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BER and PAPR Analysis of UFMC for 5G Communications

Potnuru Praneeth Kumar* and K. Krishna Kishore

Department of Electronics and Communication Engineering, GMR Institute of Technology, GMR Nagar, Rajam – 532127, Srikakulam District, Andhra Pradesh, India; ppk.pmr@gmail.com, krishnakishore.k@gmrit.org

Abstract

Objectives: In this paper, Universal Filter Multi Carrier (UFMC) is recommended for 5G communications and signal scrambling technique is used to reduce Peak to Average Power Ratio (PAPR) in UFMC**. Methods/Analysis:** UFMC is adequate for 5G communications, but it is also suffers from PAPR as in Orthogonal Frequency Division Multiplexing (OFDM). The signal scrambling technique is a base method for reducing the crest factor, in multicarrier communication so we inherit the same method for UFMC with Genetic Algorithm (GA), Particle Swarm Algorithm (PSA), Artificial Bee Colony (ABC) and Fireflies Algorithm (FA) as optimizers which are natural inspired heuristic search algorithms. **Finding:** By using UFMC we acquire best Symbol Error Rate (SER) even Carrier Frequency Offset (CFO) is applied and spectral re-growth also mitigated. PAPR is also reduced by using a signal scrambling technique with natural inspired search algorithms as optimizers.

Keywords: Fireflies Algorithm, PAPR, UFMC, 5G

1. Introduction

5G communications need a special capability than legacy technologies to satisfy the future demands and applications. The major applications in 5G are Internet of Things (IoT), Vehicle to Vehicle (V2V) communication, Machine to Any (M2X) communication and Cognitive Radios. IoT need a special capability to communicate with all digital gadgets and devices to sophisticate the human to machine interface. V2V communication requires low sensitive waveform to the CFO to establish reliable communication between mobile devices. M2X communications need a new physical and Media Access Control (MAC) layer to possible the communication between machines to machine, machine to human and machine to vehicle, etc. Cognitive radios are those devices can operate in tunable frequencies and modulation techniques depending on the user requirements. Cognitive radios can adapt to any environment by taking information from the open air interface.

1.1 Limitation of OFDM

OFDM has certain constraints like cyclic-prefix overhead, Sensitivity to frequency offset CFO, Spectral re-growth and High PAPR makes it not the most reasonable waveform for all the focused on applications of 5G. In OFDM to ride with ICI in the case of multipath fading, cyclic prefix is best ever technique used. But the cyclic prefix introducing additional bits[1] to the transmitting data so data redundancy increased. The orthogonality in OFDM is based on the perfect synchronization carriers of transmitter and receiver. If

**Author for correspondence*

frequency offset introduced between the transmitter and receiver the orthogonality will be lost in OFDM and causing Inter-Carrier Interference[2] ICI. In OFDM the orthogonality is assured with the perfect synchronization of transmitter and receiver for a symbol period. For this the OFDM symbol will be suddenly discounted the transmission after every symbol duration. This sudden discontinuity will cause spikes in the frequency domain. This out-of-band radiation will affect by the adjacent carriers. Another challenge with OFDM is the high PAPR. The high PAPR in an OFDM system essentially arises because of IFFT operation. In OFDM the transmitted samples are IFFT samples of information symbols. Different symbols loaded on to the sub-carriers are random, and depending on their nature, they can occasionally all add-up across sub-carrier to produce a high peak value that gives rise to a very high instantaneous swing with respect to the normal mean value. The nonlinearity of the power amplifier generates in-band and out-of-band distortion[3]. Because of these drawbacks researchers looking for an alternative waveform that are complement the weaker aspects of OFDM.

2. UFMC

As we discussed in previous chapter limitations of OFDM that result in major shortcoming to support applications identified to be part of a future 5G wireless communication standards. To overcome the problems of the OFDM we should have a new waveform candidate for replacing OFDM in 5G physical layer.

