An Efficient Multiplexing Technique For 5G Wireless Network: Analysis and Selection

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Abstract. The 5G cellular communication technology is intended to base on the present Long-Term Evolution (LTE) 4G networks with adopted features. Features of low power consumption and the constant power level should be the major requirement for an efficient channel allocation method. In this research work, an analysis was performed on multiplexing techniques: Orthogonal Frequency Division Multiplexing (OFDM), Generalized Frequency Division Multiplexing (GFDM), Universal Filtered Multicarrier (UFMC) and Filter-Bank Multicarrier (FBMC). Smooth power level had been analyzed according to Power Spectral Density (PSD) function *vs* normalized frequency using AWGN channel model. The simulation was done by MATLAB 2019 Simulink software for OFDM and GFDM that were further compared to existing results of UFMC and FBMC multiplexing techniques. Calculated power for OFDM and GFDM were 32.1mW and 40.23 µW respectively. Comparative results showed the better smooth power spectrum, micro-watt power consumption and better hardware configuration for GFDM. That's why GFDM channel allocation method selection is one step ahead for the next generation multiplexing technique

Keywords: Multiplexing, Power spectrum density, Normalized frequency, Fifth generation network

1 Introduction

Today the general fifth generation (5G) wireless networks are a promising technology which leads to an extensive research area on the continuous development of network upgradation to meet the changing demands. The requirements for upgraded technology needs a lot of connectivity with higher throughput, greater spectral efficiency etc. 5G networks should support the applications such as intensified mobile broadband, enormous machine type communications, radical reliable communications and almost zero latency communications-recommended by 3rd generation partnership project (3GPP) [1-3]. To meet these requirements, enhanced modulation and multiple access techniques are being investigated. This paper describes different multiplexing techniques that can identify a few points that have the most remarkable impacts on multiple access designs hereafter.

Orthogonal multiple access is the backbone to the 4th generation (4G) wireless network systems such as second generation (2G) orthogonal time-division multiple access (TDMA) and frequency-division multiple access (FDMA), third generation (3G) orthogonal code-division multiple access (CDMA) and 4th generation (4G) orthogonal frequency division multiple access (OFDMA). Traditional OFDM has been embraced in 4G networks [4]. For the current broadband solution OFDM was upgraded to reduce the delay expansion of wireless channels with a manageable detection method. This solution was done by appropriate cyclic prefix (CP) selection [5-7]. In order to avoid large interference among adjacent sub-bands, user's synchronization is essential for OFDM. But in massive machine type communications in next generation requires asynchronous data transfer in narrow bands among the sensor nodes [4, 8, 9].

Researchers have proposed multiple user interference abandonment methods. Another reason for the decelerating transmission scheme is its random amount of power spectral density (PSD) for low normalized frequency ranges. To meet the new challenges in 5G networks various multiple access and modulation techniques should be adopted. Adopted techniques have approaches such as filtering, pulse shaping, pre-coding etc. A properly designed filter can suppress out of band (OOB) leakage of OFDM signals. The subcarrier-based filtering is useful in pulse shaping technique [10-13]. The overlapping between subcarriers reduces by this filtering process [14-17]. The pre-coding technique in OFDM is another approach for the reduction of OOB leakage [18-21]. This paper discussed four multiplexing as well as modulation techniques that should be upgraded for next generation networks. Based on pulse shaping- Filter bank multicarrier (FBMC) and Generalized frequency division multiplexing (GFDM) are discussed. Based on sub-band filtering- Universal filtered multicarrier (UFMC) is also discussed.

The aim of this research work is to focus on four 4G multiplexing techniques OFDM, GFDM, FBMC and UFMC. The following are the paper contributions.

