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Article

Analysis of Cognitive Radio for LTE and 5G Waveforms

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Abstract: Spectrum sensing is one of the major concerns in reaching an efficient Quality of service (QOS) in the advanced mobile communication system. The advanced engineering sciences such as 5G, device 2 device communications (D2D), Internet of things (IoT), MIMO require a large spectrum for better service. Orthogonal frequency division multiplexing (OFDM) is not a choice in advanced radio due to the Cyclic Prefix (CP), wastage of the spectrum, and so on. Hence, it is important to explore the spectral efficient advanced waveform techniques and combine a cognitive radio (CR) with the 5G waveform to sense the idle spectrum, which overcomes the spectrum issue. The demand for spectrum is ever increasing; however, spectrum is limited and is an acutely scarce resource. To alleviate the issue, techniques like Cognitive Radios (CR) have been devised. However, such techniques are non-standardized, and many variations of CR algorithms have been tried and tested. This paper details the several spectrum sensing methods tailored for CR. We explain the benefits, uniqueness, and drawbacks of the various techniques to provide a comprehensive review of the scene, including all recent and novel techniques of CR. Finally, we provided experimental results for the performance of the CR for key 5G and beyond modulation techniques to elaborate the dependency of the CR techniques for CR applications and provide a competitive review of their performance. Experiments show that the CR integrated with NOMA shows better performance as compared with existing techniques.

Keywords: CR; Energy detection; FBMC; NOMA; OFDM

1 Introduction

In wireless communication, spectrum is always a significant constraint, but still, a large bandwidth (more than two-thirds of the available) is wasted due to improper utilization, affecting the system's QoS (Quality of Services). In the year 1990, Joseph Mitola presented a technique based on software-defined radio (SDR), which can sense the idle spectrum, known as Cognitive radio (CR) [1].

Spectrum sensing is a crucial method, which tries to utilize the spectrum efficiently. In the latest research, it is seen that 90% of the spectrum is not utilized, and there is a scarcity of spectrum due to the exponential growth of wireless applications and devices [2]. At the beginning of the 19th century, communication services of telephony, radio, and television have been regulated according to the model to provide service to the public on basic fair and condition [3]. The main motive of 5G communications is to wield large sums of data traffic and providing several applications like Industrial Internet of Things (IIOT), smart home, automation, D2D communication, and high data-rate. As a result, data consumption will increase by 30% and we need an advanced radio to process the various applications. The advanced radio needs high spectral efficiency to provide a respectable caliber of services. The major challenge in the channeling out of the spectrum sensing technique is to sense the idle spectrum in the presence and absence of primary users (PU). The quality of service (QoS) of advanced mobile communication depends on spectral efficiency, low detection delay, high data-rate, low peak power, and accessing large numbers of devices. The successful regularization of 5G depends on developing and designing an advanced modulation scheme. The regulation of radio spectrum has different characteristics, they are:

- Licensed Spectrum
- Unlicensed spectrum
- Open spectrum

Over 160000 licensed users in India utilize amateur radio. Licenses are granted by the WPC (Wireless, Planning, and Coordination wing) of the Government of India [4]. Unlicensed spectrum is the freely available spectrum range for civilian usage. Although it is unregulated, it is severely congested due to many users sharing the same spectrum. Unlicensed bands operate on the 2.4 GHz ISM and 5 GHz UNII bands. The Office of Communication (Of-Com) in US, (2010) opened the television white space (TVWS) for secondary user (Unlicensed user) utilization. TVWS is a VHF/UHF band; it is a large portion of the RF spectrum that has become vacant after switching from analog to digital TV. The band can be operated in a cognitive approach without the primary analog TV user. The basic function of CR is to sense the idle spectrum of the primary user (PU) and allocate the idle spectrum to the secondary user (SU) without any disturbance and interference to PU [5]. There are two primary aims of the CR: first, it should not create and interference and degrade the performance of PU. Secondly, it should effectively locate the idle and unused spectrum bands to enhance the system's throughput [6]. The role of spectrum sensing is vital for both PU and SU. While the SU benefits from gaining additional bandwidth, the PUs interference is kept within an acceptable limit. CR attains higher spectrum availability using dynamic spectrum access [7] by permitting unlicensed users (Secondary Users) to use the available bandwidth from licensed users (Primary Users) while preventing any interference to the Primary users' transmissions [8]. CR decreases the inefficiencies caused by spectral congestion found in standard wireless environments by giving the opportunistic application of the frequency bands that are not congested by licensed users [9]. Therefore, white space in the spectrum can be used by unlicensed users without causing any significant interference [10]. Such efficient spectrum sharing methods allow users to coexist on the same frequencies without interfering with each other [11]. The uniqueness of CR lies in its capability to dynamically re-configure to optimal network usage. CR networks are specialized wireless networks, so they face more security attacks than traditional wireless and wired networks. The general security objectives of all wireless systems are privacy, integrity, availability, and access control [12]. The main goal of CR technology is to increase the throughput of the network and minimize the obstruction for primary users. CR can measure, sense, discover and be aware of radio channels individuality, accessibility of spectrum, and radio operational setting. There are three important sensing schemes in CR. Spectrum detection techniques such as Energy Detection (ED) [13], Matched Filter (MF) [14], and Cyclostationary Detection (CD) [15] have been proposed in the recent years. Energy detection is one of the most popular and straightforward techniques which can efficiently detect the spectrum at a high Signal to Noise Ratio (SNR). In ED, the energy of the received signal is estimated and compared with the predetermined threshold value. If the energy of the received signal is greater than the threshold value, then the PU is detected else not. However, its performance reduces at low SNR and noisy channels. Cyclostationary is utilized to sense the PU's spectrum using the mean and autocorrelation function of the transmitted signal. The CR detects the idle spectrum based on the following hypothesis, where (H_1) and (H_0) indicate the presence and absence of PU [16].

$$\left\{ \begin{array}{c} H0 : X_j(t) = N_j(t) \\ . \\ H1 : X_j(t) = h_j S(t) + N_j(t), j = 1, \ldots N_u \end{array} \right\} \tag{1}$$

where $X_j(t)$ is the j^{th} SU, N_u is the number of Second Pu, S(t) is the PU signal, $N_j(t)$ is noise, and h_j is the channel's gain between PU and SUs. Cyclostationary detection is used at significantly smaller SNR conditions. It is robust to noise and can carry out better than many sensing schemes like energy power, but it has significantly more computational complications [17]. The Cyclostationary spectrum detection method performs satisfactorily compared to other detection schemes because it has noise rejection capability. However, it also has some disadvantages, including spectral leakage of high amplitude signals, non-linearity, and high cost of operation [18]. The matched filter is a robust approach for sensing the idle spectrum of PU. The performance of the matched filter is efficient when the receiver knows the channel state information in advance. It is commonly utilized in radar, wherein we measure reflected signals, to detect the initially transmitted signal [19]. The schematic of the matched filter is given in Fig. 1.

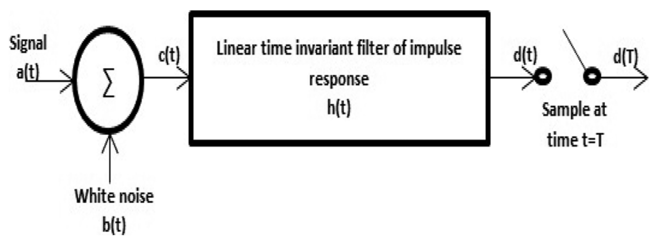

Figure 1: Sensing

The filter input $c(t)$ consists of a pulse signal $a(t)$ corrupted by noise $b(t)$, is shown by:

$$c(t) = a(t) + b(t), 0 \leq t \leq T \tag{2}$$

where T is an arbitrary internal observation, the pulse signal $a(t)$ may represent a binary symbol 1 or 0 in a digital communication system. The $b(t)$ is a sample function of a white noise process of zero mean and power spectral density $\frac{N_o}{2}$. The function of the receiver is to detect the pulse signal $a(t)$ in an optimum manner, given the received signal $d(t)$. In this work; we implement the ED spectrum sensing method for the OFDM, and Non Orthogonal Multiple Access (NOMA) systems. To enhance the spectrum efficiency of the overall system, Cognitive Radio is integrated with different modulation techniques. Probability of detection (Pd) *vs*. Probability of false alarm (Pfa), Pd *vs*. Signal to Noise Ratio (SNR), and Bit Error Rate (BER) *vs*. SNR for each of the modulation frameworks are calculated and analyzed for ED-based CR. The main objectives of the projected work are as follows:

- To implement a Cognitive radio for advanced waveforms and compare with OFDM structure.
- In this work, the detection of the spectrum is possible in both the absence and presence of the primary user.

