Performance Enhancement of Generalized Frequency Division Multiplexing using Zadoff-Chu Precoding Scheme

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Abstract

Nonlinearity introduced by the high power amplifier (HPA) is a major obstacle for all multicarrier systems due to their high peak to average power ratio (PAPR). GFDM may be considered as a suitable modulation scheme for 5G wireless systems. For the purpose of maximum power transmission, HPA is used with GFDM system. In the proposed work, zadoff-chu precoding technique is investigated for GFDM systems to analyze the PAPR and BER performances. The simulation results show that the PAPR of the proposed GFDM is reduced by 4dB and 5dB as compared to conventional GFDM signal and conventional OFDM, respectively at CCDF of 10^{-2}.

Keywords: GFDM, PA, OFDM, PAPR

1. Introduction

In recent years, high speed and broad coverage area are the basic requirements for future wireless communication systems. Though fifth generation (5G) standard promises the high data rate, higher efficiency and lower latency but implementation of machine to machine (MTM) communication and internet of things (IoT) based 5G systems is still a bigger challenge as these systems require more flexibility, relaxation of synchronization and low out of band radiation [1].

It is well known that OFDM is a popular modulation method for high data rate wireless networks as it effectively mitigates inter-symbol interference (ISI) caused by delay spread of wireless channels but the PAPR is one of the major drawbacks of OFDM system [2]. OFDM signal is also very sensitive to time and frequency offsets and to avoid it, strict synchronization between users is required [3]. To overcome these drawbacks of OFDM, some new methods like FBMC, UFMC, GFDM and RB-OFDM are proposed in the literature [4]. Among these methods the performance of GFDM is analyzed in this work to consider its suitability for 5G applications. In GFDM, the data transmission is in time-frequency block manner which reduces the requirement of large number subcarriers hence the PAPR of GFDM system may be less compared to the OFDM system for equal spectral efficiency condition. Though it introduces self induced interference which can be compensated by interference cancellation techniques at the receiver side [5]. Cyclic prefix is added to the entire block in this system which makes GFDM more spectrally efficient compared to the OFDM system [5-6].

These properties of GFDM system make it an attractive choice for 5G communication systems. However, the problem of PAPR becomes larger in GFDM if subcarriers become comparable to OFDM subcarriers and it becomes severe in the presence of high power amplifier [7].

Many PAPR reduction techniques are discussed in literature for OFDM system such as coding, partial transmit sequence, clipping and filtering, Tone reservation, Tone injection, companding, pre-coding etc. [3]. Pre-coding is an efficient technique for reducing PAPR of OFDM signals. In [8] , CAZAC precoding scheme is proposed for PAPR reduction in OFDM system. In literature, none of research paper is found in which GFDM system is implemented with polyphone sequence. In this research work, zadoff-chu pre-coding scheme is proposed for GFDM system for PAPR reduction. Simulation results show that the PAPR and BER performance of proposed GFDM system is improved as compared to the conventional GFDM, conventional OFDM and zadoff-chu pre-coded OFDM. The rest of the paper is organized in the following manner:

Section 2 presents a brief overview of Zadoff Chu sequence. In section 3, the GFDM system model with proposed scheme is described.

2. Zadoff Chu Sequence

Zadoff-chu sequences are the class of polyphase sequences and have constant amplitude zero autocorrelation. The main property of the sequence is that, the autocorrelation of the sequence with its cyclically shifted version is zero. It is capable to reduce peak to average power ratio of the signal with its constant amplitude property. The zadoff-chu sequence of length $\tilde{L}$ is represented as in [9]:

$$z_{\tilde{k}} = \begin{cases} e^{\left(j2\pi\tilde{r}/\tilde{L}\right)\left(\tilde{k}^2/2+\tilde{q}\tilde{k}\right)} & , \ \tilde{L} \text{ even} \\ e^{\left(j2\pi\tilde{r}/\tilde{L}\right)\left(\tilde{k}\left(\tilde{k}+1\right)/2+\tilde{q}\tilde{k}\right)} & , \ \tilde{L} \text{ odd} \end{cases} \quad (1)$$

where, sequence index $\tilde{k} = 0,1,......\tilde{L}-1$, $\tilde{q}$ is any positive integer , $\tilde{r}$ is any integer relatively prime to $\tilde{L}$ [140].

