Journal of Engineering and Applied Sciences 13 (Special Issue 7): 5576-5582, 2018
ISSN: 1816-949X

Performance Analysis of Universal Filtered Multi-Carrier (UFMC) Waveform for 5G Cellular Communications Using Kaiser Filter

Ravi Sekhar Yarrabothu, Narmada Kanchukommula and Usha Rani Nelakuditi
Departement of Electronics and Communication Engineering, Vignan's University, Guntur, India

Abstract: Currently, the mobile industry is working towards 5G, as the deployments of 4G LTE-advanced is happening across the world. About 5G research needs to address the existing OFDM based LTE problems such as high PAPR, spectral loss. Universal Filtered Multi Carrier technique (UFMC) can be considered as a candidate waveform for 5G communications because it provides robustness against Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI) and suitable for low latency scenarios. In this study, Kaiser filter is used instead of standard Dolph-Chebyshev for UFMC based waveform to provide better power spectrum and to avoid spectral leakage. In this study, UFMC system is simulated using MATLAB Software, a comparison study for Dolph-Chebyshev and Kaiser filters is performed and the results are presented in terms of power spectrum density analysis, complementary cumulative distribution function analysis and adjacent channel power ratio analysis. The simulated results shows a better power spectral density and low PAPR for UFMC (Kaiser based Window) when compared with UFMC (Dolph-Chebyshev) and conventional OFDM.

Key words: UFMC, 5G, Dolph-Chebyshev filter, Kaiser filter and OFDM, LTE, analysis

INTRODUCTION

The appetite of human society for more bandwidth based applications forcing the cellular industry to work towards better technologies and is fuelling the development of 5G research. By 2020 frame, 5th-generation (5G) cellular access will be a reality and already trails are going on across the world.

Currently, OFDM (Orthogonal Frequency Division Multiplexing) technique is widely used in wireless communications as well as in many modern communications for its efficiency. However, it has drawbacks like high.

Peak to Average Power Ratio (PAPR), Inter Carrier Interference (ICI). In OFDM, Cyclic Prefix (CP) causes Inter Symbol Interference (ISI) which is caused due to delay in distribution of the channel is higher than CP length (Hamiti and Sallahu, 2015).

With the aim to overcome these drawbacks, new techniques are introduced in 5G. Universal Filtered Multi Carrier (UFMC) was one of the proposed techniques. This waveform groups number of subcarriers into sub bands. In this way, UFMC procedure increases good spectral efficiency as a result of lack of cyclic prefix and diminishing out-of-band emission.

Initially, UFMC was implemented by using Dolph-Chebyshev filter (Mukherjee *et al*., 2015). It is observed that side lobe fall rate of Dolph-Chebyshev filter is not very quick which causes an increase in the spectrum leakage. Hence, Dolph-Chebyshev filter is not the best possible filter to use in the implementation of UFMC. In this study, we suggest a kaiser filter instead of Dolph-Chebyshev filter. The Kaiser filter or Kaiser bessel window is a flexible smoothing window whose shape can be by adjusted by modifying betainput. Thus, depending on the application, the shape of the window can be changed to control the amount of spectral leakage (Kaiser and Schafer, 1980). It provides a sub optimal solution for the out of band emissions. The most important factor of Kaiser filter is to provide flexibility to control stop band and the side lobes attenuation by using β input.

MATERIALS AND METHODS

UFMC architecture: UFMC is a technique where blocks of subcarriers are filtered before transmission and reception for eliminating inter carrier and inter symbol interferences. UFMC is a modulation technique that can be considered as a generalized Filter Bank Multi Carrier

---

Corresponding Author: Ravi Sekhar Yarrabothu, Departement of Electronics and Communication Engineering, Vignan's University, Guntur, India

