

Modified isotropic orthogonal transform algorithm-universal filtered multi-carrier transceiver for 5G cognitive radio network applications

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ABSTRACT

Rapid developments in modern wireless communication permit the trade of spectrum scarcity. Higher data rate and wider bandwidth emerge the development in growing demand of wireless communication system. The innovative solution for the spectrum scarcity is cognitive radio (CR). Cognitive radio is the significant technology used to utilize the spectrum effectively. The important aspect of CR is sensing the spectrum band and detects the presence or absence of the primary user in the licensed band. Moreover, another serious issue in next generation (5G) wireless communication is to decide the less complex 5G waveform candidate for achieving higher data rate, low latency and better spectral efficiency. Universal filtered multi-carrier (UFMC) is one of the noticeable waveform candidates for 5G and its applications. In this article, we investigate the spectrum sensing methods in multi-carrier transmission for cognitive radio network applications. Especially, we integrate the sensing algorithm into UFMC transceiver to analyze the spectral efficiency, higher data rates and system complexity. Through the simulation results, we prove that the UFMC based cognitive radio applications outperform the existing Orthogonal Frequency Division Multiplexing (OFDM) based CR applications.

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1. INTRODUCTION

An explosive growth in wireless communication focuses on designing the appropriate waveform. The primary goal of 5G is non-orthogonal waveform for maintaining synchronism in a system. The concept of 5G attracts the attention of industries, standardization bodies and a lot of researcher communities. The requisite for the design of 5G radio access is to provide higher connectivity and higher spectral efficiency. In recent years, several numbers of waveform candidates had been proposed for the improvement of higher data rate, low latency, high mobility and better spectrum reuse [1]. UFMC is one of the suitable 5G non-orthogonal waveform candidates who comprise the features of filtered OFDM and filter bank multi-carrier (FBMC). 5G waveform candidates offer best localization of frequency and time to fit with diverse applications like the machine to machine communication (M2M), Internet of Things (IoT), millimeter wave communication [2-4] and cognitive radio network applications. The present cellular communication networks were working based on OFDM multicarrier modulation technology [5-7]. Even though it helps for the current discussion, appending cyclic prefix squander some bandwidth. It leads to the system to spectral inefficiency. To avoid such a scenario, next-generation mobile communication improves by a robust non-orthogonal waveform candidate with cognitive radio applications, ie, UFMC-CR.

Cognitive radio network (CRN) is one of the novel technologies for the improvement of spectrum efficiency [8]. In which, the available spectrums are sensed and allocated to the other users without causing interference. Since it has the dynamic adaptation characteristics, it is helpful for M2M communications, IoT applications and also for short burst communications [9]. Spectrum sensing is the most significant issue in CRNs. Energy detection (ED), matched filtering, waveform based sensing and cyclo-stationary feature detection (CFD) are the methods used for sensing spectrum [10]. Out of all these CFD is one of the superior sensing methodologies, to sense the signal at low power.

Rest of the paper has been organized as follows. Section 2 explains the aspect of UFMC 5G waveform candidate. Section III gives the operation of Cognitive Radio Network. Section IV discusses the function of proposed CR enhanced 5G system model. Section V explains the simulation results and Section VI concludes the work.

2. UNIVERSAL FILTERED MULTI-CARRIER 5G WAVEFORM CANDIDATE

5G wireless systems and cellular networks are the future scopes of telecommunication standards away from the existing 3G, 4G Long Term Evolution (LTE) principles. Multicarrier system supports higher data rate than the conventional modulation methods. Diverse waveform candidates proposed for the 5G platform [11]. Though variety of suggestions towards the next generation networks among them, one of the admired waveform candidates is UFMC. It is the restructured adaptation of OFDM system with the features of FBMC [12-14]. The UFMC system executes sub-band filtering sub-carrier modulation. $H(Z)$ universal filter does Sub-band filtering. It also carries out serial to parallel conversion of input sequence $x(k)$. The full band is divided into 'm' number of Sub-bands and then given into down sampler. Down sampling is to reduce the system complexity because it supports Faster-Than-Nyquist (FTN) filtering. It also used for short bust communication. It decreases latency too.

