GFDM and UFMC Modulation Techniques under dispersive wireless channels for Cognitive Radio-A Technical Review

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Abstract

Day by day wireless users are increasing. So to increase the efficiency of system, we rely on Cognitive radio. It detects unused channel and sends the data through that channel. Here multicarrier modulation techniques like Generalised Frequency Division Multiplexing and Universal Filtered Multicarrier play an important role as these techniques are non-orthogonal multicarrier schemes used for sending information with low latency and higher efficiency. In this paper,a technical review on both GFDM and UFMC candidate waveforms for 5G has been given under wireless dispersive channels for cognitive radio. These use digital multicarrier transceiver concept which employs filters for pulse shaping so as to maintain control over transmitted signal's spectral properties. The advanced LTE system provides standard compliant functions for design, simulation and verification of advanced communication systems. Cognitive radio is the intelligence that guides Software defined radio to choose the mode of operation and vital parameters mainly frequency, modulation, bandwidth and power. The main aim of opportunistic cognitive radio is the modification of said parameters depending upon the radio frequency environment, user situation and demands of network etc [1].

Keywords: GFDM, UFMC, Cognitive radio,Multicarrier.

1.Introduction

The adaptive cognitive radio is used in wireless communication for detecting which channel is used for communication between transmitter and receiver so that interference and congestion can be avoided. For this, it uses SDR (Software defined radio) architecture. When the spectrum is under utilized by the authorized primary user, then cognitive radio senses and allocates the available bandwidth to the secondary user with least interference to the primary user. Cognitive radio mainly used three spectrum sensing methods namely matched filter detection, energy detection and cyclostationary feature detection [2] [3].GFDM being the latest multicarrier technique used in 5G mobile communication is based on individual frames and each frame contains sub-carriers and sub-bands. Cyclic pulse is used to avoid inter symbol interference after every frame. Adding of cyclic prefix after every frame is the point of difference between OFDM and GFDM [4-5].UFMC, a generalized filtered form of FBMC and OFDM. This is very energy efficient scheme for wireless communication. In this bandwidth is also divided in sub bands where each sub band is further divided into sub carriers. So its spectral efficiency is far better than OFDM [6].The cognitive radio based wireless network has a promising future with the applicability of GFDM/OQAM,UFMC/OQAM and C-OQAM multicarrier modulation techniques when compared to conventional OFDM and FBMC techniques[7].

2.GFDM Multicarrier

This 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 subcarriers . To avoid this issue we use serial interference cancellation technology. By this technique bit error rate also improves [8].

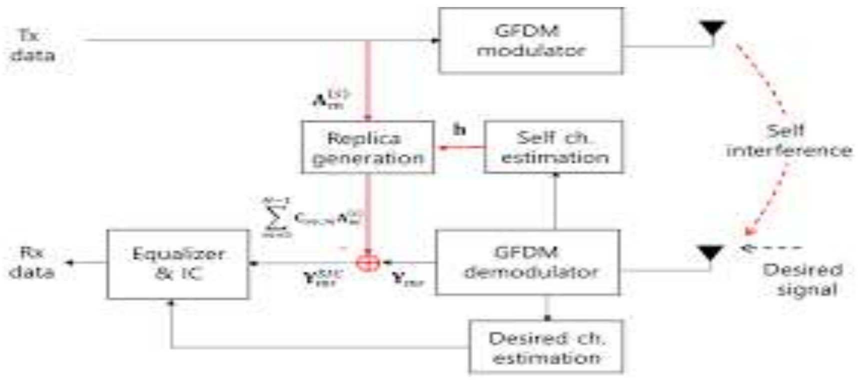

Figure 1 .Self-signal cancellation[2]

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 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[6]. One can choose GFDM over OFDM when the choice is to be done on the basis of cognitive radio physical modulation scheme [8] [9].

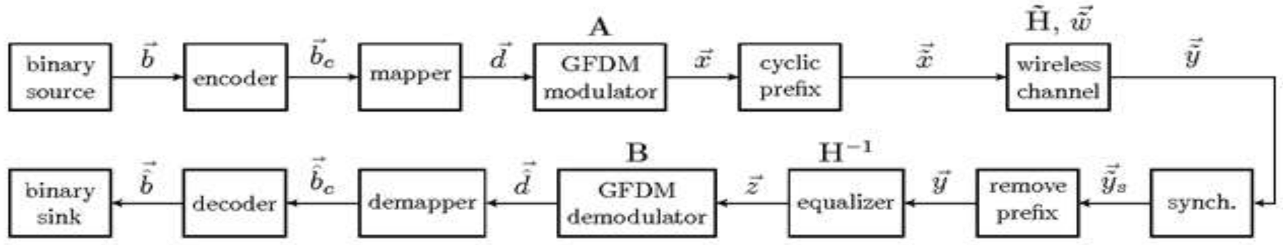

Figure 2 . Block diagram of transceiver [2]

