Spectrum Sensing Performance for Cognitive Radio Networks with GFDM Modulation over Nakagami-*m* fading Channel

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Abstract—Generalized Frequency Division Multiplexing (GFDM) which is the recent multicarrier digital modulation adds a flexibility feature to the physical layer using non-orthogonality. This feature let GFDM be a leader for serving many new applications in wireless communication networks, like that for the newly proposed cognitive radio. GFDM is provided a low out of band radiation in cognitive radio networks. In this study, we analysis spectrum sensing performance for cognitive radio networks with GFDM modulation over Nakagami-*m* fading channel. Energy detection method for spectrum sensing is implemented with GFDM. The performance of the proposed system model is investigated from the Monte Carlo simulations and presented through the receiver operating characteristic (ROC) curves both for additive white Gaussian noise (AWGN), Rayleigh and Nakagami-*m* fading channels. The simulation results verify that GFDM multicarrier modulation technique outperforms the traditional ones in terms of the spectrum sensing.

Keywords—Cognitive radio,Energy detection, GFDM, Nakagami-*m*, Spectrum Sensing.

1 INTRODUCTION

Usually the licensed frequency bands are assigned by regulatory groups like FCC (Federal Communications Commission) in USA and OFCOM (Office of Communications) in United Kingdom for application services, such as TV, radio, and cellular communication. At the present, licensed frequency bands are almost fully assigned. A licensed frequency band is specified to a primary user (PU), who has the highest priority for utilizing when there is more than one user. Recently, the number of wireless devices and wireless networks are fastly increasing, since mobile communication becomes a basic tools for our present lifestyle. Therefore, the demand for the frequency band is increasing rapidly. This motivates the researchers to exploit the holes in the licensed frequency band for the usage of opportunistic users. It is noticed that there is good portion of licensed frequency band not utilized by the primary users [1,2] for certain amount of time. One of the methods for using unoccupied frequency bands is the celebrated cognitive radio (CR), which is emerged by regulatory groups and standards, like P1900, IEEE802.11af, and IEEE802.16h. In the CR scheme, unlicensed secondary (opportunistic) users exploit the licensed spectrum temporarily when the PU is idle [2-3]. Hence the aim of CR is to enhance the spectrum efficiency by protecting the PU from any interference. This is achieved by introducing spectrum sensing. Spectrum usage can be efficiently detected by using matched filter detection [4], cyclostationary detection [5], energy detection [6], and eigenvalue-based detection [7] techniques. Every technique has different computational complexity, operational necessities, advantages and disadvantages.

In [8], it is shown that the multiband generalized frequency division multiplexing (GFDM) is a new designing for multicarrier PHY. The derived GFDM block multicarrier transmission scheme is in the form of a filter bank. The data in the GFDM block are distributed in both

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time and frequency domains. Each of them are transmitted with it corresponding adjustable pulse shaping, giving the GFDM ability to eliminate the out of band emotion. This makes the GFDM more proper than the traditional well known orthogonal frequency division multiplexing (OFDM) for CR, and be a good protector for PU when the opportunistic users transmit signal.

In [9,10], authors study the spectrum sensing performance of GFDM signals over AWGN channel in CR. Comprehensive analysis are derived to investigate the receiver operating characteristics (ROC) of the detection performance for GFDM and OFDM transceivers. These works show that GFDM multicarrier sensing performance is better than the OFDM, where the simulation results are supported with theoretical results.

In most of the cases, the fading in the wireless channel can be modeled by Nakagami-m distribution. Therefore, in this paper, we evaluate the GFDM sensing performance under Nakagami-m fading channel, which has not been considered in [18], or in anywhere. We compare our results with [18], where only Rayleigh and AWGN fading channels have been examined. Spectrum sensing is achieved by employing the conventional energy detection technique. Complementary ROC curves are also provided.

