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Theoretical Analysis and Performance Comparison of OFDM and GFDM Signals for 5G Cellular Networks: A Review

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Abstract

The mobile networks in 5G must deliver high data rates with less latency. This paper presents the review of theoretical and comparative analysis between Orthogonal frequency division multiplexing (OFDM) and Generalised frequency division multiplexing (GFDM) waveforms for 5G networks. GFDM is one of the promising candidate waveforms for 5G. This waveform supports multi-carrier system with malleable of pulse shaping filter. It supportsMultiple input and Multiple output(MIMO) and provides a high diversity gain. It meets the Industry 4.0 (I4.0) also called as smart factory requirements in with low Out-Of-Band (OOB) emissions. The GFDM transceiver is implemented on national instruments LabVIEW USRP devices and tested successfully for high data rates. The purpose of this paper is to discuss different research areas and evaluate different approaches for 5G Networks. This paper mainly focuses on some research areas such as peak to average power ratio (PAPR), Precoding techniques, index modulations, channel estimation and applications of the signal. The simulation results show that the GFDM outperforms OFDM for 5G candidate waveform race. We conclude with several promising directions for future research of GFDM waveform in this paper.

Keywords : I4.0; OOB; MIMO; GFDM; OFDM; 5G; PAPR; Index Modulation; Precoding

I. Introduction

In the year 1947, the Federal Communications Commission officially accepted the car-borne telephony service, and, but the first international mobile communication started in the year 1980. In the mid-1980's GSM, US-TDMA, Japan PDC was introduced with the same time frame. In the mid-1990s packet data became a reality with GPRS. These automations are attributed as 2.5G. With the advent of 3G (IMT 2000) and the higher-bandwidth radio interface of Universal Terrestrial Radio Access [XII].4G is an end to end internet protocol connection. Apart from the internet the additional voice quality calls require additional machinations.

Voice signal is not essentially data-centric. Voice suited LTE handsets have been slow in coming. Now the focus is shifted on the fifth generation, and the requirements go beyond higher data rates [XXXIV]. Long term evolution (LTE) being deployed worldwide and research on 5th Generation is underway. The major requirement is short latency(less than 1 ms) and high energy efficiency. Dynamic spectrum access is a dominant technology in the coming generation for high power spectral density. The authors of the paper considered FBMC, GFDM as waveforms and designed cognitive radio to use fragmented spectrum and it provides high bandwidth efficiency and better subcarrier separation [LXIX]. Reclined synchronization between the mobile users in 5G is needed.

OFDM signal suffers from carrier frequency offset because OFDM symbols expand in the frequency domain. In addition to that, the out of band radiation for OFDM is -35dB which is not suitable for 5G Requirements [LXVII]. The OFDM signal is not preferred because of its drawbacks, especially the PAPR Problem. Although many algorithms have proposed and evaluated this problem still it is not considered for 5G. The candidate waveform GFDM is slightly suffering from PAPR problem because of the power amplifiers in the transceiver, and they will saturate and cause a reduction in BER and OOB.

The authors evaluate this problem by proposing the clipping techniques with iterative receiver companding and mapping techniques which avoids the PAPR and observes the improvement in BER [LI]. There is a letter which proposes GFDM system performance can be increased by applying the Balian law theorem which proves the nonexistence of ZF receivers [XLI]. In 5G the machine two machine communication needs synchronization and less BER. With the lack of synchronization between the users results in carrier frequency offsets and residual symbol time. This paper proposes the scheme to predict the BER under synchronization errors and evaluates the performance loss introduced by the synchronization [XXIII].GFDM which makes more widespread of time-frequency mapping of modulated signals and acquires the cyclic prefix block signalling structure from OFDM. The authors in this paper identified the synchronization problem from non-orthogonal pulse shaping causes interference among the symbols

[LXII]. The major applications in 5G Cellular networks have many challenges from many different scenarios such as IoT, MTC, WRAN and enhanced broadband.

All these applications require better frequency efficiency [I]. The GFDM spectrum was tested on USRP device in LabVIEW software the signal on each subcarrier is shaped by a pulse shaping filter with roll-off factor value in order to suppress the out-of-band (OOB) radiation for better frequency efficiency[XXXVI].Another challenging application for the fifth generation is tactile internet. For this application the authors GFDM is integrated with Walsh Hadamard transform. This assimilation is convenient for low latency applications in the fifth generation. Currently, LTE licensed is accompanied by 4G users, and the upcoming different radio access technologies will co-exist and cause interference. The authors explained the scenario for upcoming 5G applications and mentioned 5G users require backhaul signalling provided by widely-deployed LTE infrastructure[XIII].