Conventional UFMC system is implemented using FIR filter. In which prior knowledge of the information required for the receiver. It may radiate the signal in the out of band (OOB). Because of that inter-carrier interference (ICI) and inter-symbol interference (ISI) is introduced into the message. To conquer such problem Isotropic Orthogonal Transform Algorithm (IOTA) prototype filter is used [15]. It achieves time and frequency localization at the transmitter stage itself. Pass band adjustment in filter reduces OOB radiation, ICI, and ISI.

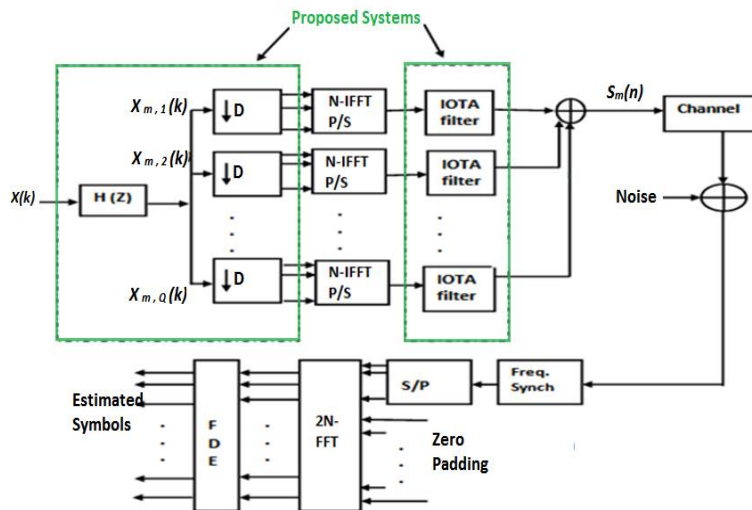


Figure 1. Proposed IOTA-UFMC Transceiver block diagram

Figure.1 describes the proposed UFMC block diagram by using IOTA prototype filter. The dashed-dot lines represent the proposed work of the system. IOTA filter achieves maximum permissible pass band pulse shaping [16]. Transmitted signal of UFMC system expressed as,

$$s(t) = \sum_{l=-\infty}^{\infty} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \left(j^{m+n} x_{m,Q}(k) g\left(nt - lT_{\Delta} \frac{T}{2}\right) \exp\left(j2\pi \frac{F_{\Delta}}{T} kT\right) \right) \quad (1)$$

In (1), 'm' represent a sub-carrier index, 'n' represent time index signal, 'M' is the number of sub-carrier and 'N' is the time instance parameter of UFMC signal. j^{m+n} -represent the component of $\frac{T}{2}$ time shifted phase-offset factor of IOTA filter. $\frac{F_{\Delta}}{T}$ -and T_{Δ} is the sub-carrier frequency and time spacing of data symbols. At the receiver, frequency domain processing and equalization is performed by FDE. The output of FDE is the estimated symbols.

3. COGNITIVE RADIO NETWORKS

For the achievement of most popular and different aspects of next-generation wireless communication systems, cognitive radio is the critical technology to utilize the available wireless networks. CRN is the novel technology to improve the spectral efficiency an enormously. The primary target of CR is to discover the unoccupied spectrum and adaptively assign it to the cognitive users [17]. Hence, the complete spectrum is effectively utilized. This kind of utilization leads the system towards the green communication. It avoids the wastage of spectrum. This technology protects the next generation wireless systems from spectral warming.

Spectral warming is the new term proposed from the name of global warming. Global warming defined as the observed temperature changes due to the climate changes and the increased level of CO₂. In the same way, spectral warming is deemed as the increasing spectral intensity at the most populated area in another way poor spectral intensity at rural area. It may lead the geo-location towards the spectral warming. CRN is one of the best solutions for establishing green communication in wireless systems. The principal function of CR is sensing the spectrum whole and allocating it to the secondary user's on-demand basis. Sensing is the crucial parameter in CR[18]. The most desired spectrum sensing method is cyclo-stationary feature detection (CFD).