The rest of this paper is organized as follows. GFDM system model is discussed in Section 2. In Section 3, the energy detection based spectrum Sensing principles are explained. Simulation results for the energy detection performance with GFDM modulation is presented in Section 4.Finally, the concluding remarks are given in Section 5.

2System model

A standard GFDM transmitter is shown in Fig.1. First, a binary data input vector $\vec{b}$ is mapped to the symbols $(\mathbf{2}^{\mu})$ by QAM mapper, where μ is the QAM modulation order. Then, it is passed through a serial to parallel converter. The resultant block structure $\vec{\boldsymbol{D}}$ contains $M \times K$complex data symbol values, that represented by$K$ subcarriers,and Msub symbols. $\vec{\boldsymbol{D}}$ can be expressed by

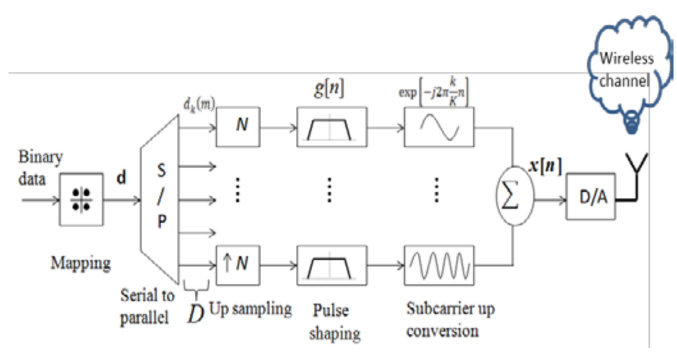

Fig. 1. General GFDM transmitter.

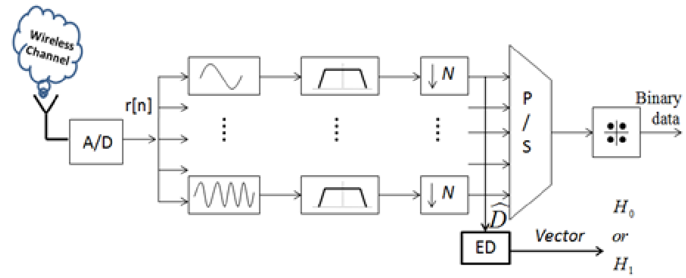

Fig. 2. General GFDM Receiver.

$$D = \begin{bmatrix} d_{0,0} & \cdots & d_{0,M-1} \\ \vdots & \ddots & \vdots \\ d_{K-1,0} & \cdots & d_{K-1,M-1} \end{bmatrix}, \qquad (1)$$

where each$d_{k,m}$ refers to the data symbol transmitted in k-th subcarrier and m-th timeslot. Here, $k = 0,1,\cdots,K-1$ and $m = 0,1,\cdots,M-1$. Each sub-symbol $d_{k,m}$ is upsampled by a factor of N, where we assume$N = K$in this work. Upsampling causes shifting in time domain that prevents any unpleasant aliasing effects. Then the up-conversion by IFFT is implemented, causing a shift in the frequency domain. In other words, each $d_{k,m}$ is pulse-shaped with a corresponding impulse-shaping $g_{k,m}[n]$. The pulse-shaping function is

$$g_{k,m}[n] = g[(n - mN) \bmod N].\exp\left[-j2\pi\frac{k}{N}n\right]. \qquad (2)$$

Here, the transmitted signal$x[n]$ can beexpressed by [11]

$$x[n] = \sum_{k=0}^{K-1}\sum_{m=0}^{M-1} g_{k,m}[n]d_{k,m}\,, \quad n = 0,1,\cdots,N-1. \qquad (3)$$

Hence, $x[n]$represents the summation of all subcarriers signal by [10].

$$x[n] = \sum_{k=0}^{K-1} x_k[n]. \qquad (4)$$

The transmitted signal can be expressed by the matrix structure, $\vec{\mathbf{x}} = \mathbf{A}\vec{\mathbf{d}}$, where $\mathbf{A}$ is the transmitted matrix of size $MK \times MK$. Columns of$\mathbf{A}$are composed of the prototype filter impulse shaping functions, i.e., $\boldsymbol{A} = [g_{0,0}(n)^T g_{0,1}(n)^T \cdots g_{1,0}(n)^T \cdots g_{K-1,M-1}(n)^T]$, while $\vec{d}$ is the transmitted data vector .

