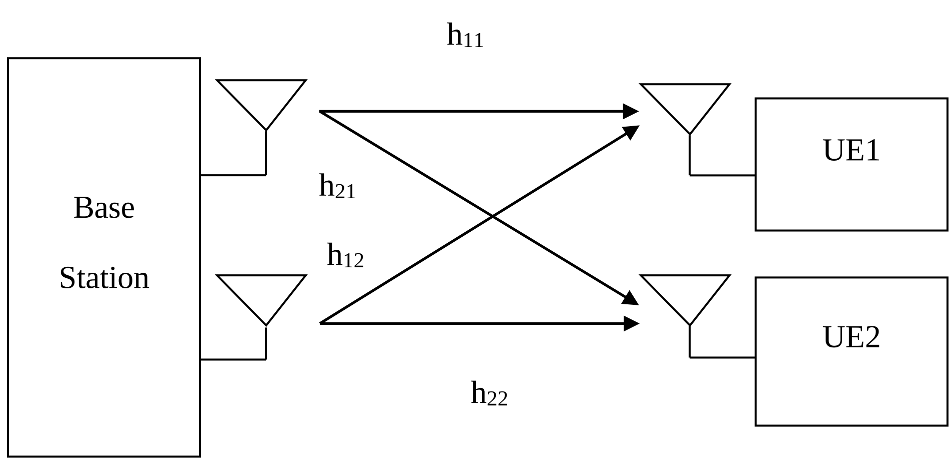

Fig. 4.3: MU-MIMO

4.4 Multi-antenna types of MIMO

MIMO is multiple-input multiple output. It has different types of antennas are used such as

1. SISO- Single input single-output
2. SIMO- Single-input multiple-output
3. MISO- Multiple-input single-output
4. MIMO-Multiple-input multiple-output

4.4.1 SISO(Single input single-output)

In which at transmitter and received side only single antenna is used. The Fig. 4.4 shown as

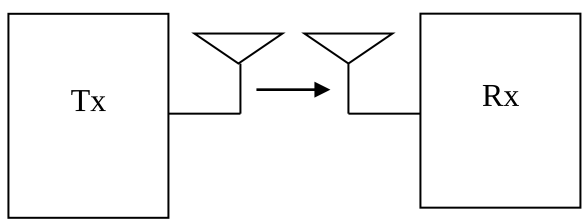

Fig. 4.4: SISO

4.4.2 SIMO (Single input multiple-output)

In which at transmitter only single antenna is used and received side multiple antennas are used. The Fig. 4.5 shown as

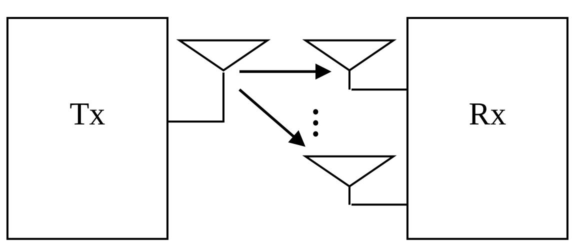

Fig. 4.5: SIMO

4.4.3 MISO (Multiple-input single-output)

In which at transmitter multiple antennas are used and at the receiver side single antenna is used. The Fig. 4.6 shown as

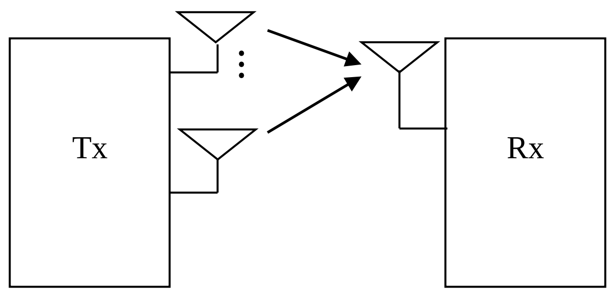

Fig. 4.6: MISO

4.4.4 MIMO (Multiple-input multiple-output)

In which at transmitter and at the receiver side multiple antennas are used. The Fig. 4.7 shown as

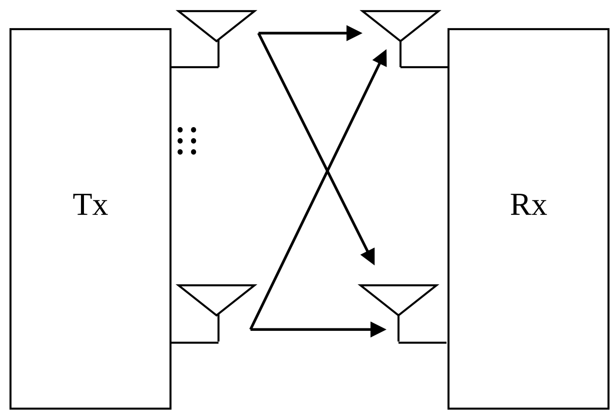

Fig. 4.7: MIMO

4.5 Techniques for MIMO

MIMO further sub-partitioned into 3 primary classes. These classes are

- Beam forming (precoding)
- Spatial Multiplexing technique (SM)

- Spatial Diversity coding.

These three different types of techniques are explained below:

4.5.1 Beamforming

The beamforming technique is also called precoding. Further broad signals, it is thought to be all spatial handling is happens at the transmission side [21]. In precoding and beamforming, a similar flag may be discharged from the both wires at the transmitter and receiver with proper stage or pick up data to such an extent where the flag power is expanded on the collector side. The advantages of precoding use for expand the gotten signal pick up - by making signals produced from various radio wires include helpfully - and to decrease the multipath blurring impact. In viewable pathway spread, beamforming brings about a very much characterized directional example. Be that as it may, traditional pillars are not a decent similarity in cell systems, which are for the most part described by multipath engendering. At the destination when the collector has various receiving antenna, the transmission beamforming or precoding cannot all the while amplify the flag term level at all of the get gathering mechanical assemblies and precoding with various streams is every now and again helpful. Watch that precoding requires learning of channel state data (CSI) at the transmission and the gatherer. To this point we have not used channel learning at the transmitter. Here we consider direct precoding at the transmitter that may rely on upon the channel acknowledgment. The precoder is used to maximizing the SNR at the receiver [26].

4.5.2 Spatial multiplexing

Spatial multiplexing has MIMO radio frequency chain setup. In this technique, a greater-rate divided into different lower-rate streams and every stream is transmitting from other transmitted gathering device in a comparable repeat channel. On the off chance that these signs get together at the recipient radio wire show with enough uncommon spatial engravings has correct CSI, it can isolate these streams into parallel channels. Spatial multiplexing is a talented strategy for stretching out channel restrained higher signal to-change degrees (SNR). The craziest number of spatial streams is confined through the base of the measure of radio wires at the transmitter or beneficiary. Spatial multiplexing can be utilized without CSI at the transmitter, however can be joined with precoding if CSI is accessible. Spatial multiplexing can in like way be utilized for synchronous transmission to different beneficiaries, known as space-division diverse for acquiring or multi-client MIMO, for this situation Channel State Information is required at the transmission side [27]. The arranging of authorities with different spatial imprints licenses awesome uniqueness.

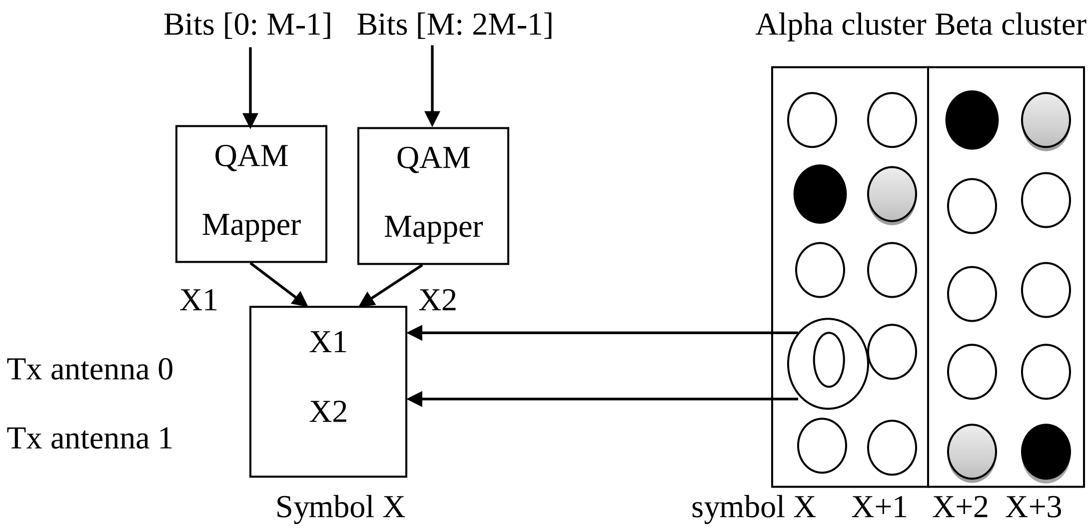

Fig. 4.8: Spatial multiplexing

4.5.3 Spatial diversity coding

Assorted qualities coding or diversity technique frameworks are used when there is no channel data at the transmitter. In this strategy a basic stream is transmitted, yet the flag or information is coded using strategies called space-time coding. The signal is delivered from all of the transmit antenna with full or close orthogonal coding. Assorted qualities coding manhandle the independent obscuring or fading in the various radio wire associations with update hail contrasts. Since there is no channel learning or affirmation, there is no beamforming or show get from grouped qualities coding. This coding can be joined with spatial multiplexing when some channel learning is accessible at the transmitter.