CR spectrum sensing requires the inventive method to progress the measured signal from the physical layer and to process the received signal while transmission to an application layer. The conventional way of sensing is energy based sensing. In this method, no needs for prior information for processing received and transmitted signal [19]. To implement CFD, the system requires partial prior knowledge about the Trans-received signal. In the conventional method, the signal of interest (SoI) is difficult to segregate from the noise signal at low signal to noise ratio (SNR). But, in CFD, SoI can be separable from the noise signal at poor SNR level. Because of saving signal power CFD is one of the advisable spectrum sensing methods [20].The subcarrier signals are processed by the spectral correlation. The power spectral components are the features of received components, i.e., it may be sampling period or frequency, rate, preamble, a prefix of the signal, encoding information, etc.

The received signal $s(t)$ is processed by the autocorrelation. From autocorrelation result, the spectral correlation function is absorbed. It is given by,

$$S_s(f; \alpha) = \int_{-\infty}^{\infty} R_x(\tau; \alpha) e^{-i2\pi f\tau} d\tau \quad (2)$$

$$R_x(\tau; \alpha) = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} R_x\left(t - \frac{\tau}{2}, t + \frac{\tau}{2}\right) e^{-i2\pi\alpha\tau} dt \quad (3)$$

where 'α' represents the cyclic frequency component of a received signal. This technology permits the sharing of the licensed band with other unlicensed users without causing interferences. The next section describes the CR enhanced 5G waveform system model towards green communication to improve spectral efficiency by reducing the spectral warming.

4. SYSTEM MODEL-CR ENHANCED 5G

The proposed system model CR enhanced 5G waveform candidates UFMC is implemented with the social aspects. Various applications of this system listed as secure cyber communication, public safety communication- emergency communication, biomedical applications, machine-to-machine communication and cloud computing IOT [21].

Figure 2 Shows the proposed system model of CR enhanced IOTA-UFMC transceiver. In the CR system, two different users involved in the process namely licensed and unlicensed user. The performance analysis of CR is evaluated by two factors.

1. The probability of detection (PD) represents the presence of licensed users at the licensed band.
2. The probability of false alarm (PF) indicates the presence of licensed users when licensed users are not available at the licensed band.

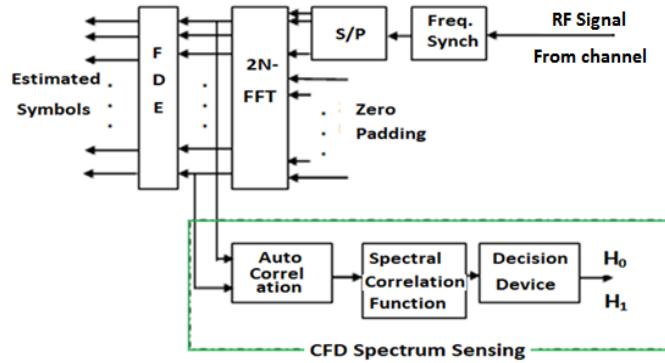


Figure 2. Proposed system model- CR enhanced IOTA-UFMC transceiver block diagram

CR system performance is right if the probability of detection is as high as possible while the probability of false alarm is as low as possible. The proposed systems can improve the in-band full duplex communication, suitable waveform design for 5G and the spectrum extension.

Let ‘ t_s ’ is the available sensing time, ‘ M ’ is the total number of samples and ‘ λ ’ is the detection threshold used in the decision device for deciding hypothesis H_0 or H_1 . For the threshold λ , the probability of detection is given by.

$$P_D(\lambda, t_s) = P_r(R_s(\tau; \alpha) > \lambda | H_1) \tag{4}$$

For the detection threshold, the probability of false alarm is given by

$$P_F(\lambda, t_s) = P_r(R_s(\tau; \alpha) > \lambda | H_0) \tag{5}$$

Selection of detection threshold is one of the most significant issues in spectrum sensing. If the selected λ is low value, then the system undergoes into spectrum handoff often. If it is high, then it leads to poor spectrum utilization. With this scenario, it is must to select the threshold in optimum. The proposed system design worked with the optimal decision threshold Varshney-Chair fusion rule [22],

$$\lambda = \sum_{k=1}^M \left[I_k \log \frac{P_D^k}{P_F^k} + (1 - I_k) \log \frac{1 - P_D^k}{1 - P_F^k} \right] + \log \frac{P(H_1)}{P(H_0)} \tag{6}$$

Where, ‘ I_k ’ is the binary decision from the k^{th} slot. If $\lambda \geq 0$, then the licensed user appears; otherwise, there exists a spectrum hole.