In order to send $x[n]$ through the wireless channel, we pass it through a digital-to-analog converter as also shown in Fig. 1. In the receiver side, a standard GFDM receiver is used with an additional energy block detector to sense any PU signal. For convenience, the receiver model shown in Fig. 2. The received signal vector $\boldsymbol{r}$ can be represented by

$$\mathbf{r} = \mathbf{Hx} + \mathbf{w}, \qquad (5)$$

where $\mathbf{w}$ is the zero-mean complex AWGN noise vector with variance σ_n^2. $\mathbf{H}$ **is** a circular convolution matrix of size $MK \times MK$ whose elements include wireless channel fading coefficients for Rayleigh and Nakagami-m multipath fading channels. When $\mathbf{H} = \mathbf{I}$, then the channel becomes AWGN [12]. $\mathbf{r}$ is converted to digital scheme by applying analog to digital conversion, corresponds to each subcarrier. The estimated data vector $\widehat{\mathbf{D}}$ can be obtained after GFDM demodulation [11]. Here the estimated data can be defined by $\widehat{\mathbf{D}} = \mathbf{Cr}$, where $\mathbf{C}$is the demodulation matrix of size $MK \times MK$. The structure of the demodulation matrix $\mathbf{C}$ relies on the receiver type. In this study, we employ zero forcing receiver (ZF) for the received GFDM signal, where $\mathbf{C} = \mathbf{A}^{-1}$ [13]. ZF structure helps removing all the self inter subcarriers interference, but with the cost of enhancement in the noise for Nakagami-m wireless channel case.

3Energy Detection Method for Spectrum Sensing using GFDM Signal

The goal of the spectrum sensing technique is to determine the spectrum holes in TV licensed frequency band, in which the absence of PU is detected, and let the opportunistic users utilize the idle frequency band in cognitive radio network. In this study GFDM based opportunistic user is considered. In the receiver side, the estimated data $\widehat{\mathbf{D}}$ represents the output of the GFDM demodulation, and also is the input signal for the energy detection block shown in Fig. 3. This can be defined with binary hypothesis testing [18].

$$\widehat{\mathbf{D}}[n] = \begin{cases} \mathbf{w}, & H_0 \\ \mathbf{Hx} + \mathbf{w}, & H_1 \end{cases} \quad (6)$$

The hypothesis H_0 and H_1 are the decisions for an opportunistic user after implementing Neyman-Pearson statistical test for the output of the energy detection block [14].

$$L = \sum_{n=1}^{2\phi} \widehat{\mathbf{D}}^2[n] \underset{H_0}{\overset{H_1}{\gtrless}} \lambda \quad (7)$$

where L is the decision statistics vector which contains H_0 and H_1 with 2ϕ degree of freedom. In here, ϕ is the number of the detected data symbol by the opportunistic receiver. The decision statistics rely on the detection threshold value, λ. When the hypothesis H_0 is decided, that it means, the received signal at the opportunistic user contains only complex noise. In this case the frequency band is not utilized by the PU, thus the SU can exploit the frequency band and send its' signal. On the other hand when the hypothesis H_1 is decided, the received signal at the opportunistic user

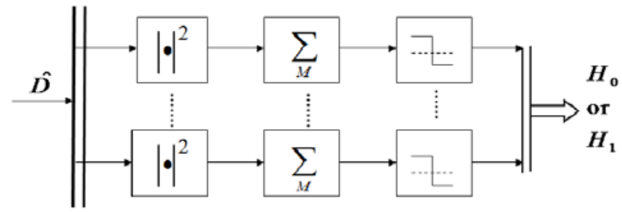

Fig. 3. Energy detection.

contains the PU signal with noise. This means SU couldn't occupy this frequency band, since it is utilized by PU.

