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Research paper

Performance Analysis of Universal Filtered Multi-Carrier -Isotropic Orthogonal Transform Algorithm for Next Generation Wireless Networks

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Abstract

In this paper, a novel time-frequency localization scheme implementation based on isotropic orthogonal transform algorithm (IOTA) prototype filter has been devised for universal-filtered multi-carrier (UFMC) system. UFMC is one of the suggested fifth generation (5G) waveform candidate. Prototype filter IOTA guarantees an optimal localization in the time-frequency domain. By orthogonal a Gaussian pulse in both time and frequency, it finds the name isotropic orthogonal. Due to the characteristics of pulse shaping, IOTA is implemented in UFMC to avoid out-of-band (OOB) radiation and so obtain high spectral efficiency. IOTA-UFMC is compatible for all kind of multiple-input-multiple-output (MIMO) application. This paper evaluate the performance of the proposed IOTA-UFMC systems through the simulations, the results of 10-4 bit error rate (BER) at low SNR and peak-to-average-power ratio (PAPR) is compared with the existing systems.

Keywords: *Out-of-band radiation, Isotropic orthogonal transform algorithm, Universal filtered multi-carrier, Peak to average power ratio.*

1. Introduction

The concept of 5G attracting the attention of research community, industry and the standardization bodies even sometimes the end mobile user. One of the most important key challenges of the 5G waveform is high spectral efficiency operation with the efficient MIMO integration; UFMC is suitable 5G non-orthogonal waveform candidate which comprises the filtered OFDM and FBMC [1]. When compared with FBMC, UFMC supports multiple subcarriers with simple filter design within a given carrier bandwidth. Typically, easy integration and implementation with MIMO leading to the future scope applications like wide area internet of things (IOT), mobile communications, millimeter wave communications, wireless body area networks and cognitive radio network applications etc., with the improved spectral efficiency [1].

The recent mobile communication networks working based on the OFDM system [2]. Though it supports variety of applications, in the aspect of spectral efficiency, its performance is poor because of the presence of cyclic prefix and time-frequency offset [3]. This kind of problem should be destroyed at the transmitter side itself. Proper implementation of time-frequency localization is the only solution for it. It is achieved by IOTA which will be discussed in section III.

In [4], 5G developments efficiently support the fragmented spectrum operations to utilize the available spectrum resources. This development promotes the application of machine to machine (M2M) communications; dynamic behavior of cognitive radio networks, communication with heterogeneous networks, and cyber-physical system radio, etc. In [5], the designs of 5G air interface modulation techniques were discussed to mitigate the problems in open loop synchronization.

It suggests autonomous timing advance (ATA) mechanism to improve the robustness against delay spread and timing misalignment among the machine type communication (MTC) devices. An ATA calculates the suffered time by round trip and apply for the timing advance.

In [6][7] the comparison of OFDM, FBMC and UFMC were completed. FBMC requires long filter length to mitigate the out-of-band emission (OOB). It is an attractive alternative for the wireless mobile communication to avoid inter-symbol interference (ISI) and inter-carrier interference (ICI). But, it is implemented using polyphase filter structure. FBMC system filter function is working per sub-carrier basis. This introduces the system complexity; multi-rate signal processing techniques [8] are the only solution for design complexity.

In [9], the UFMC system filter functions based on per sub-band per sub-carrier basis to reduce the OOB radiation and subsequently minimize the potential ICI (between adjacent users). [10] Universal filter reduces the filter length and system complexity. In [11], in case of asynchronous transmission, the co-operative multipoint universal-filtered multi-carrier (COMP-UFMC) technique offers the orthogonality between the multiple carriers for the reduction of time and frequency misalignment/offset. COMP-UFMC technique is the centralized unit. The major issue with COMP-UFMC is if any delays occur in decision (or) faults occur in system model it humiliates the system performance.