3. Proposed Scheme

The block diagram of the proposed zadoff-chu pre-coded GFDM system is shown in Fig.1.In the transmission model of the proposed scheme, zadoff-chu pre-coding matrix $\mathbf{Z_p}$ is multiplied with the QAM modulated input data symbols $\mathbf{d} = \left\{d_0, d_1,.....d_{N-1}\right\}$.The pre-coded data $\mathbf{x_p}$ is passed through GFDM modulator and after insertion of cyclic prefix (CP) insertion, then it is passed through the HPA.

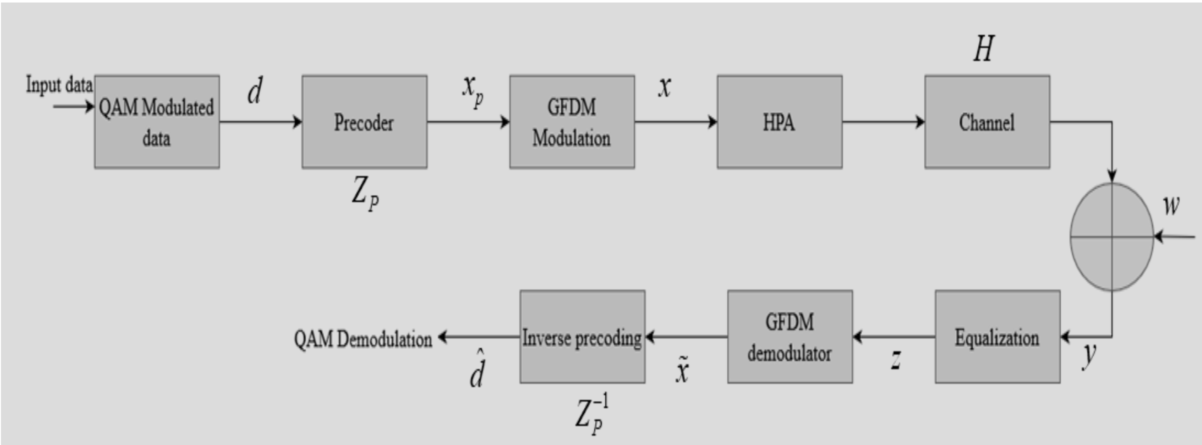

Fig.1 GFDM signal Transmission and reception with proposed method

After multiplication of zadoff-chu precoding matrix $\mathbf{Z_p}$ with data vector $\mathbf{d}$, the precoded data vector is represented as

$$\mathbf{x}_p = \mathbf{Z_p d} \tag{2}$$

where, $\mathbf{x}_p$ is a $KM \times 1$ pre-coded data vector such as $\mathbf{x}_p = \left[x_{p(0,0).....} x_{p(k,m)} ..... x_{p(N-1,M-1)} \right]^T$, $k = 0......N-1$ is subcarrier index and $m = 0,1......M-1$ is time slot index. The pre-coded GFDM results as:

$$\mathbf{x} = \sum_{m=0}^{M-1} \sum_{k=0}^{N-1} \mathbf{dg}(n - mK)_{MN} e^{j2\pi kn/N} \tag{3}$$

Equation (3) can be represented in a new matrix model in time domain as derived in [9]:

$$\mathbf{x} = \sum_{m=0}^{M-1} \mathbf{P}^{(m)} diag(\mathbf{g}) \mathbf{R}^{(M,K)} \mathbf{W}_K^H \mathbf{x}_p \tag{4}$$

where, $\mathbf{x}_p$ is the pre-coded data vector which can be converted in time domain by taking inverse IFFT matrix $\mathbf{W}_K^H$, $\mathbf{R}^{(M,K)}$ is the repetition matrix which performs M times up-sampling in time domain. Pulse shaping of each sub symbol is performed by matrix $\mathbf{g}$. $\mathbf{P}^{(m)}$ is a permutation matrix which up-converts the m^{th} sub-symbol to its respective position of time. Vector $\mathbf{x}$ can be rewritten as

$$\mathbf{x} = \sum_{m=0}^{M-1} \mathbf{P}^{(m)} diag(g) \mathbf{R}^{(M,K)} \mathbf{T x_p} \tag{5}$$

where, $\mathbf{T} = \mathbf{W}_K^H$ is called the IFFT transform matrix.