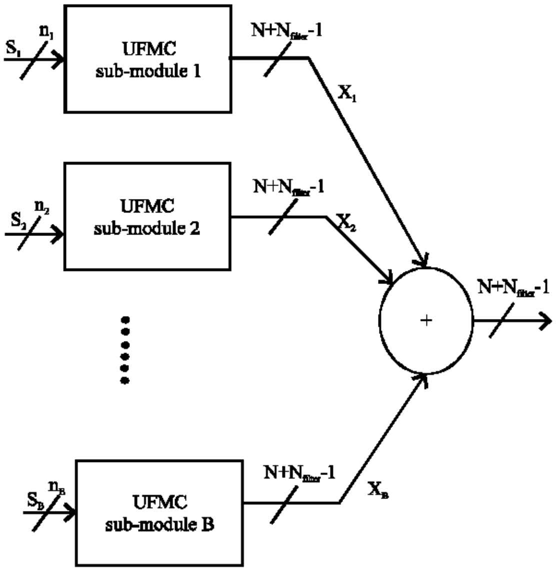

Fig. 1: General UFMC transmitter structure

technique (FBMC) and filtered OFDM. It is a multi-carrier signal format with orthogonal subcarriers to handle the problem of loss of orthogonality at the receiver end.

FBMC applies a filtering to each subcarrier while in a single shot, OFDM applies filtering to the entire multicarrier band. FBMC have many advantages like lesser ICI in case of frequency offsets or jitter. However, it increases computational complexity of the signal (Farhang, 2011). In filtered OFDM, filtering is applied to the total band. Hence, the bandwidth of the filter is large and filter length is much lesser than FBMC. In UFMC, subsets are filtered in the whole band instead of total band or single sub carriers (Germany and France, 2015).

UFMC transmitter design: General UFMC transmitter structure with B sub-bands is as shown in Fig. 1. The UFMC transmitter is designed as mentioned in (Knopp *et al*., 2016). UFMC ith sub-module where $i \in \{1, 2, ..., B\}$, generates the time-domain baseband vector x_i with $(N+N_{filter}-1)$ dimension for the sub-bands respectively which carries the QAM symbol vector S_i with dimension $n_i x_i$. Here N means number of required samples per symbol which represents all sub-bands without aliasing and N_{filter} indicates the length of the filter.

From Fig. 1, transmit vector x is synthesized by combining single sub-band signals. In downlink, multiple users get the transported data on single sub-modules over the all available frequency bands. In Up Link (UL), the user uses the assigned frequency portion.

By using IDFT spreader, the complex QAM symbol n_i are changed to time domain and then sub band filtering is performed. For a given multi carrier symbol, the time-domain transmit vector is the superposition of the sub-band wise filtered components is given in Eq. 1 (Fig. 2):

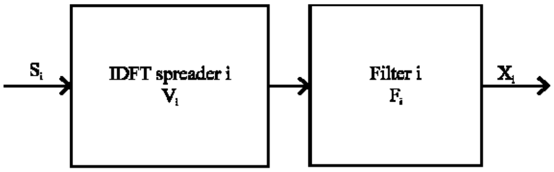

Fig. 2: UFMC transmitter sub module

$$\sum_{X=i=1}^{B} F_i V_i S_i \tag{1}$$

V_i indicates dimension N_{xni}, includes the relevant columns of the IFT matrix as per the position of sub band, F_i is a Toeplitz matrix whose dimension is $(N+N_{filter}-1)$ xN and is composed of the FIR which enables the convolution. The rewritten signal, without the summation is defined as follows:

$$\bar{F} = [F_1, F_2, ..., F_B] \tag{2}$$

$$\bar{V} = \text{diag}(V_1, V_2, ..., V_3) \tag{3}$$

$$\bar{S} = \left[S_1^T, S_2^T, ..., S_B^T\right]^T \tag{4}$$

This enables column wise piling of filter matrices, generation of an IDFT matrix and pooling up all the data symbols into a single column. This results into:

$$X = \bar{F}\bar{V}\bar{S} \tag{5}$$

Table 1 summarizes the existing design elements. Here, B depends on the UFMC transmitter spectral settings. If the system is applied to fragmented spectrum, B should be selected depending on the available number of spectral sub bands. Alternatively, for overall system stream lining and controlling the more fine-grained spectral characteristics, the single sub band can be divided into minute chunks of same size in every sub-band. These particular spectral chunks are called as Physical Resource Blocks (PRB) as in the LTE (Vakilian *et al*., 2013).