- The different parameters such as Probability of detection (Pd), Probability of false alarm (Pfa), BER, and PAPR are estimated and compared for OFDM, FBMC, and NOMA waveforms.

Tab. 1 indicates the related literature published so for in Cognitive radio.

Table 1: Literature review

S. No	References	Aim	Result
1	[20]	To improve dynamic spectrum utilization and reduces intrusion to licensed users in CRN.	Improved Efficiency
2	[21]	To estimate Channel for MIMO OFDM system.	The system can acceptably update seeing range openings probability
3	[22]	To study and implement the MIMO-OFDM system	Research shows that the MIMO-OFDM system was fully analyzed and implemented through MATLAB simulation
4	[23]	To implement new resource undertaking schemes with adaptable modulation for enlivened multipoint or truncated as COMP with multiuser varying data specific yield MIMO- OFDM	Result gives cross outspread customer impedance and rots a specific customer MIMO channel into parallel no infringing spatial layers and reduces the transmit power.
5	[24]	To analyze BPSK modulation for the MIMO-OFDM system.	Efficiency, performance, and effectiveness are analyzed.
6	[25]	To improve the BER for multihop transmission.	The simulation results show a good agreement with the theoretical results.
7	[26]	To reduce a PAPR using sub-optimal PTS with threshold	PAPR reduction up to 2 dB
8	[27]	To avoid malicious users and improve the system efficiency.	Experimental results are carried out with 0.01 PFA and 0.9 Pd.
9	[28]	To detect a 4G carrier at the receiver using detector function. Auto-coherence function detector and cyclic cross periodogram detector are used.	Auto-coherence function detector gives a better detection than another one and gives a very high data rate.
10	[29]	To sense a TV white space for a Wi-Fi network by using K-out-of-N-rule.	This rule reduces spectrum recognition fault prospect and optimal spectrum sensing time to increase data broadcast throughput. It can resolve the spectrum shortage issue due to high data traffic in Wi-Fi networks,

2 System Model

2.1 Energy Detection in OFDM System

The schematic representation of ED using the OFDM system is given in Fig. 2. It is implemented by using Inverse Fast Fourier Transform (IFFT), CP, and Fast Fourier Transform (FFT) at the transmitting and receiver terminal of the system. OFDM structure utilized a Cyclic prefix (CP) to overcome the Inter Symbol Interference (ISI), which results in a loss of spectrum. ED detection is applied to the OFDM structure to determine the status of the PU [30]. The energy of the received signal is estimated and compared with the threshold value, and the decision is made.

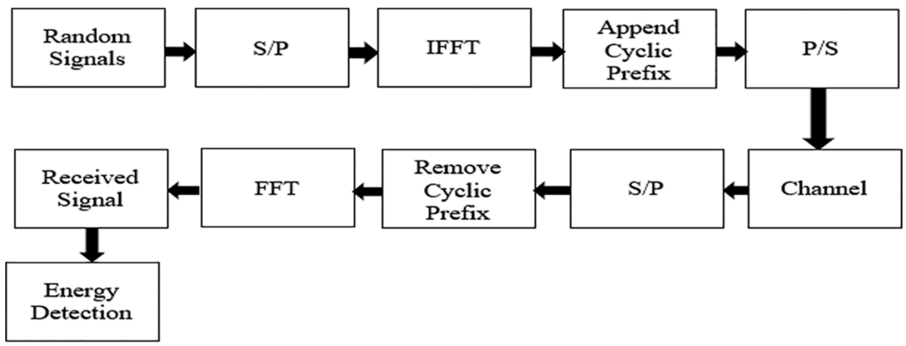

Figure 2: ED with OFDM

The OFDM symbols with N subcarriers can be written as:

$$Z = [Z_{0,}Z_1, \ldots Z_{N-1}]^T \tag{3}$$

The time-domain of OFDM symbols is obtained by IFFT:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{M=0}^{N-1} X_M \exp\left(\frac{j6.28M}{LN}\right) \tag{4}$$

where n is the index of OFDM symbols and L is denotes the overlapping value. The energy of the received signal is estimated as [31]:

$$z(n) = \frac{1}{N} \sum_{n=1}^{N} |x(n)|^2 \tag{5}$$

Energy detection is the best scheme for detecting independently distributed signals of high SNR conditions, but it is unsuitable for detecting correlated signals. The hypothesis for Ed is given as [32]:

$$\mathrm{H_0} : \mathrm{z(n)} = \sigma(\mathrm{n}) \tag{6}$$

$$\mathrm{H_1} : \mathrm{z(n)} = \mathrm{x(n)} + \sigma(\mathrm{n}) \tag{7}$$

where z(n) is the received signal, σ(n) is the noise variance, x(n)is the transmitted signal, H_0 indicates the absence of PU, and H_1 denotes the presence of PU.

2.2 Energy Detection in FBMC System

The schematic of FBMC is given in Fig. 3. FBMC is based on the multi-carrier technique and is considered one of the strong contenders for the 5G waveform. It is implemented by using an array of filters at the transmitter and receiver of the system [33].

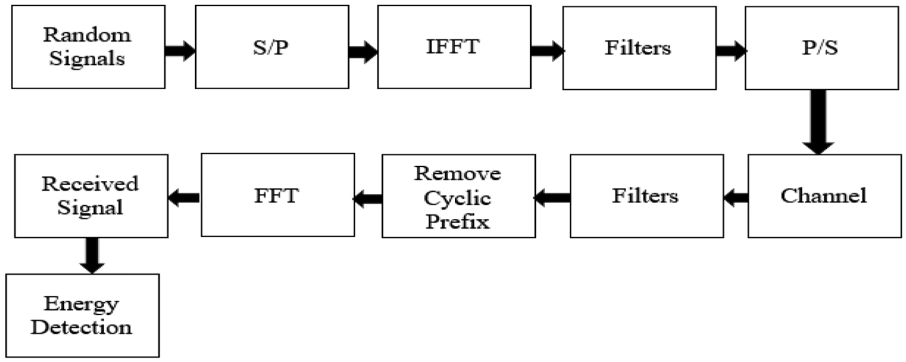

Figure 3: ED with FBMC

Let us consider an FBMC signal with S sub-blocks is given as:

$$Z_m^s = \left[Z_0^s, Z_1^s, \ldots, Z_{M-1}^S\right]^T \tag{8}$$

where $s = 1, 2, \ldots, S$ and n denotes the sub-carriers. The FBMC signal can express in real and imaginary forms:

$$Z_m^s = r_m^s + ji_m^s \tag{9}$$

The number of sub-carriers is applied to the group of filters:

$$Z_m^s(t) = r_m^s f(t - sT_s) + ji_m^s f(t - \frac{T_s}{2} - sT_s) \tag{10}$$

T_s is the duration of symbols, and f being the response of the filter. The time-domain estimation of FBMC signal is obtained by applying an IFFT, given as:

$$Z_m^s(K) = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} z_m^s(t) exp^{\frac{-j2\pi Km}{N}} \tag{11}$$

The energy of the FBMC signal is estimated as:

$$z(n) = \frac{1}{N} \sum_{n=1}^{N} \left|Z_m^s(K)\right|^2 \tag{12}$$

The hypothesis of Ed is estimated for the detection of the spectrum, given as:

$$\mathrm{H}_0 : \mathrm{z(n)} = \sigma(\mathrm{n}) \tag{13}$$

$$\mathrm{H}_1 : \mathrm{z(n)} = Z_m^s(K) + \sigma(\mathrm{n})$$

where z(n) is the received signal, σ(n) is the noise variance, $Z_m^s(K)$is the transmitted signal.