In [12], two techniques had been hosted to mitigate the effects of ICI in UFMC. Delaying the transmitted UFMC waveform corresponding to the transmitted wave in which the 10% loss of signals occurs with worst latency characteristic. [13]Implementing

window at the UFMC receiver to suppress ICI. These whole problems can be mitigated at the transmitter side itself by introducing IOTA filter into UFMC.
The rest of the paper is structured as follows. Section II introduces the state of the Art. Section III discusses the proposed system design. Section IV presents the simulation analysis and the Section V concludes the proposed system design.

2. State of the Art

In this section we deals with the conventional UFMC system and IOTA prototype filter. IOTA filter assures the localization for both time-frequency domains. Conventional UFMC system provides well-known robustness against the multipath varying fading channel.

2.1. Conventional UFMC System

In Fig.1. shows the conventional block diagram of the UFMC system. UFMC is a generalization of filtered orthogonal frequency division multiplexing (F-OFDM) and filter-bank multi-carrier system (FBMC). In UFMC, the group of carriers called as sub-carriers and a group of sub-carriers called as sub-band. Sub-band filtering is referred as a physical resource block (PRB) in LTE.
In UFMC system, the whole frequency bandwidth is separated into 'm' number of sub-bands. All sub-bands consist of 'k' number of sub-carriers in each. Offset-quadrature amplitude modulation (O-QAM) signal is fed into Inverse Fast Fourier transformation (IFFT) processor for converting frequency domain into time domain sequence. Depends on the application, the data sequences are imposed on the sub-carriers to improve the system performance. If the data sequences are less than the sub-carriers, the same sequences can be imposed or else zeros are padded over unassigned sub-carriers for the time domain conversion of the IFFT process. The IFFT output signal is filtered out by FIR filter, i.e., Dolph-Chebyshev filter is used in conventional UFMC system.
Assume the orthogonality between the sub-carriers is missed and then a number of sinc side lobes cause the higher out-of-band emission to the neighboring sub-bands. It leads to a problem of synchronization error. These kinds of problems are rectified by the filtering process in UFMC. For proposed system design; Dolph-Chebyshev filter in conventional UFMC is replaced by IOTA prototype filter. Through which the optimal time and frequency localization are achieved.
The N-point IFFT output signal is represented by,

$$x_{m,Q}(n)=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}X_{m,Q}(k)\exp\left(\frac{i2\pi kn}{N}\right) \qquad (1)$$

N-point IFFT time domain signals are fed into the FIR filter and it's summed together to generate the UFMC modulated signal. It can be expressed as,

$$s_m(n)=\sum_{i=1}^{Q}s_{m,i}(n)=\sum_{i=1}^{Q}\sum_{l=0}^{L_F-1}f_i(l)x_{m,i}(n-l) \qquad (2)$$

Where L_F is the FIR filter length.