In Fig.4.9 described as data is send from Tx to Rx in the form of bits. Decent variety Coding is the spatial coding procedures for a MIMO framework in remote channels. Remote channels extremely experience the ill effects of blurring marvels, which causes lack of quality in information disentangling.

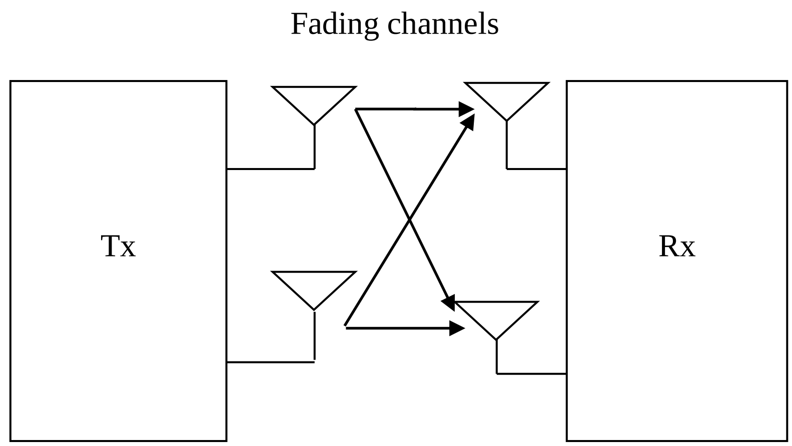

Fig. 4.9: Spatial diversity

On a very basic level, decent variety coding sends numerous duplicates through various transmit radio wires, in order to enhance the unwavering quality of the information gathering. In the event that one of them neglects to get, the others are utilized for information deciphering. MIMO accomplishes spatial assorted variety and spatial multiplexing.

4.6 Diversity combining

Diversity combining is the technique used to combine the multiple received signals of a diversity reception device into a single improved signal.

4.6.1 Techniques used in diversity

Different techniques are used in diversity combining are:

1. Maximum ratio combining
2. Selection combining or switching combining
3. Equal gain combining

- **Maximum ratio combining (MRC)**

It is mostly used as a phased array system. In this with respect to SNR (signal to noise ratio) the received signals are weighted and summed. The outcomes of SNR yields are:

$$\sum_{K=1}^{N} SNR_k \tag{4.1}$$

Where SNR_k = signal to noise ratio of the received signal k.

- **Selection combining (SC)**

In this, from the N no. of signals, stronger signal is selected. When the N signals are independent and Rayleigh distributed. Similarly as with exchanging, choice preparing presents just a single reception apparatus' flag to the recipient at any given time.

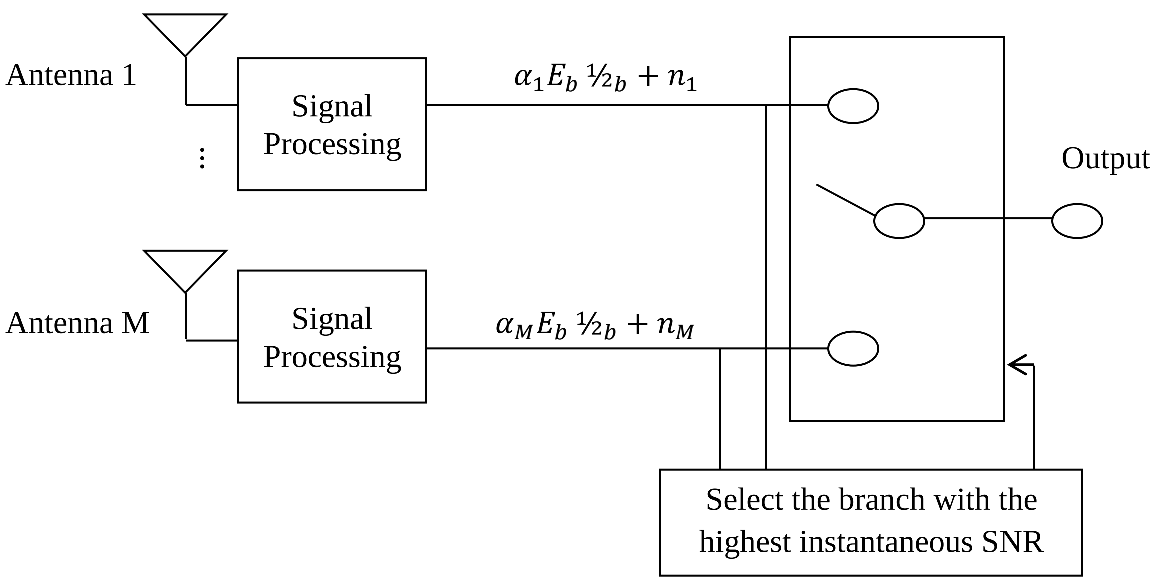

Fig. 4.10: Selection diversity

The reception apparatus picked, nonetheless, depends on the best flag to-clamor proportion (SNR) among the got signals. This requires a pre-estimation happen and that all receiving wires have set up associations (at any rate amid the SNR estimation) prompting a higher power prerequisite. The real determination process can occur in the middle of got bundles of data. This guarantees a solitary reception apparatus association is kept up however much as could be expected.

Exchanging would then be able to happen on a bundle by-parcel premise if important. The expected diversity gain has been shown to be expressed as power ratio:

$$\sum_{k=1}^{N} \frac{1}{k} \tag{4.2}$$

The no. of channels is increased then gain is also increased with it.

- **Switching combining (SC)**

The receiver signal switches to another signal when the previous signal is dropped below the predefined threshold. It is also called scanning combining. In an exchanging collector, the flag from just a single reception apparatus is sustained to the beneficiary for whatever length of time that the nature of that flag stays over some endorsed limit. In the event that and when the flag corrupts, another radio wire is exchanged in. Exchanging is the most straightforward and slightest power devouring of the receiving wire assorted variety handling methods yet times of blurring and de-synchronization may happen while the nature of one reception apparatus debases and another radio wire interface is built up.

- **Equal gain combining (EGC)**

All received signals are summed coherently. In combining, all radio wires keep up set up associations constantly. The signs are then joined and displayed to the beneficiary. Contingent upon the advancement of the framework, the signs can be included straightforwardly (break even with pick up consolidating) or weighted and included reasonably (maximal-proportion joining). Such a framework gives the best protection from blurring yet since all the get ways must remain stimulated; it additionally expends the most power.

4.7 Different Space Time Coding (STC) schemes of MIMO

It has different schemes to achieve different throughput.

- Alamouti's scheme
- Space time block coding

- Omni directional space time block coding
- Qausi space time block coding

These are explained as:

4.7.1 Alamouti's scheme

This method is used to achieve spatial diversity for two antennas in MIMO. We present the Alamouti's scheme coding, the space time code and still a champion among the most typically used. Here discuss Alamouti's coding for 2 transmitters-1receiver system (2x1) and2 transmitter-2 receiver system (2x2) [24]. For 2 transmitter and receiving antennas are shown in diagram.

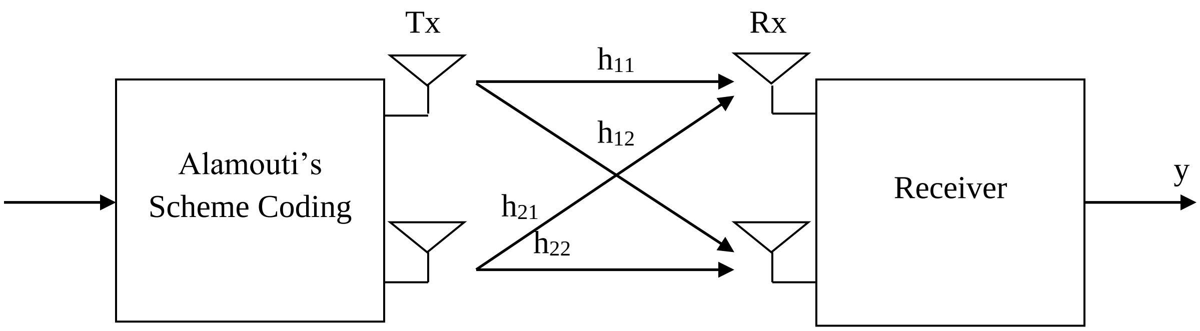

Fig. 4.11: Alamouti's scheme

Time Slot

Space (antenna) $\begin{vmatrix} X1 & -X2^* \\ X2 & X1^* \end{vmatrix}$

The basic equation of MIMO is:

$$Y = HX + N \tag{4.3}$$

Where Y = receiving signal

H = multiple channels

X = transmitted symbols

and N = noise.