The new waveform should achieve the asynchronous reception and transmission, non-orthogonal waveforms for better spectral efficiency and low latency. But at the same time, you can easily tune the subcarriers spacing and number of tones depending upon the band range and bandwidth of application that we are dealing with. In addressing scalable waveform on the same network, we can introduce filtering to the OFDM symbols that we can actually have different numerology coexistence on the same network. Some new waveform designs are more attracted by industries as well as research organizations which are less complex in design, UFMC is the most adequate for 5G[4,5].

UFMC is the method that combines the advantages of orthogonality OFDM and filter bank in FBMC. Instead of filtering each carrier like in FBMC, we have to filter a block of carriers called sub-band. Each sub-band contains a number of carriers; filter length will be depending upon the width of sub-band. In the UFMC system, the complex symbols generated from the base - band modulator. These complex symbols are converted to parallel stream, make a block of streams and given as input to the IFFT of their respective. The length of N point IFFT output will be serialized as block-wise and that output will be filtered with a pulse shaping filter of length L. The data stream X will be converted to B disjoint blocks. And each sub-block is passing through N point IFFT representing with matrix 'V'. The output of IFFT will be serialized and passing through filter representing with matrix 'F' as shown in [Figure 1]. For the i^{th} sub-band ($1 \le i \le B$) the data blocks represent with $X_{i,k}$, IFFT matrix with $V_{i,k}$ and pulse-shaping filter with $F_{i,k}$. The output of the filter bank, which is given as input to the DAC can be expressed as below.

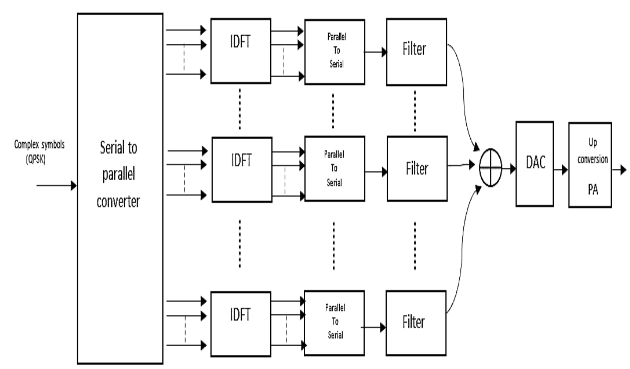

Figure 1. Block diagram of UFMC transmitter.

$$x_k = \sum_{i=1}^{B} F_{i,k} \cdot V_{i,k} \cdot X_{i,k} \tag{1}$$

The receiver section of UFMC is shown in [Figure 2]. After RF-link section the signal will pass through the time domain pre-processing window to suppress interference. After windowing, the signal will convert into '2N' parallel streams; here 'N' is the number of subcarriers. The demodulated signal is sent to the demapper, which is QPSK demodulator to retrieve the data bits from the received symbols. Other demodulation strategies, for example, Zero Forcing (ZF), Matched Filtering (MF) and Minimum Mean Square Error (MMSE) have moreover been inspected in [Figure 2].

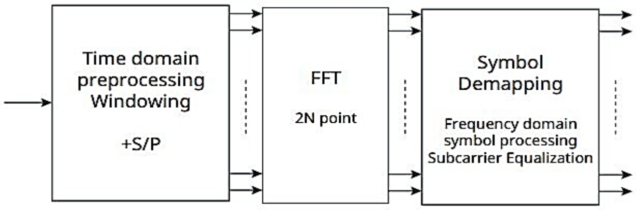

Figure 2. Receiver section of UFMC.

3. Analysis of UFMC

The filter using in UFMC is Dolph-Chebyshev of length 'L'. Length of filter depends upon the size of sub-band that is the number of carriers in sub-band. The frequency response of OFDM and UFMC resulting as shown in [Figure 3]. Because of filtered operation for each sub-band in UFMC we can observe that the spectral re-growth is (-70 dB) very low compared OFDM (-40 dB).

