Energy Detection of Spectrum Sensing for Cognitive Radio Networks Using GFDM Modulation

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Abstract

Generalized frequency division multiplexing (GFDM) is a non orthogonal, digital multicarrier transmission scheme with attractive features that address the requirements of emerging applications of wireless communication systems like cognitive radio and fifth generation (5G). In this study, we analysis and evaluate the spectrum sensing performance of a GFDM based cognitive radio networks over additive white Gaussian noise (AWGN) and Rayleigh fading channels. To improve the spectral utilization, the energy detection method for spectrum sensing is considered. The performance of the proposed system model is investigated and presented through the receiver operating characteristic (ROC) curves. The results show the validity of the recent multi carrier modulation technique, GFDM for cognitive radio networks, and point out the confirmation of the better sensing performance compared to the conventional ones.

1. Introduction

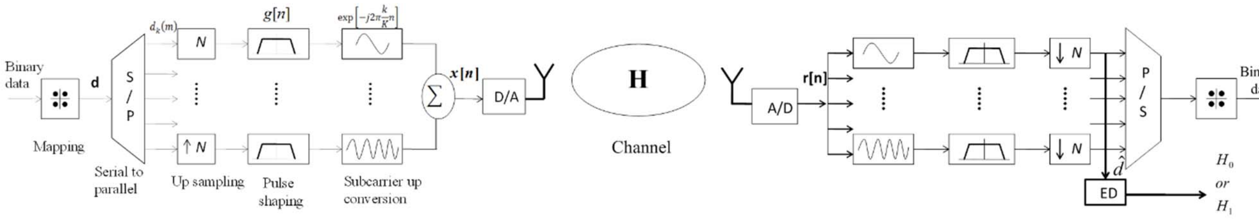
It is known that the licensed frequency band for the electromagnetic spectrum is almost completely assigned for various applications in wireless communications networks. These utilized frequency bands are dedicated for the licensed primary users (PU) who has legacy rights and higher priority of the services, based on the television and radio broadcasting, cellular communications, etc. which are governed by the regulatory bodies in the countries. On the other hand, the numbers of wireless devices and their users, mobile networks and applications working on it, have been dramatically increasing in recent years. Due to the mentioned scenario, the researchers have focused on the radio spectrum optimization, considering to utilize the idle spectrum holes opportunistically for the unlicensed secondary users (SU) without causing harmful interference to the PU. Additionally it is indicated that, the transient and geological varieties in the use of the designated spectrum is just around the 15 to 85 % [1]. Under these conditions, the idea of cognitive radio (CR) is recommended to use by the statutory enterprises like FCC (Federal Communications Commission) in United States, Ofcom (Office of Communications) in United Kingdom, and the standardization groups like P1900, IEEE802.11af, and IEEE802.16h. CR allows the unlicensed SUs to access the licensed spectrum opportunistically when it is idle [2] in order to mitigate the spectrum shortage, under the condition that the incumbent PUs have to be protected from the interference generated by the opportunistic unlicensed SUs [3].

The main objective of the CR networks is to enhance the spectrum efficiency, while protecting the incumbent users from any unsafe interference. This is accomplished by spectrum sensing techniques who has an essential role in CR. Matched filter detection [4], cyclostationary feature detection [5], energy detection [6], and lastly, eigenvalue based detection [7], are the most well-known methods implemented for the spectrum sensing. Among these, due to its low implementation and computational complexity, in our study, we considered to use energy detection technique for spectrum sensing, where it has also been most widely used in the literature. Occupying the specified frequency band by the PU leads the presence of a certain energy level, otherwise this frequency band may be available for an opportunistic user to use.

The multiband generalized frequency division multiplexing (GFDM) is a moderately new thought for designing a multicarrier physical layer modulation [8]. The multicarrier transmission scheme in GFDM has been derived based on the filter bank concept, where the GFDM data is transmitted by means of a block structure, distributed according to the time and frequency domains, while each subcarrier is pulse-shaped with the adjustable pulse shaping filter. Thus, GFDM is more appropriate for the CR physical modulation scheme, compared to the conventional Orthogonal Frequency Division Multiplexing (OFDM). GFDM based CR networks with the adaptive pulse shaping filter, for instance, root-raised-cosine (RRC) filter, are able to reduce the interference to the neighbor frequency.

