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# Comparative analysis of OFDM and GFDM

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Abstract — In recent past there are multiple, multicarrier techniques as an alternate of OFDM like Filter Bank Multi-Carrier (FBMC), Universal Filtered Multi-Carrier (UFMC) and Generalized Frequency Division Multiplexing (GFDM) as upcoming 5th Generation cellular systems. Performance of GFDM and OFDM needs to be investigated, since GFDM is increasing the performance of cellular communication system, so it needs to analyses the waveforms of both the techniques. In this work, we have checked the main characteristics of proposed wave forms and the relevant features. We conducted comparative analysis between GFDM and OFDM Bit error rate (BER) vs. Signal to Noise Ratio (SNR). GFDM is flexible in nature and its orthogonality gives it an edge over OFDM and which make it most suitable for the 5G technology.

**Index Terms**—GFDM, OFDM, pulse shaping, physical layer, MIMO, Equalization

## I. INTRODUCTION

In Code Division Multiple Access (CDMA) each user have the whole spectrum all the time [1] [2]. This is quite complex technique used for mobile communication. Transmitter uses unique spreading codes and at receiver it despread the signal by passing it through narrow band pass filter. The major disadvantage is it does not have multiband capability so it cannot be used for multiple countries with ease [3].

Frequency division multiplexing (FDM) is a technique in which multiple signals are transmitted. FDM uses a carrier sig-nal for each data stream and combines the modulated signals. It divides the available bandwidth into series of sub carriers. The optimal technique for FDM is Filter Bank Multicarrier (FBMC) [4].

OFDM is a technique of FDM used as a digital multi-carrier modulation method. OFDM have a complexity advantage over CDMA [5] as every subcarrier is orthogonal to each other [6]. So we don't need any code for every user. With large channel bandwidths, OFDM offers advantages over CDMA because of simplified receiver processing as we only need IFFT at receiver. OFDM combined with MIMO can give good gains over CDMA systems [7].

Previously two other multiple access techniques were pro-posed these are given as Time division multiple access

(TDMA) and Frequency division multiple access (FDMA). InTDMA each user transmit the signal only in a specific time-slot with a common frequency band while in FDMA there are multiple users that can be transmitted at different frequencies [8]. Both the techniques have pros and cons the complexity of FDMA technology is lower as compared to TDMA but it requires high filtering for minimizing the ISI. In TDMA each user uses non overlapping time slots but the drawback is each user have a predefined time slot this make a problem in the roaming of user from one cell to another i.e. if all the time slots in the next cell are already occupied, a call might be dropped [2].

Waveforms tells the performance of any communication system. OFDM have many advantages but still GFDM wave-forms give additional edge in the upcoming cellular systems. Single waveform cannot provide answers of all the questions raised over the technology. As a result many anticipate that the final outcome for GFDM waveforms may include an adaptive solution using the optimum waveform for any given situation.

OFDM have high peak to average power ratio (PAPR) and have more Out-of-band (OOB) emission. OOB emission is because of the rectangular pulse shaping filter used at the transmitter and the reason of higher PAPR is the random sum of the phase subcarriers. To reduce PAPR and OOB emission a lot of work has been done [9]- [13].

[14] presents a better technique for both OOB emission as well as better PAPR this technique is named as Generalized Frequency division multiplexing (GFDM) [15] [16]. GFDM must be considered as 5G candidate a it is flexible and almost have the similar structure as OFDM, just need one change among all the modules.

Following are the contribution: Implementation of GFDM and OFDM. Get the difference of OFDM and GFDM, have a comparative analysis of both technique. Different waveforms, block base and sub-carrier base communication system com-parison, the making of their matrices and how they work when we receive the signal, what is the multipath effect on GFDM, equalization techniques and there effects.