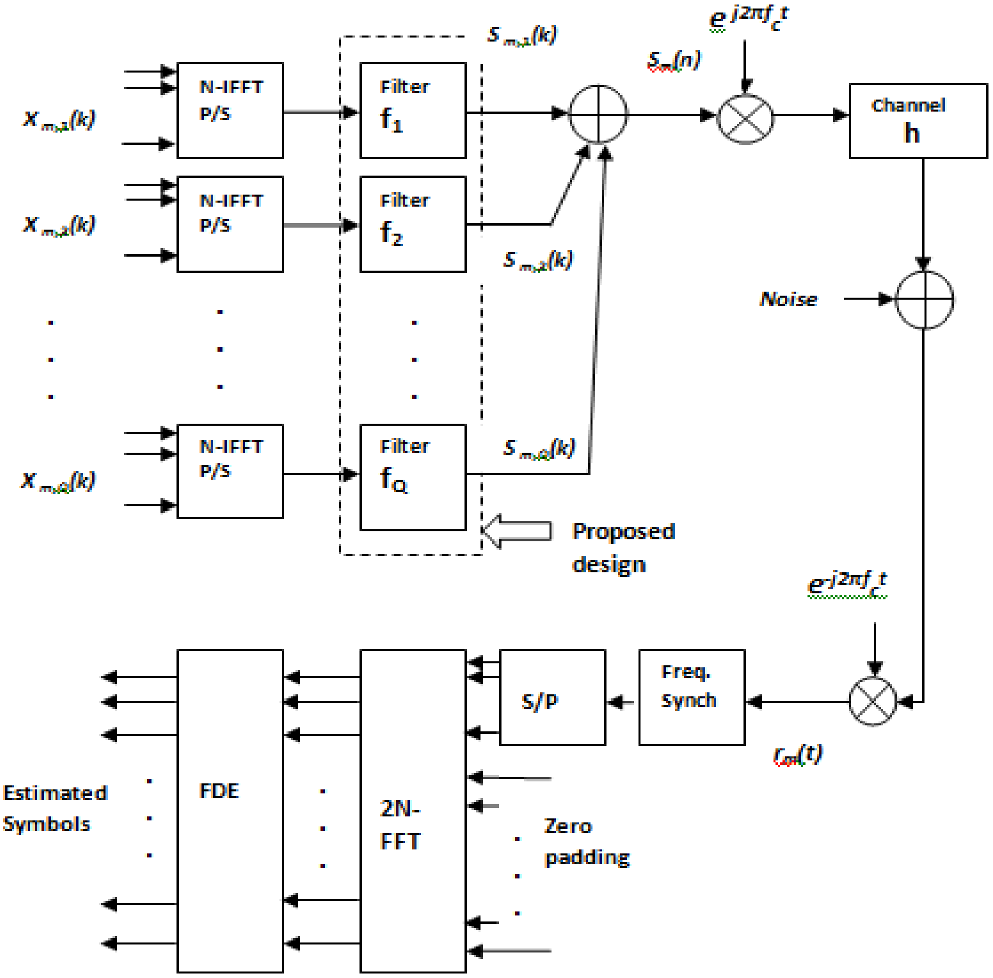

Fig. 1: Block diagram of UFMC system

2.2. IOTA Prototype Filter

IOTA implements the perfect pulse shaping with time and frequency localization for avoiding the ISI and ICI. In [14], the orthogonal analysis of Gaussian pulse with its time and frequency shifted properties were discussed.

Since the transmitted channels are time and frequency dispersive, it is required to design the system with optimal time and frequency localized to avoid interferences. Implementation of IOTA prototype filter into UFMC system offers the better spectral efficiency than the conventional system.

The properties [15] of IOTA suggest the favorable solutions for future mobile communication.

IOTA basis function can be written as,

$$I_{m,n}(t) = j^{m+n} \exp(j2\pi mft) I\left(t - \frac{nT}{2}\right) \qquad (3)$$

In which *m* is the orthogonal sub-carrier index, *n* is the orthogonal time index signal, j^{m+n} represents the phase offset factor of IOTA pulse with the time-shifted component $\frac{T}{2}$. Time and frequency localized IOTA basis Gaussian pulse can be written by,

$$s_I(t) = \sum_{l=-\infty}^{\infty} \sum_{k=0}^{K-1} \sum_{i=1}^{Q} \begin{pmatrix} j^{m+n} x_{m,i}(n)\ g(t - lT_\Delta(\frac{T}{2}) \\ * \exp\ (j2\pi \frac{F_\Delta}{T} kt) \end{pmatrix} \ldots.(4)$$

Where $s_I(t)$ represent the transmitted signal of OQAM-IOTA Gaussian pulse with the input $x_{m,i.}(n)$. $T_\Delta(\frac{T}{2})$ is the symbol period between the two real-valued data symbols, T_Δ is the time spacing, $\frac{F_\Delta}{T}$ is the sub-carrier spacing of the two real-valued data symbols and F_Δ is the frequency spacing [16].

3. Proposed System Design

In this section, we discussed about the proposed system of IOTA-UFMC and system analysis. It has an advantage of (i) superior pulse shaping to avoid the OOB radiation, (ii) reduced system complexity, (iii) Better spectral efficiency than the conventional UFMC system.