Assume we have two transmitter antennas as above matrix

I. First we send two transmission symbol in first we transmit x1 in first schedule and x2 in the next time slot.

The first receiving signal is:

$$Y1 = h1x1 + h2x2 \ + \ n1 = [h1 \quad h2]\begin{bmatrix} x1 \\ x2 \end{bmatrix} + n1 \tag{4.4}$$

II. Alamouti's prefer to send the symbols in groups in the first schedule vacancy transmit x1 and x2 and in second time slot send -x2*and x1*.

The second receiving signal is:

$$Y2 = -h1x2 * + h2x1 * + n2 = [h1 \quad h2]\begin{bmatrix} -x2 * \\ x1 * \end{bmatrix} + n2 \tag{4.5}$$

This is the simple transmission by Alamouti's space time coding. Alamouti's have some drawback that it does not have much. This is an exceptionally unique STBC. It is the main orthogonal STBC that accomplishes rate -1:

$$\begin{bmatrix} y1 \\ y2 \end{bmatrix} = \begin{bmatrix} h1 & h2 \\ h2 * & -h1 * \end{bmatrix}\begin{bmatrix} x1 \\ x2 \end{bmatrix} + \begin{bmatrix} n1 \\ n2 \end{bmatrix} \tag{4.6}$$

That is to express that it is the primary STBC that can fulfill its full varying qualities get without hoping to surrender its data rate. Totally, this is substantial for complex change pictures. Since top pick gathering diagrams rely upon complex numbers in any case, this property ordinarily gives Alamouti's code a basic favored stance over the higher-organize STBCs regardless of the way that they finish a predominant screw up rate execution. Coding rate and can't accomplish constantly most important information rate.

4.7.2 Space time block coding

Space–time block codes (STBCs) follow up on a square of information without a moment's delay (comparably to square codes)and furthermore gives diversity gain however doesn't provide coding gain [24]. It is advance type of Alamouti's plan and it holds all the vital elements of Alamouti's plan also some headway. These summed up codes are orthogonal in nature and transmit receiving wires can accomplish full differences through this:

Transmit antennas

$$\text{Time slot}\begin{bmatrix} S11 & S12\cdots & S1n \\ S21 & S22 & \vdots S2n \\ Sm1 & Sm2\cdots & Smn \end{bmatrix}$$

$$Y = Hs + n \tag{4.7}$$

As of now specified that STBC are the headway of Alamouti's Space time code in which the encoding and disentangling arrangements are the same as there in the Alamouti's on both the transmission and beneficiary sides are used for MIMO systems to enable the transmission of various copies of a data stream over different radio wires and to manhandle the diverse got types of the data to upgrade the reliability of data trade. Space time coding cements every single one of the duplicates of the got development superbly to manage ousts however much data from every one of them as could be normal. Space time square coding uses both spatial and temporary arranged qualities and thusly engage critical augmentations to be made. Space-time coding incorporates the sending of various copies data. This makes up for the multi path issues, for example, blurring and warm commotion. In spite of the fact that there is repetition in the information a few duplicates may arrive less defiled at the recipient [26]. When utilizing space-time square coding, the information stream is encoded in pieces preceding transmission. These information pieces are then appropriated for the numerous reception apparatuses and the information is likewise divided crosswise over time. STBC does not use for more than 2 antenna. There is some drawback that Sensitivity to channel estimation error, Delay Effects, Antenna Configurations.

Transmission by utilization of 2 antennas:

$$H2 = \begin{bmatrix} x(t)1 & x(t)2 \\ -x(t)2* & x(t)1* \end{bmatrix} \tag{4.8}$$

Transmission by utilization of 3 antennas:

$$H3 = \begin{bmatrix} x(t)1 & x(t)2 & x(t)3 \\ -x(t)2 & x(t)1 & -x(t)4 \\ -x(t)3 & x(t)4 & x(t)1 \\ -x(t)4 & -x(t)3 & x(t)2 \\ x(t)1* & x(t)2* & x(t)3* \\ -x(t)2* & x(t)1* & -x(t)4* \\ -x(t)3* & x(t)4* & x(t)1* \\ -x(t)4* & -x(t)3* & x(t)2* \end{bmatrix} \quad (4.9)$$

By utilization of 4 antennas:

$$H4 = \begin{bmatrix} x(t)1 & x(t)2 & x(t)3 & x(t)4 \\ -x(t)2 & x(t)1 & -x(t)4 & x(t)3 \\ -x(t)3 & x(t)4 & x(t)1 & -x(t)2 \\ -x(t)4 & -x(t)3 & x(t)2 & x(t)1 \\ x(t)1* & x(t)2* & x(t)3* & x(t)4* \\ -x(t)2* & x(t)1* & -x(t)4* & x(t)3* \\ -x(t)3* & x(t)4* & x(t)1* & -x(t)2* \\ -x(t)4* & -x(t)3* & x(t)2* & x(t)1* \end{bmatrix} \quad (4.10)$$

4.7.3 Orthogonal space time block coding (OSTBC)

OSTBC stands for orthogonal space time block coding. It gives more advantages then space time coding. OSTBC can be used for more than 2 antennas [25]. The OSTBC accomplish full diversity qualities with low decoding multifaceted nature. The exhibitions of STBC and OSTBC codes are performed in regard of Bit Error Rate (BER) and diversity qualities pick up by the Rayleigh blurring or fading channel. The OSTBC use linear STBC.

All signals orthogonal to each other. The orthogonality empowers us to accomplish full transmit differing qualities. Furthermore, in the meantime, it permits a basic ML de-ciphering. Precoded OSTBC has a higher unraveling many-sided quality and a lower coding pick up than the other two codes, since in the precoded OSTBC the data images should be together planned and decoded. Additionally, a precoded no-zero-section Toeplitz code and a precoded no-zero-passage covered Alamouti's code are likewise proposed [25]. These two codes can accomplish a higher assorted qualities arrange with straight collectors. The OSTBC Encoder piece encodes the data images from the QPSK Modulator by utilizing either the Alamouti's code for two transmit reception apparatuses or other summed up complex orthogonal codes for three or four transmit radio wires.

The quantity of transmit reception apparatuses is given to this square as an information. The yield of this square is a (Ns x Nt) variable-measure network, where the quantity of sections (Nt) relates to the quantity of transmit reception apparatuses and the quantity of columns (Ns) compares to the quantity of orthogonal code tests transmitted over each transmit receiving wire in a casing. So, dimension is Ns/2 × T/2. All info stream created is changed over to images by adjustment QPSK. AWGN (Additive White Gaussian Noise) is added to each channel. They got signs are decoded by Maximum probability strategy. The OSTBC has best performance related to signal to noise ratio than STBC. For transmitted antenna 2 the matrix is:

Table 4.1 OSTBC

Transmitted Antenna	Rate	OSTBC codeword matrix
2	1	$g = \begin{bmatrix} g1 & g2 \\ -g2* & g1* \end{bmatrix}$
3	½	$\begin{bmatrix} g1 & g2 & 0 \\ -g2* & g1* & 0 \\ 0 & 0 & g1 \\ 0 & 0 & -g2* \end{bmatrix}$
3	¾	$\begin{bmatrix} g1 & g2 & g3 \\ -g2* & g1* & 0 \\ -g3* & 0 & g1* \\ 0 & S3* & -g2* \end{bmatrix}$
4	½	$\begin{bmatrix} g1 & g2 & 0 & 0 \\ -g2* & g1* & 0 & 0 \\ 0 & 0 & g1 & g2 \\ 0 & 0 & -g2* & g1* \end{bmatrix}$
4	¾	$\begin{bmatrix} g1 & g2 & g3 & 0 \\ -g2* & g1 & 0 & g3 \\ g3* & 0 & -g1* & g2 \\ 0 & g3* & -g2* & g1 \end{bmatrix}$

Basically we use large numbers of antenna at the transmission side and receiving side to achieve data rate, high capacity and to improve the reliability. So Alamouti’s code used to achieve overall rate orthogonal space time block code (OSTBC). One advantage of OSTBC is that it has no requirement of channel state data at the transmission side for obtaining the diversity.