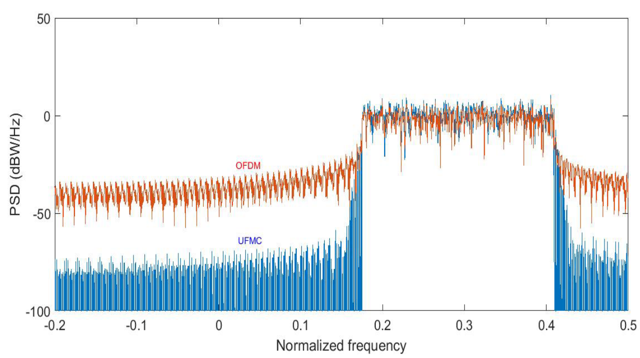

Figure 3. Frequency response of transmitting signal of OFDM and UFMC.

The SER analysis of both OFDM and UFMC are shown in [Figure 4]. The UFMC is just a bit better than OFDM at higher SNR values and almost same at lower SNR value. The real problem arrives in a condition where the CFO presents at receiver side as we discussed in the previous chapter. The performance analysis is shown in [Figure 5] in the form of SER vs. SNR plots with the CFO. From observation of results we can say UFMC is less sensitive to the CFO than OFDM, which bring more credits to UFMC to become top of the candidate list of 5G waveforms.

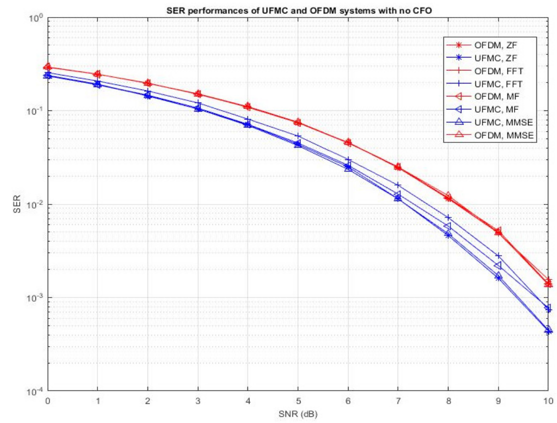

Figure 4. SER analysis of OFDM and UFMC.

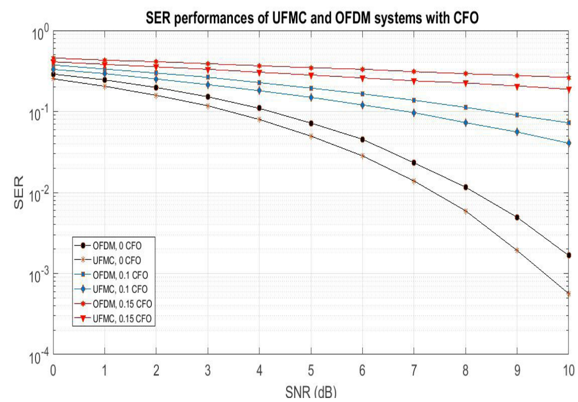

Figure 5. SER analysis with CFO.

UFMC has numerous focal points over the OFDM but on the other hand, it's having an issue with the high power amplifier (HPA) at the transmitter side because of its limited linear region. High PAPR in the time domain of input signal makes HPA work into a non-linear region, which bring out-of-band (OOB) radiation. The mathematical valuation of PAPR is defined in equation 2.

$$PAPR = \frac{Peak\ Power}{Average\ Power} = \frac{|X[k^*]|^2}{E[X]} \quad (2)$$

The simulation results show in [Figure 7]. The PAPR for UFMC and OFDM are notably very close for all conditions. So PAPR factor can't be valuable credential for choosing UFMC as the best waveform candidate of 5G. PAPR can be reduced by some signal manipulations before transmission. In multi-carrier communication like OFDM there is, different types of PAPR reduction techniques[6], the major types are signal scrambling and signal distortion. Signal scrambling is also called as probabilistic methods and in this type we need to send side data to retrieve the original signal from receiving signals.