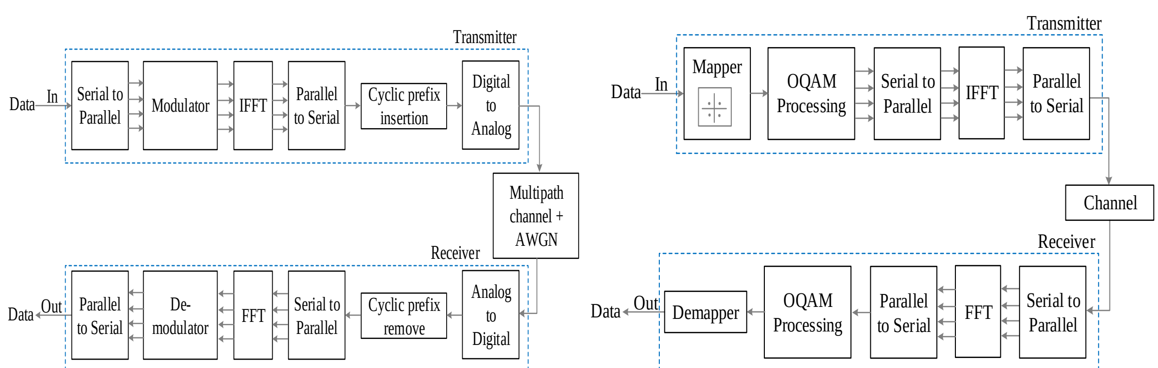
- Simulation carried out for the generation of the power spectral density (PSD) function with respect to the normalized frequency for OFDM and GFDM.
- Performance evaluation of PSD for GFDM is compared with the existing FBMC and UFMC techniques.
- Comparison between GFDM and OFDM are analyzed. The comparison based on smoothen PSD curve, required average power per unit operating area and simple design of transceiver. GFDM technique selection which is suitable for next generation communication systems.

Remaining paper is organized as follows. Research method declared in section 2 which has been divided into two sections. First one is related work and the second one contains the research methodology which has further two subsections. One subsection describes the simulation environment detailing the setup, and the other subsection shows the performance metrics discussing details for the four multiplexing techniques. Results and discussions are shown in section 3. The reason behind the findings is mentioned clearly in this section. The concluding remarks and future works are present in section 4.

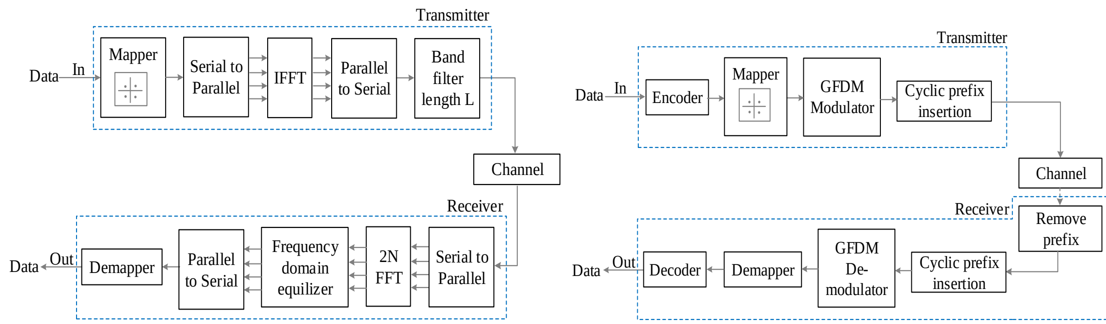
2 Research Method

2.1 Related Works

This research has focused on two parameters- one is physical stages of transceivers and another one is PSD function simulation for OFDM and GFDM. We have used a single module of transceiver in the simulation software and got the PSD function. The block diagrams of these four transceivers are shown in Figure 1(a-d).



(a) (b)



(c) (d)

Fig. 1. Block diagram of Transceiver (a) OFDM [11] (b) FBMC [25, 27] (c) UFMC [22] (d) GFDM [12]

Orthogonal Frequency Division Multiplexing (OFDM)

Present-day, OFDM technology is used by long term evolution LTE/LTE advanced and IEEE 802.11 WI-FI networks. Total bandwidth in OFDM is split up into a number of sub-carriers. The sub carriers are transmitted in parallel that raise symbol duration, data rates and lessen ISI. The summation of total sub-carriers' signals are modulated at the channels of uniform bandwidth. Usually Phase shift keying (PSK) or quadrature amplitude modulation (QAM) techniques are applied in OFDM transmission. At the transmitter, orthogonality of sub-carriers' are established by IFFT. At the receiver FFT is used to bring the signal into the frequency domain. Actually, the symbol output from FFT is the same as IFFT input. The signal in frequency domain is the requirements for demodulation also [22].

