



Comparative Study on Implementation Performance Analysis of Simulink Models of Cognitive Radio Based GFDM and UFMC Techniques for 5G Wireless Communication

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Abstract

In this paper, we studied different reduction methods for peak to average power ratio (PAPR) and bit error rate (BER) in generalized frequency division multiplexing (GFDM) and universal filtered multicarrier (UFMC) as well as the relation between UFMC and GFDM on the basis of PAPR and BER for different windowing techniques in cognitive radio for future wireless communication systems. With the help of MATLAB as well as Simulink model, we have discussed all the conclusions related to GFDM and UFMC parameters in a Comparative manner. Recently a lot of work is going on next generation i.e. fifth generation (5G). In this, generalized frequency division multiplexing and universal filtered multicarrier are the two most favourable candidates which fulfil all the requirements which are necessary for present situation. The comparative analysis done between UFMC and GFDM schemes in terms of robustness against multipath channels shows that the simulation results obtained have a deep impact on study of performance analysis of multicarrier modulation techniques implemented through Simulink models in a ubiquitous and pervasive scenario.

Keywords SLM · RCF · Tone reservation · Gabor transform · GFDM · UFMC

1 Introduction to 5G

The 5G technology provides high resolution to users and large bandwidth. It is based on software defined radios and modulation schemes as well as new error control schemes. Each terminal can handle different wireless technologies at the same time and this terminal

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is based on an open intelligent middleware in system. The uploading and downloading speed of 5G technologies is very fast because of larger bandwidth. This wireless technology is based on autonomous access techniques. The 5G technologies are loaded with all advanced level features which make 5G most powerful and in huge demand in the near future. The 5G technology supports automotive communications, huge video downloads and very low data rate applications like in remote sensors. The main aim of 5G technology is high capacity and 10Gbps network speed. 5G based equipments are cheaper with lower power consumption and lower latency than 4G. 5G is working in the growth of many industries in entertainment, agriculture, IT and manufacturing industries. 5G is mainly based on UFMC and GFDM multicarrier modulation techniques which reduce the level of peak to average power as well as bit error rate for input data as compared to the other wireless technology generations [1]. Cognitive radio is a technology that is of growing interest worldwide. At present, there is an active involvement of academicians and industrial researchers in this domain. Significant efforts have been made to focus on many technical questions regarding their feasibility in order to move this new technology from research concept to reality [2, 3].

2 Literature Review

Chan [4] discussed the new wireless communication services which involved first generation analog system to second generation digital system with rich features. The author also described many wireless system specifications and parameters like multimedia, location services, voice and data simultaneously. Bhalla and Bhalla [5] discussed in detail about the various generations of wireless systems technologies, their portals, performances, advantages and disadvantages of one generation over other. Rahnama [6] proposed the cellular network infrastructure specification of mobility management and standards which are used in global system for communication. The author also described the routing of signal, protocol layering architecture, paging message system and radio channel structure etc. Salkintis et al. [7] proposed the combination of wireless local area network and cellular networks which is capable for providing omnipresent data services and very high data rates. The author also explained the scenario of access to Third Generation Partnership Project (3GPP) circuit switched based services. C. Bettsletter et al. [8] proposed the general purpose radio services. In this, the author reused the infrastructure of GSM so that it can provide end to end package switched based services. They also proposed that GPRS provides even path for third generation mobile network, faster access speed and larger bandwidth with multiple time slots. Furuskar et al. [9] discussed the enhanced data rates for global evaluation which is accepted by Interim Standard (IS-136). They described two points about Enhanced Data Rates for GSM Evolution (EDGE); EDGE in GSM and EDGE in IS-136. EDGE enhanced the user bit rates in limited system with increase in the spectral efficiency of the system. Chuang and Sollenberger [10] proposed dynamic packet assignment for high efficiency resource management, frequency diversity, space time coding as a good power as well as flexible allocation of resources which permits services for different delay and throughput needs. Jindal et al. [11] emphasized on Wireless Microwave Access (WiMAX) technology for wireless data transfer as well as replacement of digital subscriber lines. They proposed that WiMAX provides every time and everywhere connectivity. In this, the signals propagate very close to each other. This technology is based on non-line of sight coverage as well as it overcomes the drawbacks of Wireless Fidelity (WiFi). Garber

[12] proposed that third generation is a combination of digital and packed based technology. Garber discussed all points about 3G as well as standards because it also contains some drawbacks like high cost and high BER. Honkasalo et al. [13] discussed that Wireless Code Division Multiple Access (CDMA) is air interface designed to satisfy future services and applications requirements. Wireless Local Area Network (WLAN) is used to fulfil the needs of smooth online access, additional capacity and higher bandwidth for end users without abandoned user's capacity. This provides better presentation and higher bit rates. They also defined that data rate is the main difference between the 3G and 4G technology because 4G supports 100Mbps data rate in full mobility and 1Gbps in low mobility. Fagbohun [1] proposed different wireless technologies. He discussed the comparison between 3G and 4G on the basis of speed, frequency band allocation, architecture etc. but both technologies are unable to solve the problem of bad coverage, less flexibility, deprived Quality of Service (QoS) and poor interconnectivity while 5G system overcomes all these requirements with additional advantages like network heterogeneity, intelligent networking and effective connectivity. Choi and Xu [14] proposed that 3G is based on CDMA 2000 and because of it, third generation wireless technology provides mobile internet and multimedia services. CDMA2000 with SIP protocol can easily tackle multimedia packed data for audio and video both because this protocol is used as a signalling protocol. Krenik [15] proposed that fourth generation provides downlink data rates, low latency, effective use of spectrum and low-cost design. It provides many applications for users like enlightened graphical user interfaces, high-end gaming, high-definition video and high-performance imaging. Zhen [16] discussed the expectation of users regarding internet services. For the next wireless generation, there is a need of more than 2Mbps speed which is not fulfilled by third generation technology. Hence, there is need of advancement in the third generation and introduce a new technology, that is 4G which overcomes all the drawbacks of 3G and add some new advantages. Frattasi et al. [17] gave a practical definition of fourth generation to review the user as foundation of the design. They proposed a new framework which is a conceptual and technical pillar of 4G for describing the inter dependency among the various levels. 4G has features like user friendly, user personalization, terminal heterogeneity, and network heterogeneity. Khan et al. [18] showed a new mobile technology i.e. 4G which provides better speed to customers and all IP dependent multimedia services. 4G is a global system to provide comprehensive IP resolution to users anytime and anywhere. 4G is used in deployment of a technology that can merge different systems into a single unified system. Wang [19] showed difference between frequency division multiplexing and Orthogonal Frequency Division Multiplexing (OFDM) as such in OFDM, the spectrum mutually overlap. However, OFDM carriers contain orthogonality if they are spaced in frequency exactly at the corresponding to symbol interval, which can be consummated by utilizing the Discrete Fourier transform (DFT). OFDM has many applications varying from modems, digital audio broadcast, to the next-generation high-speed wireless data communications. In particular, they design turbo receivers, including an OFDM system with frequency offset and a space-time block coded OFDM system. Sasipriya and Vigneshram [20] proposed that 5G and Cognitive Radio are two unique technologies which work under heavy traffic. These technologies provide higher capacity and a network speed of 10Gbps. 5G equipment has lower cost, lower battery consumption and lower latency than 4G equipment. They showed that 5G is the reason of growth in entertainment, agriculture, IT and manufacturing industries. CR provides the more efficient use of spectrum in 5G system. Mitola [21] discussed that radio protocol is a set of RF bands, air interfaces and spatial and temporal patterns that equitable the use of the radio spectrum. CR increases the flexibility through a radio knowledge representation language which represents understanding of

radio protocols, devices, software modules, propagation, networks and users. The software defined radio provides an ideal platform for the realization of cognitive radio. Arul and Ranjan [22] emphasized that spectrum is a very important resource in wireless systems. Wireless spectrum is getting crowded as there is not proper utilization of spectrum which becomes a major problem to deal with. They discussed about the Cognitive Radio Spectrum Management Techniques to solve issues like interference, noise and underutilization. Lu et al. [23] proposed that Cognitive radio is able to fulfil the growing demand of spectrum effectively. CR system allows secondary users to access the licensed user spectrum bands when it is free to avoid interference and collisions. This all happens because of spectrum sensing ability of cognitive radio. They discussed cooperative spectrum sensing schemes to point out the limitations of the spectrum sensing techniques. Ansari and Gulhane [24] discussed the necessity of dynamic spectrum allocation for increased wireless technology. Cyclostationary based Spectrum Sensing method uses the cyclic prefix of the received signal. Windowing techniques are used to decrease the spectrum leakage which is introduced due to Fast Fourier Transformation. This technology gives the best results with Kaiser Window as it provides low SNR.