The authors in [9] investigate the performance of GFDM over the Nakagami-*m* fading channel. They studied symbol error rate analysis while maximal ratio transmission is employed. In [10], the authors examine the GFDM for the 5th generation cellular networks as a proof-of-concept and implementation aspects for the next generation 5G networks. Also in [11-12], the analytical bit error rate and performance evaluation for GFDM have been derived for various fading channels. Furthermore, the studies in [13-14] consider the spectrum sensing performance for CR networks with GFDM over additive white Gaussian noise (AWGN) channel. Although spectrum sensing with GFDM for the CR networks have been considered in the previous manuscripts, as far as we know there has not been any notable research on the spectrum sensing performance with GFDM over Rayleigh fading channel, presenting with rigorous data for varying signal-to-noise ratio (SNR) values and the detection thresholds.

In our research, in order to evaluate the GFDM sensing performance, we use a standard GFDM receiver for sensing an opportunistic signal. Even if the spectrum sensing method in CR networks is substantially used to detect the TV white space, it is also convenient to use for the GFDM receiver as a sensing device for other CR signals. Complementary ROC curves are obtained for sensing with a GFDM over Rayleigh fading channel. Besides,



a) Transmitter side b) Receiver side

Fig. 1. GFDM system model

AWGN channel performance is also considered and compared with the Rayleigh fading channel.

The remaining of this paper is organized as follows. GFDM system model is discussed in Section 2. In Section 3, the energy detection based spectrum sensing with GFDM is presented. Simulations results are obtained in Section 4. Finally, the concluding remarks are given in Section 5.

2. GFDM System Model

GFDM is considered as a multi-carrier modulation technique with flexible pulse shaping. In the GFDM transmitter system model, shown in Fig. 1 a), the input binary data vector is mapped to the 2^{μ} symbols, using quadrature amplitude modulation (QAM), where μ is the modulation order, resulting in a data block structure, $\mathbf{d}$ as follows:

$$\mathbf{d}=\begin{bmatrix} d_0(0) & \cdots & d_0(M-1) \\ \vdots & \ddots & \vdots \\ d_{K-1}(0) & \cdots & d_{K-1}(M-1) \end{bmatrix}. \tag{1}$$

In here, each $d_k(m)$ refers to the data symbol transmitted in *k*-th subcarrier and *m*-th time slot $(k=0,\ 1,\ ...,\ K-1$ and $m=0,\ 1,\ ...,\ M\ \text{-}1)$. Here, *K* is the number of subcarriers and *M* is the length of symbols in one block. Thus, the total number of symbols is $N=KM$. In order to avoid unpleasant aliasing effects, each sub-symbol $d_k(m)$ is transmitted with its' corresponding pulse shaping filter $g_{k,m}[n]$ which is implemented by a version of a prototype filter $g[n]$, with time and frequency shifted data. This is achieved by upsampling the data sequence by a factor of N in time domain, and by multiplying complex exponential in frequency domain as expressed in [10]

$$g_{k,m}[n]=g[(n-mK)\bmod N]\exp[\text{-}j2\pi\frac{k}{K}n] \tag{2}$$

where n is the sampling index. Finally the GFDM transmitted signal can be given as [10]

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

In other words, the transmitted signal is given by $\vec{x}=\mathbf{A}\vec{d}$, where $\mathbf{A}=\left(\vec{g}_{0,0}\cdots\vec{g}_{K-1,0}\ \vec{g}_{0,1}\cdots\vec{g}_{K-1,M-1}\right)$ is the complex-valued transmitter matrix with the size of *KM* by *KM* consist of $g_{k,m}[n]$ which are prototype pulse shaping filters shifted in time and frequency domains, and $\vec{d}$ is the transmit data vector. In order to send this signal over the wireless communication channel, first it is sent to digital-to-analog (D/A) converter.