Initially, the modulation of binary data is done and it is divided into sequences of K × M complex valued data symbols. Total number of sequence is N=KM. Each sequence d[l], l=0 ,1,⋯,KM−1, is spread across K subcarriers and M time slots for transmission. The data is shown by means of block structure described in equation as below.

$$D = [d0, d1, \ldots\ldots\ldots dK - 1]^T \qquad [9]$$

$$D = \begin{bmatrix} d0[0] & \cdots & d0[M-1] \\ \vdots & \ddots & \vdots \\ dK-1[0] & \cdots & dK-1[M-1] \end{bmatrix}$$

where dk[m] ∈ C is the data symbol transmission on kth subcarrier and in m[th] time slot. Up-sampling is done on data by factor N,

$$d_k^N[n] = \sum_{m=M}^{M-1} d_k[m]\partial[n = mM] \qquad m= 0, 1, 2 ,\ldots\ldots M\text{-}1[9]$$

Here $\partial[.]$ is a dirac delta function.

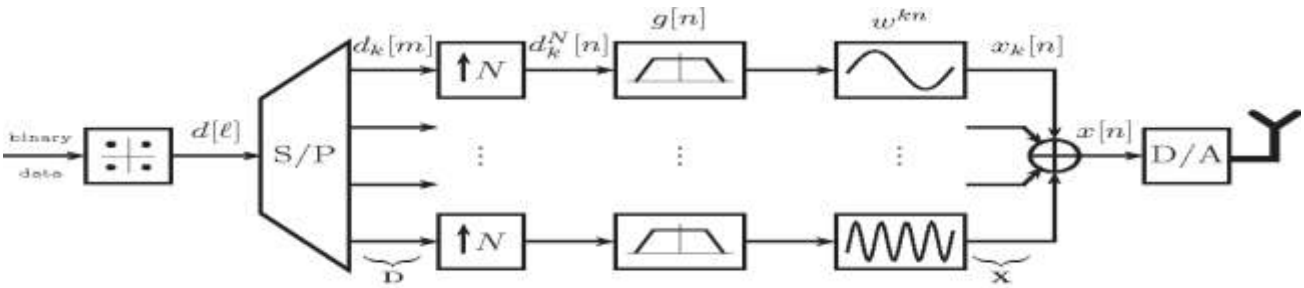

Figure 3. GFDM transmitter system model [9]

To avoid the unnecessary aliasing, use pulse shape filter g[n].The final subcarrier transmit signal is captured mathematically by the equation written as

$$x_k[n] = [d_k^N \circledcirc g]\,[n]\,.w^{kn} \quad [9]$$

where © represents circular convolution and $w^{kn} = e^{-\frac{j2\pi}{N}kn}$. Now sum all the sub-carriers and convert this digit data into analog by using digital to analog converter. After converting pass this information on wireless channel.

$$x[n] = \sum_{k=0}^{K-1} x_k[n] \quad [9]$$

Table.1 Parameters for GFDM [4]

Parameter	Values
No. of time slots	9
No. of sub carriers	64
Total no. of symbols	576
SNR	0-18db
Modulation	4-QAM
CP length	10 symbols
Channel	Frequency selective Rayleigh fading

3.Universal Filtered Multicarrier

UFMC is the advance form of FBMC(without CP) and OFDM(with CP) because it uses the positive points of Filter Bank Multicarrier and removes their drawbacks which make this technique better than other two[10]. In UFMC,a group of sub carriers are filtered as compared to FBMC, where the filtering is done on each sub-carrier and in OFDM, filtering is done over entire frequency band. It reduces the inter carrier interference by using filtering on sub band basis instead of cyclic pulse because of non-orthogonal sub-carriers. So, there is no need of synchronization.Hence, it is known as universal filtered OFDM. So it has greater potential than other schemes. UFMC is complex similar to OFDM and using same processing but unlike OFDM, position of filters is after the IFFT. UFMC effectively transmit small bursts without CP under very tight response time requirements. But UFMC is very sensitive for the applications where we required loose time synchronization [11].Dolph-Chebyshev filter is used in UFMC instead of cyclic pulse to decrease the spectral side-lobes outside the sub-band to improve the suitability for fragmented spectrum. In this length of filter is smaller than FBMC, hence it is applicable for short burst communication. UFMC performs very well in vehicle-to-vehicle (V2V) channels communication. With N total number of subcarriers in the system, which are further divided into B sub-bands,N_i is the consecutive subcarriers in each sub-band. Thus ,