Sattarov et al. [25] discussed that 4G wireless communication system is based on OFDM because of using adaptive modulation, sufficient synchronization like OFDM's important features. They also proposed the OFDM suffers from high Peak to Average Power Ratio (PAPR). Kumar and Santosh [26] emphasized that OFDM has many disadvantages which are not suitable for next generation wireless communication. They proposed that GFDM gives better spectral efficiency, less Out of Band Radiation (OOB) radiation with $(MN)^2$ number of multiplications but it also suffers from high PAPR. Datta et al. [27] proposed flexible digital radio with multicarrier modulation scheme to maintain low out of band radiation and spectrum efficiency. In Generalized Frequency Division Multiplexing (GFDM), ICI cancellation scheme is used to improve efficiency of the GFDM system. They proposed two PHY design schemes to implement better BER performance. Hence, simple equalization with some additional flexibility of shaping filters provides low OOB leakage. Fettweis et al. [28] discussed about GFDM which exhibits high degrees of spectrum fragmentation. They showed GFDM features which are: low PAPR, ultra-low out-of-band radiation and a block-based transmission using cyclic prefix insertion and efficient FFT-based equalization. Low PAPR in GFDM permits low hardware cost and power consumption. It also provides a high degree of flexibility and efficient multi-user scheduling. Datta et al. [29] proposed that in cognitive radio if obligatory user doesn't need for White Space Device's (WSD) operation for opportunistic users use in the same spectrum then Generalized Frequency Division Multiplexing multicarrier modulation technique makes it possible because GFDM provides extremely low out-of-band radiation which makes it a good choice for the PHY layer of cognitive radio. Vakilian et al. [30] discussed a new multicarrier scheme i.e. Universal Filtered Multicarrier (UFMC) to reduce the Inter Carrier Interference (ICI) by apply filtering operation to a group of sub-carriers. It also reduces the out of band radiations in case of asynchronous transmission. They discussed a coordinated multi-point (CoMP) reception in which base stations send the received signals to a CoMP central unit (CCU) for processing. UFMC outperforms the CP-OFDM for both perfect and non-perfect frequency synchronization. They also discussed about the effect of imperfect carrier frequency offset (CFO) compensation on the symbol error rate (SER) performance. Wunder et al. [31] proposed LTE and LTE-Advanced to deliver high bandwidth users but it also has certain drawbacks like immense efforts are needed to manage strict synchronization and orthogonality among sub carriers, hence it will produce new PHY and MAC layer concepts to meet the future needs. Schaich and Wild [32] proposed

the need of UFMC in 5G because UFMC is a combination of advantages of FBMC and OFDM and avoids the drawbacks of both. They emphasized that 5G can support Internet of Things (IoT) and user centric processing by designing the fundamental physical layer. They proposed that UFMC has many advantages like small bursts communication, higher spectral efficiency and durability to multi user interference. Wild et al. [33] discussed 5G air interface design for waveforms, multiple access and frame structure. They also used multiple access for inflexible synchronization because OFDM has spectral based limitations while FBMC has offset-QAM and longer filter lengths. The Interleave-Division Multiple-Access (IDMA) is used to separate multiple users with additional degrees of freedom and improved robustness. Universal filtered orthogonal frequency division multiplexing (UF-OFDM) can be explained as a generalization of filtered OFDM and FBMC. Cho and Yan et al. [34] proposed a new Universal filtered multi-carrier (UFMC) model which supports asynchronous transmissions. They used filters at the receiver which can separate target signal over asynchronous transmission. They also introduced a coarse timing synchronization algorithm over Additive White Gaussian Noise (AWGN). Hence, this frame structure provides better Symbol Error Rate (SER) performance than synchronous single carrier frequency division multiple access transmission. Chen et al. [35] discussed the comparison from interleave division multiple access (IDMA) to frequency division multiple access on Orthogonal Frequency Division and UFMC. IDMA provides enhancement for low rate users and UFMC introduces the additional protection to high-rate users. They also compared CP-OFDM with UFMC. UFMC uses short-length Finite Impulse Response (FIR) filters to reduce OOB radiation which increases the robustness against Inter-Carrier Interference. Rani et al. [36] proposed that UFMC has some attractive properties like better sub carrier separation and less complexity which makes it better choice for future wireless technology. They also discussed about hybrid technique which reduces the PAPR value. Bauml et al. [37] proposed a selective mapping method to reduce the peak to average power ratio of multicarrier modulation schemes. This method is suitable for large area applications as its complexity level is moderate. A notable gain can be achieved by selective mapping method. Zhang et al. [38] discussed that system with high PAPR has to face many challenges specially in demodulation and hardware design of the system receiver. They proposed an improved genetic algorithm for selective mapping technique to reduce the PAPR without any information distortion. They also discussed that Bit Error Rate (BER) or Power Spectral Density (PSD) remains unaffected because of this proposed technique. Li and Cimini [39] proposed clipping and filtering technique to reduce the peak to mean envelope power ratio of the multicarrier schemes. They used crest factor at various percentiles of the cumulative distribution function to get the better characterization of signal's peak value. Jebbar et al. [40] discussed the different techniques for PAPR reduction in 5G communication. All techniques were introduced for OFDM but it is successfully adjusted for new multicarrier waveforms also. Krongold and Jones [41] discussed the tone reservation technique in which reserved tones are used to design a system which cancels the peak of signals and reduced the PAPR of the transmitted data as this method is based upon the active set methods. Wang et al. [42] discussed about the reduction of peak to average power ratio of OFDM system using companding techniques. Because of the Gaussian distribution of the OFDM signal, the companding technique can be quite effective, since a large OFDM signal only occurs infrequently. The peak-to-average power ratio of an OFDM system and the optimal companding coefficients are determined in his paper. The symbol error rate of the systems after the companding has been derived. The performance of the system with and without the companding has been compared. Ren et al. [43] proposed a random filtering method for reducing PAPR in generalized frequency division multiplexing

signal. This reduced the PAPR around 5 db from original GFDM signal without Repeated Filtering Method. This method improves the efficiency of the GFDM signal in radio communication and decreases the complexity of the system. Sharifian et al. [44] discussed a polynomial based PAPR reduction technique in GFDM. In this, a compressor is used before cyclic prefix at transmitter side and an iteration algorithm is used at the receiver end. They proposed a trade off between PAPR and bit error rate performance. They also showed that as the order of polynomial is increased, there is reduction in PAPR of GFDM. Liu et al. [45] discussed an effective companding transform technique which is non linear in nature and is used to reduce the PAPR in GFDM. In this, a companding method is applied at the transmitter side and to compensate this effect, an interactive algorithm method is used at the receiver side to achieve a better BER performance as well as reduced PAPR. Sourck et al. [46] discussed the linear Precoding method which is used to reduce the PAPR for GFDM multicarrier scheme. In this method, variance of the instantaneous power is reduced with the help of precoder bit and their average value of Internet Protocol (IP) remains unchanged. They also proposed that this effective technique reduces the PAPR value without affecting the out of band radiation and bit error rate. Sendrai et al. [47] introduced a receiver for noise estimation and alleviation. This method is totally based on the roll off factor α ($0 < \alpha < 1$). They showed that due to clipping method, the non-linear noise gets reduced and performance is improved. Zhong and Guo [48] emphasized on a combination of time reverse space time coding and GFDM to decrease the error due to different noise channels. They also compared the performance of BER for single input single output and multiple inputs and multiple outputs for GFDM.