UFMC receiver design: UFMC receiver processing is done as depicted in Fig. 3. In reception, processing is done on the elements for simplicity which deals with blocks like channel estimation/equalization, error correction in the UFMC signal processing.

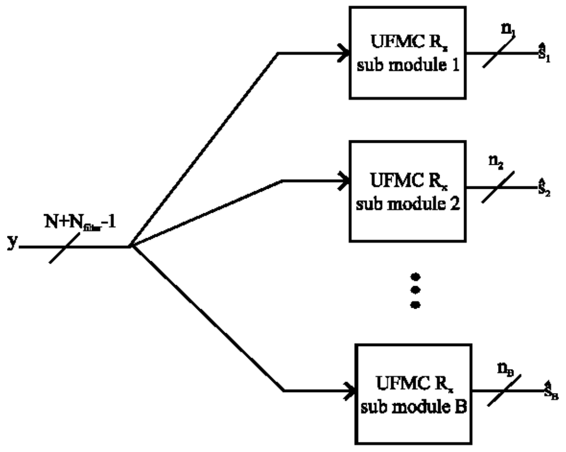

Fig. 3: General UFMC receiver structure

Table 1: Design elements for UFM

Elements	Design
B	No. of sub bands
n_i: block size	No. of sub carriers in sun band i
N	Overall No. of sub carries
Filter i	Bandwidth or length

From Fig. 3, y is the received signal vector through the channel after propagation with Toeplitz structure by convolution matrix H including noise n is given in Eq. 6:

$$y = Hx+n = H\bar{F}\bar{V}\bar{S}+n \tag{6}$$

Each Rx sub-module of UFMC transmits the output symbol vectors to the respective sub-bands along with distortions. In Up Link (UL) the Rx sub-modules are used for data transmissions to cover the complete frequency range where as in Down Link (DL) the receiver acts as a part of the user device. Active single sub modules or the PRBs carry the data, control messages relevant to an assigned user.

Different methods for the design of UFMC receiver are still under research. In an ideal linear receiver case under an AWGN channel, Zero Forcing filter (ZF) and Minimum Mean Square Error (MMSE) can be given as

$$W_{ZF} = \left(\overline{FV}\right)^{+} = T^{+} \tag{7}$$

$$W_{MMSE} = \left(T^{H}T+\sigma^{2}I\right)^{-1}T^{H} \tag{8}$$

Where:

T^+ = The Moore-Penrose-inverse of a matrix

T^H = The Hermitian Transpose

σ^2 = The noise variance

I = Identity matrix

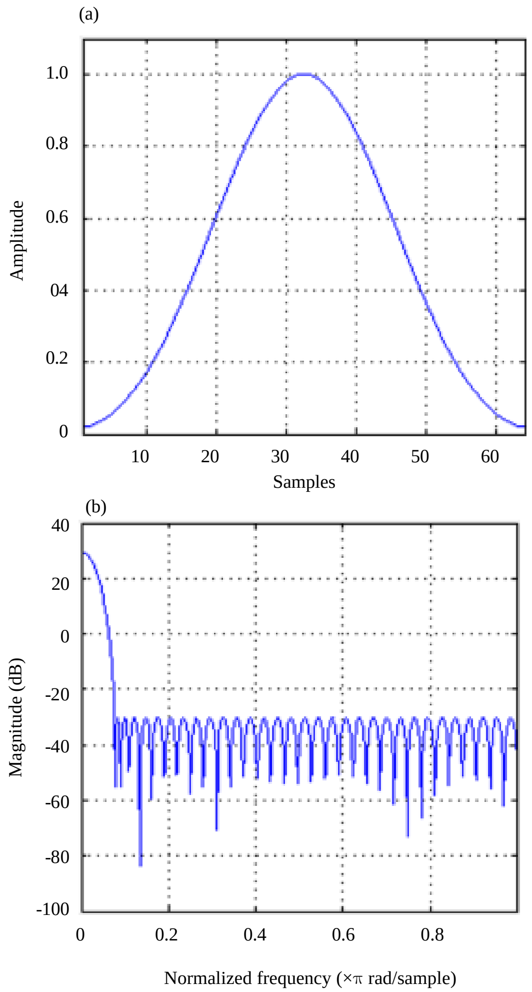

Fig. 4: Time and frequency domain charecterstic of Dolph-Chebyshev (length: 64, attenuation: 60 dB)

The receiver operation is given in Eq. 7 and 8 can be viewed as a concatenation of inverse filtering and DFT de-spreading.