2.3 Energy Detection in NOMA System

The schematic of NOMA is given in Fig. 4. It is also considered one of the best contenders for 5G waveform. The distribution of resources based on the Super Coding algorithm (SC) and interference is mitigated by Successive Interference Cancellation (SIC) [34]. The distribution of resources is uniform for all users. Hence, it guarantees a maximum throughput of the system. However, complexity in the receiver framework is seen as one of the constraints of NOMA [35].

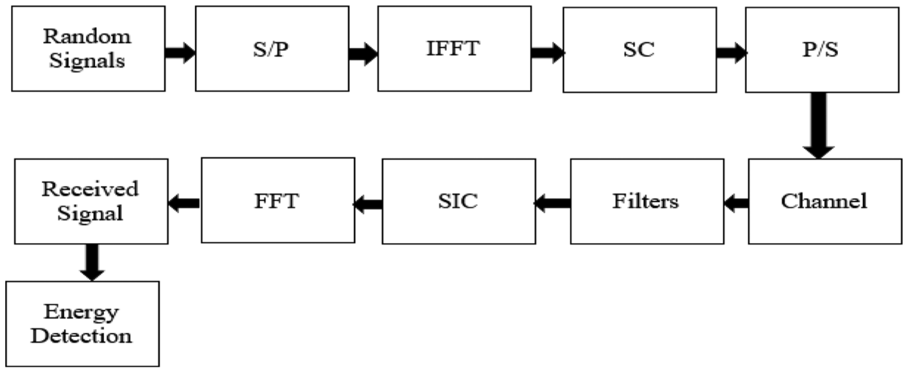

Figure 4: System model

Let us consider a NOMA signal with S subcarriers given as:

$$X = [X_{0,}X_1, \ldots X_{S-1}]^T \tag{14}$$

The response NOMA signal with Successive Interference cancellation (*SIC*), Super Coding (SC), filters, IFFT and FFT is give as:

$$z(n) = exp^{j2\pi F_c t} \sum_{n=0}^{S-1} \mathrm{x(n)} * c(t - sT) \tag{15}$$

where $h(t - nT)$ denotes the characteristics of the filter. The energy of FBMC signal is estimated as [36]:

$$y(n) = \frac{1}{N} \sum_{n=1}^{N} |z(n)|^2 \tag{16}$$

The hypothesis of Ed is estimated for the detection of spectrum, given as:

$$\mathrm{H_0 : y(n)} = \sigma(\mathrm{n}) \tag{17}$$

$$\mathrm{H_1 : y(n)} = z(n) + \sigma(\mathrm{n}) \tag{18}$$

where y(n) is the received signal, σ(n) is the noise variance, $z(n)$is the transmitted signal.

3 Simulation Results

Matlab R21 is used in an Intel core i7 CPU platform as a simulation environment. The effect of cognitive operation for the key modulation techniques. To estimate the performance of ED-based CR, we consider the following specifications: Quadrature Amplitude Modulation (16-QAM), Rayleigh channel, 64-subcarriers, 600 symbols and, 64-length FFT. The probability of detection (Pd) performance of ED is shown in Fig. 5. It is seen that the Pd is maximum at the SNR of –3, 4, and 4 dB for NOMA, FBMC, and OFDM. Hence it shows that ED with NOMA gives better performance as compared with FBMC and OFDM. The PFA curves of waveforms with ED are shown in Fig. 6. It is observed that the ED with OFDM has a high probability of detecting noise as the desired signal. However, the false detection characteristics of NOMA and FBMC are similar and better than the OFDM. The PAPR performance without applying the reduction algorithms is shown in Fig. 7. At the Complementary Cumulative Distribution Function (CCDF) of 10^{-3}, the PAPR of OFDM is 10 dB, FBMC is 8.8 dB, and NOMA is 7 dB. Hence, it is concluded that the NOMA achieves a gain of 1.8 and 3 dB as compared with FBMC and OFDM. The

BER performance of ED-based CR with OFDM, FBMC, and NOMA is shown in Fig. 8. The BER of 10^{-5} is achieved at the SNR of 5.8 dB for NOMA, 7.6 dB for FBMC, and 9.6 dB for OFDM. Hence, it is concluded that the efficiency of ED-based CR for NOMA is better than that of OFDM and FBMC.