3 A Brief Overview: PAPR, BER and Window Techniques

The PAPR explains the relation between the maximum instantaneous power of a sample in a transmit symbol and the average power of that symbol. PAPR is the ratio of peak power to the average power of a signal expressed in dB. The RF communication system contains a high power amplifier at the transmitter side to produce adequate power of transmission. If PAPR is high then it forces the high power amplifier to have a large back-off in case of linear characteristics which diminishes the effectiveness of the amplifier but for non linear characteristics, it will reduce the BER performance of the system. Hence, PAPR reduction is necessary to make the receiver error prone because it makes the system poorly efficient to power. The main reason of PAPR occurrence is out of phase sub carriers [2]. To reduce the PAPR, Crest Factor Reduction technique is used so that power amplifier can work efficiently. There are many Clipping Filtering Reduction (CFR) algorithms namely Clipping and Filtering, Peak Windowing, Peak Cancellation etc. and the choice of reduction algorithm depends on the multicarrier scheme adopted. The Bit Error Rate is a crucial parameter in the interpretation of data channels. When information is transmitted from one side to other in a wireless communication system, then errors are introduced on wireless telecommunication channel. In the presence of errors, the information quality of the system may be degraded. Bit Error Rate is present in everything from fibre optic connections, to Wi-Fi, cellular communications, IoT links and many more. Bit error rate shows as how frequently a packet or other data unit has to be retransmitted because of presence of an error. To measure the BER, one can use pseudorandom bit stream to interface followed by counting the erroneous bits leading to the bit error rate computation by comparing data from transmitter to receiver. To make this measurement easier, it is possible to define BER

in terms of a probability of error [2] In a communication system, BER gets affected by the transmission channel noise, interference, distortion, bit synchronization problems, attenuation, wireless multipath fading etc. The BER can be reduced by using a strong signal, a slow and powerful modulation scheme and by applying channel coding schemes. Normally, the transmission BER is greater than the information BER. The information BER is affected by the power of the forward error correction code. It is essential to stabilize all the available factors to get an acceptable bit error rate as it is used to determine the proper communication path between transmitter and receiver [2]. The Window functions are used to limit the signals for improving the artefacts of the transform as windows are used for spectral analysis. Many types of window functions are available in literature. Kaiser developed a function in terms of Bessel functions of first kind. In this, by varying a parameter α , level of side lobe is controlled with respect to the main peak lobe. The Kaiser Window function is described in [3]. The Hamming window is used in the narrow band applications. This is formed by using a raised cosine with non-zero end points. The causal Hanning window function is another variant of Hamming window function. Dolph chebyshev window function decreases the transition region by increasing the filter order. This function reduces the chebyshev norm of the side lobes [3].

4 Role of GFDM and UPMC Techniques in Wireless Communication

GFDM and UPMC are used to overcome the shortcomings of OFDM and are also used in future wireless communication systems.

4.1 Generalized Frequency Division Multiplexing

The Generalized Frequency Division Multiplexing is a generalised form of OFDM. This is basically a new idea for designing a multicarrier. It is best choice for cognitive radio as well as in future wireless communication because the choice of filters makes peak to average power ratio, bit error rate and out-of-band radiation extremely small. When compared with orthogonal frequency division multiplexing, GFDM provides lesser inter symbol interference to the adjacent frequency bands. GFDM, when first sensed reliably provides necessary protection to opportunistic users so that any other CR signal is not transmitted when a GFDM signal is present in the frequency band of operation [27]. However, rectangular pulse shaping that is used in OFDM produces extensive spectral leakage to the adjacent frequency bands but by using pulse shaping filters in GFDM, inter-carrier interference is reduced and performance of the system gets improved. GFDM is one of the most advanced multicarrier modulation schemes for the fifth generation wireless communication system as it gives supplementary characteristics. The cyclic prefix and pulse shaping helps in eliminating the inter carrier interferences and inter symbol interferences. It is also used in small burst applications. GFDM has $(MN)^2$ number of complex multiplications [28].

4.1.1 GFDM Transmitter

Initially, the binary data is modulated and mapped then divided into sequences of $K \times M$ complex valued data symbols using serial to parallel converter. Each such sequence $d[l]$, $l=0, 1,$

..., $KM - 1$, is spread across K subcarriers and M time slots for transmission. The data is represented by means of a block structure (Fig. 1) is defined in Eq. 1 as given in [28],

$$D = [d_0, d_1, \dots, d_{K-1}]^T \tag{1}$$

$$D = \begin{bmatrix} d_0[0] & \dots & d_0[M-1] \\ \vdots & \ddots & \vdots \\ d_{K-1}[0] & \dots & d_{K-1}[M-1] \end{bmatrix} \tag{2}$$

where $d_0[m]$ is the data symbol transmitted on the K th sub carriers and in the m th time slots. In the K th branch of the transmitter, the complex data symbols $d_K[m]$, $m=0, 1, \dots, M-1$ are sampled by factor N resulting in,

$$d_K^N[n] = \sum_{m=0}^{M-1} d_K[m] \delta[n - mN], \dots, n = 0, 1, \dots, MN - 1 \tag{3}$$

where $\delta[\cdot]$ is the Dirac Delta function. Consequently $d_K^N[mN] = d_K[m]$ and $d_K^N[n] = 0$ for $n \neq mN$. The pulse shaping filter $g[n]$ is applied on the data followed by digital subcarrier conversion. Hence, the resulting sub carrier signal $x[n]$ is represented as discussed in [28],

$$x_K[n] = (d_K^N \circledast g)[n] * w^{Kn} \tag{4}$$

where \circledast denotes the circular convolution and $w^{Kn} = e^{\frac{j2\pi Kn}{N}}$. The transmit data can be expressed in a block structure as follows,

$$X = [x_0, x_1, \dots, x_{K-1}]^T \tag{5}$$

$$X = \begin{bmatrix} x_0[0] & \dots & x_0[MN-1] \\ \vdots & \ddots & \vdots \\ x_{K-1}[0] & \dots & x_{K-1}[MN-1] \end{bmatrix} \tag{6}$$

The overall data is obtained by summing up all sub carrier signals according to

$$x[n] = \sum_{k=0}^{K-1} x_k[n] \tag{7}$$

This signal is then converted into analog by using digital to analog converter and sent over the additive white Gaussian noise channel.

4.1.2 GFDM Receiver

In Fig. 2, the GFDM Receiver, $y[n]$ which is obtained after transmitting the data $x[n]$ on additive white Gaussian noise $w[n]$ can expressed as [28],

$$y[n] = H \cdot x[n] + w[n] \tag{8}$$

This signal is again converted into digital signal by using analog to digital converter and then followed by serial to parallel conversion. Now, estimate the signal by applying frequency division estimation and get $\hat{y}[n]$. After digital down conversion and receiver matched filter, signal is expressed as,

$$\hat{y}_k[n] = y[n]w^{-kn} \quad (9)$$

$$d_k^N[n] = (\hat{y}_k \odot g)[n] \quad (10)$$

This signal is now down sampled and serialized by using parallel to serial converter to retrieve the original data. GFDM receiver can be of two types: Matched Filter Receiver and Zero Forcing Receiver.

(a) Matched Filter Receiver

In this type of receiver, the correlator receiver is used. Each correlator has a match with different subcarriers. Now multiply the received signal with circularly shifted versions of the pulse shape $p[n]$ and complex exponentials and addition is done over an interval of MK and then result is sampled. Correlation receiver is based on classical integrate-dump operation [49]. In this, multiply the equalized version of the received signal with A^H . In this case, d_{MF} can be represented as, where A represents matrix

$$\hat{d}_{MF} = A^H \cdot y_{eq}[n], \quad (11)$$

(b) Zero Forcing Receivers

This is simply multiplication of inverse of the matrix A and received signal which is expressed as [49],

$$d_{ZF} = A^{-1} \cdot y_{eq}[n]. \quad (12)$$

4.2 Universal Filtered Multicarrier

UFMC is one of the 5G waveform candidates which is also based on filtering method like filtered bank multicarrier. UFMC has great potential in wireless communication. In UFMC as shown in Fig. 3, the successive sub carriers make a group which is called sub band and filter is applied on each sub band. Total number of sub carriers in each sub band depends on the requirement of design while in FBMC, filter is applied on each sub carrier and in OFDM, filtering is done over entire frequency band. As the number of sub carriers increase in sub bands in UFMC, there is less load on base band processing but overall performance rate is reduced [29].

UFMC helps in reducing the effect of interference of side lobes with the adjacent sub channels. Hence, UFMC has higher quality of robustness and finer suitability for fragmented spectrum operation. FBMC and OFDM both need a long filter length, that's why they are not applicable for short burst communication but filter length in UFMC is shorter as compared to FBMC and OFDM, hence, it is used for short bursts communication. Thus UFMC is used to overcome the shortcomings of FBMC and OFDM and combine the advantages of orthogonality of OFDM and filter bank in FBMC. It provides support to 5G based segmented spectrum communication [50]. UFMC can achieve many possibilities like asynchronous transmission and reception, short latency, less complicated design etc. This is a non orthogonal waveform through which better spectral efficiency can be achieved. But

at the same time, we can easily tune the subcarriers spacing and also the number of tones depending upon the band range and bandwidth of application [30, 31]. UFMC decreases the ICI by applying filters on sub bands in place of cyclic pulses as it removes the need of synchronization. Figure 4 shows the UFMC Transceiver Architecture [32].