Fig. 1 b) shows the GFDM receiver system model. In here, $\boldsymbol{r}[\boldsymbol{n}]$ is the received signal vector that can be defined as

$$\boldsymbol{r}[\boldsymbol{n}]=\mathbf{H}\,\boldsymbol{x}[\boldsymbol{n}]+\boldsymbol{w}[\boldsymbol{n}] \tag{4}$$

where $\mathbf{H}$ is the $N\times N$ circular convolution channel matrix for Rayleigh multipath channel, $\boldsymbol{w}[\boldsymbol{n}]$ denotes the noise vector with length N, containing complex AWGN samples with zero mean and σ_n^2 variance.

The estimation data can be obtained from the received data symbols $\boldsymbol{r}[\boldsymbol{n}]$ according to [10]:

$$\hat{\vec{\boldsymbol{d}}}=\mathbf{C}\,\vec{\boldsymbol{r}} \tag{5}$$

where $\mathbf{C}$ is $N\times N$ demodulation receiver matrix of GFDM, can be expressed as, $\mathbf{C}=\mathbf{A}^{\mathbf{-1}}$ depending on the zero forcing receiver type [15].

3. Energy Detection based Spectrum Sensing with GFDM

The aim of the spectrum sensing is to determine the absence of the PU in a licensed frequency band in order to allow for the opportunistic user to utilize the spectrum holes. In other words, spectrum sensing let the SU test the white space if it is occupied by another cognitive user or not. In this paper GFDM based opportunistic user is considered. The signal at the input of energy detector, $\hat{d}[n]$ can be expressed with binary hypothesis testing problem [16, 17].

$$\hat{d}[n]=\begin{cases} w[n] & ;\ H_0 \\ h[n]\ x[n]+w[n] & ;\ H_1 \end{cases} \tag{6}$$

where $h[n]$ is the channel fading coefficient, and $x[n]$ is the transmitted GFDM signal. The hypothesis H_0 is the decision for an opportunistic user after implementing Neyman - Pearson

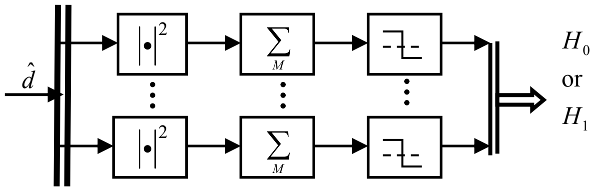


Fig. 2. Energy detector block diagram for GFDM [13].

statistical test [13, 14], defined in the below equation, and giving a decision depending on the detection threshold, λ means that, the received signal at an opportunistic user is only a complex noise. That is to say, the spectrum is not occupied by an incumbent user, and the opportunistic user may exploit this frequency band to transmit its' signal. On the other hand, if the decision is based on the hypothesis H_1, this situation means that the received signal at an opportunistic user detects the incumbent signal with noise, and decides that the frequency band is busy with the PU.

$$L = \sum_{n=1}^{2\rho} \hat{d}^2[n] \underset{H_0}{\overset{H_1}{\gtrless}} \lambda \tag{7}$$

In (7), L is the decision statistics with 2ρ degrees of freedom.

The performance of energy detection based spectrum sensing with GFDM algorithm is mainly determined by two parameters: The first one is the probability of false alarm, P_{fa} and second one is the detection probability, P_d [18-19]. $P_d = \Pr ob\{L > \lambda / H_1\}$ represents the detection probability of a PU signal in the specific frequency band. P_d is a measure of the interference level, for the protection of the incumbent users. Low P_d value results in deciding for the absence of the PU. Besides, the probability of missed detection is denoted by $P_{md} = (1 - P_d)$. On the other hand, $P_{fa} = \Pr ob\{L > \lambda / H_0\}$ defines that the opportunistic user makes a wrong decision about the occupation of the considered frequency band. That is to say, the opportunistic user decides for a dedication of an incumbent user on the specified frequency, gives a decision with H_1 while the correct one is H_0. An increase in P_{fa} results in low spectrum utilization by an opportunistic users. So, for a better performance, P_{fa} should be kept as small as possible [9, 20].