After GFDM modulation, the signal is passed through HPA and channel. The received signal vector after passing through the channel can be represented as

$$\mathbf{y} = \mathbf{H}\,\mathbf{x} + \mathbf{w} \tag{6}$$

where, $\mathbf{H}$ is the channel matrix of size $MK \times MK$ and $\mathbf{w}$ is AWGN noise vector. Then the received vector $\mathbf{z}$ after equalization will be

$$\mathbf{z} = \mathbf{H}^{-1}\mathbf{y} \tag{7}$$

After equalization, the received signal passes through GFDM demodulator, which performs inverse operation of GFDM modulation. The signal output of GFDM demodulator $\tilde{\mathbf{x}}$ in frequency domain can be represented as:

$$\tilde{\mathbf{x}} = \mathbf{W}_K \left(\mathbf{R}^{(M,K)}\right)^T diag(\xi)\left(\mathbf{P}^{(m)}\right)^T \mathbf{z} \tag{8}$$

where, $\mathbf{W}_K$ is FFT transform matrix, $\left(\mathbf{P}^{(m)}\right)^T$ is a inverse permutation matrix which down-converts the m^{th} sub-symbol, ξ is the filter impulse response of GFDM demodulator, $\left(\mathbf{R}^{(M,K)}\right)^T$ is the inverse repetition matrix which performs M times down-sampling of the signal and $\mathbf{z}$ is the equalized received vector at the input of GFDM demodulator. In the present work, ZF equalization is considered. After passing through the inverse precoder with precoding matrix $\mathbf{Z}_\mathbf{P}$, the actual data can be recovered.

$$\hat{\mathbf{d}} = \mathbf{Z}_P^{-1}\tilde{\mathbf{x}} \tag{9}$$

4. Simulation Results

In this section, MATLAB simulations are performed to evaluate the PAPR and BER performances of GFDM system. In simulations, the Rapp's SSPA model is used for HPA. To compare the PAPR and BER performances, the proposed scheme, conventional OFDM and GFDM, C+F GFDM and OFDM systems are simulated. The system parameters used in the simulations are given in Table 1. It is to be noted here that the OFDM and GFDM systems are simulated at same spectral efficiency condition.

Table 1
Simulation Parameters for GFDM system and proposed method

Parameter	GFDM	OFDM
High power amplifier	TWTA	TWTA
Modulation technique	16QAM	16 QAM
No. of Frequency slots K	256	512
No. of time slots M	2	1
Smoothness parameter of HPA	1.5	1.5
RRC filter with roll-off factor a	0.3&0.4	0.3

To observe the effect of out-of-band (OOB) radiation of conventional GFDM system and proposed GFDM (GFDM with Zadoff chu sequence) in presence of HPA, both these systems are simulated and the OOB radiation results are plotted in Fig.2. From Fig.2, it is clearly observed that the use of Zadoff-chu sequence reduces the out of band radiations of GFDM system. The nonlinearity effect in GFDM systems due to HPA can be observed from the signal constellation diagram. To see the effect of nonlinearity in conventional GFDM and the Zadoff-Chu sequence precoded GFDM systems, the signal constellations are presented in Fig.3. It can be seen from Fig.3 that the HPA nonlinearity effect in precoded GFDM systems is very less as compared to the conventional GFDM system.