4.3 UFMC Transmitter

In UFMC, position of filter is after the Inverse Fast Fourier Transform (IFFT) and we can use different types of filters. UFMC is able to process small bursts without CP under time requirements. But UFMC is very sensitive for the applications where we require loose time synchronization. Different filters like Dolph-Chebyshev filter, hamming, hanning etc. can be used in UFMC instead of cyclic pulse to decrease the out of band radiation to improve the suitability of spectrum and as the length of filter is lesser than FBMC, hence it is a good choice for short burst communication. UFMC performs very well in vehicle to vehicle channel communication. With N total number of subcarriers in the system, which are further divided into B sub bands [33, 34]. In the UFMC’s transmitter side, the complex symbols generated from the baseband modulator are further mapped with Quadrature Amplitude Modulation (QAM). Then these complex symbols are altered to parallel stream by using serial to parallel converter and applied this as input to the respective IFFT. The output of N point IFFT is filtered and then serialized by doing parallel to serial conversion to convert its output into RF signal. Figure 5 below shows the transmitter section of UFMC [29].

At UFMC transmitter, transmitted signal from m th user can be expressed as given in [34]

$$S^{th}(n) = \sum_{i=1}^{N_B} S_i^m(n) \dots 0 \leq n \leq N + L - 1 \tag{13}$$

N_B is the total number of sub bands for m th user and $S_i^m(n)$ is the i th sub band signal which can be written as,

$$S_i^m(n) = \sum_{l=0}^{L-1} f_i(l)x_i^m(n-l) \dots 0 \leq n \leq N - 1 \tag{14}$$

where $f_i(l)$ is the l th filter or window coefficient corresponding to i th sub band as,

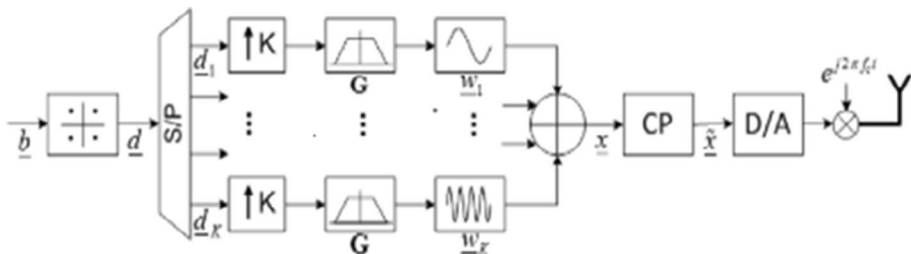


Fig. 1 Block diagram of GFDM Transmitter [28]

$$f_i(l) = f(l)e^{\frac{j2\pi lc_i}{N}} \dots 0 \leq l \leq L - 1 \tag{15}$$

where c_i is the centre sub carrier index of i th sub band and N is the size of IFFT. Moreover, $x_i^m(n)$ is the IFFT output which is,

$$x_i^m(n) = \frac{1}{N} \sum_{k \in B_i^m} X_i^m(k)e^{\frac{j2\pi kn}{N}} \dots 0 \leq n \leq N - 1 \tag{16}$$

B_i^m is the i th sub band allocation for m th user and X_i^m is the complex data symbol corresponding to i th sub band m th user. Hence transmitted signal on the AWGN channel is,

$$r_i(n) = \sum_{l=0}^{L-1} f_i(l)S_i^{m_i}(n - l) + w_i(n) \tag{17}$$

where $w_i(n) = \sum_{l=0}^{L-1} f_i(l)w(n - l)$ the additive is white Gaussian noise and w_i is the corresponding user which is allocated at the i th sub band B_i^m .

4.4 UFMC Receiver

In the receiver side of UFMC as shown in Fig. 6, RF signal is again converted into base band signal and passes through the time domain window to suppress inter channel interference. After windowing, the signal is converted into parallel signals by using serial to parallel converter and followed by 2 N-point FFT; here ‘N’ is the number of subcarriers. The demodulated signal is sent to the quadrature amplitude modulation (QAM) de mapper to retrieve the data bits from the received symbols. The basic idea of receiver is to involve the odd sub-carriers in the decoding of data. In UFMC, odd as well as even sub-carriers carry same signal power. The proposed receiver has higher complexity than conventional but due to this our system’s performance increases, so increased complexity and cost is acceptable [35].

5 PAPR reduction techniques for UFMC and GFDM

GFDM and UFMC both suffer from BER and high PAPR. There are some techniques like selective mapping, reduced clipping filtering, tone reservation, Iteration method etc. which are used to reduce the PAPR as well as BER values in GFDM and UFMC. The brief description of all the above methods is as follows:

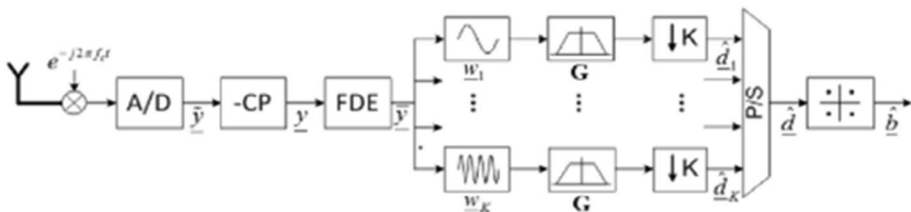


Fig. 2 Block diagram of GFDM Receiver [28]

5.1 Selective Mapping (SLM)

An original data contains a lot of independent data frames/blocks and all these frames represent the same information. After getting independent data frames, phase rotation is applied on each block and passed each of them from their respective IDFT. Then a block with very small value of PAPR is chosen for transmission [36, 37]. The phase rotation sequence is expressed as

$$\theta = \{\theta_m\}_{0 \leq m \leq K-1}, \text{ K is the number of sub carriers} \tag{18}$$

$$\text{Here } \theta_m = e^{j\varphi}, \varphi \in [0, 2\pi], \tag{19}$$

After phase rotation, mapping symbol $\{X_m\}$ becomes $\{X_m^R\}$ which is expressed as

$$X_m^R = X_m * \theta_m = X_m * e^{j\varphi} \tag{20}$$

The performance of the SLM technique depends on the selection of phase rotation factor θ_m which has a great impact on PAPR performance. Complexity and data rate loss are two drawbacks of this technique [38].

5.2 Reduced Clipping and filtering (RCF)

This is one of the easiest methods to reduce PAPR. In this, the input transmitted signal is clipped off and peaks of the signal are reduced. Thus, the transmitted signal after clipping is expressed mathematically as shown in [39],

$$y_c[n] = \begin{cases} -Ay[n] & \leq -A \\ y[n]|y[n]| < A \\ Ay[n] & \geq A \end{cases} \tag{21}$$

Here, A is the clipping factor. But in this method out of band radiation is produced. Hence, clipping reduced the PAPR value but at the cost of out of band radiation and higher BER. The out of band radiation can be decreased by using filtering after clipping but BER performance gets reduced. Repeated Clipping and Filtering is advanced form of clipping and filtering method and gives improved results which are used in UFMF to reduce PAPR. In fact, the peak regrowth generated in filtering can be reduced through RCF process, which minimizes this in a multicarrier system [39, 40].

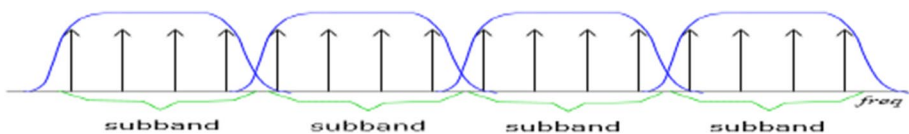


Fig. 3 Filtering on groups of sub carriers [29]

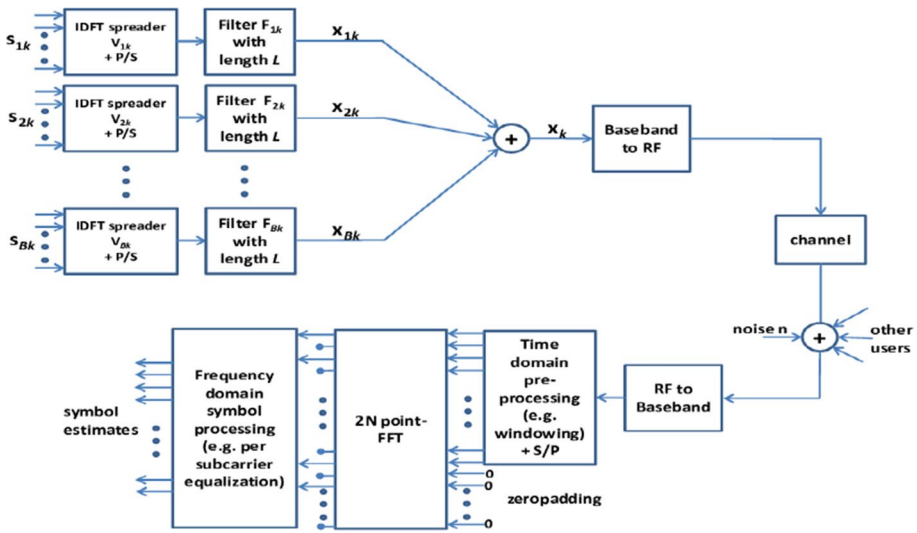


Fig. 4 UFMC Transceiver Architecture [32]

5.3 Tone Reservation

In this technique, some subcarriers are reserved for communication of peak reduced signals. These reserved subcarriers don't carry any data information and are used only for reducing PAPR. There is absence of distortion as well as absence of requirement of side information. It increases its average energy per bit and spectral efficiency is also reduced due to tone reservation. But it has a problem of increased power and loss of data rate [41].