Proposed UFMC with Kaiser Window: Already few researchers have tried alternatives to Dolph-Chebyshev filter as to overcome its deficiencies. A Dolph-Chebyshev Window applies FIR-coefficients which are parameterized on basis of side lobe attenuation. Here, Dolph-Chebyshev Window maximizes the attenuation of side lobe for any given main lobe width. Figure 4 shows characteristics in time domain and frequency domain for ideal settings with filter length: 64, side lobe attenuation: 60 dB.

In order to control the spectral leakage an FIR filter, Kaiser Window is used in the current research. The DPSS Window based uponbessel functions are well-known as the Kaiser Window (or Kaiser-bessel Window). Definition:

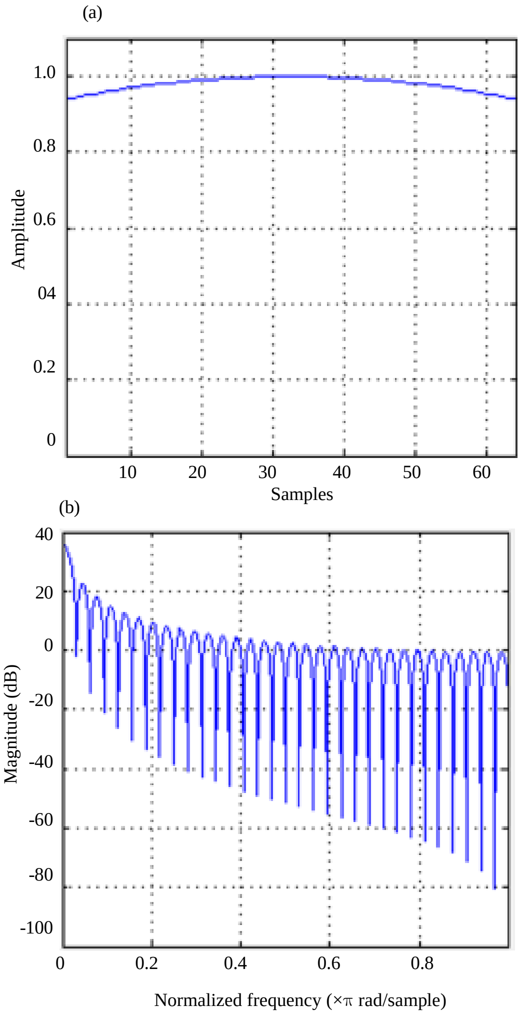

Fig. 5: Kaiser filter characteristics in time domain and frequency domain (side lobe attenuation: 0.5 dB, filter length: 64

$$w_k(n) = \begin{cases} \dfrac{I_0\left(\beta\sqrt{1-\left(\dfrac{n}{M/2}\right)^2}\right)}{I_0(\beta)}, & -\dfrac{M-1}{2} \le n \le \dfrac{M\_1}{2} \\ 0, & \text{elsewhere} \end{cases} \tag{9}$$

Window transforms: The Fourier transformof the Kaiser Window w_k (t) is given in Eq. 10. Here t is a continuous signal:

$$W_{(w)} = \frac{M}{I_0(\beta)} \frac{\sinh\left(\sqrt{\beta^2-\left(\dfrac{M_w}{2}\right)^2}\right)}{\sqrt{\beta^2-\left(\dfrac{M_w}{2}\right)^2}} \tag{10}$$

$$W_{(w)} = \frac{M}{I_0(\beta)} \frac{\sin\left(\sqrt{\left(\dfrac{M_w}{2}\right)^2-\beta^2}\right)}{\sqrt{\left(\dfrac{M_w}{2}\right)^2-\beta^2}} \tag{11}$$

where, I_0 is the zero-order modified bessel function of the first kind:

$$I_0(x) = \sum_{k=0}^{\infty}\left[\frac{\left(\dfrac{x}{2}\right)^k}{k!}\right]^2 \tag{12}$$

From Fig. 5, beta input in the kaiser window affects the side lobe attenuation parameter of the fourier transform. The β parameter provides continuous control over the window exchange betweenmain lobewidth and side lobelevel. Larger β values with lower side lobe levels provide a wider main lobe.