The frequency domain discrete Gabor transform is proposed for GFDM signal to overcome the interference of Inter symbolic Interference and Inter-Carrier Interference[LXII].The investigation on the second-order cyclo-stationary method for estimation of symbols under frequency selective channels is done on this paper in which the authors develop algorithms to blindly estimate pure block duration, overall block duration, symbol duration and the number of subcarriers. The proposed algorithms are robust to timing and eligible for 5G networks[X].

The filter which supports even values for subcarriers and sub-symbols for GFDM signal and its design is verified by evaluating the SIR for the matched frequency receiver and the NEF of the zero forcing receivers [XLVI].TheTS-OQAM GFDM was demonstrated from self-generated interference. It achieves the same SER performance of OFDM signals. This paper proposes the FS-OQAM-GFDM which is used to reduce the system latency[XXVI].The proposal was made to GFDM signals do not fall in the null space[XXX].The advantage of GFDM is its high bandwidth and the authors taking the advantage form channel matrix H and designed modem structures of GFDM has proposed[XXII].

A digital communication system based GFDM with prolate spheroidal windows as pulse shaping filters can compensate for orthogonality loss. GFDM using these windows outperforms conventional orthogonal system [IV]. The Gaussian waveform which exhibits non-orthogonality nature can considerably decrease the sensitivity to distortions and synchronization errors which helps the 5G networks[LIII].DGT based GFDM receiver will eliminate the ISI and ICI which depends on pulse shaping filters[LXIV].The pulse shaping filter design makes GFDM have a non-singular transformation matrix which gives real-time applications for 5G networks[LXVIII].

II. SYSTEM MODEL

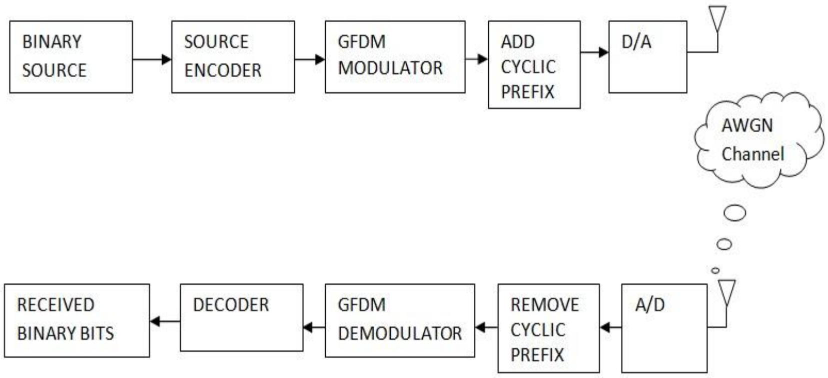

Fig.1. GFDM Block Diagram

The binary source generates the binary digits (bits) randomly. The information source may be a speech signal which is in the frequency range of 3.5 KHz or the video signal which is in the range of 4.5 MHz. These generated bits are passed through source encoder along with probabilities the encoder may be Shannon or Huffman etc. these encoder bits are given to quadrature amplitude modulation in which the symbols are mapped in the rectangular constellation diagram.