4.1. Tradeoff: sensing time-throughput

Sensing time is the term to measure the period of sensing of secondary users to access the spectrum hole. It consists of three scenarios, i) No primary user available, the spectrum hole is detected without false alarm ii). Spectrum holes are detected when the primary users are available iii). No primary user present, no spectrum hole is detected. The achievable throughput is interpreted with the probabilities of these three scenarios. ‘ \mathfrak{R} ’ represents the rate of achievable throughput for the secondary user with respect to PD, PF, and the probability of miss detection PMD.

$$\mathfrak{R}(t_s) = \mathfrak{R}_D(\lambda, t_s) + \mathfrak{R}_F(\lambda, t_s) + \mathfrak{R}_{MD}(\lambda, t_s) \tag{7}$$

We can define,

$$\Re_D(\lambda, t_s) = \frac{T - t_s}{T} C_1 (1 - P_D(\lambda, t_s)) P(H_1) \quad (8)$$

$$\text{where } C_1 = \log_2(1 + \text{SNR}_s)$$

$$\Re_F(\lambda, t_s) = \frac{T - t_s}{T} C_0 (1 - P_F(\lambda, t_s)) P(H_0) \quad (9)$$

$$\text{where } C_0 = \log_2 \left(1 + \frac{\text{SNR}_s}{\text{SNR}_p} \right)$$

$$\Re_{MD}(\lambda, t_s) = \frac{T - t_s}{T} (1 - P_F(\lambda, t_s) - P_D(\lambda, t_s)) P(H_0) \quad (10)$$

4.2. Spectralefficiency analysis

The UPMC system bandwidth is measured by $B = (K - 1)f_{c\Delta} + \Delta f$ where Δf is the frequency deviation, $f_{c\Delta}$ is represented by carrier spacing of adjacent carriers, K -number of subcarriers. Spectral efficiency for UPMC system is calculated by $\eta = \frac{RKM}{B} = \frac{M}{f_{c\Delta}T_s}$

Where, R is the information rate of M number of bits per symbol.

The spectral efficiency of existing OFDM system is measured by $\eta = \frac{M}{f_{c\Delta}T_s + f_{cp}T_s}$, in which f_{cp} is the

cyclic prefix band. When compared with the existing OFDM system, our proposed UPMC system is $f_{cp}T_s$ times better in spectral efficiency.

5. SIMULATION RESULTS

In this section, the proposed system model CR enhanced UPMC transceiver performance is analyzed by Monte-Carlo simulations. The typical simulation parameters are listed in Table 1.

Table 1. Simulation parameters

Parameters	
Number of DFT (N)	512
Prototype Filter	IOTA
Filter length	31
Normalized Cut-off frequency	0.25
Side-lobe attenuation	40 dB
Pass band ripple	0.30 dB
Modulation scheme	QAM/OQAM
Sub-carriers per user	13
System bandwidth	20MHz
Cyclic Prefix Length	30
Sampling frequency	20MHz
Primary users	4
Secondary users	3
Statistical channel parameter	AWGN, Generalized Extreme value distribution

Figure 3 depicts the BER Vs SNR performance comparison of Existing OFDM, UPMC, FBMC system achieves BER of 10^{-3} at the SNR of 24dB, 19.7dB, 12.5dB respectively. Whereas, proposed OFDM-IOTA, IOTA-UPMC achieves the BER of 10^{-3} at 15 dB and 13dB SNR itself. Hence the proposed IOTA-UPMC system saves SNR of 11dB and 6.7dB than existing OFDM and UPMC system respectively.