Output of IFFT is

$$X_n = \left(\frac{1}{N}\right) \sum_{p=0}^{N-1} X_{[p]} \,.\, e^{j2\pi.p.n/N}, \qquad 0 \leq n \leq N\text{-}1 \qquad (1)$$

Output of FFT is

$$X_p = \sum_{p=0}^{N-1} X_n \,.\, e^{-j2\pi/Nnp}, \qquad 0 \leq p \leq N\text{-}1 \qquad (2) \quad [22]$$

Where, X_n is the transmitted complex symbol with orthogonal conditions.

When the transmitted signal is distorted by other transmitted symbols, fading and multipath delay such as inter symbol interference (ISI) occurs at the receiver side that damages the communication system. Cyclic prefix (CP) is usually used in this multiplexing technique in order to address the delay extension of wireless channels. If the range of the CP is greater than the delay span then the channel distortion will be the multiplication of channel frequency response and convolution in single-carrier systems [4, 23]. Then the detection of OFDM is much easier. CP helps to remove ISI easily and also converts the channel into sub channel carriers. OFDM supports MIMO. Capacity and Robustness are the two properties also. For the time-limited OFDM signal, the out-of-band (OOB) leakage is high enough for asynchronized users. The guard band is used between two adjacent users to fix this issue with a CP in the time domain. But it can reduce the spectral efficiency for the narrow frequency band users [4, 24]. Filter banks can solve the OOB issue.

Filter Bank Multicarrier (FBMC)

Mandeep Singh et. al. (2020) has discussed on the FBMC to upgrade the performance of 5G networks. They focused on cognitive radio (CR) and massive MIMO to upgrade the communication. In the FBMC multiplexing and modulation technique, the whole information is split up into a number of sub-carriers where the filtration of sub-carriers is done one after another. A set of homologous data symbols Sk(n) is used for transmission. Eq. (3) is used to synthesize the transmitted signal [25]-

$$x(t) = \sum_n \sum_{k \in K} S_k[n] P_T(t - nT) e^{j2\pi(t-nT)f_k} \quad (3)$$

where, K denotes a set of effective symbol indices and $j = \sqrt{-1}$ in a traditional OFDM where p_T represents the rectangular pulse.

The primary information at the transmitter is binary encoded. Orthogonal quadrature amplitude modulation (OQAM) is used for constellation mapping. Pre-processing needs to convert the complex data to real data that can maintain the orthogonal symbols. IFFT is used to arrange the information bits parallel to serially encoded in FBMC signal, then transmit through AWGN wireless channel towards the receiver. At the receiver, to retain the orthogonal symbols OQAM post-processing is mandatory. De-mapping needs for the recovery of original information bits. FBMC techniques avoid inserting CP. FBMC needs a long filter length. The expected length is three- or four-times symbol length. Each subcarrier band go through filtering process that's why long filter length is necessary [26, 27].

Universal Filtered Multicarrier (UFMC)

Sathipriya (2016) has implemented next generation universal filtered multi carrier frequency offset. UFMC, based on filtered OFDM (OFDM) and FBMC technique. Usually, the entire band is filtered in OFDM and each sub carrier is filtered using FBMC. But UFMC is based on filtering for a group of sub carriers. Grouping of sub carriers reduces the length of the filter. QAM modulation is used. The total band with 'N' number of sub carriers that are divided into different sub bands. Every sub band has a specific number of sub carriers. In the transmitter, all sub bands do not participate in transmission. To avoid sub band carrier interference, IFFT is the solution. Sub bands are computed for every N-point IFFT where unallocated carriers are represented by zeros [28].

In the receiver, it increases the receive time window two lengths of next power. This is for FFT operation. Main lobe of each sub-carrier is indicated as an alternate frequency value. In order to balance the synchronization of channel and sub-band filtering, equalization is done on each subcarrier. No need to add CP inside the sub-carriers. So, it can avoid the same bit of reception. Therefore, spectrum efficiency is improved. The transmitted signal can be defined as –

$$X_k = \sum_{i=1}^{n} (S_{i,k} \times V_{i,k} \times F_{i,k}) \quad (4)$$

where, $S_{i,k}$ is i-th sub-band for data block, $V_{i,k}$ is IFFT matrix and $F_{i,k}$ is Chebyshev filter matrix.