Other sections are as following: Section II presents the possible physical layer techniques for 5G, Section III contain the system model of GFDM and OFDM and the comparison of both techniques, Section IV presents different Equalization techniques and there effect on the performance of OFDM and GFDM, Section V is about the waveforms and effects of mul tipath on GFDM. Finally Section VI will be the conclusion

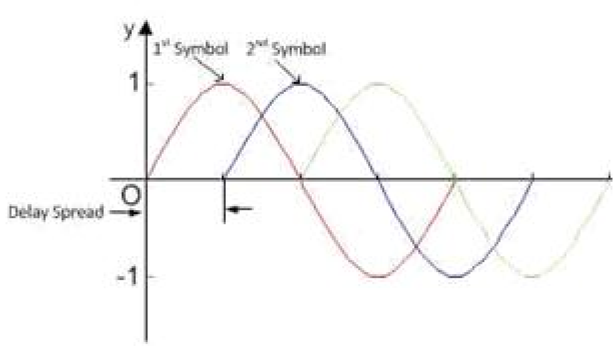



Fig. 1: OFDM symbols and Delay spread

II. PROPOSED TECHNIQUES FOR 5G

There are four different physical layer techniques proposed for the 5G technology [14]. These are given below:

1) Filter Bank Multi Carrier (FBMC)

2) Universal Filtered Multi Carrier (UFMC)

3) Bi-Orthogonal Frequency Division Multiplexing (BFDM)

4) Generalized Frequency Division Multiplexing (GFDM) FBMC is the most investigative filtered multi carrier phys-

ical layer technique. Every symbol is passing through pulse shaping filter. This thing helps to reduce the OOB emission. Pulse shaping filter length is equal to four times of the symbol length (Here symbol means a pulse in digital baseband trans-mission) [14]. Because the sub carriers have narrow bandwidth usually the impulse response of the transmitted filter is long. This will leads to good spectral efficiency only when the number of transmitted symbols are large. On the other way around i.e. for low latency this solution is not favourable. In UFMC a group of subcarriers are filtered, although we reduce the OOB emission as this is doing filtering in the form of group of subcarrier so its impulse response will be reduced so by this we can achieve high spectral efficiency in short burst transmission. Spectral efficiency is nothing but the information rate that can be transmitted over a given bandwidth. The total length of block (means N number of symbols passing in time T) will be equal to CP plus the symbols of OFDM because we dont have a need of CP in it [17]. But UFMC is very sensitive for the applications where we required loose time synchronization. BFDM have well localized pulses which are orthogonal to each other. Well localization mean they are localized in time domain as well as in frequency domain [18]. But to localize these pulses we need offset Quadrature Amplitude Modulation (OQAM). This makes the system complex and we cannot integrate the MIMO aiming diversity. As MIMO have multiple transmitters and multiple receivers so it will become extremely complex because we need off-set for every symbol .MIMO diversity is an important application of 5G.

GFDM is the most flexible digital multicarrier technique. It can achieve higher spectrum efficiency because it does not

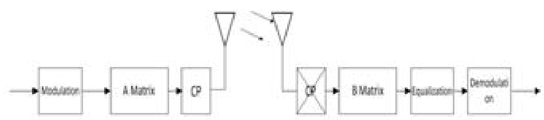



Fig. 2: GFDM Block Diagram

need to use virtual subcarriers to Inter-carrier Interference (ICI) [19].This is a generalized form of OFDM. This is one of the closest solution among all. In this technique a symbol composed of several subcarriers and several sub-symbols to transmit a data block, where each subcarrier is pulse shaped with a transmission filter. In order to avoid spending additional samples on ramp up and ramp down of the filter response, the impulse response is applied by using circular convolution. Circular convolution process is discussed in the next section. Different pulse-shapes can be used as prototype filters, which introduces a new degree of freedom to the system. Subcarrier filtering reduces OOB emissions, but also might introduce ICI and inter-symbol interference (ISI). However, receiving techniques such as zero-forcing or a matched filter in com-bination with successive interference cancellation (SIC) can reduce the impact of self-generated interference and lead to an error rate performance equivalent to OFDM. GFDM have MK samples. Where M are the subcarriers and K are the sub-symbols. This is suitable for low latency as well as for loose time synchronization. In GFDM we use only one CP after the whole block of M K symbols. This thing improve the spectral efficiency, multiple input multiple output (MIMO) is the main feature of 5G technology. It has the adaptability of synchronization algorithms of OFDM [19].