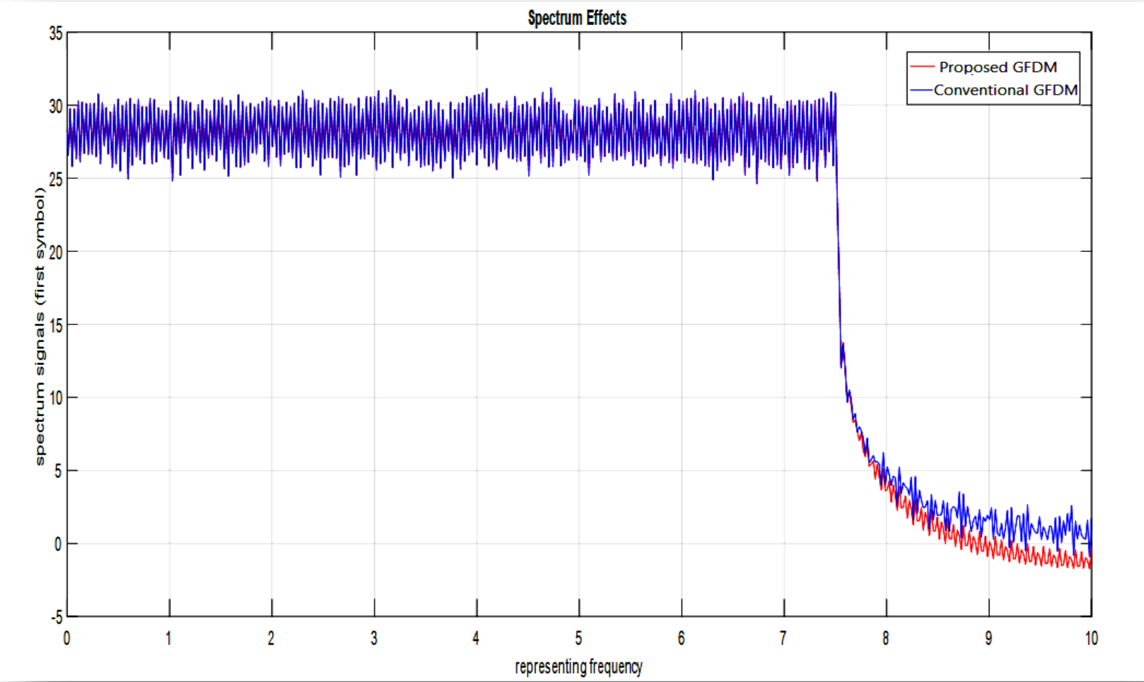

Fig.2 OOB Radiation in GFDM with and without Zad-off chu sequence

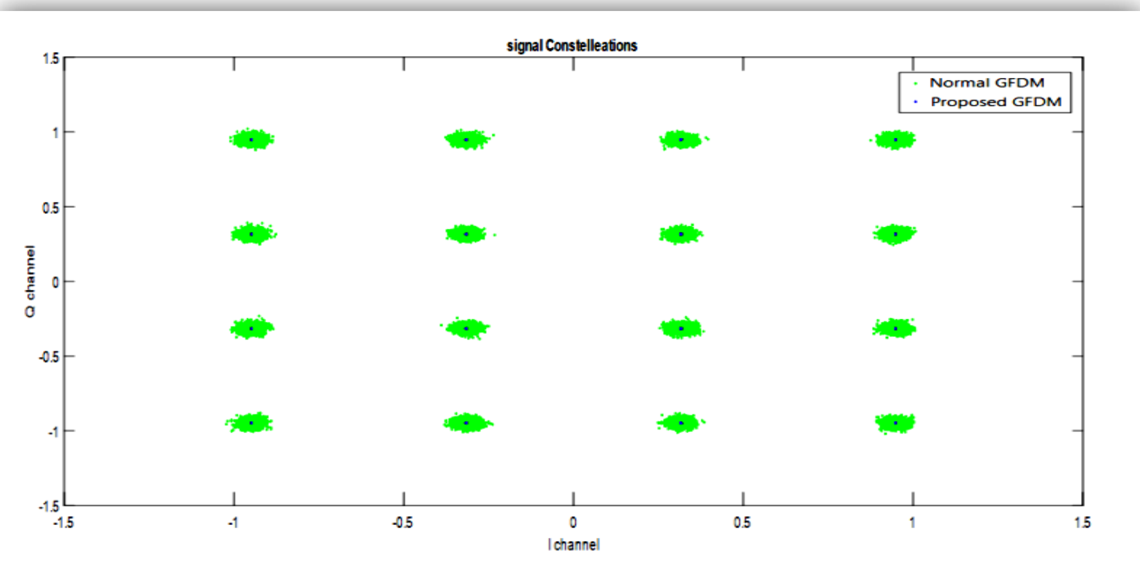

Fig.3 Signal constellation representation of Proposed GFDM

The PAPR performance of conventional OFDM, GFDM and proposed GFDM systems are shown in Fig.4. These results are obtained at roll off factors of value 0.3 & 0.4. It is revealed from the results that for roll of factor of 0.3, the PAPR of the proposed GFDM is reduced by 4dB and 5dB as compared to conventional GFDM signal and conventional OFDM, respectively at CCDF of 10^{-2}. The PAPR of the proposed GFDM system is also compared with C+F GFDM, C+F OFDM and zadoff-chu precoded OFDM system. The comparison results are presented in Fig.5. It can be seen from these results that at CCDF of 10^{-3}, the PAPR of the proposed GFDM system is improved by 2.5dB as compared to C+F GFDM system. The BER versus E_b/N_0 plots for the proposed method, C+F GFDM and C+F OFDM systems are depicted in Fig 6. It is observed from the results that the BER of the proposed scheme is comparable to that of OFDM system. It can also be observed from the results that the proposed method outperforms in terms of BER as compared to C+F GFDM system. The improvement in the performance of the proposed scheme with respect to C+F GFDM at BER of 10^{-3} is about 1dB.