$$N = \sum_{i=0}^{B} N_i$$

The time domain signal for the i-th sub-band is,

$$s_i = \frac{1}{\sqrt{N}} \sum_{k \in O} S_i \, e^{-\frac{j2\pi kl}{N}} \qquad l=0, 1, \ldots\ldots N-1[12]$$

where O represents the set of subcarrier indices. Filtering is done on each sub-band in UFMC. The signal transmitted is shown as,

$$x(l) = \sum_{i=1}^{B} s_i(l) * f_{i(l)} \qquad l=0, 1, \ldots\ldots\ldots N+L-2 \ [12]$$

The linear convolution is denoted by * .

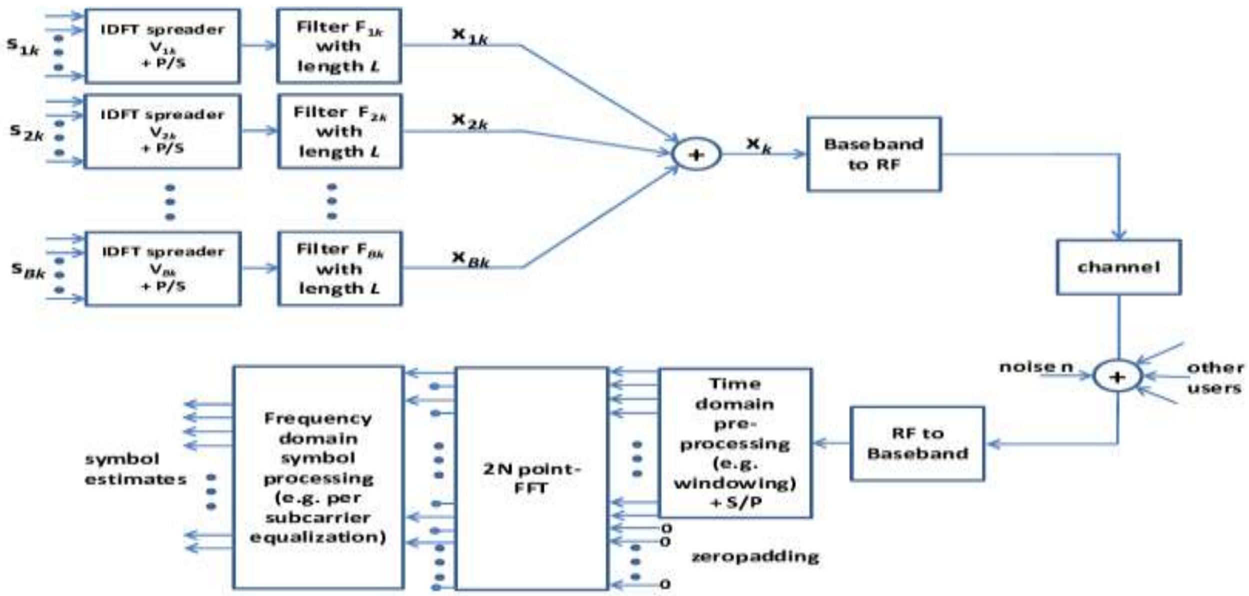

Figure 4. Block diagram of UFMC transceiver [13]

3.1 UFMC Receiver Design

In UFMC two types of receiver are used: conventional receiver and proposed receiver. In conventional receiver zero padding is performed on the output of the serial to parallel conversion device. After this 2N- fast fourier transform is applied on signal to convert it into frequency domain signal. This method is quite simple to improve power efficiency. Hence, one can use a proposed receiver to improve the efficiency [14] . The basic idea is to involve the odd sub-carriers in the decoding of source code/data. In UFMC odd as well as even sub-carriers carry same signal power. Proposed receiver has higher complexity than conventional but due to this our system's performance increases, so increased complexity and cost is acceptable.