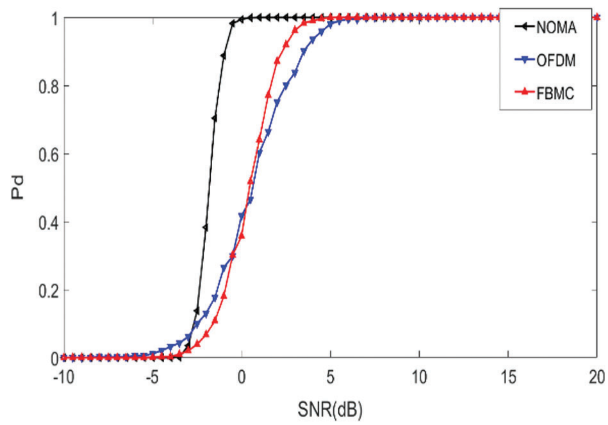

Figure 5: Pd performance of ED

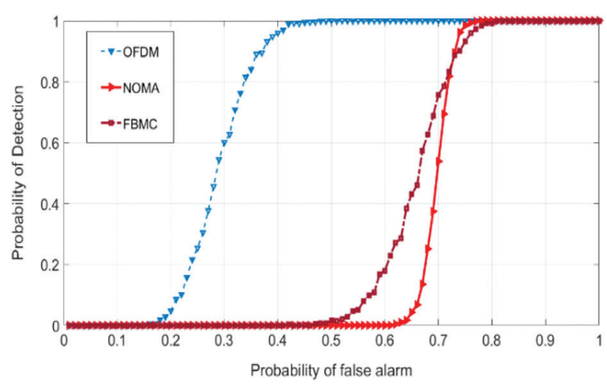

Figure 6: ED with PFA

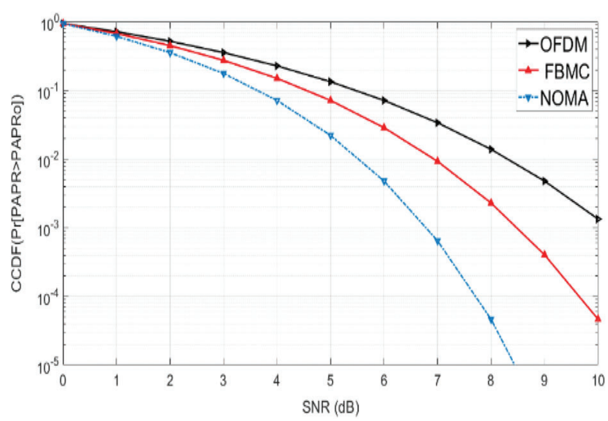

Figure 7: PAPR performance

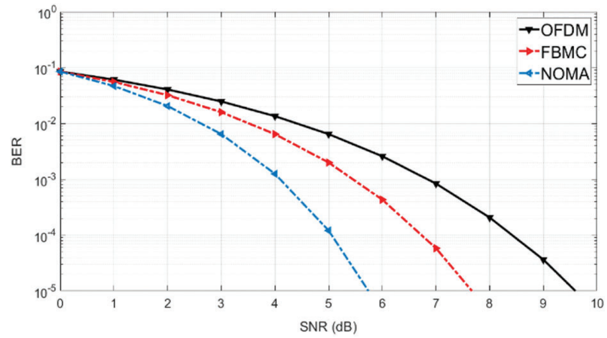

Figure 8: BER performance

4 Conclusion

In this article, we propose ED-based Cognitive Radio for modern beyond 5G modulation like NOMA, OFDM, and FBMC waveforms. The main aim of the proposed work is to analyze the spectral efficiency and capacity of the different systems mentioned above. The simulation results reveal that the Probability of detection and false alarm performance of ED with NOMA is better and achieved a gain of 2.1 and 3.2 dB as compared with FBMC and OFDM. Further, the throughput of the CR for different waveforms is studied by estimating the BER and PAPR. It is seen that the ED with NOMA outperforms the existing waveforms. Thus, we expose NOMA to be a primary candidate for beyond 5G modulation, which increases the capacity of the system and results in low PARP compared to the current modulation scheme.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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