$$g_{k,m}[n] = g[(n-mk) \bmod N].e^{[-j2\pi \frac{k}{K} n]} \tag{1}$$

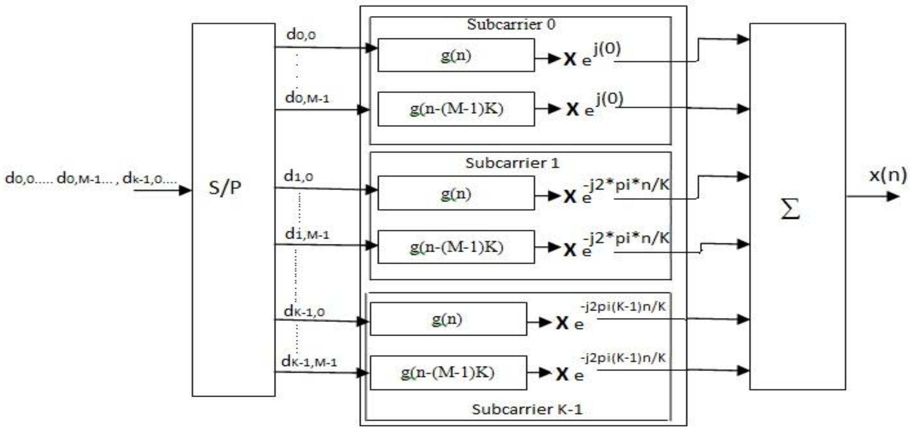

Fig.2. GFDM Modulator

Subcarrier-wise digital pulse shaping and subcarrier upconversion is applied. Each dk,m is transmitted with the corresponding pulse shape. Each gk,m[n] is a time, and frequency shifted version of a prototype filter g[n]. The modulo operation makes gk,m[n] a circularly shifted version of gk,0[n] The complex exponential performs the shifting operation in frequency. The transmit symbol [n] obtained by superposition of all transmit symbols as shown in figure 2.

$$x[n] = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} g_{k,m}[n] d_{k,m} \quad (2)$$

$$x = G * \mathrm{d} \quad (3)$$

Circular convolution is used for pulse shaping. Root Raised Cosine filters with roll-off factor 0.1 and 0.5 are used as pulse shaping filter. Lastly, on the transmitter side a cyclic prefix of NCP samples are added to produce [n]. Cyclic prefix is added to preserve the circular structure of the transmit signal. It enables to make frequency domain equalization possible at the receiver after multi-path effects apply in the channel. While in OFDM every symbol is prefixed, in GFDM one CP is added for every block of M symbols Time and frequency synchronization are performed, yielding $y_{s.}$ The cyclic prefix is removed Cyclic Prefix allows employing zero-forcing channel equalization as efficiently used in OFDM However, the proper choice of the pulse shape and appropriate interference cancelling algorithms in the receiver enable GFDM to match the performance of OFDM in AWGN channels GFDM applies subcarrier filtering for pulse shaping, but in a block-wise and circular manner to avoid inter burst tails, block-wise CP is added to eliminate inter-block interference in multipath channel. Simulation results which are shown in table 1 are taken from [XLIX].

$$\vec{y} = \vec{H}\vec{x} + \overleftrightarrow{z} \quad (4)$$

$$B_{Zeroforcing} = G^{-1} \quad (5)$$

$$\bar{d} = B\vec{y} \quad (6)$$

Table 1: Simulation conditions of GFDM Transceiver

Error Correcting Codes	Concatenated codes, Convolutional and turbo codes
Code rate,Decoding algorithms	1/3,Log-MAP, Viterbi, Trellis diagram
No of Decoding iterations	8,16,32.
Roll off rates(alpha) [prototype filters]	0.9,0.1,0.2,0.5 and optimum values
Modulation techniques	QAM,QPSK, 2PAM, 4PAM
GFDM parameters[K,C,M]	16,3,15
Subcarrier filters	Raised Cosine, RRC, Xia, RC TD, RC FD
Channel models	AWGN, Rican, Rayleigh, Naga kami, EPA
Demodulation schemes	ZF,MMSE,LS, SPA, WLE-ZF, Low-complex

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III. RESEARCH AREAS IN GFDM

Peak to Average Power Ratio

The polynomial-based companding technique is proposed for GFDM signal to overcome the problem of PAPR. Based on MATLAB program results enormous amount of PAPR reduction is accomplished [LIV]. Many algorithms have proposed to overcome the problem of PAPR in GFDM, but all the methods use DFT in the transmitter and receiver section. In this paper, the authors replaced DFT with DWT, i.e. multitaper GFDM to further reduce the PAPR. The simulation results show the PAPR values surpass both OFDM and DFT-GFDM by 7.5 dB[VI]. The link level performance of GFDM is studied. Offset quadrature amplitude Modulation accords low PAPR when compared with quadrature amplitude modulation [LXXV]. This paper employs a Walsh-Hadamard transform in TR-STC-GFDM systems to reduce PAPR value [LXX]. This paper proposes some algorithms to overcome the PAPR problems in GFDM. The methods are solid-state power amplifiers, different PTS technique such as O-PTS, RS-PTS, I-PTS and artificial algorithms such as ABC-PTS, BFO-PTS [XXXVII]. The proposed paper investigates the impact of pulse shaping filter on PAPR value. They concluded that by selecting the proper values and filters, the PAPR is restrained and applied the system in underwater acoustic communication [LXV]. This paper explores the GFDM advantages in two ways: First, it has low PAPR which helps in low power consumption of mobile devices. Secondly, the power spectral density (PSD) of GFDM is less which gives less leakage of energy on the side lobes which helps in reduction of OOB radiation [LV]. The PAPR of GFDM SLM is compared to conventional GFDM and OFDM SLM in terms of PAPR reduction enhancement via numerical simulations [L]. The feasibility of utilizing the fragmental spectrum of the GFDM system was analyzed, namely adaptive to a different channel, adaptive spectrum and adaptive shaping filter. Simulation results show that, compared with OFDM, the GFDM signal spectrum can be adaptive designed, GFDM signal own ultra-low out-of-band radiation about 20dB, lower PAPR about 1.5dB than OFDM signal[XLVII].if x(t) is the input signal then PAPR formula is given as equation 7.