3.1. IOTA-UFMC System

In figure.1, the dotted line represents the proposed design of IOTA-UFMC system. In which the FIR filter is replaced by the IOTA prototype filter. This filter offers the pulse shaping with the maximum permissible passband. The presence of IOTA achieves the time and frequency localization.

Step 1: Let us consider the symbols of n -th sub-band of m -th branch as $x_{m,Q}(k)$,

$$X_{m,Q}(k) = \alpha_{m,n}(k) + j\beta_{m,n}(k) \qquad \ldots\ldots\ldots\ldots(5)$$

Where $\alpha_{m,n}(k)$, $\beta_{m,n}(k)$ is the real and imaginary valued information in the O-QAM symbol

Step 2: The baseband signal $X_{m,Q}(k)$ is fed into N-point IFFT block, which produces the output as $x_{m,Q}(n)$. Represented by in eqn. (1).

Step 3: These time domain signals pass through the IOTA filter. Eqn.(2) can be changed as,

$$s_m(n) = \sum_{i=1}^{Q} s_{m,i}(n)$$

$$= \sum_{i=1}^{Q} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \begin{pmatrix} j^{m+n} x_{m,Q}(n) \exp(j2\pi mft) \\ * I(t - \frac{nT}{2}) \end{pmatrix} \ldots\ldots\ldots..(6)$$

IOTA-UFMC system output can be expressed as,

$$s(t) = \sum_{l=-\infty}^{\infty} \sum_{m=0}^{M-1} \sum_{n=0,Q}^{N-1} \begin{pmatrix} j^{m+n} x_{m,Q}(k) g(nt - lT_\Delta \frac{T}{2}) \\ * \exp(j2\pi \frac{F_\Delta}{T} kT) \end{pmatrix} \ldots..(7)$$

In this *N*, *M* represents the number of sub-carrier and time instance parameter of UFMC system. Because of these appreciable characteristics of IOTA filter, though the signal transmits over the poor dispersive channel, it can avoid ISI and ICI. The signal dispersion is corrected by the IOTA-UFMC system. It offers better spectral efficiency. It is proved by the spectral efficiency analysis below.

3.2. Analysis of Spectral Efficiency

Let us consider the UFMC system, in which K - number of subcarriers carries M –number of bits per symbol. The overall system bandwidth is represented by $B = (K - 1) f_{c\Delta} + \Delta f$ where $f_{c\Delta}$ is the carrier spacing between the adjacent carriers, Δf is the frequency dispersion and T_s is the sampling period. The rate of information is represented as $R = \frac{1}{T_s}$. The spectral efficiency is calculated by, $\eta = \frac{RKM}{B} = \frac{M}{f_{c\Delta} T_s}$. In other words, the spectral efficiency regarding density is $\rho_u M, \ where\ \rho_u = \frac{1}{f_{c\Delta} T_s}$ The UFMC system can progress the maximum efficiency $\eta = M$ when the UFMC density ρ_u approaches unity. It means the carrier spacing between the adjacent carriers should be equal to the symbol rate.

Now, Let us compare UFMC spectral efficiency with the existing OFDM system. In which M number of bits per symbol is carried by the K number of subcarriers. The overall system bandwidth is represented by $B = (K - 1) f_{c\Delta} + \Delta f + f_{cp}$ where f_{cp} is a spectrum of the cyclic prefix. All other notations are same as the previously mentioned. The spectral efficiency is calculated by

$$\eta = \frac{M}{f_{c\Delta}T_s + f_{cp}T_s} = \rho_o M \text{ when } \rho_o = 1,$$

$T_s \propto \dfrac{1}{f_{c\Delta} + f_{cp}}$ which means the symbol rate depends upon the carrier spacing as well as the spectrum of cyclic-prefix. i.e., as the reduction of cyclic prefix spectrum band improves the spectral efficiency. The spectral efficiency is saved by $f_{cp}T_s$ times than the existing OFDM system.