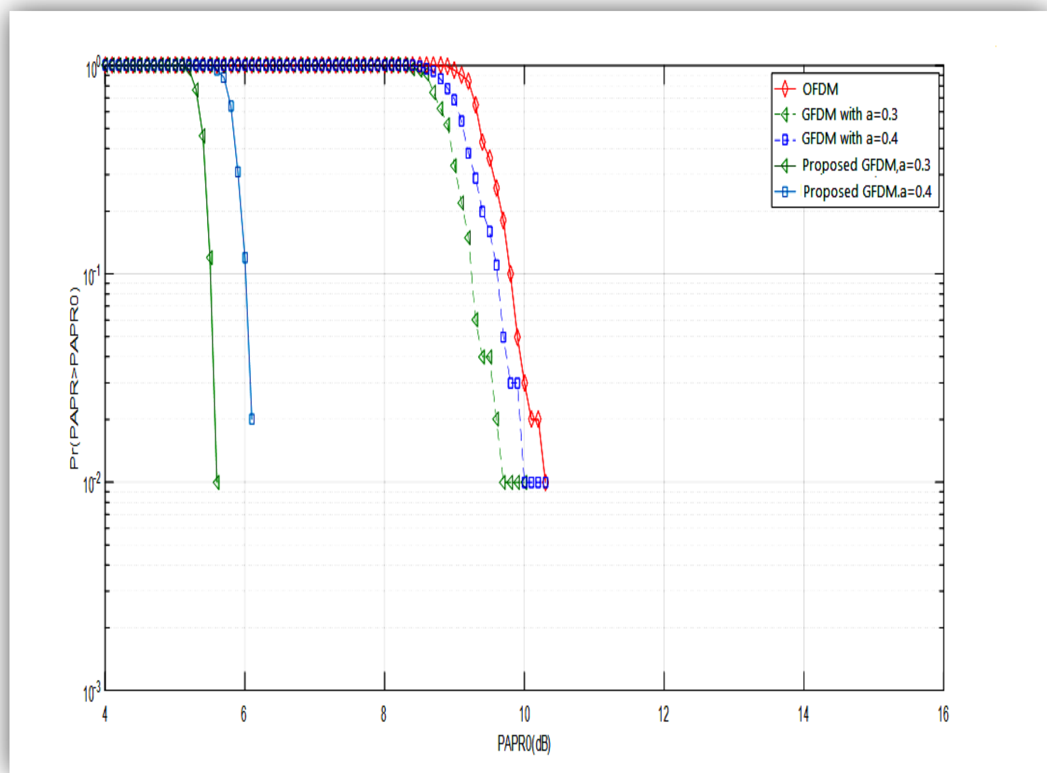

Fig.4 PAPR performance comparison of OFDM, normal GFDM and precoded GFDM for K=256, M=2