Generalized Frequency Division Multiplexing (GFDM)

In present years, different waveforms have been proposed to alleviate the obstacles of OFDM, FBMC and UFMC. Fettweis (2014) et al. discussed on GFDM for 5^{th} generation cellular networks where they have analyzed the vital properties of the proposed waveform and highlight suitable attributes. They introduced the GFDM as an enhanced version of OFDM. GFDM uses filtering for every subcarrier band and can reduce overlapping among the subcarriers. Here synchronization among the users is not the key requirement for the multiple user application. GFDM uses only one CP for a group of symbols instead of CP per symbol. That's why, it is bandwidth efficient than OFDM. Another point is, in OFDM, a single QAM symbol can modulate only a single tone. In GFDM, a single QAM symbol can modulate multiple tones. For a GFDM block, every block consists of data symbols with complex value denoted by $N = M \times K$. Where N represents the total number of symbols. $d_{k,\,m}$ represents complex data symbols. Here the data symbols transmit on the m-th sub-symbol of the k-th sub-carrier. This is done by a pulse shaping filter. Identical filter in GFDM transceiver can be make use of when $f\times[n] = g\times[-n]$ [4, 29, 30].

$$g_{k,m}[n] = g[(n - mk) modN]^{j2\pi kn/K} \quad (5)$$

where, n represents sampling index. The filter $g_{k,m}[n]$ represents delayed version (time and frequency) of $g[n]$. Superposition of K subcarrier signals according to the Eq. (6) formulates the signal.

$$x[n] = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} \left(g_{k,m}[n] \times d_{k,m}\right), \quad 0 \leq n \leq N\text{-}1 \quad (6)$$

where, $x = [x\ [0]\ \ldots,\ x[N\text{-}1]]$. The vector form representation of Eq. (6) is $X = \boldsymbol{G}.d$. Here $\boldsymbol{G} \in \boldsymbol{C}^{N\times N}$ is the transmit matrix and d is a vector.

In GFDM, binary encoded information is constellation mapping, then the GFDM algorithm is applied for modulation purposes. CP code is added to contribute guard-band which can eliminate inter-symbol interference and then send down AWGN wireless channel. In the receiver section, the received signals are equalized. To adjust the quality and attribute of the information, the information is allowable for the dedicated frequency bands for either amplification or attenuation. After Demodulation and De-mapping, we can get the original information at the destination [29, 30].

2.2 Research Methodology

Simulation Environment Detailing the Setup

In section 2.1.1 we see, the total bandwidth is divided into a number of sub-carriers for OFDM. These sub-carriers are transmitted in parallel for the reduction of ISI and achieve a higher bit rate. That's why, to check the power spectral density of OFDM for a number of subcarriers, first divide the overall band into a number of sub-bands. Each sub-band among the sub-bands has a number of sub-carriers. For 200 overall sub-carriers, when split up into 10 sub-bands, then each sub-band contains 20 sub-carriers. Sub-carriers contain different numbers of bits such as 2, 4, 6 or 8.

We have chosen 4 bits per subcarrier. The summation of sub-carriers' signals modulated at the channels of identical bandwidth. Typical modulation technique is either PSK or QAM. Selection of the best modulation scheme is QPSK for the reduction of bit error rate (BER) for the transmitting-receiving balance antenna configuration. GFDM is an enhanced version of OFDM. It uses only one CP for a group of symbols. For better spectral utilization, a smoother PSD is required. MATLAB 2019 Simulink software helps us to check the PSD function. Note that, PSD is a measure of signal's power content with respect to frequency [31, 32]. PSD is denoted by

$$Power\ (dB) = PSD \times frequency \quad (7)$$

$$Power\ (W) = 1W.(10^{P_{dBm}/10})/1000 \quad (8)$$

The simulation of PSD *vs* normalized frequency across the AWGN channel, carrier sensing for multiplexing and demultiplexing are done by the MATLAB 2019 Simulink software. For the simulation, the chosen frequency is LTE 10 MHz. The chosen frequency divided by the sampling frequency that will give the normalized frequency. The simulation parameters for a single module of transceiver to visualize the operation are shown in Table I. Note that, for AWGN channel, consider adjoining channel leakage, chosen 36 carriers with 10 guard-bands. Simulation specifications are shown in table 1.