The performance of the spectrum sensing with energy detection technique based on GFDM is mainly evaluated by the detection probability, P_d and the probability of false alarm, P_{fa} [15 - 17]. $P_d = Prob\{ L > \lambda/H_1 \}$ is defined as the probability of detecting the PU signal for a specific frequency band. So, the low value of P_d means the low utilization of the frequency band by PU. On the other hand, $P_{fa} = Prob\{ L > \lambda/H_0 \}$ is expressed by the probability that, the opportunistic user makes a wrong decision for the utilization of the specific frequency band. In other words, if the opportunistic user detects the PU signal and make the decision with H_1 , while actually this frequency band holds the noise signal, in this case the corrected decision is H_0 . For better performance, P_{fa}should be kept as small as possible [19].

The energy detector block shown in Fig.3 is implemented for the spectrum sensing using GFDM receiver. The output of the GFDM demodulation (the estimation data $\widehat{\mathrm{D}}$) is first applied to the square low device in order to calculate the energy for all data in the data block $\widehat{\mathrm{D}}$. Then, the energy of all samples in each subcarrier are summed up, which is represented by L decision metric. Finally the Neyman-Pearson statistical test is applied for each subcarrier to make the decision, while the resulting vector contains the decisions of H_0 and H_1 for all subcarriers in the cognitive radio network.

4 Simulation Results for the Energy Detection Performance with GFDM Modulation

In this section the energy detection based spectrum sensing performance is described by the simulation results. A perfect synchronizing GFDM receiver is considered. In the simulations, we set the number of subcarriers, $K = 32$, samples per symbol, N to 32, the number of symbol per subcarrier, $M = 5$, and the prototype filter roll-off factor, $\alpha = 0.1$. It is assumed that the root raised cosine (RRC) filter and 4-QAM are used.

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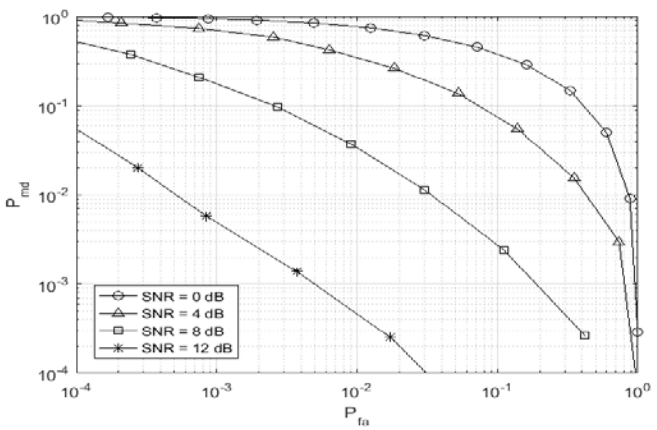

Fig. 4.P_{md} vs. P_{fa} for SNR = (0, 4, 8, 12) dB.

The P_{md} vs. P_{fa} performance analysis over Nakagami-m fading channel is illustrated in Fig. 4, while the fading parameter, m=3 is used and different SNR values (SNR=0, 4, 8, 12 dB) are considered.

In Fig. 5,the P_{md} performance comparison for AWGN and Nakagami-m fading channels (Rayleigh is a special case while m=1) are plotted. In here, SNR is changing from 0 dB to 20 dB, and the fading parameter is taken as m = 1, 2, 3 successively. From the figure, it is seen that the P_{md} is decreasing with the increase of SNR which is an expected result, for the mentioned AWGN and fading channels. In addition, AWGN outperforms Rayleigh fading channel. This result closely matches with the previously published studies. To summary, higher P_d is obtained for higher SNR, since $P_d = 1 - P_{md}$.