4. Reduction of PAPR

In UFMC the data symbols are divided and applying individually to N point IFFT blocks, called resource blocks and filter individually and combined to form a UFMC symbol. So we propose a method that applies the phase rotation to the each resource block to form a low PAPR combination of 'B' resource blocks and phase vector 'P' of length 'B'. One optimizer has to design to select an optimum solution of resource block and phase vector combination as shown in [Figure 6]. The resultant UFMC as described in below equation.

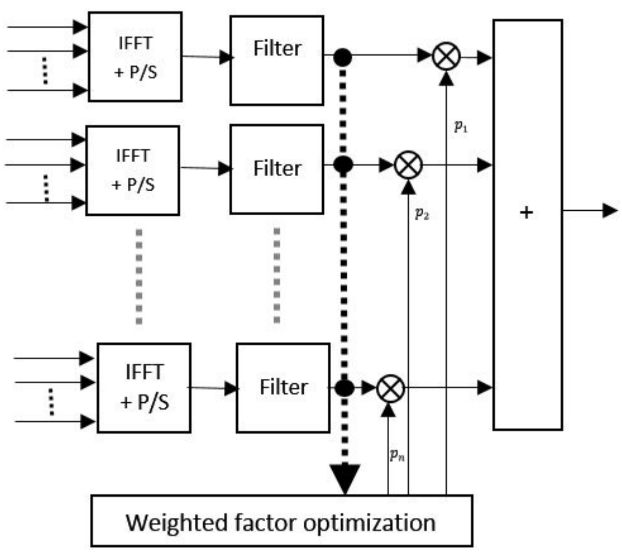

Figure 6. Block diagram of signal scrambling technique for UFMC.

$$x_k = \sum_{i=1}^{B} F_{i,k} \cdot V_{i,k} \cdot X_{i,k} \cdot P_B^{'} \quad (3)$$

$P_B^{'}$ is best phase vector which gives the low PAPR. This optimal phase $P_B^{'}$ vector have to send as side data to receiver to retrieve the original UFMC symbol. The optimizer has to select the phase factor by capture the data from the output from the filter and search the vector of dimensions 'B'. If possible phase factors are 'a' then size of a vector space is a^B. Here for simulation, we are taking 20 resource blocks and 4 possible phase factors, so there will be 4^{20} size vector space. So we need a heuristic search method to find an optimum solution from a large search space. There are a lot of heuristic search methods which are inspired by natural evolution procedure. In this paper we are using GA7, PSO8, ABC9 and FA10 which are meta-heuristic algorithms as optimizers. FA has two major benefits over other algorithms

- Automatically subdivision
- Ability of managing multimodality

FA depends on attraction to the light so attractiveness decreasing with distance. This prompts the whole people can normally part into smaller groups, and every gathering can swarm around neighborhood best. Among all these neighborhood arrangements, the best global optima can be found. This subdivision allows the fireflies to have the ability to find all optima at the same time if the population size is satisfactorily higher than the amount of modes which lead parallel computing automatically for faster convergence to optimal solution.

4.1 FA

Firefly algorithm was first developed by Xin-She Yang in late 2007 at Cambridge University[10], which relied on upon the flickering illustrations and behavior of fireflies. Generally, Firefly calculation three admired rules[11] that

1. Fireflies are unisex
2. The possibility of information sharing between fireflies is depending upon the brightness
3. The brightness of a firefly is proportional to the cost function.