Table 1. Simulation Specifications

Parameter Specifications	Standard (unit)
Size of FFT	1024
Sampling frequency	15.36 MHz
Sub-band size	20 MHz
Number of sub-bands	10
Offset value of each sub-band	156
Length of the filter	43
Bit carries by sub-carrier	4
Signal-to-noise ratio	15 dB

Performance Metrics Discussing Details

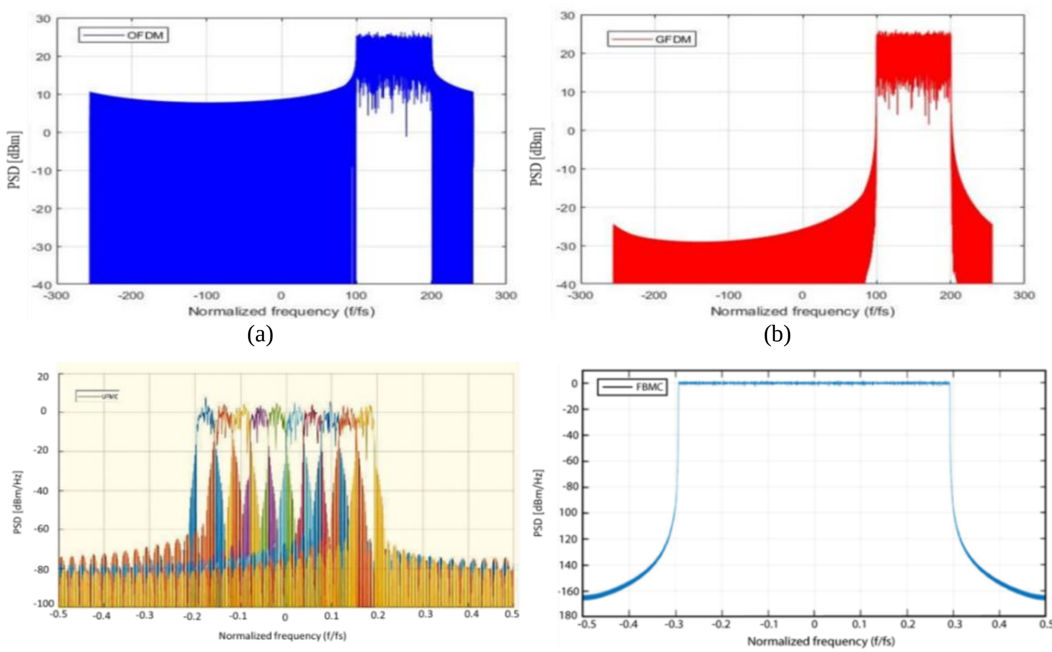
Table 2. Performance metrics for OFDM, GFDM, FBMC, and UFMC multiplexing techniques

Multiplexing techniques	Advantages	Limitations	Cyclic Prefix (%)
OFDM	For every two sub-carriers there is one CP which is inserted in between. It can eliminate ISI and ICI (inter-carrier interference). Frequency selective fading is lower than single carrier systems.	Out-of-band (OOB) emission is high enough. RF power amplifiers are necessary that have higher PAPR in order to avoid noise.	3.13
GFDM	Lower OOB radiation compared to OFDM for the use of adjustable Tx-filter. Lower PAPR. Multiple user scheduling on time and frequency domain can be obtained.	Complex receiver. Time synchronization error creates enhanced noise. ISI can be reduced using Higher order filter and tail biting process.	0.63
FBMC	It shows very small sensitivity to the carrier frequency offset. Robust during high mobility.	For wide bandwidth as well as high dynamic range system design, it faces a lot of challenges. Guard channel is required in between the users of frequency selective beam.	No need
UFMC	Better spectral efficiency. Reduced OOB emission. Low latency.	High data rate is not satisfactory. Increased delay spread. Partially overlapping sub-bands cause interference.	No need

3 Results and Discussions

At first, we simulate the power spectral density (PSD) function for OFDM and GFDM through the AWGN channel model. Simulation was carried out via MATLAB 2019 Simulink software. Table 1 in section 2.2.1 shows the simulation parameters. Figure 2 (a, b) shows the simulation outcomes. Whereas Figure 2(c,d) shows the reference PSD function for UFMC and FBMC for comparison purpose. After that we discussed on the smoothness of PSD function among those techniques. The discussion done in tabular (Table-3) form. Simulated results show little rippling for OFDM and smoothen PSD function for GFDM. Whereas the reference graph for UFMC shows much higher rippling and smooth for FBMC. Rippling PSD produces heat which initiate noise and distortion in electronic circuit. And it reflects the wastage of power.