$$PAPR_{dB} = 10\log\left(\frac{max[x(t)x^{*}(t)]}{E[x(t)x^{*}(t)]}\right) \tag{7}$$

Table 2: BER performance Comparisons of PAPR techniques

Article	Techniques/Algorithms	BER performance
[LIV]	Polynomial based companding technique	Better than threshold
[VI]	Multi-taper Implementation	PAPR values surpass both OFDM and DFT-GFDM by 7.5 dB
[LXXV]	OQAM-GFDM	Outperforms OFDM PAPR value by 3 dB
[LXX]	Walsh-Hadamard transform in TR-STC-GFDM	Better than [VI]

[XXXVII]	O-PTS, RS-PTS, I-PTS	Outperforms OFDM PAPR values by 4dB
[LXV]	Impact of Pulse shaping filter on PAPR	Better than [LIV], [VI].
[LV]	SLM	Better than [LXX], [XXXVII] and [LXV].
[L]	Adaptive shaping filter	Lower PAPR about 1.5dB when compare to conventional method
[XLVII]	Polynomial based companding technique	Better than threshold

GFDM-OAM, GFDM with Space and Frequency Index Modulation:

In order to overcome these Inter symbolic interference and intercarrier interference problems a new modulation concept is used, i.e. offset quadrature amplitude modulation. These signal effects are studied over AWGN and Rayleigh fading channels. The simulation results show that SER provides much improvement to OFDM [VII]. The index modulation (IM) concept which emanates technique for the fifth generation because it provides high spectral efficiency. It depends on additional bits. The GFDM is integrated with space and frequency IM (SFIM) technique, and authors evaluated the error performance of the GFDM-SFIM scheme and proved its superiority by making comparisons with the spatial modulation (SM)[XIV]. Space-time coding (STC) helps GFDM system performance in terms of robustness against fading multipath in the channel [XXXVIII]. This paper applied the conventional method of orthogonal frequency division multiplexing (OFDM) with interleaved subcarrier-index modulation (OFDM-ISIM) into generalized frequency division multiplexing (GFDM), which is referred as interleaved subcarrier-index modulation GFDM (ISIM-GFDM). Simulation results show that ISIM-GFDM outperforms GFDM and SIM-GFDM in terms of bit error rate [LXVI]. Due to self-Inter Carrier interference, the bit-error rate performance of GFDM is affected by low SNR values. To control this problem, space shift keying (SSK) has been proposed and applied to GFDM. The system performances are analyzed under a flat Rayleigh fading channel using MATLAB software and provide less BER in V-BLAST based GFDM system [XV].

Table 3: SER performance comparisons of different techniques

Article	Techniques	SER performance
[VII]	OQAM	Better than threshold
[XIV]	space and frequency IM	Better than Spatial modulation technique by 1.5 dB
[XXXVIII]	Space-time coding	Better than[XIV]
[LXIV]	Interleaved subcarrier-index modulation	Better than OFDM by 7 dB
[XV]	SSK-GFDM	provides less SER in V-BLAST based GFDM system