Proposed IOTA-UPMC system is enhanced with CR application. The critical parameter of CR is spectrum sensing. Cyclo-stationary feature detection spectrum sensing method is more excellent than other sensing techniques. CR application is tested by Receiver operating characteristics (ROC). CR enhanced IOTA-UPMC transceiver ROC characteristics simulated and plotted in Figure 4. It infers that, at 15 dB SNR, if the channel state information is not known to the receiver then the probability of false alarm significantly increases with the probability of detection. Channel state information moderately supports the CR application.

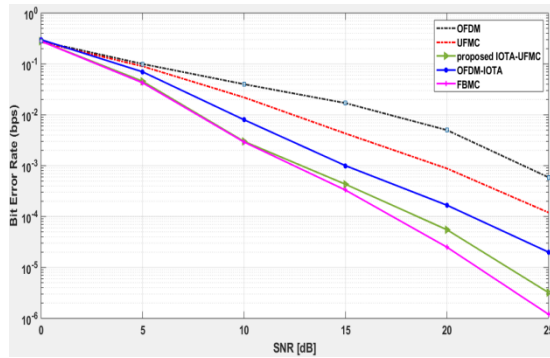


Figure 3. BER Vs SNR performance of various 5G waveform candidates

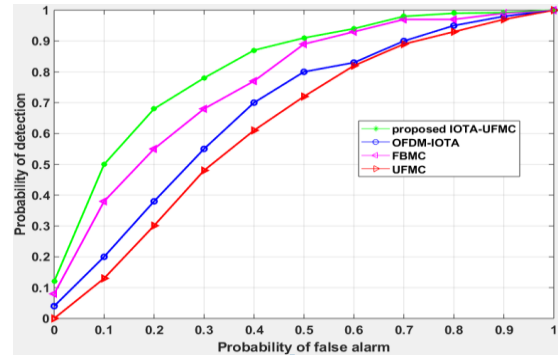


Figure 4. ROC with Un-Known channel co-efficient with SNR=15dB

Figure 5 depicts the analysis of ROC with the known channel state information (AWGN) at 15 dB SNR. For the 10% of probability of false alarm, 62% 80% probability of detection is achieved using CR enhanced FBMC system and IOTA-UFMC systems respectively. If the channel characteristics are very poor, then the detection probability of FBMC system is low compared to the proposed IOTA-UFMC systems. It is proved by the Figure 6 existing and proposed systems are tested under the generalized extreme value (GEV) distribution channel at 15 dB SNR. Our proposed IOTA-UFMC system achieves 69% of probability of detection with 10% of probability of false alarm. But, FBMC system achieves only 42% of detection probability. Hence, our proposed IOTA-UFMC system performs better than existing FBMC and OFDM system under poor channel states.