4.7.4 Quasi-orthogonal space time block coding (QOSTBC)

QOSTBC stands for Quasi-orthogonal space time block coding. Another approach for Quasi-Orthogonal space time piece coding (QO-STBC) is proposed, with essential straight translating by methods for most extraordinary likelihood revelation. The proposed MIMO-OFDM signals with QOSTBC using 8X8 reception apparatus arrangement has better execution as far as BER versus SNR than the other system. The regular QOSTBC can accomplish the full correspondence rate, however at the cost of the unraveling many-sided quality and the assorted qualities increase due to the obstruction terms in the discovery framework. It also overcomes the decoding complexity. The QOSTBC can accomplish full rate yet impedance terms will show up from the neighboring signals amid the flag identification and increases the detection complexity and decreases the gain throughput. By utilizing semi orthogonal plan, sets of transmitted images can be decoded autonomously; the loss of assorted qualities in QOSTBC is because of some coupling terms between the evaluated images. When we use more than 2 transmitted antennas than the rate of OSTBC cannot be more than ¾. For obtaining rate more than ¾ for 2 transmitted antennas we use QOSTBC method. Alamouti's code is better for achieving full rate diversity. The usage of Alamouti's code but for more than 2 transmitted antennas. QOSTBC is a full rate STBC for more than one radio wire. To configuration full rate codes with real and imaginary grouping, we assume non-orthogonal codes for the 4 transmit antenna and for 8 transmitted antennas at transmission rate one so QOSTBC constructed by using Alamouti's code. To calculate BER we use QOSTBC with modulation BPSK. If we place greater number of transmitted and receive antenna then the SNR increases and BER performance decreases rapidly so QOSTBC used for transmission rate up to 1, ½ and 3/4. So QOSTBC overcome the disadvantage of OSTBC:

$$\text{A12} = \begin{bmatrix} s_{11} & s_{12} \\ -s_{12}^* & s_{11}^* \end{bmatrix} \text{A34} = \begin{bmatrix} s_{13} & s_{14} \\ -s_{14}^* & s_{13}^* \end{bmatrix} \tag{4.11}$$

$$\text{A56} = \begin{bmatrix} s_{15} & s_{16} \\ -s_{16}^* & s_{15}^* \end{bmatrix} \text{A78} = \begin{bmatrix} s_{17} & s_{18} \\ -s_{18}^* & s_{17}^* \end{bmatrix} \tag{4.12}$$

- **Matrix for 8*8 antenna using QOSTBC:**

$$B = \begin{bmatrix} A12 & A34 \\ -A34* & A12* \end{bmatrix} = = \begin{bmatrix} s_{11} & s_{12} & s_{13} & s_{14} \\ -s_{12}^* & s_{11}^* & -s_{14}^* & s_{13}^* \\ -s_{13}^* & -s_{14}^* & s_{11}^* & s_{12}^* \\ s_{14}^* & -s_{13} & -s_{12} & s_{11} \end{bmatrix} \quad (4.13)$$

$$c = \begin{bmatrix} A56 & A78 \\ -A78* & A56* \end{bmatrix} = \begin{bmatrix} s_{15} & s_{16} & s_{17} & s_{18} \\ -s_{16}^* & s_{15}^* & -s_{18}^* & s_{17}^* \\ -s_{17}^* & -s_{18}^* & s_{15}^* & s_{16}^* \\ s_{18}^* & -s_{17} & -s_{16} & s_{15} \end{bmatrix} \quad (4.14)$$

On Combined equation (4.12) and (4.13) the antenna configuration is:

$$Q = \begin{bmatrix} B & C \\ -C* & B* \end{bmatrix} =$$

$$\begin{bmatrix} s11 & s12 & s13 & s14 & s15 & s16 & s17 & s18 \\ -s12* & s11 & -s14* & s13* & -s16* & s15 & -s18* & s17* \\ -s13* & -s14* & s11* & s12* & -s17* & -s18* & s15* & s16* \\ s14* & -s13 & -s12 & s11 & s18* & -s17 & -s16 & s15 \\ -s15* & -s16* & -s17* & -s18* & s11* & s12* & s13* & s14* \\ s16 & -s15 & s18 & -s17 & -s12 & s11 & -s14 & s13 \\ s17 & s18 & -s15 & -s16 & -s13 & -s14 & s11 & s12 \\ -s18* & s17* & s16* & -s15* & s14* & -s13* & -s12* & s11* \end{bmatrix} \quad (4.15)$$

This method to improve Quasi-Orthogonal-STBC execution with iterative disentangling, which obviously accomplishes higher unwavering quality however builds deciphering intricacy. In some new translating techniques were proposed to lessen the computational many-sided quality.

4.8 Disadvantages of MIMO

- Complexity.
- More power consumption.
- Costly.

- Limited number of antennas.

4.9 Applications of MIMO

- It is efficient for OFDM when multipath fading will occur.
- It gives reliable communication.
- It also increases capacity.

5.1 AWGN channel with maximum ratio combining

AWGN channel is the channel which is defined by the linear addition of the white noise along with the Gaussian distribution of the amplitude. The various filters considered for the implementation of MRC in GFDM under AWGN channel are simulated and they are explained below:

5.1.1 RC filter in AWGN channel with maximum ratio combining

The relation between the Bit Error Rate (BER) and Signal to noise ratio (SNR) for maximum ratio combining technique is investigated in the Fig. 5.1. This technique is further evaluated by

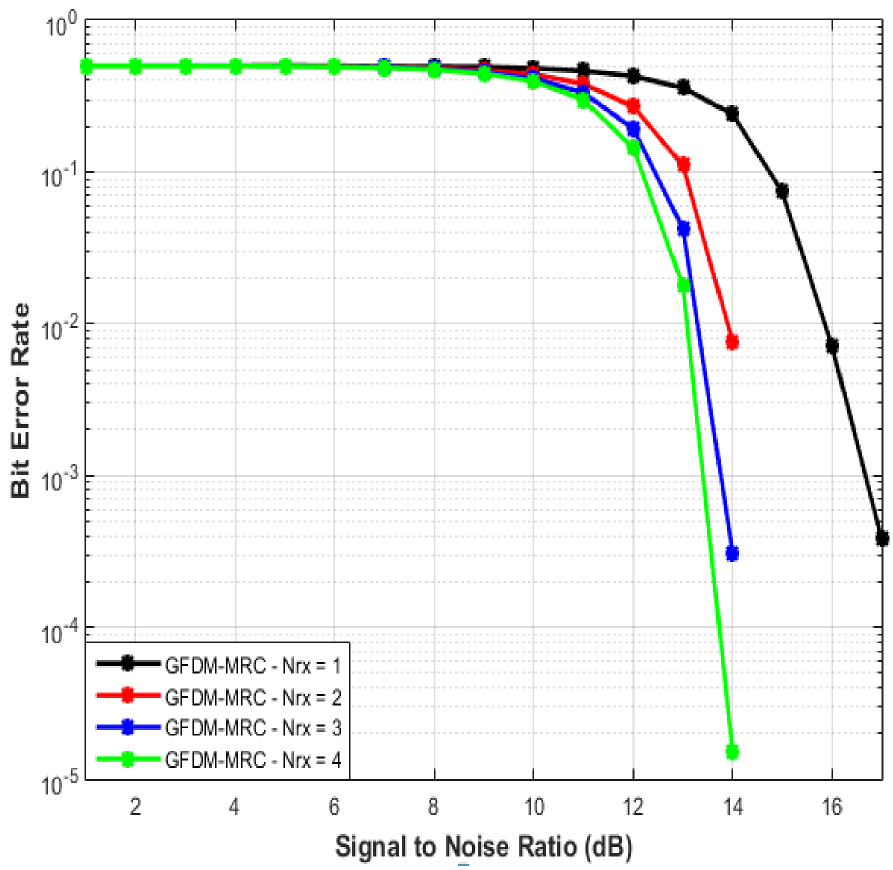

Fig. 5.1: Performance of RC filter in AWGN channel with maximum ratio combining

doing comparison of it with various channels. The channels used here are AWGN and Rayleigh. The SNR values increases and corresponding to it the BER remains constant up to a certain point.

Fig. 5.1 shows that after 8 dB SNR the BER starts decreasing while taking the usage of raised cosine (RC) into consideration. In GFDM-MRC, the N_{rx} value can also be varied. The BER is more for $N_{rx}=1$ in Fig. 5.1. As the value of N_{rx} is increased the BER starts decreasing. The $N_{rx} = 4$ case has the lowest BER in GFDM-MRC when there is 14dB SNR which nearly approaches to its minimum value.

5.1.2 Gaussian filter in AWGN channel with maximum ratio combining

When Gaussian pulse shaping filter is considered under AWGN channel, we obtain the similar shape curves. Out of the four curves, GFDM-MRC curve with $N_{rx} =4$ gives the significant results as shown in Fig. 5.2. At 18 dB SNR value we obtain the BER which is minimal and is the need of the system.