In this paper, we consider the block diagram of an energy detector system on the spectrum sensing with GFDM, as shown in Fig. 2. Herein, the estimated data after the demodulation, $\hat{d}[n]$ in the GFDM receiver system model, is sent to the energy detector block. First, the square law device is applied for all samples in $\hat{d}$, then the summing operation is implemented to get the energy values of them along each subcarrier. Finally, this calculation is used for the device, where the decision on the occupancy of a subcarrier, by comparing the decision metric L with a detection threshold λ. The decision for the output is given regarding the frequency band is idle or occupied with incumbent users with the help of the two decision values; either H_0 or H_1 for all the subcarriers in CR network.

4. Simulation Results

In this section, the simulation results are provided to evaluate the performance of the proposed energy detection based spectrum sensing with GFDM algorithm. In the simulations, in which Monte Carlo method is used, we set the number of subcarriers $K = 64$, the number of samples per symbol $N = 64$, the data block length $M = 5$, and the roll-off factor $\beta = 0.1$. It is assumed that root raised cosine (RRC) filter and 4-QAM are used. Moreover, we consider a perfect synchronization at the GFDM receiver.

In Fig. 3, the ROC (P_{md} vs. P_{fa} curve) performance analysis over AWGN channel is illustrated for different SNR values. The obtained results are similar to previous studies reported in [13]. The spectrum sensing performance with GFDM over Rayleigh fading channel with varying SNR values is shown in Fig. 4.

The performance comparison of the AWGN and Rayleigh fading channels in terms of P_{md} with varying SNR is plotted in Fig. 5. For AWGN channel, when SNR is 0 dB and 16 dB, P_{md} is around 0.8 and 0.18, respectively. That is to say, P_{md} decreases with the increase of SNR. This means, we get higher P_d for higher SNR. Besides, it can be observed from the simulation results in Fig. 5 that, AWGN outperforms Rayleigh channel in terms of the detection probability as expected.

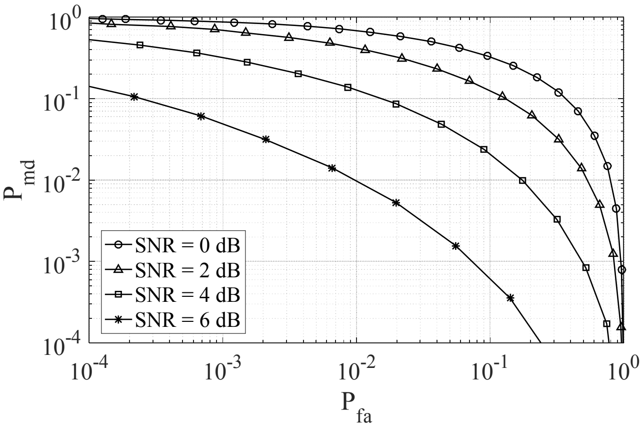


Fig. 3. Complementary ROC curve for spectrum sensing with GFDM over AWGN channel with varying SNR.

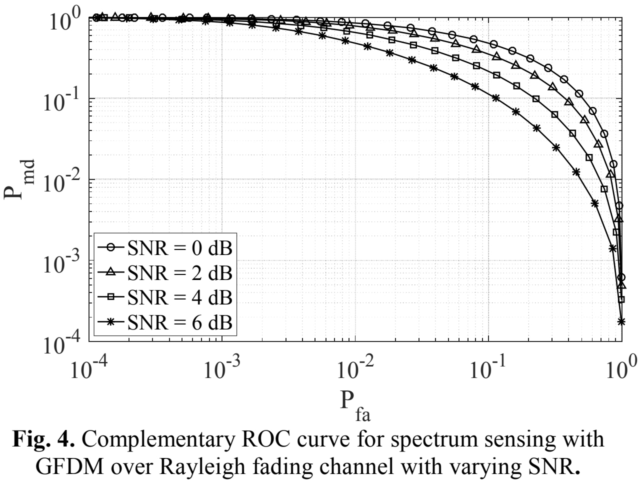


Fig. 4. Complementary ROC curve for spectrum sensing with GFDM over Rayleigh fading channel with varying SNR.