Table.2 UFMC Receiver Design Parameters[14]

Parameter	Values
Filter	Dolph-Chebyshev filter
Filter length	43, 63, 83
Modulation	QAM
FFT size	256, 512, 1024
Bits per carrier	2, 4, 6
Sub band size	20
Number of sub bands	10

4.Literature Review

Kamran Arshad [1] discussed about the major challenge in cognitive radio is the detection of the presence of primary users in order to reduce any interference to licensed communication. So, better spectrum sensing,spectrum sharing,spectrum management and spectrum mobility are the important aspects of a cognitive radio. Rohit Dutta and Nicola Michaliow [2] emphasized that GFDM seems suitable in a fragmented spectrum for different applications, as one has a choice of using a pulse shape which allows decrease in the out-of-band leakage of cognitive radio signals in the incumbent frequency space. They explained how self-interference can be minimized by double-sided serial interference cancellation which shows that such cancellation techniques may improve the bit error rate in GFDM. Ning Xiyaon [4] proposed the GFDM to meet the requirements of bandwidth for next generation broadband mobile communication. GFDM system was analysed mainly adaptive to the different channel, adaptive spectrum and adaptive shaping filter. R.Datta and Gerhard Fettweis [6] considered the spectrum sensing issue by detecting opportunistic users in GFDM. Beside the fact, that there is no incumbent transmission, the secondary user first senses the channel to ensure that no other user is using the same channel. W.Hong, Z,Zhayong et al.[7] proposed a UFMC scheme, known as UFMC-AIC, which uses active interference cancellation in UFMC to counter the inter-sub-band interference. The simulation results show that lesser cost of filter can achieve better bit error rate as compared to basic UFMC with different carrier frequency offsets for Rayleigh fading channel. R.Datta and Zollt Kohler et al.[8] suggested serial inter-carrier interference cancellation technique to improve the GFDM system performance. Gerherd Fettweis[9] discussed that GFDM provides lower PAPR in comparison to OFDM ultra-low out-of band radiation, due to adjustable Tx-filtering and block-based transmission with cyclic prefix insertion and efficient FFT-based equalization. Lei Zhang[12] proposed that UFMC is not an orthogonal system in multipath channel environment and could cause performance loss. The authors analyzed the conditions for interference-free one-tap equalization when transceiver imperfections are absent. The authors established an analytical system model as a summation of desired signal, intersymbol interference, intercarrier interference, and noise. R.J.Atif [13] suggested that in addition to acceptable spectral performance, investigation on computational complexity reduction can help in the selection of suitable waveforms for 5G. In this context, in UFMC waveform construction, few reduced complexity solutions for UFMC transmitter implementation have been suggested. W.Mengting [14] proposed an advanced receiver for UFMC as for the conventional receiver in UFMC, the even subcarriers are used to decode the source data while odd subcarriers are considered containing interferences and discarded. It has been shown that as odd subcarriers contain useful information of the transmitted signal.So,a novel receiver using minimum mean square error criteria has been proposed to exploit the overall subcarriers to get enhanced performance gain. G.Wunder et al.[15] challenged the paradigm of orthogonality and synchronism when applied to LTE system for efficiency and scalability in the physical layer technology. F.Schaich[16] compared the candidate multicarrier waveforms for air interface of 5G and judged their time-frequency efficiency when transmitting very small bursts and under very tight response time requirements for vehicle to vehicle communications.Although FBMC is very efficient while transmitting long sequences, it suffers when having to transmit short bursts or frames. T.Wild [17] discussed that a new alternative required is Universal-Filtered OFDM known as Universal Filtered Multi-Carrier (UFMC), is a recent technology close to OFDM. Xiao Chen[18] proposed the adaptive filter configuration algorithm can dramatically eliminate the interference caused by different Carrier Frequency Offsets, and achieve a higher rate than the conventional scheme. M.Bellanger [19] provided an overview of the work carried out in the European research project EC-FP7-Phydyas (physical layer for dynamic access and cognitive radio).Lu Zhang[20] showed that, the UFMC-based datacenter interconnect can achieve great system overhead reduction and support different subband width division rules, which can be well suitable for the agile optical transmission of datacenter interconnect. X.Wang [21] compared UFMC based on filters with two optimization approaches against UFMC with Dolph-Chebyshev filters and against OFDM in a setting with non-perfect frequency alignment. The performance gains of the optimized filters are demonstrated in link level simulations.Almost 10 dB and 7 dB SIR improvement can be achieved by using the first and second criterion, respectively. Suiyan Geng [22] analyzed the performance of UFMC system. UFMC signals are generated with Dolph-Chebyshev, Hamming and Hanning filtering. Experimental results show that UFMC signals have better performance than OFDM signal, by means of side-lobe attenuation, bit-error-ratio (BER) and Error Vector Magnitude (EVM). The results can provide useful information on the design of multi-carrier radio systems. The work has its impact on Performance Enhancement of GFDM and UFMC based cognitive radio under different wireless dispersive channels in a ubiquitous and pervasive environment [23-27].