Introduction motivates the problem again, emphasizing why it is important and what are the practical applications. Use references wherever possible to support have well localized pulses which are orthogonal to each other. Well localization mean they are localized in time domain as well as in frequency domain. But to localize these pulses we need offset QAM (OQAM). This makes the system complex and we cannot integrate the MIMO aiming diversity. MIMO diversity is an important application of 5G [20].

III. OFDM VS GFDM

GFDM is an advance technique of multicarrier. Fig 2 is the block diagram of GFDM. The difference is coming at the inverse fast Fourier (IFFT) block. We replace it with A matrix and FFT block is replaced by B matrix. The explanation is given below:

OFDM:

OFDM is the orthogonal frequency division multiplexing this technique uses digital multi-carrier modulation. This carry the data streams in parallel because its channels are orthogonal. The subcarriers are modulated by modulation schemes (e.g. QAM, PAM 16-QAM, 64-QAM etc.).

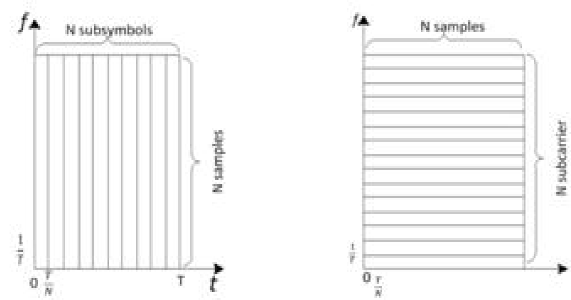



Fig. 3: SC-FDM and OFDM symbols

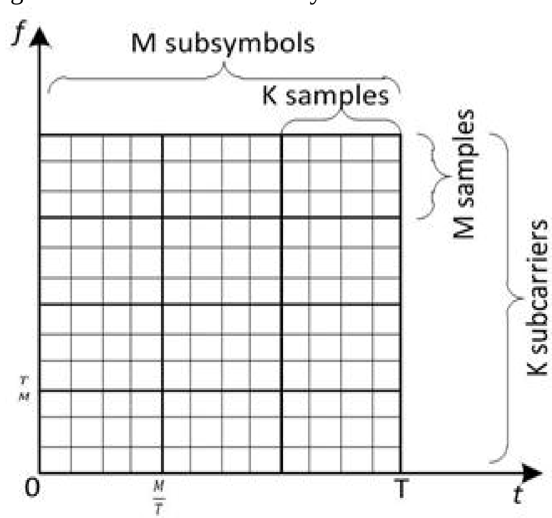



Fig. 4: SC-FDM and GFDM

The main advantage of this technique over SC-FDM is, we can use multi carriers in this technique without using complex equalization filter. This technique have very low symbol rate as to make sure that they are completely orthogonal, this technique include a guard interval between the symbols to make sure that there will be no ISI between all the symbols. Although this consumes too much bandwidth but still have a better data rate as compared to SC-FDM. The figure 3 shows the data flow diagram of OFDM and SC-FDM. We have seen division [23-40] in the frequency in case of OFDM. There are N number of subcarriers at a given time slot t. While in SC-FDM there is division in time. The Fig.4 shows the GFDM data flow diagram here one block will be of 4 3 boxes and similarly one frame will be equal to M K.

Block diagram of OFDM is given in Fig.5 . First come the bit stream this is basically nothing but the data which is been sent by the sender. After modulation we do pass it through inverse fast Fourier Transform (IFFT) this block is used to make the signal into a time sequence. Subsequently we add CP so the symbol length is increased or extended. CP is nothing but the last part of symbol which is added at the start of sequence. Its length must be more then the delay spread of the channel [21]. This will help in mitigating the effect of ISI. After that we send the signal.