5.4 Companding

In the companding process, expanding the small signals is followed by compressing the large signal to increase the immunity of small signals from noise is done. By enlarging the small signal, there is no effect on peak value, hence, average power is increased and peak to average ratio is reduced. This compression of signal is done after the output is taken from IFFT block at the transmitter side as this design method is simple and less complicated [42].

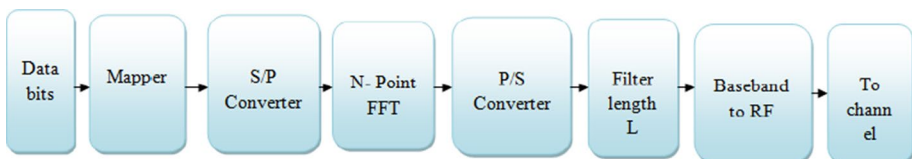


Fig. 5 Transmitter section of UFMC [29]

5.5 Random Filtering method

The highest peak power of radio over fibre may be greater than the linear range of optical components which leads to distortion. Hence, random filter mapping method is used to reduce peak to average power ratio mainly by decreasing the likelihood of the same phase multicarrier signal. Hence, in this technique, we can use radio over fibre with GFDM for wireless access with reduced PAPR. This method works on Opti Sim and MATLAB software and flowchart for RFM is as follows [43]. Figure 7 explains the entire flow process involved from filtering stage to the calculation of PAPR signal for the sake of transmission.

5.6 Polynomial-Based Compressing and Iterative Expanding

In this, PAPR reduction technique, a compression system is applied before cyclic prefix at the transmitter side and at the receiver, an iterative algorithm is used. This system provides a minor increase in signal to noise ratio to attain a BER in the expanding operation and result of expanding is integrated with FFT. For making this procedure applicable for GFDM, expanding procedure is generalized at the receiver end. Hence, it reduces PAPR with a satisfactory BER performance. It shows trade-off between PAPR and BER performance but complicated structure is the main drawback of this procedure [44].

5.7 Efficient Non Linear Comanding Transform

In this method, an efficient nonlinear companding transform is used at the transmitter side and an iterative reception operation at the receiver side for de-companding. The basic idea is to transform the statistics of input signals into Probability Density Function (PDF) which uses the time invariant half sine function. This function only changes the amplitude of the GFDM signal while phase and frequency of the signal remain constant. As the average power of the signal remains unchanged, so, power efficiency of the system is improved. An iterative reception at receiver eliminates the companding noise which is introduced during the non linear companding at the transmitter. Hence, this method shows the trade off between BER and PAPR [45].

5.8 Linear Precoding Technique

In this method, a linear precoder which is used to decrease the variance of instantaneous power is decreased so that value of PAPR for GFDM signals can be reduced but it

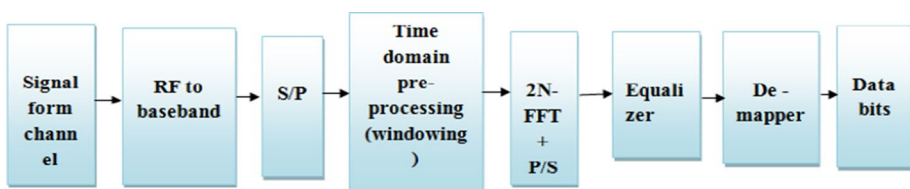


Fig. 6 Receiver section of UFMC [36]

maintains the average value of IP constant. Hence, this technique decreases the PAPR value of GFDM system without any changes in bit error rate as well as out of band radiation. In this method, gradient search algorithm is also used to lead to sub optimal solution due to non convexity of the cost function [46].

6 BER Reduction Techniques for GFDM

6.1 Iterative Receiver for Clipped Signal

Clipped method is mainly used to reduce the peak to average power ratio but with the use of iterative reception, BER of the GFDM signal is also reduced by affecting PAPR of the system. Hence, the signal after transmitting through AWGN channel at the receiver is as written [47];

$$y[n] = \alpha * x[n] + d[n] + w[n] \quad (22)$$

When the receiver knows the value of attenuation factor α and the nonlinear noise $d[n]$, then the nonlinear noise can be compensated by,

$$\hat{y}[n] = \frac{1}{\alpha}(y[n] - d[n]) = x[n] + w'[n] \quad (23)$$

The standard GFDM receiver is extended by the iterative detection operations which represents the design for the reconstruction of clipped GFDM signals. Hence, BER value depends on the roll off factor value α and the optimum value for roll off factor is 0.22 ($0 < \alpha < 1$).

6.2 Multiple Inputs and Multiple Outputs GFDM Method

Multiple-Inputs Multiple-Outputs Generalized Frequency Division Multiplexing is constructed by the combination of time-reverse space time coding and GFDM to revoke the depletion of error which is introduced because of different frequency-selective channels. It also reduces the self-interference effect and gives better results for BER performance in AWGN and frequency-selective channels. MIMO-GFDM shows better diversity gain than single input single output (SISO)-GFDM [48].

6.3 Gabor Transform Method

This is a frequency domain based Gabor transform method in which Discrete Gabor Transform (DGT), based on frequency domain reduces the process of recovery of the GFDM signal. By analyzing the interference caused by the frequency-domain DGT, the channel with high coherence and a small roll-off factor of the synthesis window can lead to small interference to the received signal. So, local DGT is used to reduce the complexity of system. It also reduces the bit error rate of the system. There is not any specific method to

reduce the BER in UPMC, but method like DFT spreading and wavelet filtering can be used to reduce BER as well as PAPR [51].

7 Simulink Models for UPMC and GFDM

Cognitive radio is based on Software defined radio (SDR) architecture which helps a radio to work on different frequency bands by reconfiguration the system according to the requirement. The CR is always familiar with its surroundings and changes its waveforms according to the needs. Hence, CR improves the utilization of spectrum in this way. The recent work has its focus on the performance of universal filtered multicarrier based cognitive radio and generalised frequency division multiplexing based cognitive radio under different filtering methods to reduce the peak to average power ratio and bit error rate. The main reason behind PAPR and BER is the summation of multiple sinusoids during transmission and with the increase in sinusoids, PAPR and BER also gets increased. Cognitive radio can work on many frequency bands at a time for many users. All these users are modulated by using different modulation techniques. All the modulated signals are added up and overall signal is created. With spectrum sensing, one can develop a practical approach to detect the primary user, after this demanded slot is given to the primary user. If a new user comes, then assign the empty slot, if any, to the secondary user. During this some peak power is introduced and signal to noise ratio produced reduces the efficiency of the system. So, there are separate methodologies which are adopted by GFDM and UPMC but one thing remains common i.e. both are working on various kinds of window techniques and methods are used to reduce peak to average power ratio as well as bit error rate.

7.1 Methodology Embraced by UPMC and GFDM

UPMC is the advance form of FBMC (without CP) and OFDM (with CP). It reduces the inter carrier interference by using filtering on sub band basis instead of cyclic pulse because of non-orthogonal sub-carriers even that it also suffers from PAPR and BER problem. To reduce the both parameters, we follow a flowchart which is shown in Fig. 8a, b and we also made a Simulink model for it to calculate PAPR as well as BER as shown in Fig. 9.

GFDM is based on block transmission in which each block is divided into sub-symbols and subcarriers in frequency and time domain, so as to allocate the resource partitions to the input signals. By using pulse shaping filter, each sub-carrier is pulse shaped. To protect from false users, there is a need to sense all the signals carefully, to avoid the transmission of other cognitive radio signal when a GFDM signal is already there in the frequency band under consideration. By using pulse shaping filter, each sub-carrier is pulse shaped accordingly.