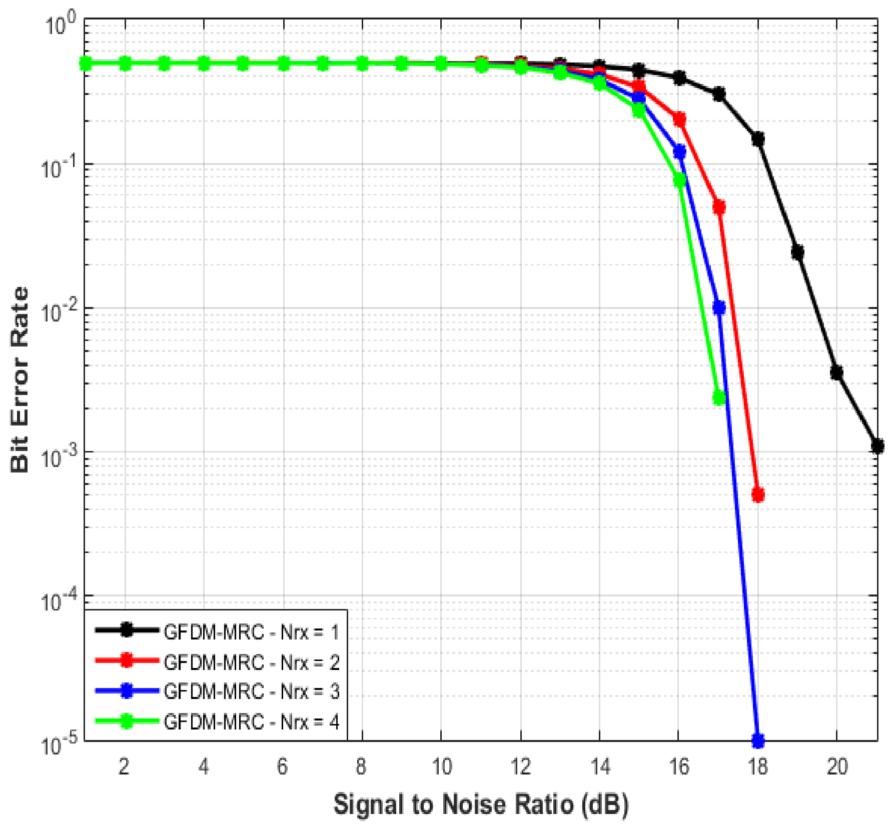

Fig. 5.2: Performance of Gaussian filter in AWGN channel with maximum ratio combining

5.1.3 SRRC filter in AWGN channel with maximum ratio combining

The Fig. 5.3 shows that the BER of GFDM-MRC decreases when the SNR is 14 dB. Both N_{rx} = 3 and N_{rx} = 4 have different BER for the same value of SNR. Below given graph depicts that BER of SRRC is slightly more at 14 db as compared to the RC filter usage under AWGN channel

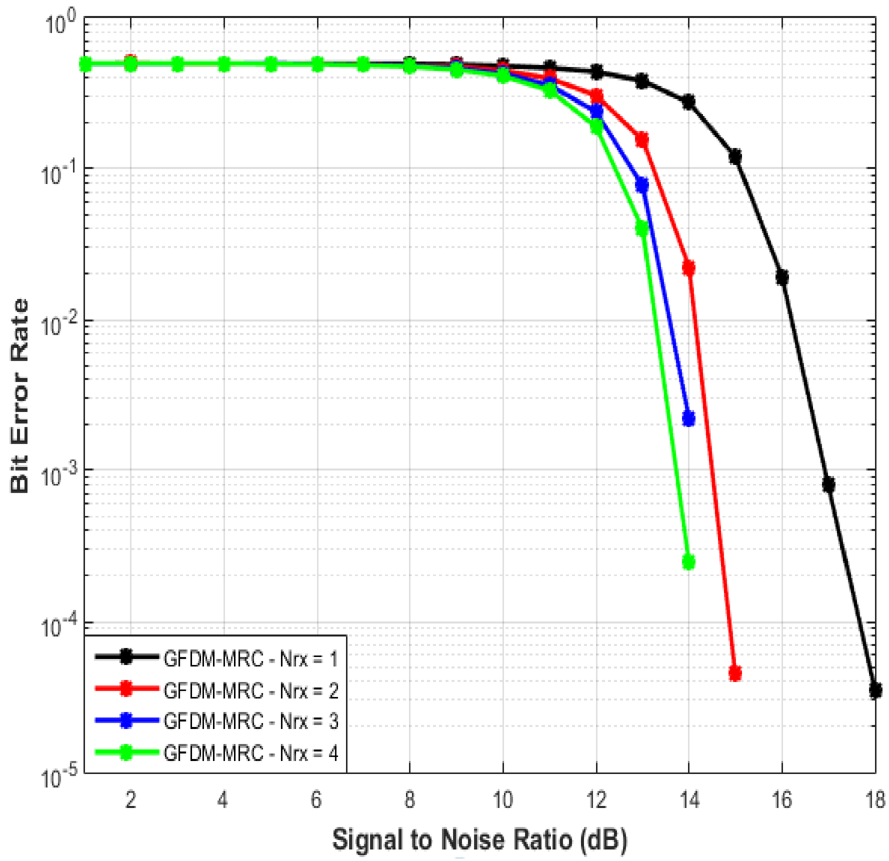

Fig. 5.3: Performance of SRRC filter in AWGN channel with maximum ratio combining

5.2 AWGN channel with selection combining

AWGN channel is the channel which is defined by the linear addition of the white noise along with the Gaussian distribution of the amplitude. The various filters considered for the implementation of SC in GFDM under AWGN channel are simulated and they are explained below:

5.2.1 RC filter in AWGN channel with selection combining

Selection combining can also be depicted with the various pulse shaping filters that are discussed above. Fig. 5.4 depicts that the SNR Vs BER graph shows the similar curves like it shows with the GFDM-MRC under AWGN channel. At 16 dB SNR value, we obtain the BER equal to the minimum value (approximately between 10^{-4} and 10^{-5}) for which the N_{rx}=3 is assumed for raised cosine filter. At N_{rx}=4 in GFDM-SC the BER increases to the highest value as compared the other three as shown below:

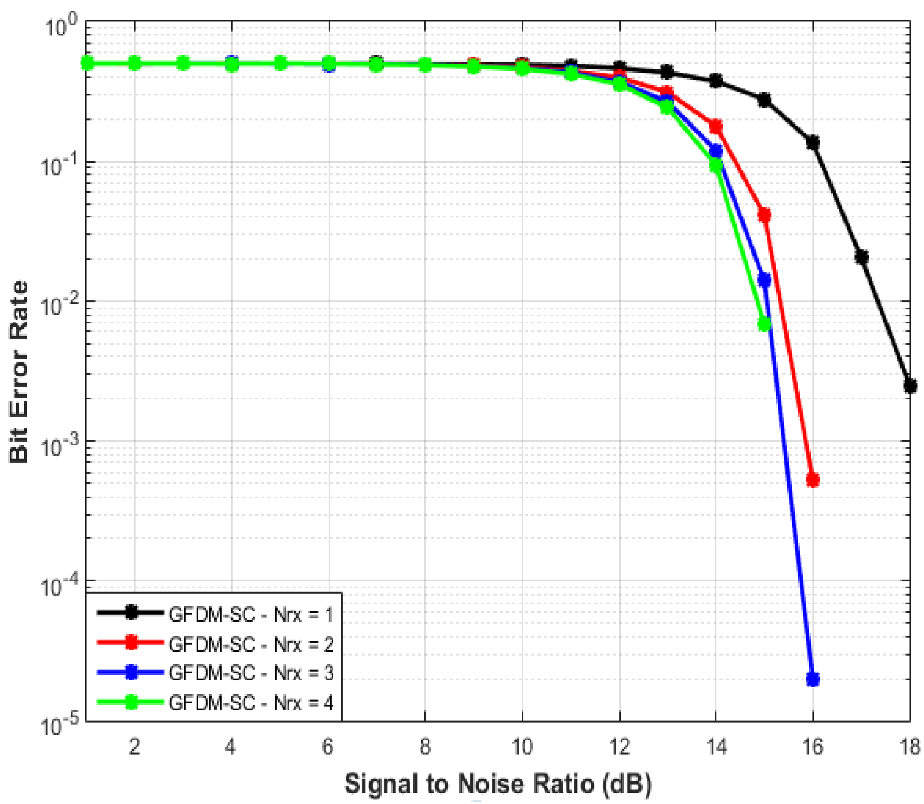

Fig. 5.4: Performance of RC filter in AWGN channel with selection combining

5.2.2 Gaussian filter in AWGN channel with selection combining

From Fig. 5.5 one can clearly get that at SNR equals to 20 dB we obtain the least BER at N_{rx}=3 as compared to N_{rx}=1, N_{rx}=2 and N_{rx}=4. The BER obtained at final is equal to 10^{-5}. At N_{rx}=1, the BER is nearly equal to 10^{-3}. The BER is in between 10^{-3} and 10^{-4} for N_{rx}=1 case. The BER is in between 10^{-2} and 10^{-3} for N_{rx}=4 case.