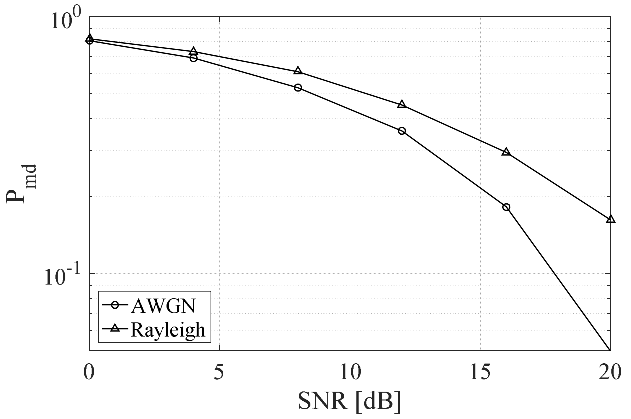


Fig. 5. P_{md} vs. SNR for both AWGN and Rayleigh channels.

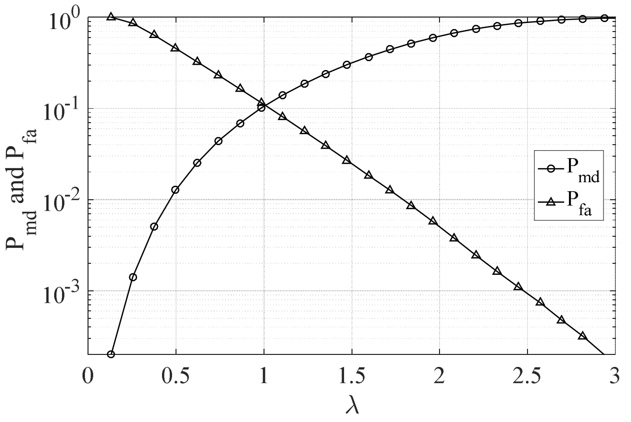


Fig. 6. P_{md} and P_{fa} vs. detection threshold (λ) over Rayleigh fading multipath channel.

Finally, Fig. 6 shows the P_{md} and P_{fa} changes with detection threshold (λ) values over Rayleigh fading channel. Fig. 6 clearly shows that P_{md} significantly increases, thus the spectrum sensing performance decreases with the increase of λ. In the same figure, while the detection threshold λ increases, the P_{fa} decreases as expected.

5. Conclusions

In this paper, we studied the performance analysis of energy detection based spectrum sensing with GFDM in cognitive radio networks. We considered both AWGN and Rayleigh fading channels in this paper. We provide a comprehensive analysis for spectrum sensing performance (P_{md} vs. P_{fa}) using varying SNR. We then present a GFDM sensing characteristics for both AWGN and Rayleigh channels. Finally, P_{md} and P_{fa} performance analysis subject to λ values are investigated. The simulation results show that the detection performance for the opportunistic users increases while the SNR is increasing.

6. References

[1] *Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies*, FCC 03-322, Federal Comm. Commission, Washington, DC, USA, Dec. 2003.

[2] S. Haykin, “Cognitive radio: Brain-empowered wireless communications”, *IEEE J. Sel. Areas Comm.*, vol. 23, no. 2, pp. 201–220, Feb. 2005.

[3] Q. Zhang et al., “On exploiting polarization for energy-harvesting enabled cooperative cognitive radio networking”, *IEEE Wireless Comm.*, vol. 20, no. 4, pp. 116–124, Aug. 2013.

[4] J.G. Proakis, Digital communications, McGraw-Hill, 5th edn., 2008.

[5] W.A. Gardner, C.M. Spoone, “Signal interception: performance advantages of cyclic-feature detectors”, *IEEE Trans. Comm,* vol.40, no. 1, pp. 149-159, Jan. 1992.