7.1.1 Rectangular QAM Mapper

Quadrature Amplitude Modulation employs both amplitude and phase components to provide high efficiency in spectrum usage because QAM contains larger distance between adjacent points in the I-Q plane and this adjustment improves the noise immunity [49]. It is able to provide a highly effective form of modulation for data and as such it is used in everything from cellular phones to Wi-Fi and almost every other form of

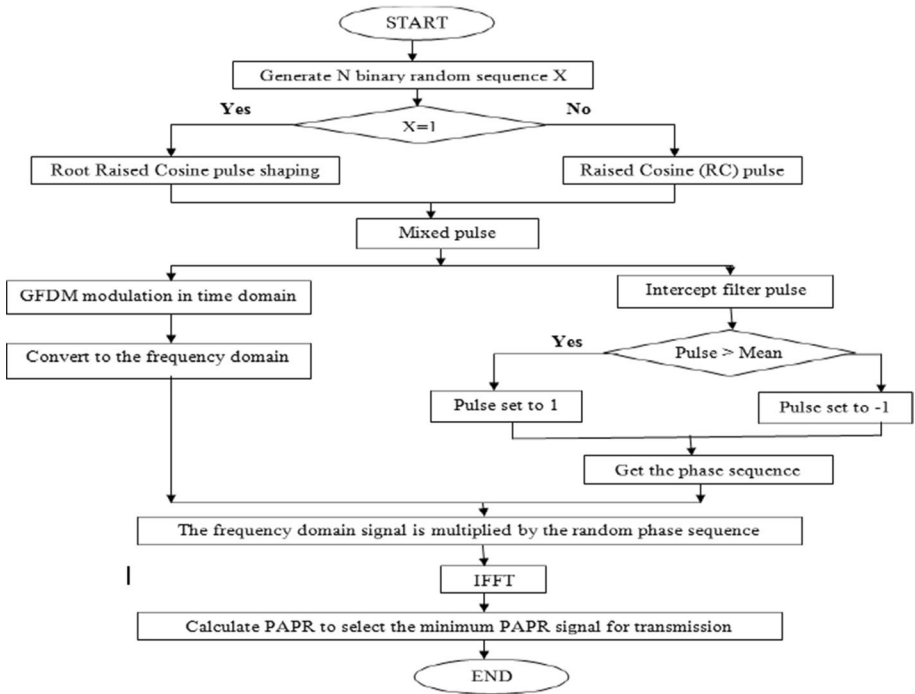


Fig. 7 Flowchart for Reduced Filtering Method [43]

high speed data communications system. QAM when used for digital transmission for radio communications applications is able to carry higher data rates. The Rectangular QAM Modulator Baseband block modulates using M-ary QAM with a constellation on a rectangular lattice. The output is a baseband representation of the modulated signal. This block accepts a scalar or column vector input signal [49].

7.1.2 IFFT block

The Fourier transform and its inverse converts between data sampled in time and space and data sampled in frequency. The IFFT function allows control on the size of transform. In short, the signal is easily synthesized in discrete frequency domain in the transmitter and to transmit it must be converted to discrete time domain by IFFT. The full band of subcarriers is divided into sub-bands. Each sub band has a fixed number of subcarriers and not all sub-bands need to be employed for a given transmission. An N -pt IFFT for each sub band is computed and zeros are inserted for the unallocated carriers [49].

7.1.3 Window Function

This block is used to apply the filters on a group of sub carriers. In this block, we use different windows like Dolph-chebyshev, Kaiser, Hamming and Hanning. Each and every window gives different results for PAPR and BER. Each subband is filtered by a

filter of length L and the responses from the different sub-bands are summed. Then filtering is done to reduce the out-of-band spectral emissions [49].

7.1.4 AWGN channel

This is a basic noise model which is used to introduce the effect of noise on the transmitted signal. This channel is able to add any type of noise into the input data. It also has uniform power across the frequency band for the system and works in time domain with an average time domain value of zero [29, 49].

7.1.5 FFT Block

Fourier analysis converts a signal from its original domain (time or space) to the frequency domain and vice versa. The FFT block computes the Fast Fourier transform across the first dimension of an N -D input array. This transform is a divide and conquer algorithm that computes either Discrete Fourier transform of a sequence or its inverse (IDFT). FFT divides the signal into two smaller signals, apply Fourier transform and join them to get the signal with larger size [49].

7.1.6 Equalizer

Equalization is an opposite process of distortion which suffers by a signal transmitted through a channel. This device is used to harden or weaken the energy of specific frequency bands. There are many types of equalizer which can be used in communication which are: Micro, Small and Medium Enterprises (MSME) equalizer, Linear equalizer, Zero forcing Equalizer, Decision feedback equalizer, Blind Equalizer, Adaptive Equalizer, Viterbi Equalizer, Turbo Equalizer [49]. We have used Decision feedback equalizer because it reduces the distortion on present signal which was introduced due to previous signals. Table 1 and Fig. 10 shows the data and graph between samples and BER for GFDM at different number of bits and different number of errors. If samples per frames increase then after certain limit, system gives high BER value because number of errors also increase. Blue color denotes the total number of bits transmitted whereas red color denotes the number of erroneous bits.

8 Methodology of GFDM Simulink Model

GFDM is a non-orthogonal multicarrier scheme which assures the flexibility to pick a pulse shape to reduce the out-of-band leakage effect in cognitive radio signals at the price of reduction in orthogonal sub carriers. To avoid this issue, we use serial interference cancellation technique to improve the bit error rate value [52, 53]. GFDM for the physical layer cognitive radio is an apt choice. For better spectrum sensing with a GFDM cognitive radio receiver, its entire process is based on the block transmission (Figs. 11, 12).

8.1 Up and Down Sampling

Up sampling is used to increase the number of points in a digital signal to match the sampling rate with some other signal and down sampling is usually used to conserve memory and signal processing time in case of oversampling. Signals are up sampled when signals continue to move through synthesis filter bank while down sampled as they pass through a series of analysis filter bank. The original signal can be recovered if the filters are chosen properly. In the up sampling process, there is no loss of information while in down sampling information may be lost because of lack of accuracy yet more important. Up sampling is also called interpolation which is used to improve the filter performance and reduces noise while down sampling also called decimation helps in reducing data size.

8.2 Digital Up and Down Conversion

Digital up converter is used to convert digital baseband samples into digital IF samples. Digital to analog converter is used after this block in order to convert digital IF samples into analog IF signal. RF up converter follows D/A converter which converts IF signal to RF signal for transmission. In our system, we use RF Digital Up Converter (DUC). The Digital Up Converter consists of following modules namely Interpolation filter, Digital Mixer, Digital Local Oscillator. Interpolation filter is used to increase the sampling frequency of baseband signal by factor of N which is known as interpolation factor (Fig. 13).