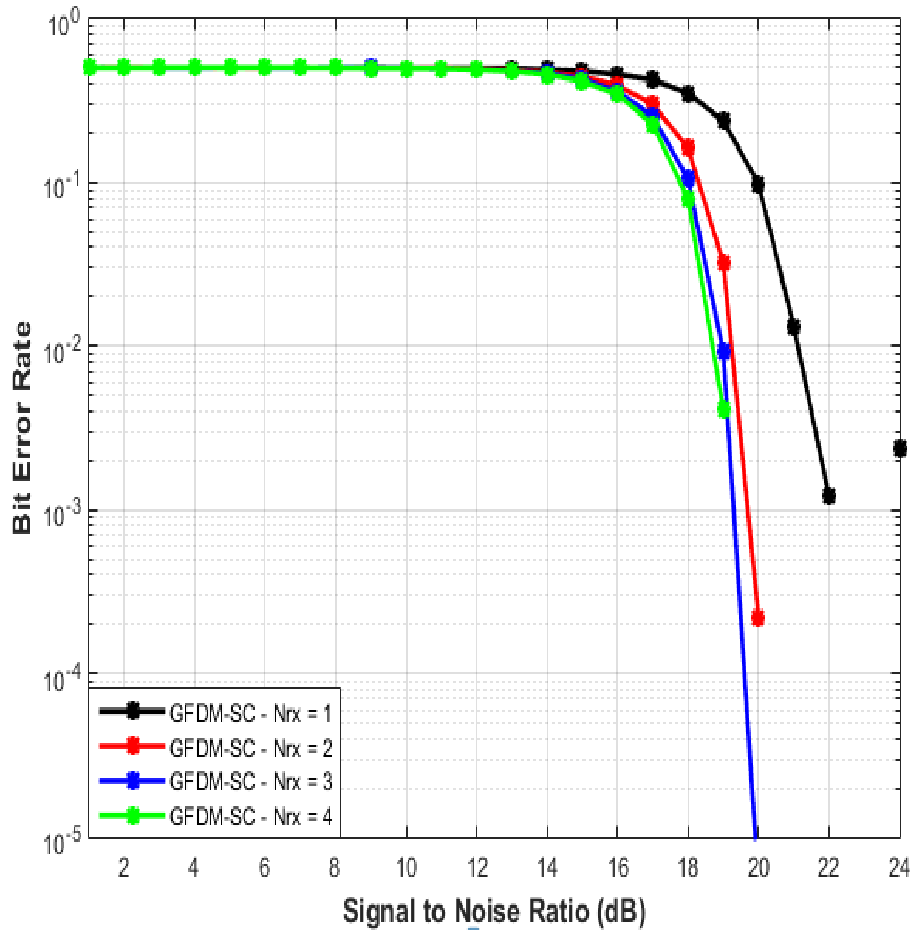

Fig. 5.5: Performance of Gaussian filter in AWGN channel with selection combining

5.2.3 SRRC filter in AWGN channel with selection combining

In addition, Fig. 5.6 highlights that at N_{rx}=1 the BER is significantly high at high value of SNR. The GFDM-SC with N_{rx}=2 shows that at 16 dB the BER obtained is high as compared to N_{rx}=1. At the same value of SNR the BER got reduced which lies somewhere in between 10^{-4} and 10^{-5}.

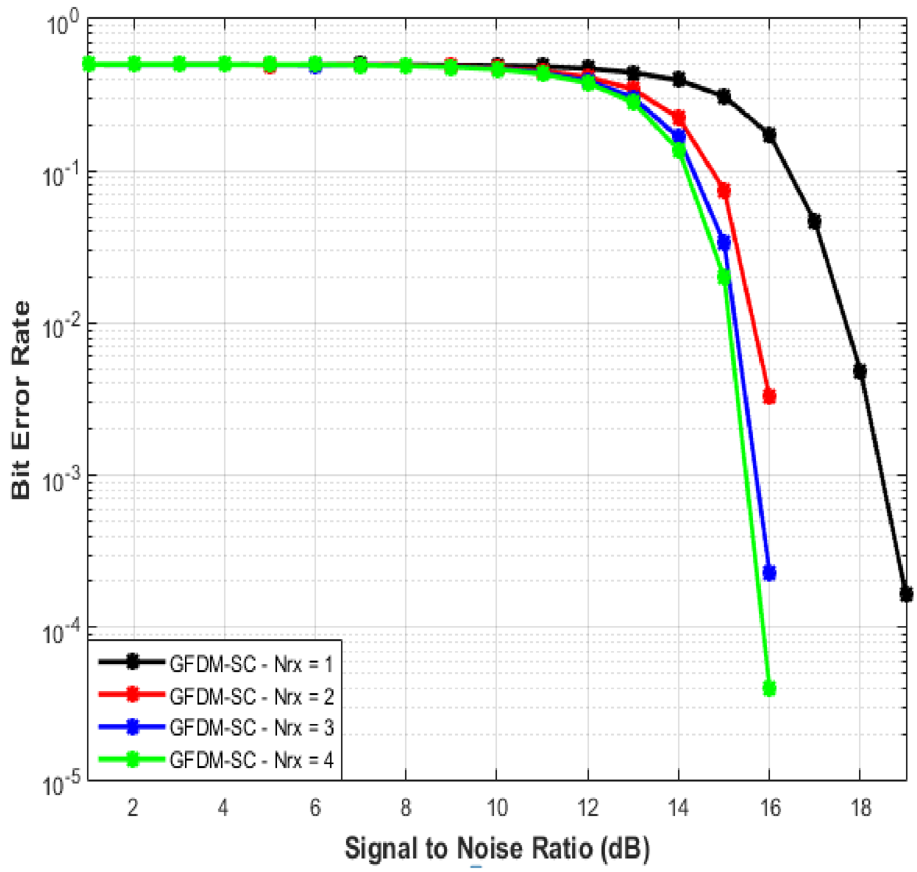

Fig. 5.6: Performance of SRRC filter in AWGN channel with selection combining

5.3 Rayleigh channel with maximum ratio combining

Rayleigh channel is the channel in which the signal magnitude varies randomly according to the Rayleigh distribution. The various filters considered for the implementation of MRC in GFDM under Rayleigh channel are simulated and they are explained below:

5.3.1 RC filter in Rayleigh channel with maximum ratio combining

The same RC pulse shaping filter can be applied under the Rayleigh channel under which we can obtain the nearly optimum BER at 15 dB SNR as shown in Fig. 5.7. For GFDM-MRC the $N_{rx} = 1$ is having the highest BER value which approaches somewhere between 10^{-3} and 10^{-4} and after that it start increasing.

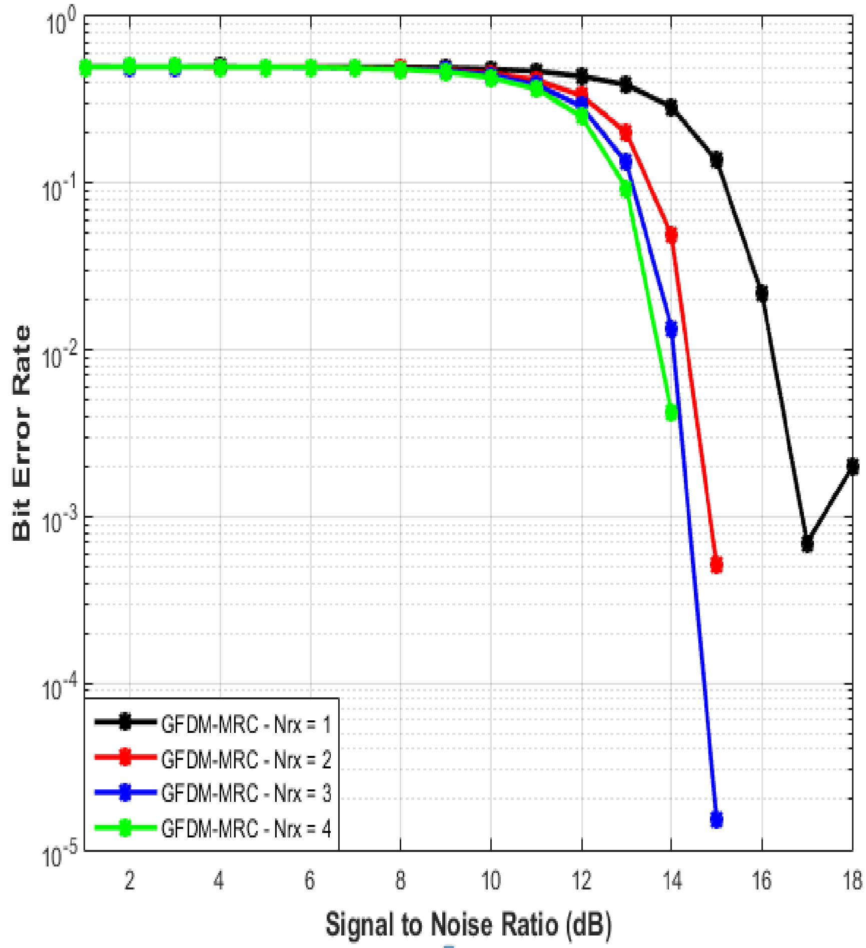

Fig. 5.7: Performance of RC filter in Rayleigh channel with maximum ratio combining

5.3.2 Gaussian filter in Rayleigh channel with maximum ratio combining

For the condition we use Gaussian pulse shaping filter under the Rayleigh channel we obtain the least BER approximately near to 19 dB SNR as shown in Fig. 5.8. At 19 dB, N_{rx} = 2 is assumed for GFDM-MRC. At 18 dB, the BER of GFDM-MRC N_{rx} =3 is having BER between 10^{-2} and 10^{-3} and at the similar SNR when N_{rx} =4 BER is in between 10^{-3} and $10^{-4.}$