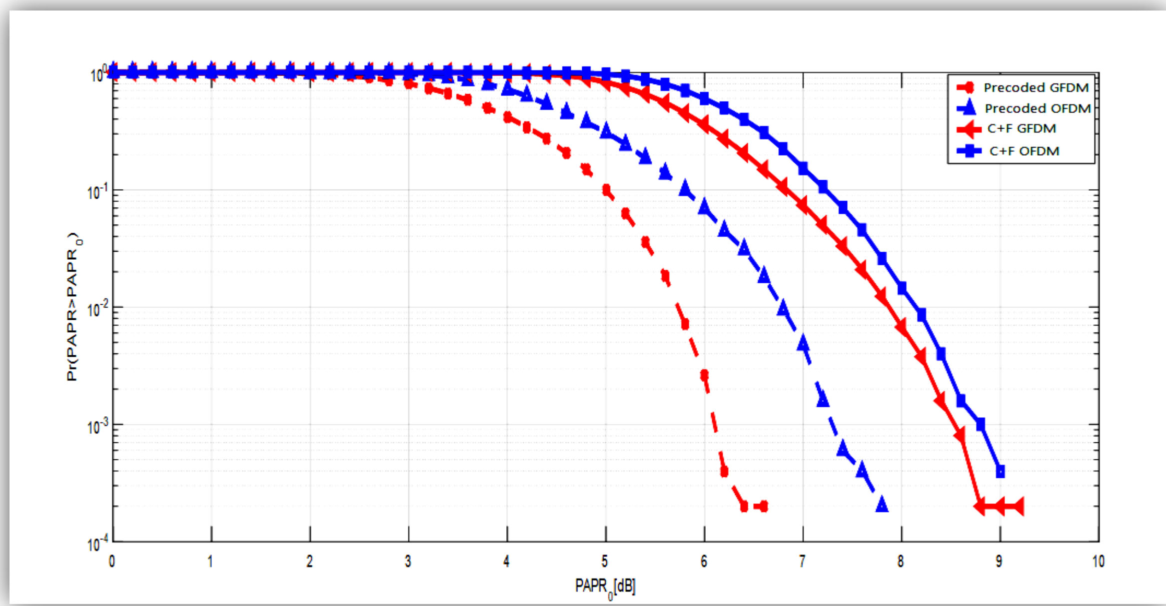

Fig.5 PAPR comparison curves for clipped and filtered GFDM and proposed method for K=256, M=2 and a=0.3

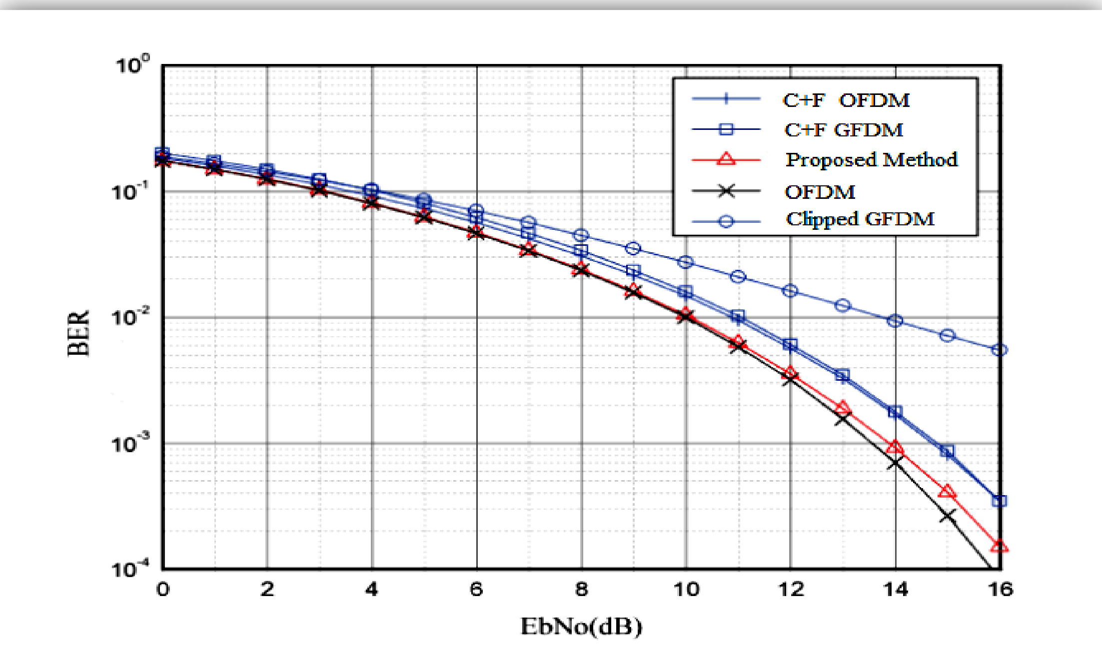

Fig. 6 BER performance comparison of proposed method and Clipped and Filtered GFDM scheme

5. Conclusion

At the end, it can be concluded that the PAPR is a major issue of multicarrier systems and it must be solved to make these systems compatible with future wireless generations. Keeping this in mind, some new methods have been suggested for OFDM and GFDM to make these systems more power efficient by improving their performance in terms of PAPR and BER. In this paper, the PAPR and BER performances of OFDM and GFDM systems are compared. The performance of GFDM with zad-off chu sequence is also analyzed. From the simulation results it may be concluded that the proposed GFDM system performs better than that of conventional GFDM in terms of PAPR and OOB radiation. Thus from the proposed work, it can be concluded that, GFDM signal is a better choice for future wireless communication systems with low PAPR and improved efficiency.

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