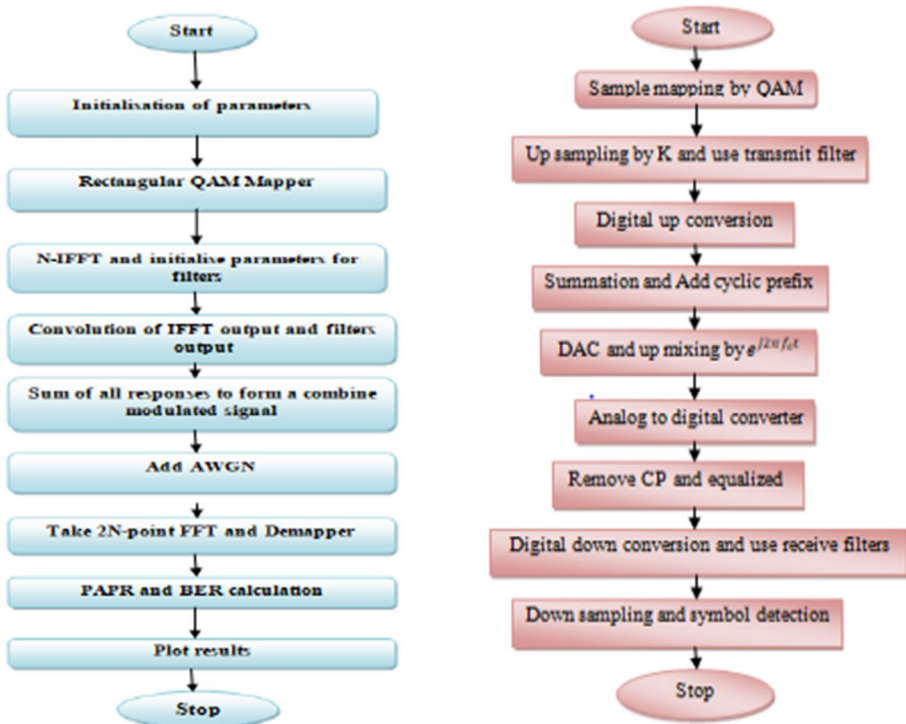


Fig. 8 a Flowchart for UFMC, b Flowchart for GFDM

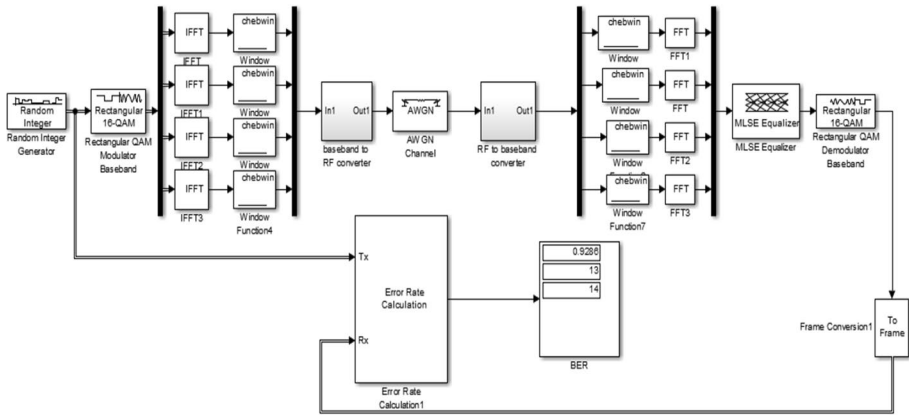


Fig. 9 Simulink model for UPMC

While Digital down converter is used to convert digital IF samples into digital baseband samples. The Digital Down Converter consists of following modules, namely Digital Mixer, Digital Local Oscillator, Low Pass Filter. In decimation process, one sample is kept out of every N digital samples. If the decimated output sample rate is more than twice the output bandwidth then no information will get lost. Digital Down Converter (DDC) performs frequency translation with the help of variable Local Oscillator (LO) device and Low Pass filtering with bandwidth controlled by the decimation process (Fig. 14).

8.3 Add and Remove cyclic prefix

In cyclic prefix guard interval is introduced between groups of symbols to decrease the inter-symbol interference which is produced due to delay spread in the transmission channel. CP achieved by taking a copy of the last portion of the data symbol is appended to the front of the symbol during the guard interval. There is repetition of CP in signal rather than adding any new information. Addition of CP doesn't introduce any distortion in the signal in the presence of multipath and this allows the receiver to avoid the frequency domain. At the receiver side, extra symbols are removed to attain the original signal [49].

8.4 AWGN channel and Equalizer

Additive White Gaussian Noise channel is used to introduce the noise into the transmitted signal so that we can calculate the BER & PAPR and Equalizer is used to reverse the distortion incurred by a signal transmitted through a channel in the GFDM system. In this section, we have explained the working of GFDM and UPMC with the help of flowchart. We also explained how the simulink models for GFDM and UPMC schemes have an impact of each and every block on the input information in the system [49, 53].

9 BER results for UPMC Simulink Model

In this section, we show the results for bit error rate on the basis of our conclusions for universal filtered multicarrier and generalized frequency division multiplexing simulink models. We have found the results for PAPR and BER with the help of MATLABR2015a version. Table 2 and Fig. 15 show BER values in UPMC for different type of window techniques. Hence, Hanning windowing (purple color) reduces the errors which were introduced in the signal during the transmission process.

9.1 BER Results for GFDM Simulink Model

Figures 16 and 17 show the relation between the number of sub carriers and bit error rate at different cyclic prefix lengths and relation between signal to noise ratio and bit error rate respectively for different modulation schemes and different windowing techniques. Table 3 represents our results which we calculated with the help of Matlab and Simulink model. From figure, it is clear that raised cosine filter gives better result with decreasing trend in BER. In Fig. 16, higher PAPR values are noted for 60 subcarriers in case of QAM with Cyclic Prefix32. In Fig. 17, the BER values are lower for raised cosine window function with attained $E_b/N_0 = 13$ dB.

9.2 Comparison for PAPR in Between GFDM and UPMC

Figure 18 represents the comparison for peak to average power ratio between UPMC and GFDM. According to it, PAPR value for GFDM is very large in comparison to PAPR value for UPMC and among these values hanning window (yellow) is showing the best results because value of PAPR is very small for hamming in UPMC. Hence, UPMC with hanning window can be used to reduce the value of peak to average power ratio in next generation wireless communication under cognitive radio because higher PAPR is the main drawback for orthogonal frequency division multiplexing, that's why OFDM is not able to work better with future wireless technology, hence, we recommend the use of UPMC technique instead of GFDM.

Table 1 Bit error rate in UPMC by simulink model

Total no. of bits sent	No. of errors	BER
22	21	0.9545
21	20	0.9524
20	19	0.95
18	15	0.8333
17	15	0.8824
16	15	0.9375
15	14	0.9333
14	13	0.9286
13	12	0.9231

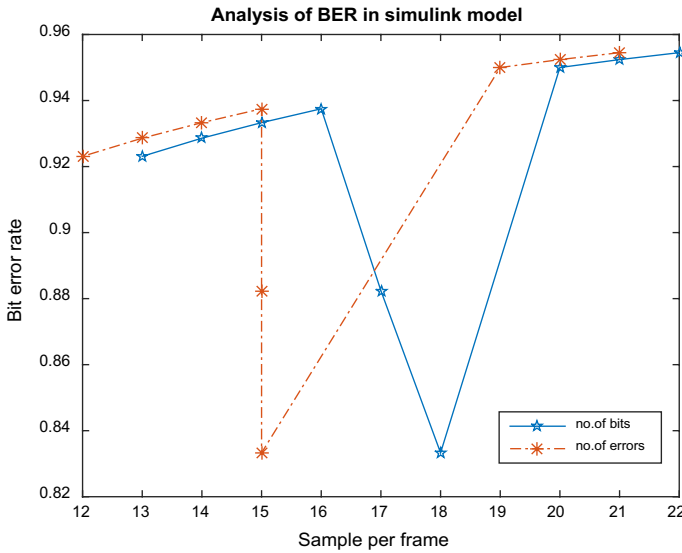


Fig. 10 Performance analysis for BER by UFMC Simulink model

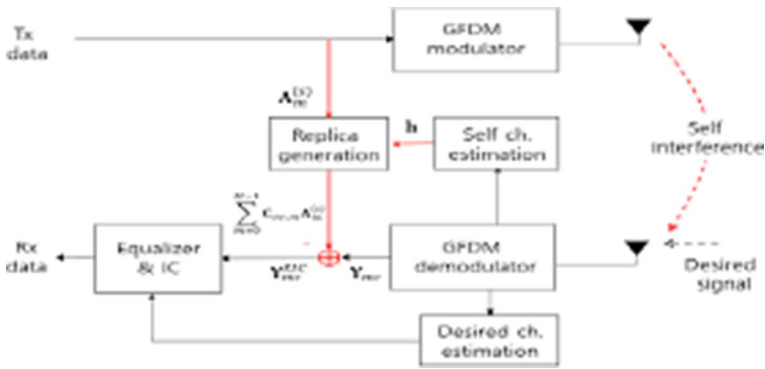


Fig. 11 Self Cancellation in GFDM [52]

9.3 Comparison for BER in Between GFDM and UFMC

Figure 19 shows the comparison between UFMC and GFDM for bit error rate parameter in form of power spectral density estimation because power spectral density function shows the strength of the energy as a function of frequency. Hence, it shows at which frequencies variations are strong and at which frequencies variations are weak. Therefore, we can obtain energy within a specific frequency range by integrating PSD within that frequency range. The Computation of PSD is done directly by FFT or computing autocorrelation function and then transforming it. Thus, fluctuations shows the level of noise in signal and UFMC gives better results for BER reduction. Figure 20 shows

Table 2 BER values for different windowing techniques in UFMC

Filter length	BER (Dolph-chebyshev)	BER (Kaiser)	BER (hamming)	BER (hanning)
43	0	0.01375	0	0
63	0.01375	0.07625	0.0075	0.00625
73	0.03	0.07875	0.0225	0.01375
80	0.06125	0.085	0.04125	0.02875
83	0.065	0.06375	0.04375	0.025
90	0.10375	0.06125	0.07125	0.05125
100	0.13875	0.09125	0.10375	0.08875

