ABSTRACT

Beside the hardware implementation problems in Cognitive Radio Networks (CRNs), some communication criteria’s are considering to generate CRN with improvement, reliability and motivation communication system. One of these criteria’s is how to maximize total throughput of the spectrum sharing CRNs to improve the Quality of Services (QOS) of Secondary Users (SUs), and adapt its communication parameters to communicate concurrent with primary system while assuring the QOS of primary users (PUs). In this paper, proposed optimization technique studies the power allocation strategies to maximize the total throughput of underlay CRN. This optimizing technique is based on Genetic Algorithm (GA) under the consideration of the maximum transmit power and interference constraints. Furthermore, this proposed technique will be applied on two different multicarrier modulation systems which are Orthogonal Frequency Division Multiplexing (OFDM) and Generalized Frequency Division Multiplexing (GFDM). Moreover, some OFDM problem will be solved such as cyclic prefix and subcarrier overlapping in CRNs. Finally, the performance of the proposed technique for maximization of throughput will be investigated by using different number of PUs, SUs, subcarriers M, noise levels and fully utilized system under maximum power and interference constraints while ensuring the QOS of PUs.

KEYWORDS

Cognitive radio network, spectrum sharing, throughput, genetic algorithm, OFDM system, GFDM system

1 INTRODUCTION

Recent years, Wireless communication has become an essential tool for the modern society. Over and above these years, it has witnessed a rabidly increased in the demand on new wireless communication systems, applications and wireless services. In accordance with that the traditional approaches to spectrum, managements become more crowded by licensed systems, in the sense that more frequency bands are needed to be acclimated with the rapidly communication demands requirements. Based on the report of the Federal Communication Commission (FCC) [1] indicated that the radio spectrum is allocated by the licensed (primary) systems and these systems have utilization to their spectrum bands from 15 % reached to 85% under maximum usage. From this perspective, cognitive radio [2-4] is a new hopeful and promising technique. It is suggested to improve the spectrum utilization and efficiency. Cognitive radio based on very intelligent devices, network entities and software radio defined which have the ability be programmed and configured dynamically and can automatically detect channels behaviors in a wireless spectrum and change both transmission and reception parameters enabling more communications to run concurrently and also improve radio operating behavior. In CRNs, there are two main modes of operation. i) Opportunistic spectrum access (overlay) [5], which SU’s in the cognitive radio system are allowed to access on the licensed spectrum of the primary system only if PU’s are not allocated to this band (spectrum hole). ii) Spectrum sharing (underlay) [6, 7], which SU’s are allowed to access on the licensed spectrum and share this band with PU’s to achieve QOS requirements of PU. It will be done by making interference on the primary users...
below a specified threshold level [1]. Actually, the main target of the most CRNs is how to maximize the total throughput of the system without effecting on the licensed systems under some constraints. Many searches study this target by selecting best modulation systems and intelligent power allocating techniques using optimization algorithms [8-9]. Where these algorithms are used to select the optimal power values to maximize throughput under power and interference constraints to improve QOS of the SUs without effecting on QOS of PUs. Many researches supposed OFDM [10] as a one of the promising modulation systems with different power allocation strategies. In [11], different resource allocation algorithms are developed for the downlink of multiuser OFDM wireless communication systems and compared with the other classic techniques based on complexity. Different optimal and suboptimal power allocation schemes for OFDM-based on CRNs were investigated in [12]. Lagrangian optimization technique was proposed in [13]. Using Lagrangian and water filling algorithms to maximize the system capacity based on multiuser OFDM in the downlink CRN under interference constraints was discussed in [14]. In [15], Fair multiuser resource allocation algorithm based on greedy approaches for OFDM in CRN was proposed. Moreover, the minimization of cost function and complexity of these algorithms was made. Another efficient power allocation techniques based on barrier method added with subchannel allocation was suggested in [16, 17]. Actually, there are many problems with using OFDM system in CRNs like cyclic prefix (CP) over head [18], peak to average power ratio PAPR [19-22], out of band radiation (OOB) [23], synchronization and symbol error rate (SER). Many searches studied how to solve these problems but at the expense of the total system throughput. Therefore, a proposed technique was used GFDM system [24] based on a filter bank approaches [25] to solve most of OFDM problems with improvement in the total throughput in CRN. Further, many optimization techniques were used a differential evaluation algorithms based on convex optimization [16] problems for a power allocation strategies in CRN. In this paper, power allocation strategies to maximize the total throughput of underlay CRN based on proposed technique under two constraints will be suggested. The first constraint is the maximum transmit power at SU access point and the other is the interference on the PU must be below the interference threshold level to save the QOS of the PU. Furthermore, this proposed technique will be studied under using two different multicarrier modulation systems, OFDM and GFDM. Then the improvement in total throughput under different modulating techniques will be investigated. Beside them, some OFDM problems will be solved in CRNs such as cyclic prefix. Moreover, the performance of the system with different number of PUs, SUs, subcarriers, and fully utilized system under maximum transmit power and interference constraints will be investigated. The rest of the paper is organized as the follows: Section 2, describes the proposed system model based on two modulation techniques. In Section 3, Analysis of the total throughput will be made. In Section 4, Optimization technique will be presented. Simulation results will be made in Section 5. Finally, Conclusions will be done in Section 6.