RESULTS AND DISCUSSION

UFMC system is simulated using MATLAB Software with both Kaiser Window and Dolph-Chebyshev filters. The general input parameters used for the simulations are as shown in Table 2. For Kaiser filter, side band attenuation is 1dB and remaining other parameters are same as mentioned Table 2.

Waveform filters: The simulated UFMC filter characteristics in time domain for both Dolph-Chebyshev filter and Kaiser filter are respectively in Fig. 6 and 7. The impulse responses of the filter shows that the UFMC filter pass band is narrower than the OFDM filter which increases the better use of the spectrum mainly fragmented spectrum application.

The simulated UFMC filter characteristics in frequency domain for both Dolph-Chebyshev filter and Kaiser filter are depicted in Fig. 8 and 9, respectively.

From Fig. 8 and 9, it is observed that the UFMC filter sideband attenuation with Kaiser is slightly better than both the UFMC (Dolph-Chebyshev) and OFDM. The frequency responses show that the Kaiser based UFMC filter provides small main lobe width which indicates steepness than Dolph Chebyshev filter, hence, it provides better power spectrum.

Power spectral density analysis: Figure 10 and 11 show the PSD analysis results for the 60 dB SNR situation when both OFDM and UFMC utilize the MMSE estimation

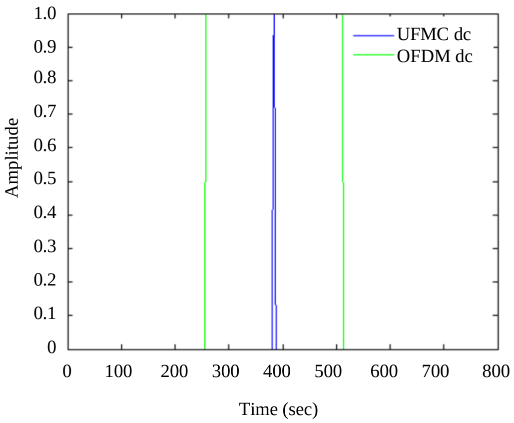

Fig. 6: UFMC with Dolph-Chebyshev and OFDM filter characteristics-time domain

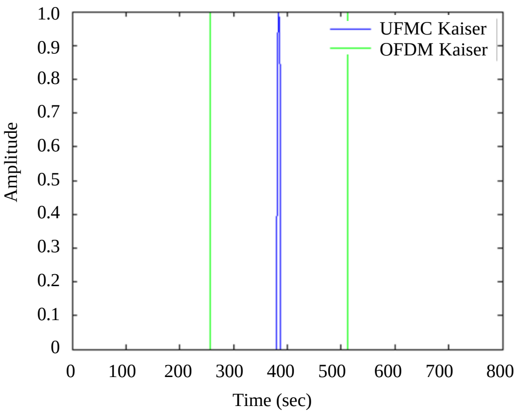

Fig. 7: UFMC with Kaiser and OFDM filter characteristics- time domain

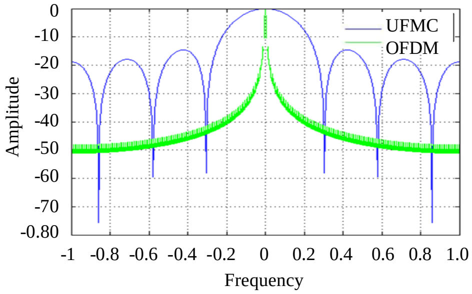

Fig. 8: UFMC with Dolph-Chebyshev and OFDM filter characteristics-frequency domain