Channel estimation Techniques and Multitaper Implementation

Channel estimation is required to compensate for the distortion introduced in the symbols, as they travel through the channel, and to take into account SNR. The receiver's equalizer has to untwist the incoming symbols back into their intended shape, in order to decode them accurately, and in two-way communications, channel estimation allows negotiation of an optimal constellation. The MRC technique improves Symbol error rate of GFDM receiver[XXXIX]. Intrinsic interference in GFDM comes due to the overlap of filter response of a subchannel from the two adjacent subchannels. To overcome this interference, the authors designed two prototype filters for GFDM. The simulation results show the improved bit error rate[XXXI]. The intercarrier interference (ICI) effect was observed in GFDM because of carrier frequency offset (CFO). This paper studies the CFO effect on the GFDM and applied the extended Kalman filter (EKF) to decrease the CFO[XXIX]. GFDM employed with the design of in-band full duplex transceivers. The authors developed refined frequency domain cancellation architecture to cut out the self-interference in these transceivers[IX]. Due to non-orthogonality nature in GFDM system, the inherent interference will affect channel estimation. With Discrete Prolate Spheroidal Sequences (DPSSs) an improved orthogonal GFDM system can be developed. In this paper, the investigation on channel estimation methods for DPSS GFDM or multitaper GFDM (MGFDM) systems with and without Discrete Fourier Transform (DFT) is done. DFT based CE methods provide better estimates of the channel [V]. The proposal was made to replace the cyclic prefix block by deterministic sequence, known as a unique word in GFDM systems. Simulations show that the proposed unique word GFDM system outperforms preceding efforts[XVI]. A compensate method is proposed for phase and quadrature imbalance caused by radio frequency front-end for GFDM [LIX]. The frequency-domain channel estimation algorithms for MIMO is investigated and compared with the conventional MIMO-OFDM systems [XIX]. The investigation on the problem of pilot symbols in GFDM channel estimation was analyzed by MATLAB software. The analysis was done with multiple pilots per subcarrier within a single GFDM block [XXI]. Pulse shaping filter causes an inherent interference in the receiver section and has a negative impact on pilot-based channel estimation. This work proposes an iterative method for interference cancellation at the receiver. With orthogonal match pursuit recovery algorithm, the performance of the iterative algorithm is very close to the Cramer-Rao bound [LXII]. Current channel estimation techniques do not give any acknowledgement about out-of-band (OOB) radiation. The authors proposed a method of placing preambles in the sequence for channel estimation. 5 to 20 dB lower OOB radiation is achieved compared to the existing preamble based estimation[XXV]. Pilot Interference Cancellation algorithm is proposed for channel estimation in which interference is pre-cancelled only at pilot symbols. The Transmitter IC algorithm which allows cancelling the interference at both data and pilot symbols [LX].

$$h_{LS} = X^{-1}y$$
$$where \quad X = diag\{x_0, x_1, \cdots x_{N-1}\}$$
$$y = \begin{bmatrix} y_0 \\ \vdots \\ y_{N-1} \end{bmatrix} \qquad (8)$$

$$h_{MMSE} = FR_{gy}R_{yy}^{-1}y \quad where$$
$$F = \begin{bmatrix} W_N^{00} & \cdots & W_N^{0(N-1)} \\ \vdots & \ddots & \vdots \\ W_N^{(N-1)0} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix} and$$
$$W_N^{nk} = \frac{1}{N}e^{-j2\pi\frac{n}{N}k} \qquad (9)$$

where$R_{gy}$and $R_{yy}$is cross-covariance matrix between g andy and the auto-covariance matrix of y respectively.

Precoding Techniques

This paper proposes a data non-partisan precoder to curtail the variance of the spontaneous power, subject to the coercion of unchanged average IP as a means for PAPR contraction. This proposed paper gives improved PAPR reduction [LVI]. In this paper, the circular convolution based GFDM is designed to reduce the complexity. Also, precoding is introduced to increase GFDM flexibility further, addressing a more comprehensive set of applications [XXVI]. Block inverse discrete Fourier transform based precoding schemes are found to outperform Minimum mean square error based GFDM receiver [LVII]. The precoding transforms proposed to illustrate the aids of precoded GFDM. They are Walsh Hadamard transform, CAZAC transform and discrete Hartley transforms [XLIII]. The authors applied the Walsh-Hadamardprecoding scheme to Circular filter bank multicarrier communication (WHT-C-FBMC) to exploit the frequency diversity in a multipath channel. Results show WHT-C-FBMC is admirable to WHT-GFDM[IX]. This paper explains the calculation of Signal to interference plus noise ratio according to related GFDM models with different weighted-type fractional Fourier transform precoding orders. Correspondingly PAPR and out of band power suppression are observed [LXI].