At the receiver side we do the reverse of the transmitter blocks we first remove the CP then do the fast Fourier transform (FFT) to convert the time domain signal back to frequency domain signal. There are a few drawbacks of OFDM which are enlisted below:

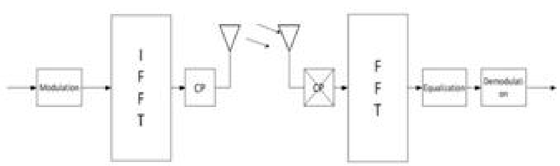



Fig. 5: OFDM Block Diagram

1) OFDM have very low spectral efficiency due to the addition of CP
2) OOB emission is very high

3) There will be high spectrum leakage in OFDM as we are using rectangular windows for filtering

GFDM:

GFDM is a flexible multicarrier technique. If we compare GFDM with OFDM block by block we can clearly see there is not much different in the GFDM except A matrix but when we go deeper, we observe that there are some differences in GFDM. As we have scene when bits are coming in the modulation block we do similar operation as like of OFDM which is we do Quadrature Amplitude modulation(QAM). After modulation there is an A matrix block which is the main difference we have seen when it comes to intuitive comparison. Here A matrix is nothing but a transmission matrix which contains sub carriers and sub symbols. Input bits are converted into data streams which are equal to M x K where M are the sub carriers and K are the sub-symbols. GFDM have M time slots and for each time slot we have K sub carriers. For pulse shaping we use the equation given below

$kg_{k;m}$ [n] = g[(n mK)modN] exp[ j2 n] (1) K

Here n is the sampling index. $g_{k;m}$ [n] is the time and frequency sifted version of g[n]. We do it in matlab by circular shifting of $g_{k;0}$ [n] while exponential perform the shifting in frequency. Shown in the figure

Implemented A matrix having length of KM x KM have a structure given in the equation.

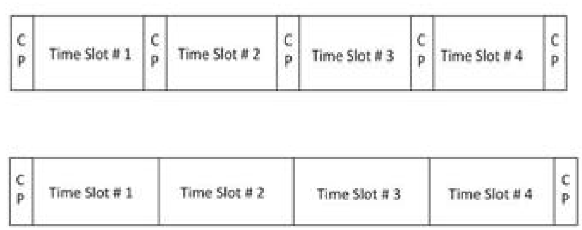
$$A = g_{0;0} \cdots g_{K\ 1;0}\, g_{0;1} \cdots g_{K\ 1;M\ 1} \quad (2)$$

GFDM modulation is don by multiplying A with the modu-lated input signals as mentioned in the equation

$$x = Ab \quad (3)$$

After GFDM modulation block we add CP which has the same length as OFDM but the difference in this CP is we place CP after every frame to avoid inter-frame interference (IFI) while in OFDM we add CP between two time-slots as shown in the given below Fig. 6.

The signal is then passing through the channel. First we remove CP then do GFDM demodulation which is H Zero Forcing Equalization (ZF)




Zero Forcing Equalizer is a linear equalization algorithm. It applies the inverse of frequency response. We take the inverse of overall channel. This needs not to have the information (a) OFDM of the transmitted signal at receiver.Match filter equalization satisfy $B_{ZF} = A^{1}$ where B is the received matrix and A is the transmit matrix. Inverse is the most complex operation to perform in the communication systems.

(b) GFDM

Fig. 6: OFDM Vs GFDM symbols pattern input modulate dsigna l $A^H$ where H is a circular convolu-tion matrix. The next block is very interesting i.e. Equalization. We have several techniques for equalization but for this particular report we apply two techniques one is match filtering equalization and the other is zero forcing equalization. The results of these techniques will be discussed later in this report. Next block is QAM demodulation, this block is same as of OFDM [22].

Table 1 shows the major differences between OFDM and GFDM.

IV. EQUALIZATION

Equalization is a reversal of distortion occurred when signal passed through the channel. There are several techniques which can be implemented to get the signal back these techniques are given below:

1) Minimum Mean Square Error Equalization (MMSE)

2) Zero forcing Equalization (ZF)

3) Match filtering Equalization (MF)

Minimum Mean Square Error Equalization (MMSE)

This is an error estimation technique we estimate the error by squaring the difference of input signal and the received signal. To find the MMSE estimation $B_{MMSE} = (R^2 + A^H H^H HA)^{1} A^H H^H$ here $R^2$ denotes covariance matrix of the noise. This is quite complex equation and we need a lot of operation to do.
Match Filter Equalization (MF)

The matched filter is a linear filter to maximize the signal to noise ratio (SNR) in the presence of additive white noise. Match filter equalization is done $B_{MF} = A^H$ . This equation shows that we need only hermitian of the transmitted matrix. which is not as much complex as the inverse is.