Secondly, we take the average PSD (dBm) value over a range of normalized frequency and convert it to Watt using Eq. (2). Another way to convert the data easily using dBm to Watt calculator Then we compare the power required among the techniques. Comparison between the simulated graphs we get GFDM that requires little power which further matched to the reference techniques also. The discussion from the performance metrics on Table-1 we have found lower out-of-band (OOB) leakage, lower peak to average power ratio (PAPR), lower transceiver circuit design complexity for GFDM multiplexing technique. And finally, we can say GFDM can be consider for the multiplexing and modulation technique for 5G technology. Discussion of Figure 2 is presented in tabular (Table 3) form also.



(a) (b) (c) (d)

Fig. 2. PSD versus normalized frequency (a) OFDM (b) GFDM (c) UFMC [22] (d) FBMC [25]

Table 3. PSD *vs* normalized frequency graph analysis

Multiplexing Technique	Normalized Frequency	PSD (dB/Hz)	PSD smoothness	Comments
OFDM	0 100	10 25	Smooth PSD found between 100-200 normalized frequency	It can be recommended for 5G enabled devices and equipment.
GFDM	0 100	22 26	Almost constant value of the PSD found between 100-200 normalized frequency	It can be recommended for 5G enabled devices and equipment.
UFMC	-0.5 to -0.2 -0.2 to +0.2	-100 to-6 -6 to +6	Rippling PSD curve	It produces heats that initiate noise and distortion. Power wastage occurs due to ripple. It can be recommended for 5G.
FBMC	-0.5 to -0.3 -0.3 to +0.3	-150 to 0 0	Almost smooth PSD in between -0.3 to +0.3	Circuit complexity higher for lower normalized frequency ranges. But shows smooth PSD. If it solves mentioned problem, it can be recommended for 5G.

Table 4 shows required average power per unit operating area for three techniques GFDM, FBMC and UFMC

Table 4. Comparison among GFDM, FBMC and UFMC

Multiplexing techniques	PSD ranges (dB/Hz)	Normalizedfrequency (f/fs)	Average PSD values (in Watts)
GFDM	-40 to -20	100 to 200	39.82×10^{-6}
UFMC	-100 to -75	-0.2 to 0.2	5.02×10^{-7} [22]
FBMC	-100 to -10	-0.3 to 0.3	5.02×10^{-14} [22, 25]

The comparison among GFDM, and OFDM is shown in Table-5.

Table 5. Comparison between GFDM and OFDM

Multiplexing techniques	PSD ranges (dB/Hz)	Normalized frequency (f/f_s)	Average PSD values (Watts)
GFDM	-40 to -20	100 to 200	40.23 µW
OFDM	-40 to 10	100 to 200	32.1 mW

Table-5 shows 1000 times reduced power required for GFDM compared to OFDM. Very recently, 4G LTE transceivers operated at 13.3 mA current rating. The characteristics of dynamic adoption of pulse shape optimization for GFDM in the time and frequency fading channels gives higher energy and spectrum efficiency [29]. It is another reason which allows simple transceiver design for GFDM. Both the power and hardware configuration required for the trade-off to select an efficient channel allocation method for 5G. That's why GFDM meets the efficient ones among these four multiplexing techniques for 5G mobile network.

4 Conclusion

This paper presented the OFDM and GFDM as a contestant waveform for multiplexing technique. The performances have been analyzed for OFDM and GFDM and simulation outcomes show the proof of concept. A lot of issues still need to be settled. However, the research result has shown GFDM multiplexing technology is suitable for next generation wireless networks. In the next generation, the characteristics of a future waveform should be flexible. That's why our next target for different applications with different parameters should be resolved by a single solution instead of multiple solutions.

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