MIMO-GFDM System

The GFDM system capacity limits need to be tested for 5G applications. To achieve the capacity, the interaction of data symbols in time and frequency connected with MIMO. This proposed system applies expectation propagation for systematic receiver design [LXX]. Linear receivers cannot achieve optimal maximum likelihood performance. A nonlinear detection algorithm is proposed. The observations indicate that MIMO GFDM detector as a joint operation between the signal demapper and channel decoder is more promising for the accomplishment of capacity gains [LXI]. Spatial modulation GFDM is proposed to avoid the interference, and it is compared with SM-OFDM in the Rayleigh multipath fading channels [LII]. Different GFDM characteristics such as reduced latency and increasing the robustness in the real-world environment were studied with the help of LabVIEW USRP device [XVII]. The impact of pilot design on the signal properties, including power spectral density and PAPR is studied and analyzed in MIMO GFDM [XIX]. The paper gives the solutions for MIMO GFDM channel estimation problem with the aid of known reference signals also referred to as pilots. For various pilot arrangements, the performance is evaluated with LS and LMMSE estimators [XX]. The algorithm which incorporates the maximum likelihood and successive interference cancellation detection techniques that allows exploiting the inherent frequency diversity of GFDM coming from self-interference. This proposed scheme outperforms the traditional OFDM [XLII]. To encounter the interference minimum mean squared error with parallel interference cancellation algorithm is applied to the iterative receiver structure to GFDM [XLIII]. MIMO-GFDM is integrated with time-reverse space-time coding and GFDM to remit the reduction of error performance caused by frequency-selective channels[LXXIV].

Table 4: BER performance comparison of different techniques

Article	Techniques/ Algorithm	BER performance
[LXX]	Expectation Propagation	More efficient than Conventional MIMO-OFDM method by 2 times
[LXI]	Nonlinear detection algorithm for MIMO GFDM	GFDM outperforms OFDM at SNRs beyond 10 dB
[LII]	Spatial modulation GFDM	Outperforms OFDM by 4.5 dB
[XIX]	The pilot design on MIMO-GFDM Rx	MMSE receiver can reduce the noise enhancement in low SNR and improve the BER performance at high SNR
[XX]	LS and LMMSE estimators	Better performance in fine and coarse search is obtained for GFDM signals with N_{CW}=0.
[XLII]	Interference cancellation detection techniques	Amount of Interference is reduced when alpha=0 compared with alpha=1.
[XLIII]	Parallel interference cancellation algorithm	Better performance than ZF receiver in[XLIII]
[LXXIV]	Time reverse space-time coding	This scheme provides SER< 10^{-3} at high SNR values compared to OFDM

Applications

GFDM is one of the new waveforms for the 5G physical layer. It was identified to give many requirements for 5G networks such as high data rate and low latency. The researches mentioned that this new waveform must maintain uniform consistency from current 4G technology. The performance of MIMO-GFDM is investigated in connection with LTE-A using the 3D 3GPP-ITU channel model. So it is considered as a key factor for many 5G applications such as M2M and IoT [III]. Industry (I4.0) closed-loop control applications require ultramodern low latency and extremely high reliability. With the help of the GNU radio framework, the compact GFDM software is designed [XVIII]. The performance of GFDM is analyzed in the LTE Advanced which is a mobile communication standard in 3GPP-ITU channel model. The simulation results show that GFDM achieves tantamount packet error rate (PER) with reduced out of band radiation[II]. In radio communications, an uplink is the portion of a feeder link used for the transmission of signals from earth to a satellite. The hybrid training structure in GFDM Pilot symbols is proposed for the uplink scenario[XXXII]. A chart was plotted in reference to base stations and mobile users. It is plotted with four scenarios on the x-axis and multiplications per symbol on the y-axis. The multiplications per symbols are normalized by the number of transmitted QAM symbols. They scenarios are (1) narrowband downlink is allotted per mobile user. (2) Broadband downlink allotment. (3) narrowband uplink allotted per mobile user (4) broadband uplink allotment

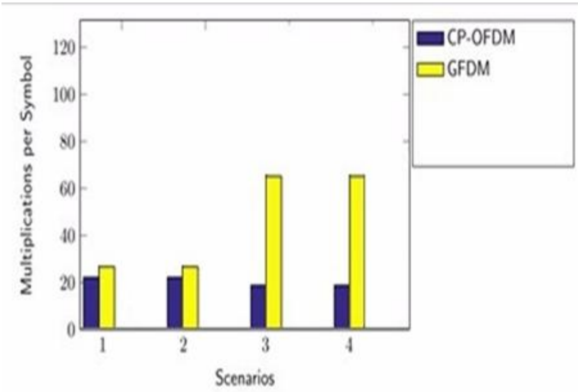

Fig 3.Chart plotted against multiplications per symbol in the wireless communication station.