5.Comparison between GFDM and UFMC

UFMC with OFDM highlights the merits of the candidate modulation scheme for Fifth Generation communication systems. UFMC was considered as an alternate waveform to OFDM in the 3GPP RAN study phase I during 3GPP Release14.OFDM,has been widely adopted by 4G communication systems, such as LTE and Wi-Fi. It has many advantages like robustness to channel delays, single-tap frequency domain equalization, and efficient implementation.. New modulation techniques are, thus, being considered for 5G communication systems to overcome the spectral efficiency loss due to higher sidelobes and the strict synchronization requirements. For comparison sake,an example has been taken which highlights UFMC technique. E.g. A LTE system at 20 MHz channel bandwidth uses 100 resource blocks of 12 subcarriers each, at an individual subcarrier spacing of 15 kHz. This utilizes only 18 MHz of the allocated spectrum, leading to a 10 percent loss. Additionally, the cyclic prefix of 144 or 160 samples per OFDM symbol leads to another ~7 percent efficiency loss, for an overall 17 percent loss in spectral efficiency. Now, with newly defined ITU requirements for 5G applications require higher data rates, lower latency and more efficient spectrum usage. This proven fact through this example compares Universal Filtered Multi-Carrier with OFDM within a generic framework[28-29].

5.1 System Parameters for UFMC Modulation

The following system parameters can be modified to explore their impact on the system[28][29].

Table.3 System Parameters for UFMC Modulation

Parameter	Value
No of FFT Points	512,1024
Sub band size(Must be >1)	20,40
No of Subbands(numSubbands*subbandSize <= numFFT)	10
Subband Offset	156
window design parameters	Dolph-Chebyshev
Dolph-Chebyshev filter Length	63 (similar to cyclic prefix length)
sidelobe attenuation, dB	40
% bitsPerSubCarrier	4, for 2:4QAM,4 : 16QAM, 6: 64QAM, 8: 256QAM
SNR (dB)	15

UFMC can still use QAM as it retains the complex orthogonality which works with existing MIMO schemes. Each subband has a fixed number of subcarriers and not all subbands need to be employed for a given transmission. An *N*-pt

IFFT for each subband is computed, inserting zeros for the unallocated carriers. Each subband is filtered by a filter of length *L*, and the responses from the different subbands are summed. Different filters per subband can be applied, however, in this example, the same filter is used for each subband. A Chebyshev window with parameterized sidelobe attenuation is employed to filter the IFFT output per subband [28][29].

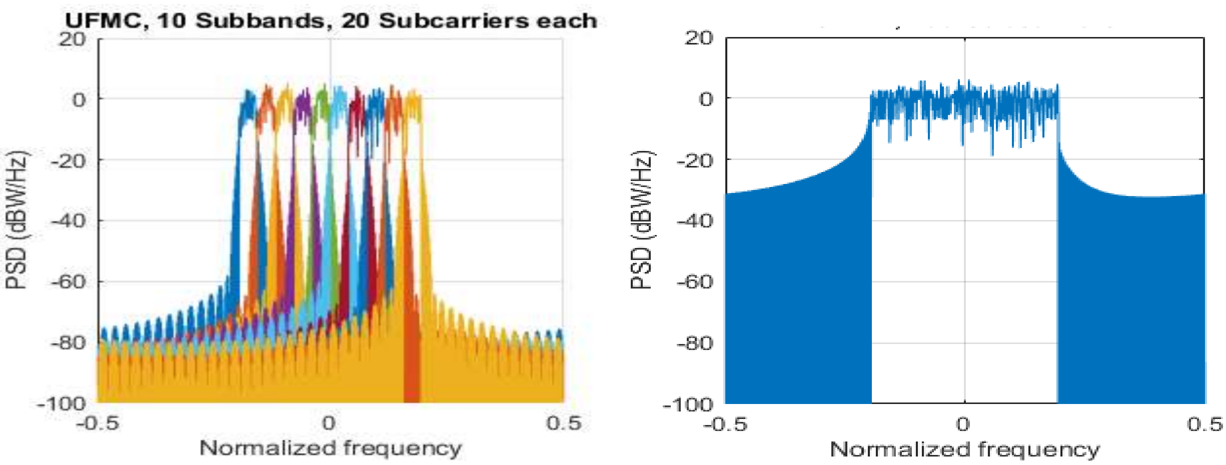

Figure .5.Power Spectral Density versus Normalized Frequency Plots for UFMC and GFDM technique[28][29]

Comparing the plots of the spectral densities for GFDM and UFMC schemes, UFMC has lower sidelobes. This allows a higher utilization of the allocated spectrum, leading to increased spectral efficiency.