Table 2: UFMC and OFDM simulation parameters

Variables	Values
Total number of used carriers	256
Number of symbols in a frame	20
Modulation	64QAM
UFMC estimation	MMSE estimation
UFMC Block size	16
UFMC number of resource blocks	16
Filter length	7
Filter sideband attenuation	40 dB
Channel	Perfect, no noise

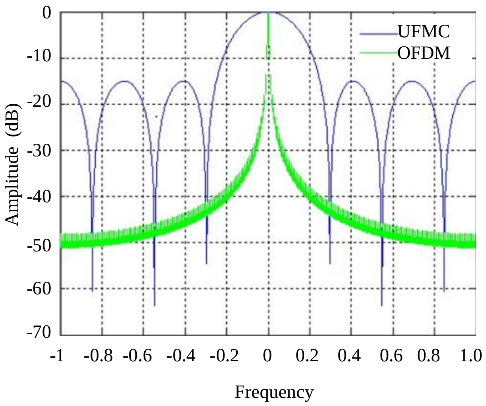

Fig. 9: UFMC with Kaiser and OFDM filter characteristics -frequency domain

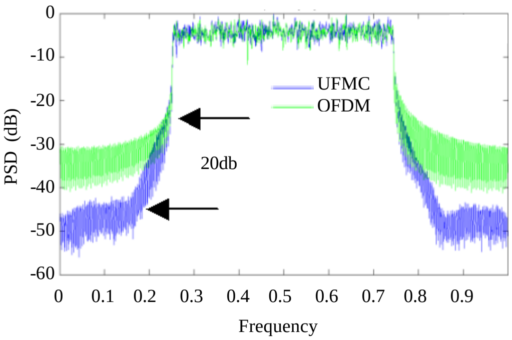

Fig. 10: PSD analysis using Dolph-Chebyshev Window

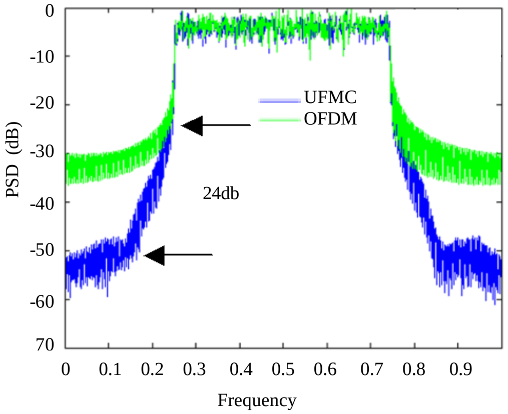

Fig. 11: PSD analysis using Kaiser Window

for both Dolph-Chebyshev filter and Kaiser filters, respectively. As seen in Fig. 10, UFMC has around 20 dB better performance on the stop band because of Dolph-Chabychev filter.

As seen on Fig. 11, UFMC has around 24 dB better performance on the stop band because of Kaiser filter. From Table 3 and 4, UFMC with Kaiser filter performs about 22 dB better than OFDM.

Table 3: Channel power measuring values for Dolph-Chebyshev filter

System	SNR	AWGN	ACPR
OFDM	60	Yes	-62.9805
OFDM	---	No	-64.7169
UFMC (DC)	60	Yes	-80.3931
UFMC (DC)	---	No	-83.5258

Table 4: Channel power measuring values for Kaiser filter

System	SNR	AWGN	ACPR
OFDM	60	YES	-63.5876
OFDM	---	NO	-64.1924
UFMC (Kaiser)	60	YES	-87.5264
UFMC (Kaiser)	---	NO	-85.8745