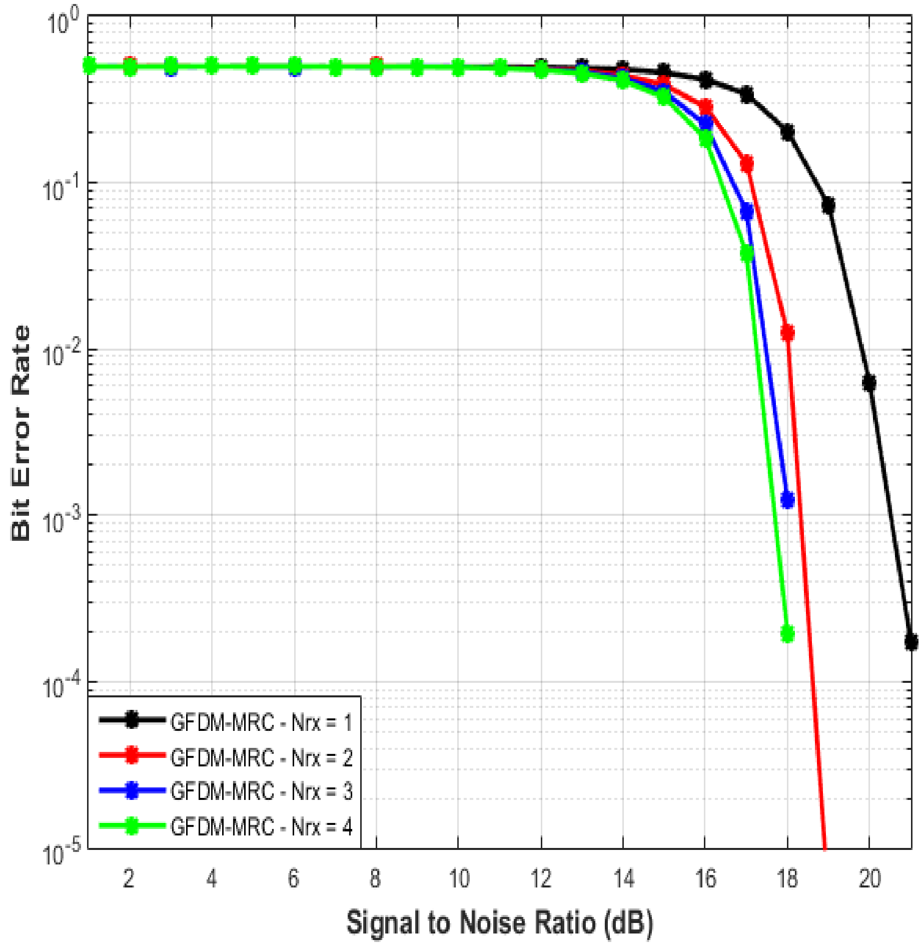

Fig. 5.8: Performance of Gaussian filter in Rayleigh channel with maximum ratio combining

5.3.3 SRRC filter in Rayleigh channel with maximum ratio combining

From Fig. 5.9, one realizes that we obtain the lowest BER at 15 dB SNR value. The BER value normally remains unaffected from 0 to 8 dB SNR value and after that it starts decreasing up to the lowest value. When GFDM-MRC uses SRRC pulse shaping filter in Rayleigh channel then we obtain optimum BER at $N_{rx} = 4$ as shown below:

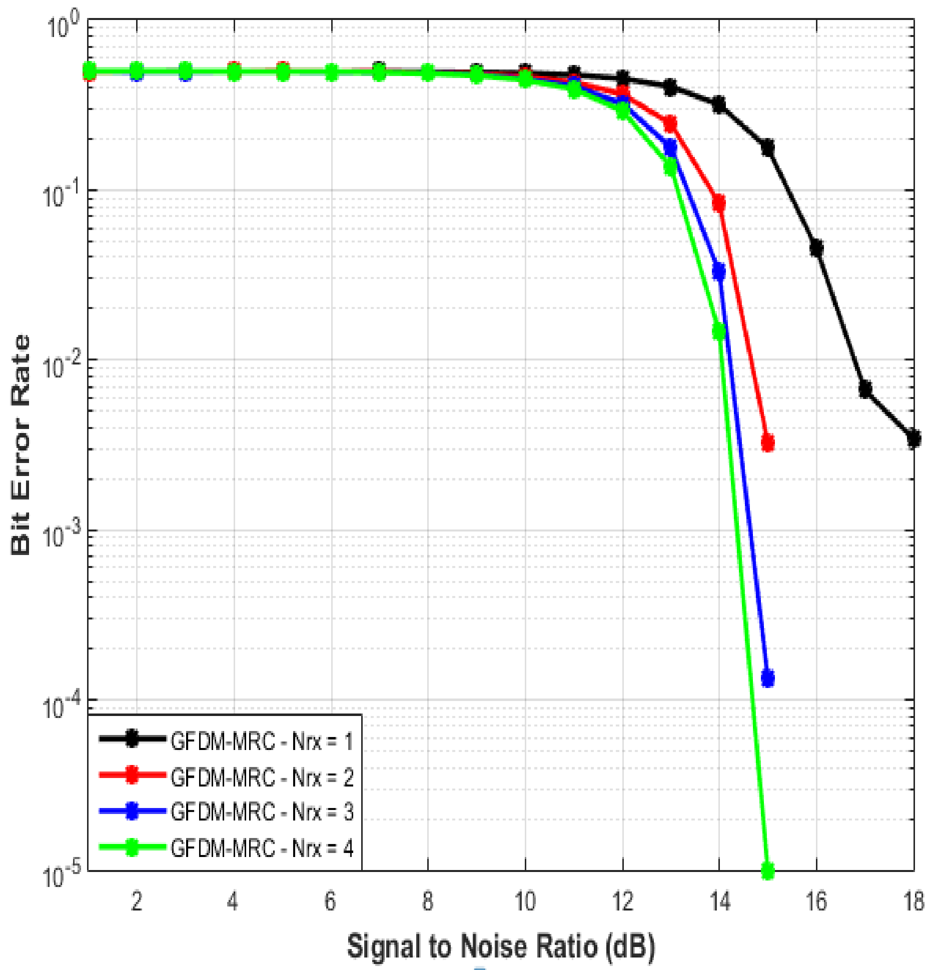

Fig. 5.9: Performance of SRRC filter in Rayleigh channel with maximum ratio combining

5.4 Rayleigh channel with selection combining

Rayleigh channel is the channel in which the signal magnitude varies randomly according to the Rayleigh distribution. The various filters considered for the implementation of SC in GFDM under Rayleigh channel are simulated and they are explained below:

5.4.1 RC filter in Rayleigh channel with selection combining

From Fig. 5.10, one can analyze that when RC filter is used in Rayleigh channel then the BER obtained is quite high. At SNR equals to 16 dB, we got the least BER at N_{rx}=4 and highest at N_{rx}=2. The N_{rx}=1 is the case when the BER is between 10^{-2} and 10^{-3} for the SNR value equals to 19 dB.

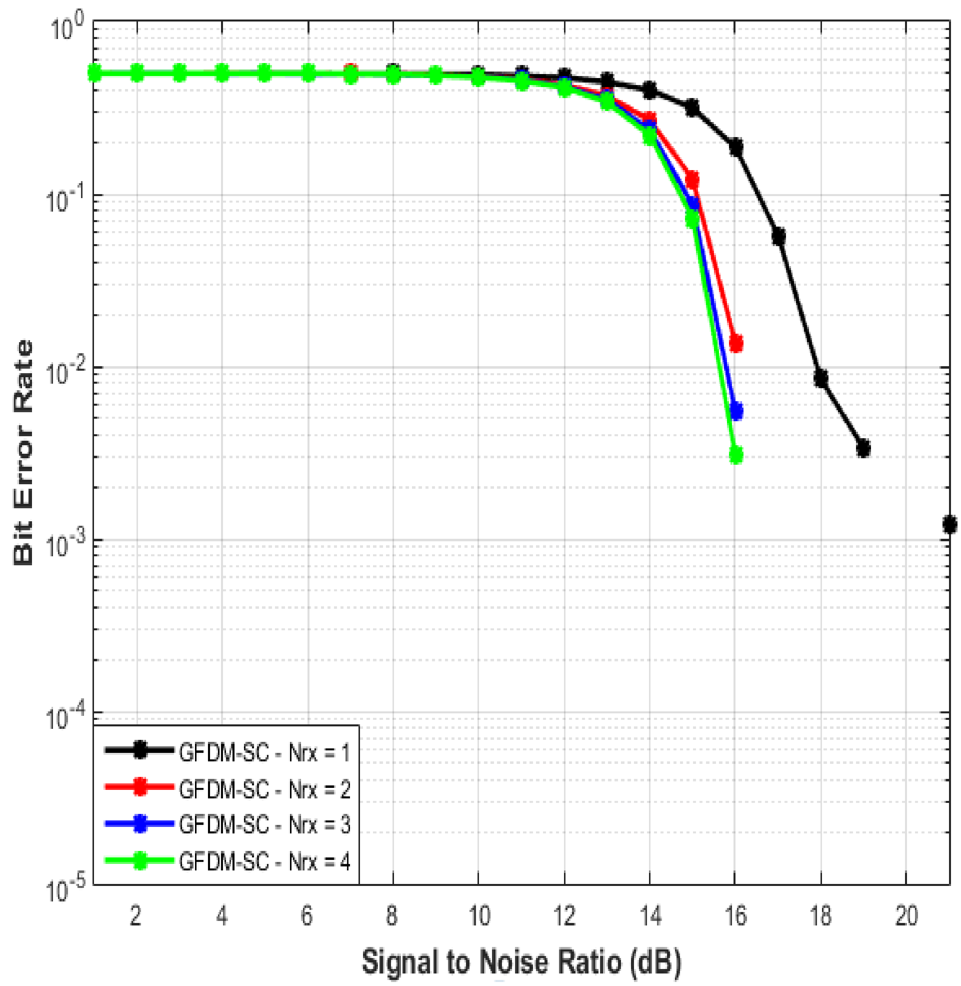

Fig. 5.10: Performance of RC filter in Rayleigh channel with selection combining

5.4.2 Gaussian filter in Rayleigh channel with selection combining

Along with the above graphs, we can add that under the Gaussian filter usage in Rayleigh we obtain lowest BER at SNR greater than 22 dB in Fig. 5.11. At SNR = 20 dB, we obtain the least BER in N_{rx}=4 and highest BER at N_{rx}=2.