5.2 UFMC Receiver with No Channel

The example next highlights the basic UFMC receive processing, which, like OFDM, is FFT-based. The subband filtering extends the receive time window to the next power-of-two length for the FFT operation. Every alternate frequency value corresponds to a subcarrier main lobe. The per-subcarrier equalization is used to equalize the joint effect of channel and subband filtering. Here, only the subband filter is equalized as no channel effects are being modelled. Noise is added to the received signal to achieve the desired SNR[28][30].

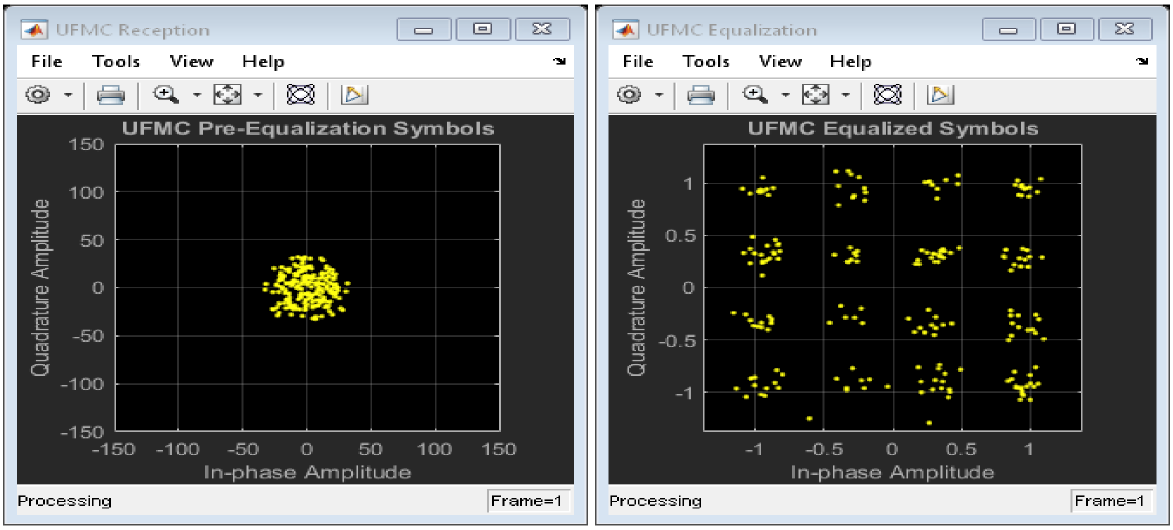

Figure.6.In-phase versus Quadrature Phase Amplitude for UFMC Receiver and UFMC Equalization[29]

Through this example, different system parameter values for the number of subbands, number of subcarriers per subband, filter length, sidelobe attenuation, and SNR have been seen leaving an impact on the performance of UFMC transceiver.

UFMC is considered better in comparison to GFDM by offering higher spectral efficiency. Subband filtering has the benefit of reducing the guards between subbands and also reducing the filter length, which makes this scheme attractive for short bursts. The latter property also makes it attractive in comparison to FBMC, which suffers from much longer filter length [28][29].

Table.4 Generalized Comparison for GFDM and UFMC for dispersive wireless cognitive radio system

Sr.no.	Characteristics	GFDM	UFMC
1.	Cyclic pulse	Add CP after every frame	Instead of CP, use match filter and zero padding
2.	Flexibility	Most flexible	Less than GFDM
3.	Time synchronization	Moderate	Tight
4.	Burst size	Greater than UFMC	Small
5.	Energy	Energy efficient	Wastage of some energy because of CP
6.	Even and odd sub-carriers carry	Different signal power	Same signal power

6.Conclusion

UFMC and GFDM are used as a waveform for secondary system which opportunistically uses 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. We can compare the different filtered multicarrier techniques in terms of robustness against multipath channels, power spectral density, and spectral efficiency. Based on these technical review we tend to provide an idea about the suitability of 5G Multicarrier Modulation techniques for industrial, scientific and medical band wireless communications to Cognitive radio.

7.Impact of Study and Future Scope

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.

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