3.3. Analysis of ISI and ICI

When the signal travels on the channel, the nature of the transmitted signal is slightly modified so that its protuberance on the pattern will cause ICI and ISI due to lack of orthogonality. With the presence of IOTA prototype filter, the new requirement of time and frequency localization is achieved to overcome the flaw of ICI and ISI.

The analysis of ICI and ISI consist of following requirements,

i). The resulting modulating signal is time invariant. So that, after taking Fourier Transform the orthogonality will be maintained in the time domain, it leads the system continue orthogonality in frequency domain too.

ii). The bandwidth and duration of the signal are to be closed to the value of Gaussian pulse.

iii). The bandwidth of the IOTA-UFMC filter is considerably lesser than the FIR filter used in conventional UFMC.i.e., Narrowband filter for IOTA-UFMC. Because of that, the interference caused by the time offset between the transmitting users is eliminted.

4. Simulation Results

In this section, various simulation analyses are conducted to prove the proposed IOTA-UFMC system is superior to the existing conventional UFMC and OFDM systems. Considering the common simulation parameter as Size of FFT (N) is 128, number of users are 7, number of subcarrier per user is 13, inter-carrier spacing is 15kHz, the conventional FIR window is Dolph-Chebyshev with the standard side-lobe attenuation 40dB, Filter length (LF) is 31, cyclic prefix length (LCP) is 32, O-QAM Modulation scheme.

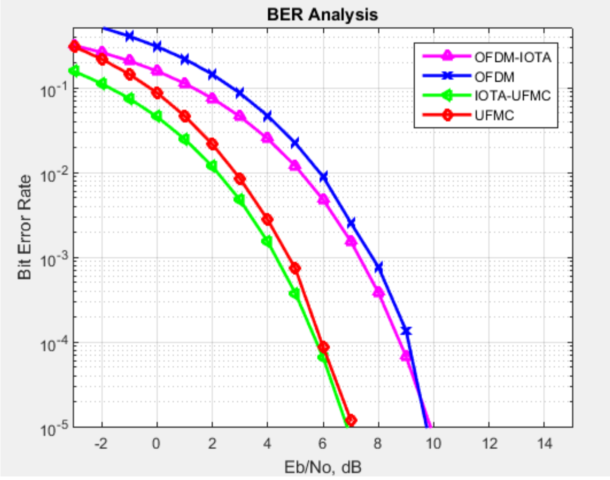

Fig. 2: Bit error analysis of IOTA applied UFMC and OFDM system

In Fig. 2, the bit error rate 10-4 is obtained at 5.8dB for the proposed IOTA-UFMC system and the same bit error rate 10-4 is obtained at 6.1dB for the conventional UFMC system. OFDM system and OFDM-IOTA system consist of the bit error rate 10-4 at 9 dB and 8.7 dB respectively. This infers that the proposed IOTA prototype filter is used to improve the system performance by 3dB SNR level.

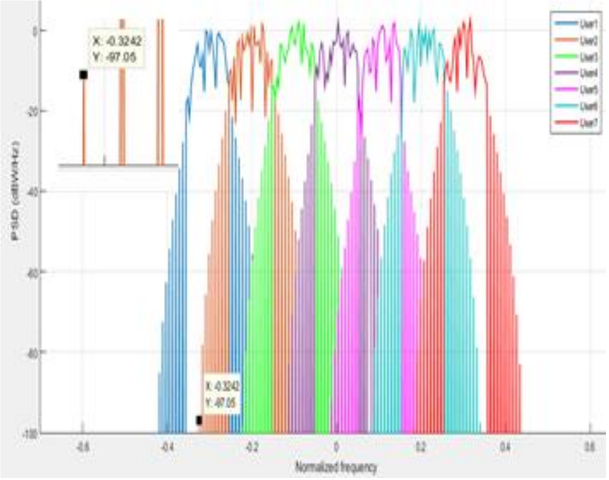

Fig. 3: Analysis of Out-of-band radiation for the proposed IOTA-UFMC

In Fig. 3.the proposed IOTA-UFMC system reduces the side lobes from -75dBW/HZ into -97dBW/Hz. When compare with the existing system, the proposed system is -22dBW/Hz advanced in side lobe avoidance.