V. WAVE FORMS

This section contain the comparative analysis of different bit error (BER) vs signal to noise ratio (SNR) curves. Table II is defining the parameters which are used in the graph im-plementation. We have seen in the figure that MF equalization is giving better BER curve as compared to ZF. The reason is that the transmit matrix A in not orthogonal. As A is not a unitary matrix because it doesn't obey $AA^T = I$, here A is the transmit matrix. This curve shows that MF equalization is a bad choice for GFDM. GFDM is more complex system because inverse of any matrix is one of the most complex operation when it comes to the practical implementation.

Next curve is telling about multipath effect on GFDM as when we increase the number of multipath there will be BER will decrease. Now we have two more interesting concepts covered in this curve these are Multipath Fading and Multipath Diversity

Multipath Fading and Multipath Diversity

Fading is nothing but the fluctuation in the signal. There might be small fluctuation also known as small scale fading or a large fluctuation also called large scale fading. As signal arrive at the receiver from transmitter through more then one path. This may cause multipath interference which will eventually cause multipath fading.
Table: II

| Parameters | Values |
|---|---|
| Number of time-slots (M) | 9 |
| Number of Sub-carriers(K) | 64 |
| Total Number of Symbols | 576 |
| SNR | 0-18 dB |
| Modulation | 4-QAM |
| Roll-off | 0.1 and 0.9 |
| Transmit Filter | RC |
| CP length | 10 symbols |
| Number of Realizations | 1000 |
| Channel | Frequency Selective Rayleigh Fading |

This may cause several effect on the signal one is the rapid change in the signal strength and the time dispersion of the signal. There can be many reason of multipath fading like multipath propagation,

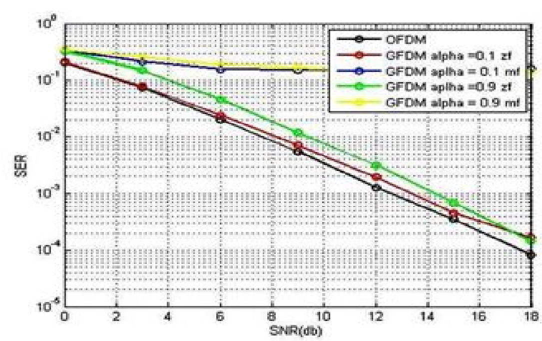



Fig. 7: SNR vs BER curve of OFDM and GFDM

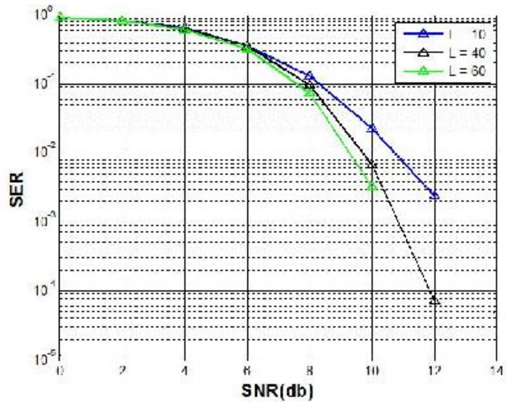



Fig. 8: Multipath effect on GFDM

speed of mobile or communication device and speed of surrounding objects etc. To nullify this effect we use multiple selective combining RAKE receiver. RAKE receiver is use to counter the effects of multipath fading. It does this by using several ”sub-receivers”. These sub-receivers are called fingers,i.e. these are several correlators each assigned to a different multipath component. Each finger independently decodes a single multipath component at a later stage the contribution of all fingers are combined in order to make the most use of the different transmission characteristics of each transmission path. This could very well result in higher SNR in a multipath environment than in a ”clean” environment.

Hence due to multipath diversity we get better results when we have higher number of multipath.

## VI. CONCLUSION

This paper conclude that by using match filter equalization we can get the desired performance of GFDM almost equal to OFDM. But in case of OFDM we can get this performance by using zero forcing equalization technique which is far less complex as compared to match filtering equalization. So we can conclude that in case of GFDM we have low paper as compared to OFDM at the cost of complexity.

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