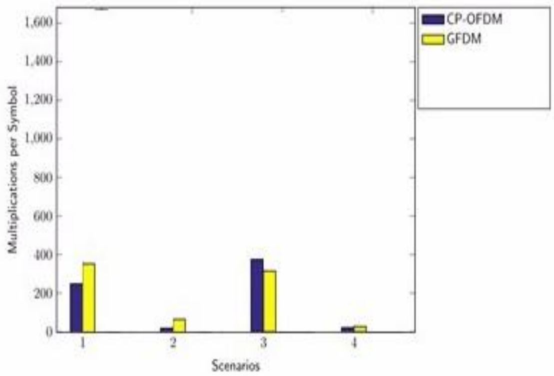

Fig 4.Chart plotted against multiplications per symbol in the mobile station.

Figure 3 & 4 explains the chart with respect to OFDM and GFDM technologies. In which GFDM outperforms OFDM in some scenarios. Present wireless communications in all the industries depend on IEEE 802.11, IEEE 802.15.1 or IEEE 802.15.4. They lack potential for future requirements to overcome these problems the new waveform for physical layer must be proposed. This article considered the GFDM-OQAM modulation as the candidate for 5G and simulated in terms of bit error rate, power spectral density and spectral efficiency over highly dispersive channels [XXXIII]. The bidirectional data interaction among the vehicles in GFDM for the fifth generation was investigated in this paper. This work is limited for synchronization and equalization algorithms in the receiver section [LXXV]. This paper presents a solution for achieving transmit diversity with GFDM for applications in 5G [XXXIV]. Doppler scale estimation for underwater acoustic (UWA) communications is demanding. This paper presents a Doppler scale estimation approach exploiting the cyclo-stationary of orthogonal frequency-division multiplexing (OFDM) signals. The proposed estimation method turns to be more significant for ZP-OFDM systems, which is usually used for underwater communication to save energy[LVIII]. The integrated radar and communication system integrated with OFDM and referred to as OFDM-IRCS is introduced for applications in radars [XXVII]. This work proposes to enhance the physical layer security for wavelength division multiplexing orthogonal frequency division multiplexing in passive optical networks for demanding growth of users in 5G [XLV]. While coming to application part of non-orthogonal multiple accesses GFDM which is based on heterogeneous cellular networks. The downlink radio resource allocation for heterogeneous traffic is considered and analyzed[XXVIII].

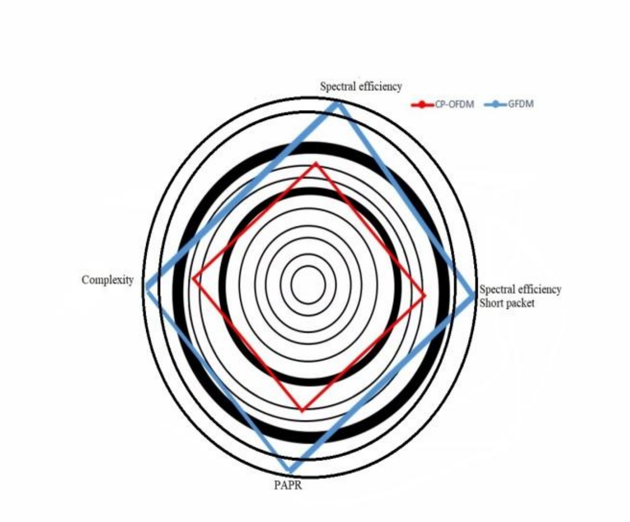

Fig 5.Chart plotted against multiplications per symbol in the wireless communication station.

A synthesis chart is depicted in Figure 5. GFDM is compared with OFDM in terms of circles. They are four parameters which we consider are named as PAPR, Spectral efficiency, spectral efficiency over packet and complexity. The comparisons between GFDM and OFDM are drawn in red color and green color with four parameters. So the GFDM is used for many applications in the future directions. All the figures 6, 7 and 8 used in this paper are taken from [XXVIII].