2 SYSTEM MODEL

GFDM [26-27] is a flexible multicarrier modulation with pulse shaping based on filter bank approaches, which data spread across two dimensional block structures over time and frequency, but OFDM is a flexible in orthogonal multicarrier
modulation which data spread across one dimensional block structure (frequency) as illustrated in figure 1. In the OFDM, the total bandwidth is divided into narrowband subchannels, which each subchannel with a bandwidth much smaller than the coherence bandwidth of the channel. Where the high rate data stream is split into substreams of lower rate which are modulated into \( N \) OFDM symbols and transmitted simultaneously over \( N \) orthogonal subcarriers.

![Figure 1. OFDM and GFDM data structure.](image)

Considering the downlink of multiuser GFDM or OFDM system coexists with the primary system, Both \( L \) PUS are served by Base Station (BS) in the licensed system and \( K \) SUs are served by Access Point (AP) in CRN arranged randomly in circuit with radius about 1Km and shared the same licensed spectrum band \( W \) as illustrated in figure 2. The total bandwidth is divided into \( M \) subchannels with band \( W_S \). Perfect channel state information will be assumed. In GFDM [28], all transmitted symbol can be expressed by,

\[
X[n] = \sum_{m=1}^{M} \sum_{v=1}^{K} g_{m,v} [n] d_{m,v}
\]

Where binary data is encoded and QAM with modulation order \( j \) maps it into \( d \) data vector that contains MV element. \( d_{m,v} \) is the data transmitted on the \( m \) th subcarrier and \( v \) th subsymbol.

\[g_{m,v}\] is pulse shape response with \( n \) sampling index. There are different types of pulse shape filter [29] using in transmitting side such as raised cosine, root raised cosine, Xia pulse, Gaussian pulse and dirichlet pulse. The choice of pulse shape filter has hardly affected on reduction of OOB, the spectral properties and symbol error rate. In the receiving side, the use of ZF receiver (for OOB reduction) or MF receiver (for interference cancelation) was made. Pulse shape filter determined the roll-off factor \( \sigma \) which determines the overlap of subcarriers in the frequency domain and takes the range from \((0, 1)\). The pulse shaping is used at transmitter to reduce the OOB radiation on the cost of noise at receiving side. Where, the noise factor \( E \) (NF) increased with the roll-off factor due to higher overlapping of subcarriers.