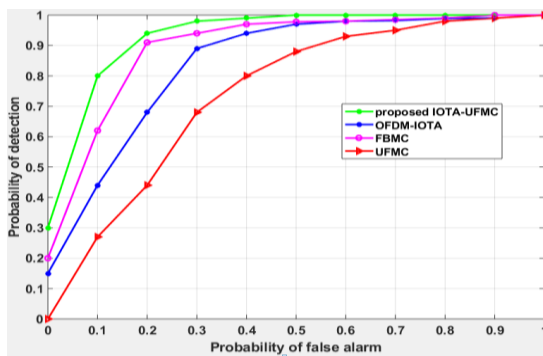


Figure 5. ROC with Known (AWGN) channel co-efficient M=3 and SNR=15dB

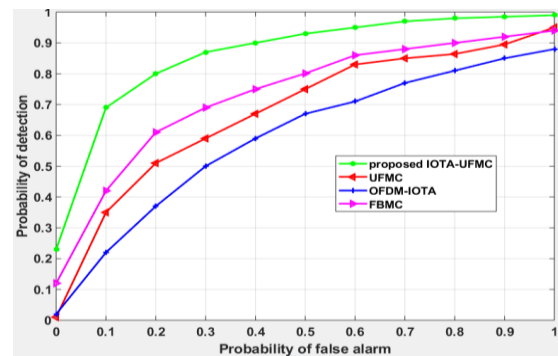


Figure 6. ROC with GEV distribution at SNR=15 dB

Figure 7 describes the ROC of CR enhanced IOTA-UFMC system. Existing and proposed systems are simulated using the pilot signal to improve the CR capability. The proposed system achieves 90% of detection probability at 10% of false alarm with known channel co-efficient M=3 at 15dB SNR with the pilot signal. Figure 8 shows the throughput analysis of CR secondary user when M=3. The optimum sensing time of CR system is 6ms. Concerning 6ms, 0.93 normalized throughputs are achieved using the proposed IOTA-UFMC system, 0.92 normalized throughputs are achieved using FBMC system, 0.86 for UPMC, 0.81 for IOTA-OFDM and 0.79 for conventional OFDM systems. Hence, the proposed IOTA-UFMC system achieves 14%, 7% and 1% improvements in throughput compared to OFDM, UPMC and FBMC systems respectively.

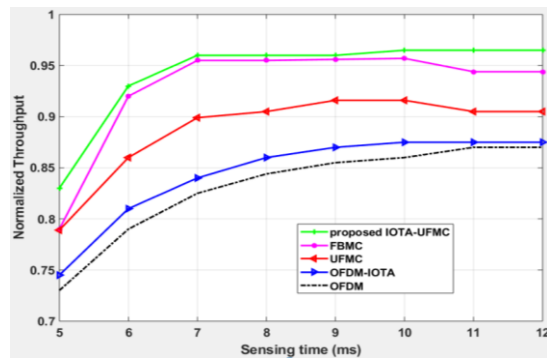


Figure 7. ROC of CR enhanced 5G waveform with $M=3$, $SNR=15$ dB, Pilot signal

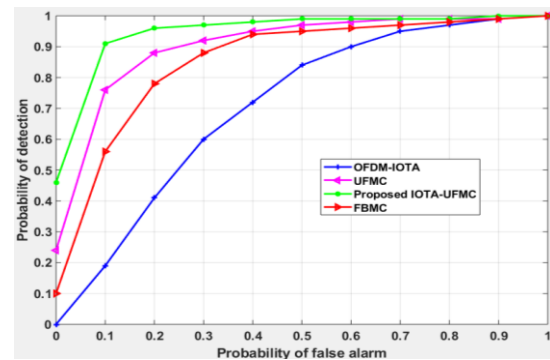


Figure 8. Normalized throughput for secondary user when (AWGN) channel co-efficient $M=3$

ROC analysis of CR system is tabulated in Table 2 According to Federal Communication Commission (FCC), an acceptable probability of false alarm is 10%, and the optimum probability of detection is 90%. The proposed IOTA-UFMC system achieves 91% probability of detection at 15dB SNR with known pilot signal. This is higher than all other systems. Hence, our proposed system closely meets the standard.

Table 2. Comparison of Probability of detection for various 5G waveforms with respect to standard probability of false alarm 10%

		Probability of detection			
		IOTA- UFMC	FBMC	IOTA- OFDM	UFMC
Probability of false alarm (0.1)	Un-known	0.5	0.38	0.2	0.13
	AWGN	0.8	0.62	0.44	0.27
	GEV	0.69	0.42	0.35	0.22
	Pilot signal	0.90	0.77	0.19	0.57

6. CONCLUSION

This paper has been delivered a complete performance analysis of proposed CR enhanced IOTA-UFMC transceiver. Through the Monte Carlo simulations, we achieved 95% of throughput with minimum sensing period of 6ms also it is proved that the UFMC based cognitive radio applications outperform the existing Orthogonal Frequency Division Multiplexing (OFDM) based CR applications. Therefore, Cognitive radio is one of the significant technologies used to utilize the spectrum effectively. Hence, our proposed CR enhanced IOTA-UFMC system supports spectral efficiency and higher data rate for the growing wireless environment. Therefore, IOTA-UFMC is one of the novel 5G waveform candidates for supporting M2M communications, cognitive radio applications, IOT and millimeter wave communications.

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