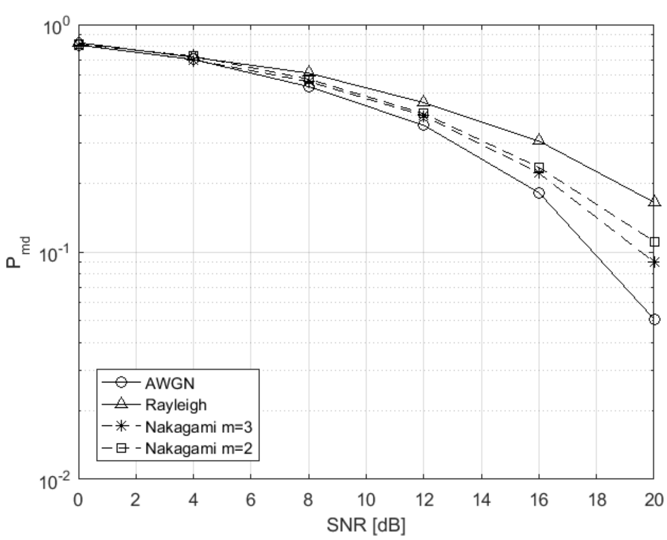

Fig. 5.P_{md} vs. SNR for AWGN, Rayleigh, and Nakagami-m fading channels.

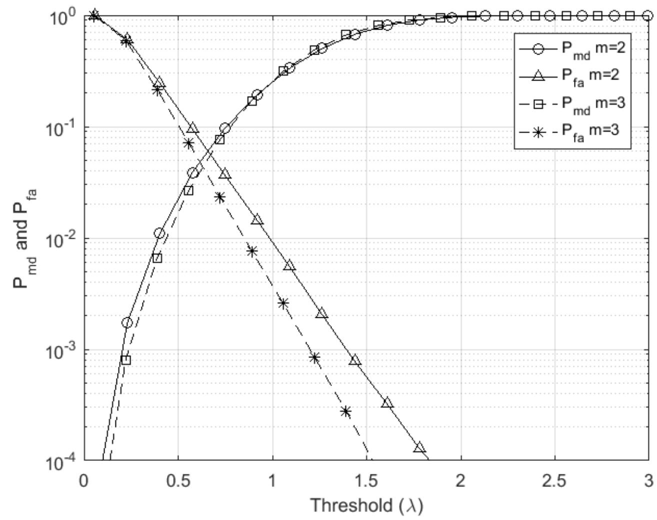

Fig. 6. P_{md} and P_{fa} vs. detection threshold.

Finally, Fig. 6 describes the relation between P_{md} and P_{fa} with varying detection threshold, λ values, over Nakagami-m fading channel for m=2, and m=3. Fig. 6 clearly shows that (probability of missed-detection) P_{md} significantly increases, thus the spectrum sensing performance decreases, with the increase of λ. In addition, the detection performance is increased with the increase of m fading parameter values. In the same figure, while the detection threshold λ increases, the P_{fa} decreases, as expected.

5 Conclusion

In this article, we analyzed the spectrum sensing performance for cognitive radio networks with GFDM modulation over Nakagami-m fading channel. In this comparison study, we considered the P_{md} performance over AWGN, Rayleigh and Nakagami-m fading scenario with varying SNR.Then, we provided a comprehensive analysis for spectrum sensing performance (P_{md} vs. P_{fa}) under Nakagami-m fading distribution for different SNR values. Furthermore, P_{md} and P_{fa} performance analysis subject to λ values are investigated. The simulation results show that the probability of missed-detection decreases in case of strong Nakagami fading, means that, better detection performance is achieved with higher value of$m$fading parameter. Also detection performance for the opportunistic users increases while the SNR is increasing, since the probability of missed-detection decreasing.

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