IV. Simulation Results and Analysis

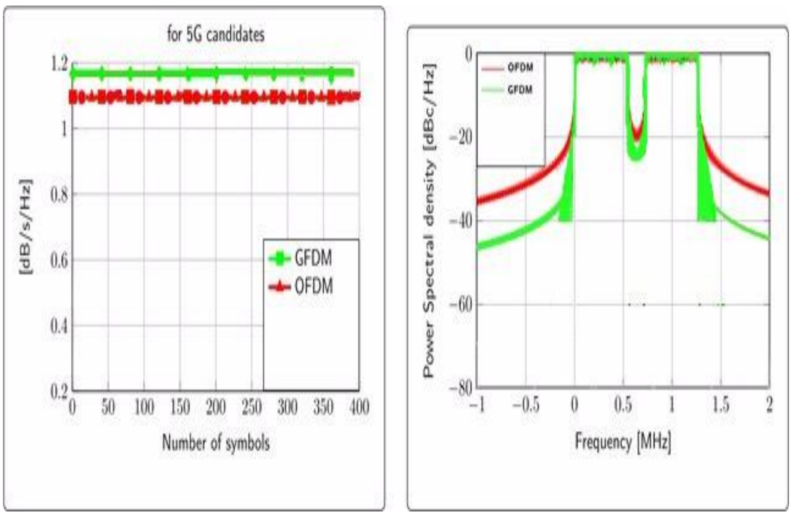

Fig 6. Power spectral density plot of candidate waveforms

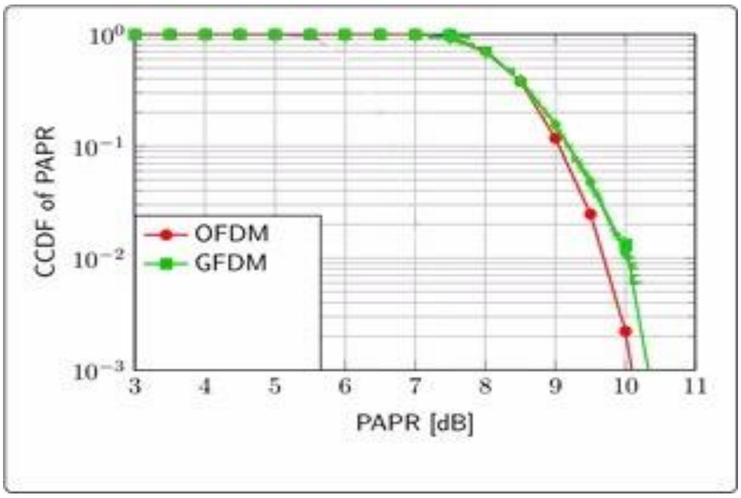

Fig 7.CCDF of PAPR plot of OFDM and GFDM

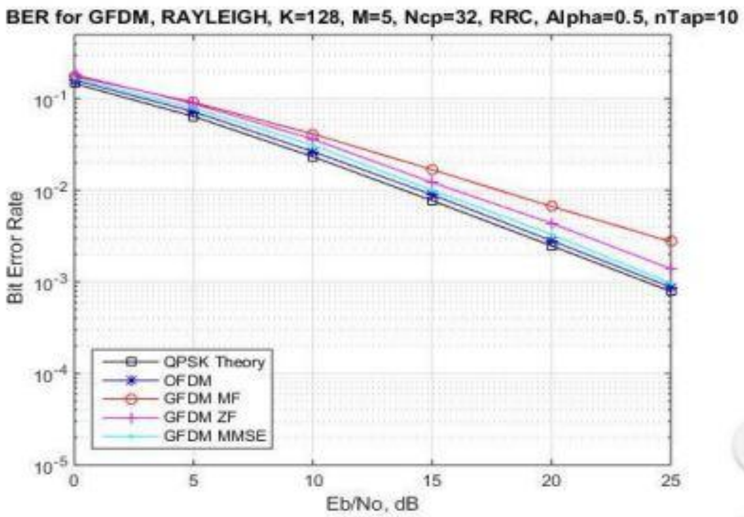

Fig.8.BER Analysis of GFDM and OFDM for different receivers

V. Conclusion

This paper attempts to provide a comprehensive survey of GFDM waveform for 5G Wireless Networks. This survey article assumes a general knowledge of present scenario in the area of wireless communication, and it emphasizes the classification of the existing research articles, and we tried to give an idea, recent developments on the GFDM technologies and its evaluating trends which shows many future directions in the field of research. We believe the efficient use of unused spectrum is one of the key challenges that future 5G systems. We surveyed GFDM in different ways such as precoding techniques, integration with multiple inputs and multiple output technology, a performance comparison of PAPR techniques and main applications for 5G networks. GFDM is a promising candidate for the fifth generation because of its high spectral efficiency and non-orthogonality between the subcarriers which is the main requirement for the upcoming future generations. This survey explains the comparison between OFDM and GFDM in many ways, and we strongly conclude that GFDM is a promising candidate for fifth generations in many research directions.

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