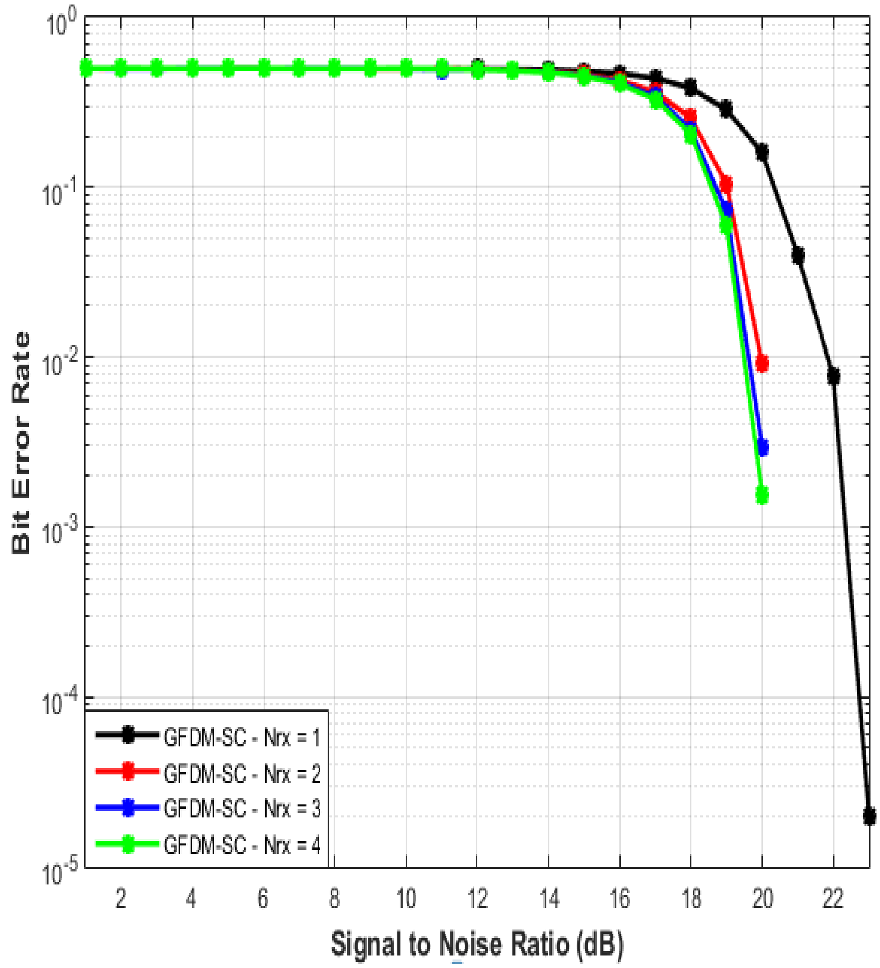

Fig. 5.11: Performance of Gaussian filter in Rayleigh channel with selection combining

5.4.3 SRRC filter in Rayleigh channel with selection combining

The analysis of Fig. 5.12 shows that when SRRC filter is used in Rayleigh channel then it gives better BER value at SNR equals to 17 dB or near to it. After SNR equals to 10 dB, the BER starts decreasing. In GFDM-SC, when N_{rx}=1 the BER is quite high as compared to case of N_{rx}=2, N_{rx}=3 and N_{rx}=4. At SNR equals to 17 dB, we got the least BER and after that the case of N_{rx}=3 comes where the BER is near to it.

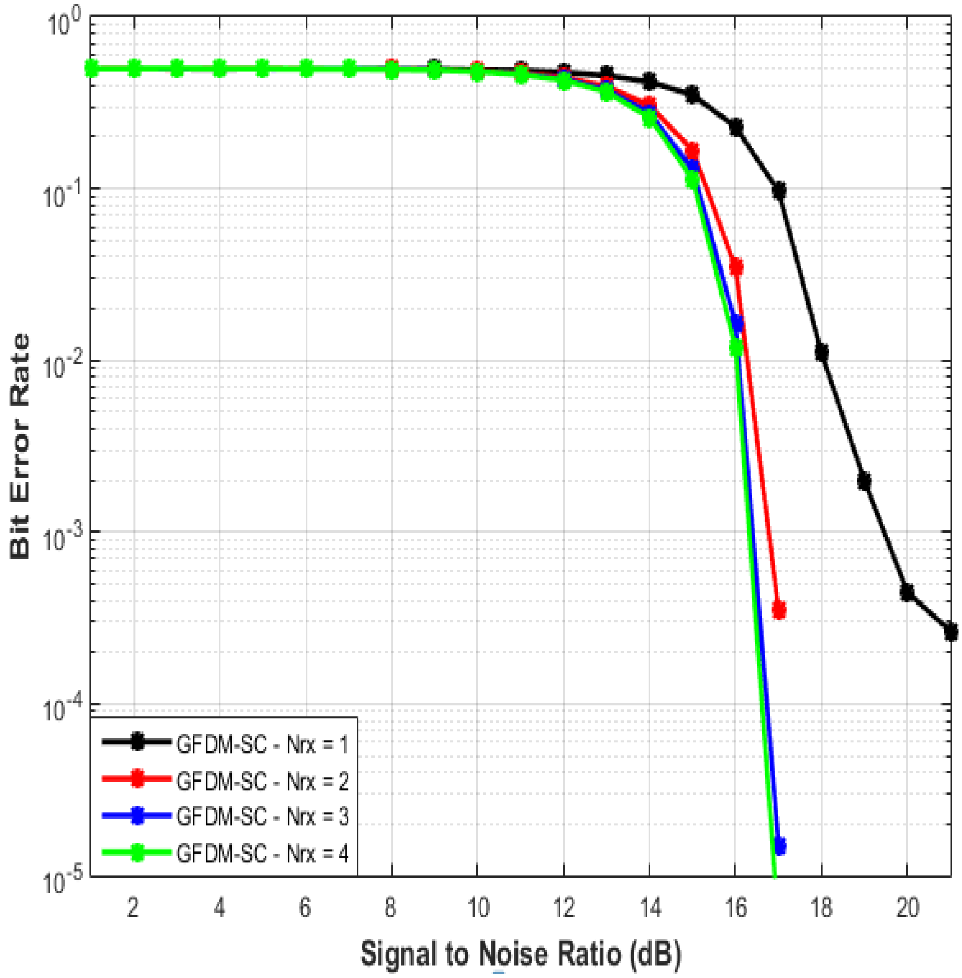

Fig. 5.12: Performance of SRRC filter in Rayleigh channel with selection combining

CHAPTER 6 CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusions

GFDM is a multicarrier modulation scheme in which the pulse shaping is employed to each subcarrier in order to reduce the BER, OOB and PAPR. Since the subcarriers are not orthogonally spaced with respect to each other, it may suffer from self interference. BER of the GFDM were evaluated with respect to the MIMO using different pulse shaping filters. These pulse shaping filters enables GFDM to achieve the required performance metrics. The BER is calculated for RC, Gaussian and SRRC filters with the scenario of maximum ratio combining and selection combining.

The BER calculated for GFDM is explaining that the RC and SRRC helps in achieving low BER at low SNR values. Whereas in the case maximum ratio combining and selection combing while using Gaussian pulse shaping filter we obtain the BER which is more as compared to the previous two filters at higher values of the SNR. As the SNR increases corresponding to that the BER remain constant up to a certain point and after that it start decreasing.

6.2 Future scope

In future the GFDM can be replaced by the other modulation schemes if they remove all the issues of GFDM. The bit error rates can be calculated for the Raised Cosine (RC), Gaussian, Square Root Raised Cosine (SRRC), Xia, Dirichlet , Flipped Hyperbolic Secant (Fsech) and Flipped Inverse Hyperbolic Secant (Farcsech). Along with this the MIMO diversity schemes like Maximum Ratio Combining (MRC), Selection Combining (SC) and Equal Gain Combining (EGC) can be implemented on GFDM. The bit error can also be calculated for the diversity schemes in MIMO-GFDM over various channels like AWGN and Rayleigh channels.

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