Every firefly has its allure β depicted by the monotonically diminishing capacity of the separation (r) between two any fireflies:

$$\beta(r) = \beta_0 e^{-\gamma r^m} \quad m \geq 1 \quad (4)$$

β_0 is the attraction coefficient value and γ is the light absorption coefficient, the distance between fireflies at position x_i and x_j can be defined as follows:

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \quad (5)$$

Here $x_{i,k}$ is the k-th component of the spatial coordinate. The movement of a firefly is calculated by the following form:

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha\left(rand - \frac{1}{2}\right) \quad (6)$$

The initial population of fireflies is generated in the following form:

$$x_i = LB + rand \cdot (UB - LB) \quad (7)$$

Here UB and LB are upper bound and lower bound of i^{th} firefly.

4.1.1 *Problem formulation*

The objective function for optimization is PAPR of time domain transmitting signal as defined in equation 8.

$$f(P) = PAPR(P) \quad (8)$$

$$PAPR(P) = \frac{Peak\ Power\{x(P)\}}{Average\ Power\{x(P)\}} \quad (9)$$

$$P = (p_1, p_2, \ldots \ldots \ldots, p_B) \quad (10)$$

Initial population of fireflies "p_i (i=1,2,…,B)". Light intensity of each firefly is calculated by objective function which is equal to PAPR at p_i. For all fireflies that means for all p_i. The best cost function will be considered as optimized value after performing maximum iterations. The corresponding firefly position is taken as best solution which is considered as the best phase vector.

4.2 PAPR Analysis

In this section the PAPR analysis of OFDM, UFMC and signal scramble based UFMC systems is evaluated. The cost function given to the optimizer is PAPR(p) which evaluates the PAPR value of time domain signal (x) with respect to phase factor vector (p). PAPR reduction ability is measured by the value of CCDF (Complementary cumulative distribution function). CCDF is defined as

$$CCDF[PAPR(x)] = Prob(PAPR(x) > PAPRo) \quad (11)$$

The parameters of experimental frame are showcased in [Table 1]. The comparison of PAPR for OFDM, UFMC and UFMC with different optimizers displayed in [Figure 7]. The OFDM and UFMC getting average PAPR around 9.5 dB, but the UFMC with FA getting around 6.7 dB. We can observe that the maximum possibility of PAPR for proposed method is 6.9 dB, whereas for the same 6.9 dB threshold the OFDM and UFMC having a probability of 1. The minimum values of PAPR for OFDM and UFMC are more than their optimized maximum value.

Table 1. Parameters of experimental frame

Parameter	Value
Resource blocks	20
Resource block size	12
Constellation type	QPSK
Bits / symbol	2
Number of phase factors	4 (1, -1, j, -j)
Number of fireflies (population)	25
Max iterations	50

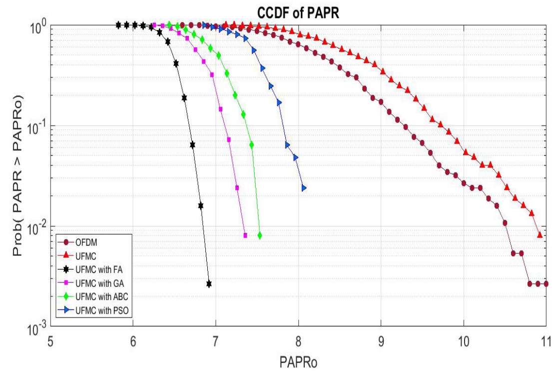

Figure 7. CCDF comparison of PAPR.

5. Conclusion

In this paper UFMC is analyzed for 5G communications. By using UFMC we can achieve all requirements of applications which are associated in 5G. The parameters used for investigation of UFMC were includes: SER, Spectral re-growth, PAPR. Obtained results can be concluded as mentioned below:

- The SER is better for UFMC than OFDM even if the CFO is present.
- The spectral re-growth is very less in UFMC because of filter-bank used at output of IFFT blocks.
- PAPR also reduced with signal scrambling technique.
- The optimal solution is converging very fast because we are using natural inspired search algorithm as an optimizer in signal scrambling method.
- UFMC with FA optimizer showing better results than GA, PSO and ABC optimizers.

6. References

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