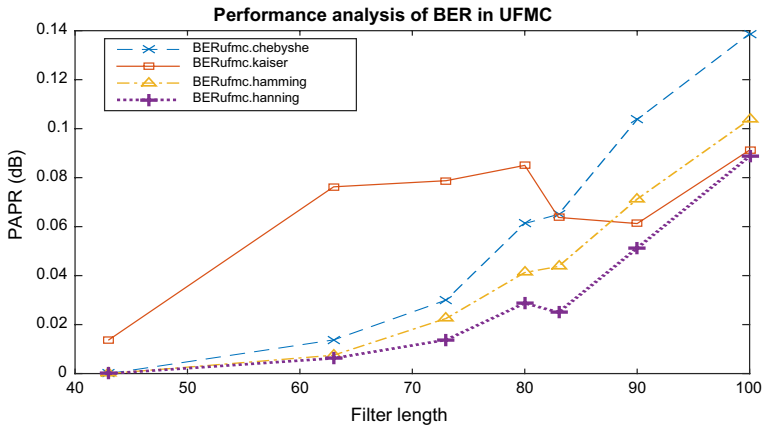


Fig. 15 Comparison of BER among Dolph-chebyshev, Kaiser, Hamming and Hanning windows

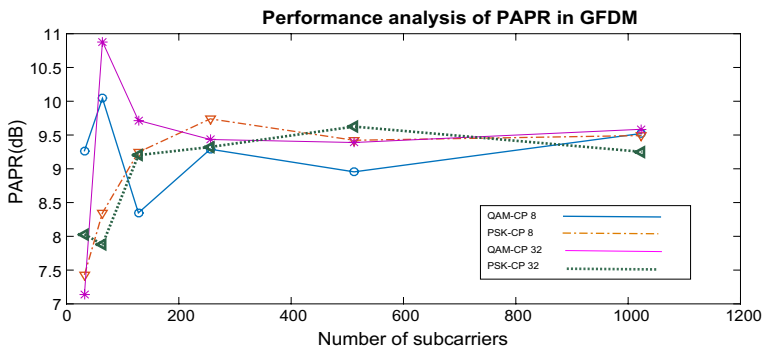


Fig. 16 Plot between number of sub carriers and PAPR for GFDM

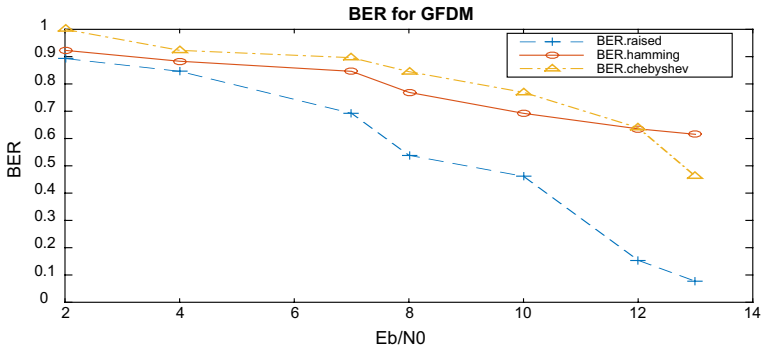


Fig. 17 Plot between Eb/No (dB) versus BER for GFDM for different windowing techniques

Table 3 BER for different filters or windowing techniques

Eb/N0	No. of errors	BER (Raisedcosine)	No. of errors	BER (Hamming)	No. of errors	BER (Dolphchebyshev)
2	12	0.8931	12	0.9231	13	1
4	10	0.8462	11	0.8832	12	0.9231
7	9	0.6923	11	0.8462	11	0.8962
8	7	0.5385	10	0.7692	9	0.8451
10	6	0.4615	9	0.6923	8	0.7692
12	2	0.1538	8	0.6355	3	0.6395
13	1	0.07692	5	0.6154	2	0.4615

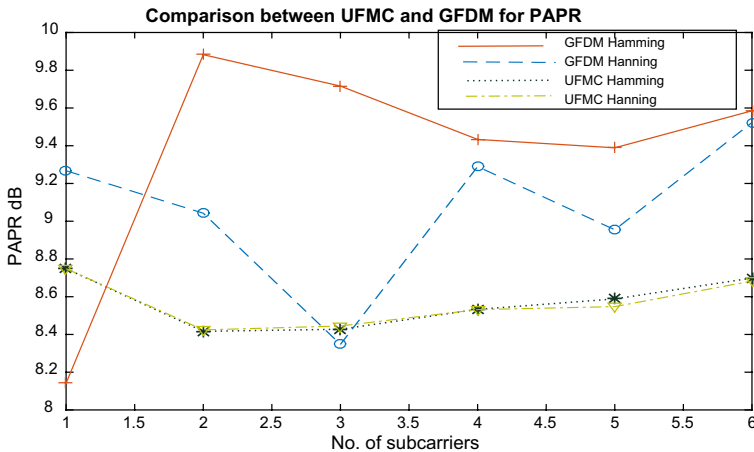


Fig. 18 Comparison in UFMC and GFDM for PAPR

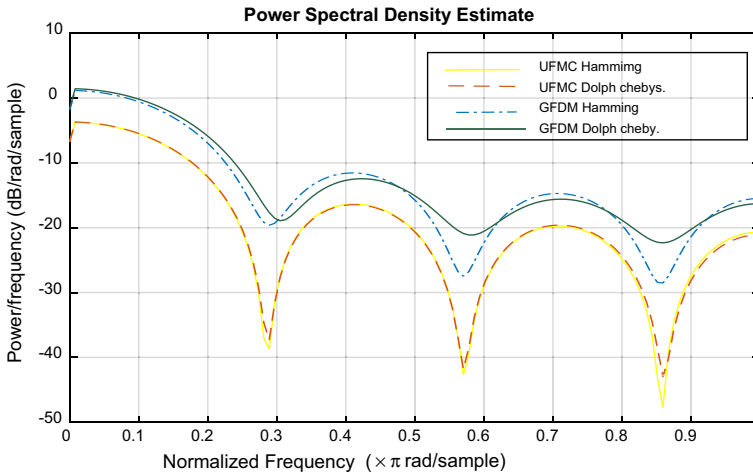


Fig. 19 Comparison in UFMC and GFDM for BER in the form of PSD

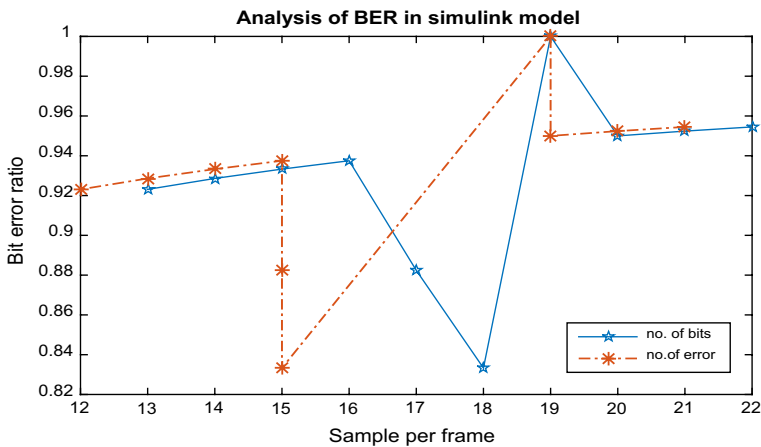


Fig. 20 Comparison between UFMC and GFDM for BER

10 Conclusion

We have discussed about the journey of changes in wireless technology from first generation analog based system to fifth generation universal filtered multicarrier and generalized frequency division multiplexing based system. We also studied how different windowing techniques like Kaiser, Hamming and Hanning in modulation affect the performance of the system by varying parameters of the system. Also, value of PAPR and BER changes with the change in windowing techniques. UFMC and GFDM are used as a waveform for secondary system which opportunistically use spectrum holes in primary LTE system. Both UFMC and GFDM have a much lower adjacent channel

leakage ratio, even when it operates without time or frequency synchronization to the primary system. According to our conclusion, UFMC with Hanning Window improve the spectrum sensing ability of cognitive radio by reducing PAPR and BER values so that it can become favourable choice for 5G communication. We also do comparative analysis between UFMC and GFDM schemes in terms of robustness against multipath channels, power spectral density and spectral efficiency and show the simulation results under cognitive radio through MATLAB and Simulink models. Our study also proposed that Hamming windowing is more effective in improving the PAPR and BER of the system than Dolph- chebyshev, Kaiser and Hamming Window.

11 Impact of Study and Future Scope of Work

In the earlier work done, both GFDM and UFMC have been implemented and parameterized to fit the sampling and framing of the LTE standard. LTE algorithm and physical/MAC layer development, aids reference verification and testing which will enable the generation of test waveforms. One can make and reuse the test bench for verifying the design prototypes and all other implementations complying with LTE standards. The work can be extended to standard compliant propagation channel models. Different interactive tools can be used for BER testing. Even with the application feasibility of these multicarrier modulation techniques, one can work towards the recovery of low level parameters such as cell identity [54–56]. The work presented in this paper will be helpful in preparing the roadmap for newer and innovative 5G technology models and verticals for providing better services to the next generation wireless communication driven society.

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