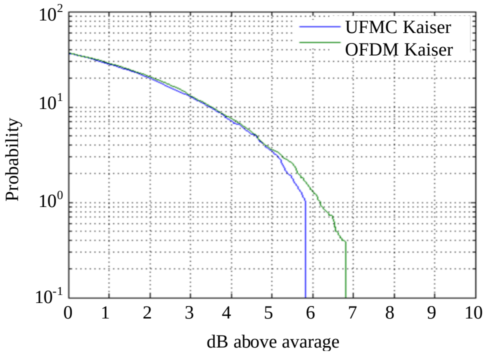

Fig. 12: CCDF Analysis with the use of Dolph-Chebyschev filter

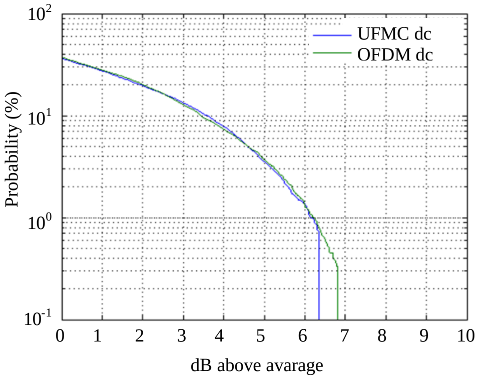

Fig. 13: CCDF Analysis with the use of Kaiser filter

Adjacent Channel Power Ratio (ACPR) analysis for OFDMA and UFMC is performed by using both the Dolph-Chebyshev filter and Kaiser filters is captured in Table 3 and 4.

From Table 3 and 4, we can notice that the UFMC with Kaiser filter is slightly better ACPR compared to UFMC with Dolph-Chebyshev and superior to OFDM system.

CCDF analysis: Complementary Cumulative Distribution Function (CCDF) shows about peak to Average Power Ratio (PAR). As the name indicates it shows the distribution of power in dB above average power. In communication systems small PAR is better where as high PAR values causes saturation in both transmitter and receiver.

Average power in dB is represented by the horizontal axis and probability of the existence of the signal power on vertical axis. Figure 12 and 13 illustrates the CCDF analysis for the OFDM and UFMC transceivers for both Dolph-Chebyshev filter and Kaiser filter, respectively. One can infer from the figures that OFDM has slightly higher probability of carrying signals with higher PAR compared to UFMC. And also it can observed that the UFMC system with Kaiser filter has low PAR, when compared with UFMC (D-C filter).

CONCLUSION

The simulation results shows that the UFMC with Kaiser Window can provide slightly better PAPR characteristics and side lobe suppression compared to UFMC based on Dolph-Chebyshev. Future research can be performed on UFMC with MIMO case.

REFERENCES

Farhang, B.B., 2011. OFDM versus filter bank multicarrier. IEEE. Signal Processing Magazine, 28: 92-112.

Germany, F.E.H. and A.C. France, 2015.5G waveform candidate selection. TU Dresden, Dresden, Germany. https://www.is-wireless.com/wp-content/uploads/2015/07/5GNOW-Deliverables-5G-Waveform-Candidate-Selection.pdf

Hamiti, E. and F. Sallahu, 2015. Spectrum comparison between GFDM, OFDM and GFDM behavior in a noise and fading channel. Intl. J. Electr. Comput. Eng. Syst., 6: 39-43.

Kaiser, J. and R. Schafer, 1980. On the use of the I0-sinh window for spectrum analysis. IEEE. Trans. Acoust. Speech Signal Process., 28: 105-107.

Knopp, R., F. Kaltenberger, C. Vitiello and M. Luise, 2016. Universal filtered multicarrier for machine type communications in 5G. Proceedings of the European Conference on Networks and Communications (EUCNC). June, 27-30, 2016, IEEE, Athens, Greece, pp: 1-5.

Mukherjee, M., L. Shu, V. Kumar, P. Kumar and R. Matam, 2015. Reduced out-of-band radiation-based filter optimization for UFMC systems in 5G. Proceedings of the 2015 International Conference on Wireless Communications and Mobile Computing Conference (IWCMC), August 24-28, 2015, IEEE, Dubrovnik, Croatia, ISBN:978-1-4799-5344-8, pp: 1150-1155.

Vakilian, V., T. Wild, F. Schaich, T.S. Brink and J.F. Frigon, 2013. Universal-filtered multi-carrier technique for wireless systems beyond LTE. Proceedings of the 2013 IEEE Workshops on Globecom (GC Wkshps), December 9-13, 2013, IEEE, Atlanta, Georgia, USA., ISBN:978-1-4799-2851-4, pp: 223-228.