[6] A. Taherpour, S. Gazor, M. Nasiri-Kenari, “Wideband spectrum sensing in unknown white Gaussian noise”, *Comm., IET*, vol. 2, no. 6, pp. 763-771, Jul. 2008.

[7] T. Yucek and H. Arslan, “A survey of spectrum sensing algorithms for cognitive radio applications”, *IEEE Comm. Surveys Tuts.*, vol. 11, no. 1, pp. 116–130, Mar. 2009.

[8] G. Fettweis, M. Krondorf, and S. Bittner, “GFDM - Generalized frequency division multiplexing”, *in Vehicular Tech. Conference* (*VTC), IEEE 69th,* Apr. 2009, pp. 1 –4.

[9] A. Yenilmez, T. Gucluoglu, and P. Remlein, “Performance of GFDM-Maximal ratio transmission over Nakagami-m fading channels”, *in IEEE Int. Sym. on Wireless Comm. Systems* (*ISWCS),* Sep. 2016.

[10] N. Michailow, M. Matthe, I. S. Gaspar, A.N. Caldevilla, L.L. Mendes, A. Festag, and G. Fettweis, “Generalized frequency division multiplexing for 5th generation cellular networks”, *IEEE Trans. on Comm.*, vol. 62, no. 9, pp. 3045-3061, Sep. 2014.

[11] S. Tiwari, S.S. Das, K.K. Bandyopadhyay, “Precoded generalised frequency division multiplexing system to combat inter-carrier interference: performance analysis”, *IET Comm.,* vol. 9, no. 15, pp. 1829-1841, Sep. 2015.

[12] S.K. Bandari, A. Drosopoulos, V.V. Mani, “Exact SER expressions of GFDM in Nakagami-m and Rician fading channels”, *in 21th European Wireless Conf., May 2015, pp. 295-300.*

[13] R. Datta, N. Michailow, S. Krone, M. Lentmaier, and G. Fettweis, “Generalized frequency division multiplexing in cognitive radio”, *in 20th European Signal Processing Conf. (EUSIPCO)*, Aug. 2012, pp. 2679–2683.

[14] R. Datta, K. Arshad, and G. Fettweis, “Analysis of spectrum sensing characteristics for cognitive radio GFDM signal”, *IEEE 8th Int. Wireless Comm. and Mobile Computing Conference (IWCMC),* Aug. 2012, pp. 356-359.

[15] A. Farhang, N. Marchetti, and L. Doyle, “Low complexity transceiver design for GFDM”, *IEEE Trans. on Signal Processing,* vol. 64, no. 6, pp. 1507-1518, Mar. 2016.

[16] Y.C. Liang, Y. Zeng, E.C.Y. Peh, and A.T. Hoang, “Sensing-throughput tradeoff for cognitive radio networks”, *IEEE Trans. on Wireless Comm.*, vol.7, no. 4, pp. 1326–1337, Apr. 2008.

[17] Z. Quan, S. Cui, A.H. Sayed, and H.V. Poor, “Optimal multiband joint detection for spectrum sensing in cognitive radio networks”, *IEEE Trans. on Signal Processing*, vol. 57, no.3, pp. 1128–1140, Mar. 2009.

[18] M. Namdar, H. Ilhan and L. Durak-Ata, "Dispersed Chirp-z transform-based spectrum sensing and utilization in cognitive radio networks", *IET Signal Processing*, vol. 8, no. 4, pp. 320-329, Jun. 2014.

[19] M. Namdar, H. Ilhan and L. Durak-Ata, "Optimal detection thresholds in spectrum sensing with receiver diversity", *Wireless Personal Comm.*, vol. 87, no. 1, pp. 63-81, Aug. 2016.

[20] I.F. Akyildiz, W.Y. Lee, M.C. Vuran, and S. Mohanty, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks a survey", *Elsevier Computer Network*, vol. 50, no.13, pp. 2127–2159, Sep. 2006.