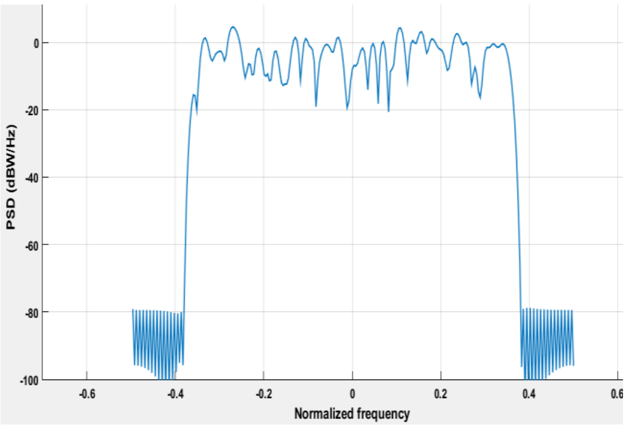

Fig. 4: Analysis of Out-of-band Emission for OFDM-IOTA

The IOTA prototype filter is examined with OFDM system also. In Fig. 4, inters that the OFDM-IOTA system reduces OOB radiation from -60dBW/HZ into -80dBW/Hz. In OFDM-IOTA, OOB radiation is reduced by 20dBW/Hz. Fig.3 and 4 shows that the IOTA prototype filter performance is superior in OOB radiation.

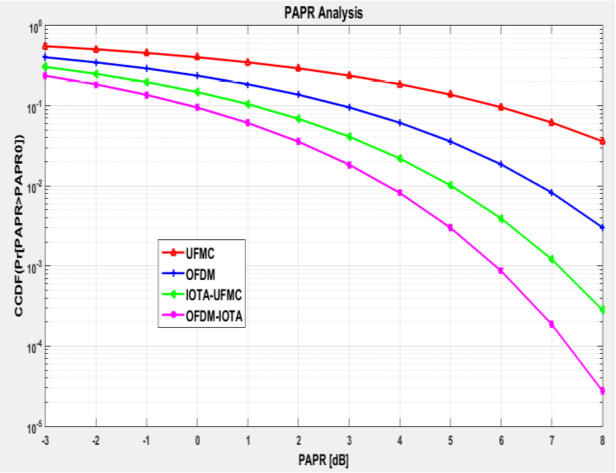

Fig. 5: Analysis of peak-to-average power ratio (PAPR)

The peak-to-average power ratio performance is analyzed in Fig. 5. The conventional UFMC has highest PAPR 8dB for complementary cumulative distribution function (CCDF) of 3.6X10-2. The conventional OFDM has better PAPR 8dB for CCDF of 3X10-3. This result infers that the proposed IOTA-UFMC and OFDM-IOTA has the PAPR of 7.2dB and 6.1dB respectively. The PAPR of OFDM-IOTA is about 2.9dB higher than the conventional OFDM and 1.1dB higher than the IOTA-UFMC system. Thus, the prototype IOTA filter supports the PAPR reduction.

5. Conclusion

This paper has analyzed the complete performance of both IOTA-UFMC and OFDM-IOTA system. Though the aspect of PAPR reduction of OFDM-IOTA superior to the IOTA-UFMC, it infers that the IOTA filter is suitable for the PAPR reduction and out-of-band emission. It proves that the IOTA prototype filer is one of the novel time and frequency localization scheme. The simulation results prove the superiority of the system on out-of-band radiation, significant improvement in PAPR, BER performance and spectral efficiency. From the detailed system performance analysis, we can conclude that the proposed IOTA-UFMC system is one of the potentially attractive and suggested 5G waveform candidates for the next generation wireless mobile networks.

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