### 3 ANALYSIS OF THE THROUGHPUT

Sum rate for all SUs over all subcarriers in GFDM can be achieved by the following statements [30] and select the parameter from Table 1. For OFDM modulation, \( E \) will assume 1. The achievable rate over subchannels \( m \) employed by the SU \( i \) is given by,
The achievable rate over all subchannels $M$ employed by the SU $i$ is denoted by,

$$C_i = \max_M \left\{ \sum_{m=1}^{M} \delta_m W_S \log_2 \left[ 1 + \frac{G_{i,m} P_{i,m}}{\gamma \left( \sum_{k \neq i} G_{i,k} P_{i,m} + \rho_i P_P G_{p,j} + \epsilon N_0 W_S \right) } \right], \right\},$$  \hspace{1cm} (2)

The sum rate of all SU$s$ can be formulated as follows,

$$\max_K \sum_{i=1}^{K} \left\{ \sum_{m=1}^{M} \delta_m W_S \log_2 \left[ 1 + \frac{G_{i,m} P_{i,m}}{\gamma \left( \sum_{k \neq i} G_{i,k} P_{i,m} + \rho_i P_P G_{p,j} + \epsilon N_0 W_S \right) } \right], \right\},$$  \hspace{1cm} (3)

s.t.

$$\sum_{i=1}^{K} \sum_{m=1}^{M} P_{i,m} \leq P_S,$$  \hspace{1cm} (5)

$$P_{i,m} \geq 0, \rho_i \in \{1,0\}, \delta_m \in \{1,0\},$$  \hspace{1cm} (6)

$$\sum_{i=1}^{K} P_{i,m} G_{i,p} \leq \varphi_m,$$  \hspace{1cm} (7)

Where $G_{i,j}$ is the channel power gain for data channel to SU $i$, $P_{i,m}$ optimum power transmit for SU $i$ over subchannel $m$ and $\Gamma$ is a factor related to bit error rate over QAM mapper. $G_{p,i}$ is the channel power gain for PU transmitter to SU $i$ receiver and $G_{i,k}$ is the channel power gain for SU $i$ transmitter to SU $k$ receiver. $P_P$ is the PU transmit power and $G_{i,p}$ is the channel power gain for SU $i$ transmitter to PU receiver. $\rho_i$ represents the activity of the PU and $\delta_m$ is the subchannel activity. $\varphi_m$ is the interference threshold at PU and $N_0$ is the noise power of additive white Gaussian with zero mean and variance $\sigma^2$. Noise $P_S$ is the maximum power allocated by access point.

### 4 OPTIMIZATION TECHNIQUES

Genetic algorithm (GA) [26] is the proposed algorithm aimed to maximize the sum data rate (total throughput) for all SUs in down link CRNs. This occurred by selecting the optimum power level for each subcarrier to all SUs under both power and interference constraints. The operation of GA is shown in figure 3.

#### Table 1. GFDM and OFDM parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>OFDM</th>
<th>GFDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of SUs</td>
<td>$K$</td>
<td>8..64</td>
<td>8..64</td>
</tr>
<tr>
<td>Mapping</td>
<td></td>
<td>16 QAM</td>
<td>16 QAM</td>
</tr>
<tr>
<td>Number of subcarriers</td>
<td>$M$</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Number of subsymbols</td>
<td>$V$</td>
<td>1...9</td>
<td>9</td>
</tr>
<tr>
<td>Number of cyclic prefix</td>
<td>$N_{CP}$</td>
<td>$V^8$</td>
<td>8</td>
</tr>
<tr>
<td>Number of cyclic suffix</td>
<td>$N_{CS}$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Subcarrier distance</td>
<td>$W_S$</td>
<td>0.3 MH</td>
<td>0.3 MH</td>
</tr>
<tr>
<td>System bandwidth</td>
<td>$W_T$</td>
<td>10 MH</td>
<td>10 MH</td>
</tr>
<tr>
<td>Roll off factor</td>
<td>$\sigma$</td>
<td>--</td>
<td>0.1 ... 0.9</td>
</tr>
</tbody>
</table>

![Figure 3. GA operation.](image-url)
Depending on random solutions called chromosomes of all optimization variables are calculated. These values in the acceptable pounders are required to the optimization problem and this process called a population. Then the algorithm starts to calculate the objective function based on the population. By selection (parents) mutation and cross over trying to improvement the objective function by generate a new population from old one is calculated and repeating this step until reached to the stopping criteria. At stopping criteria, the optimum values for all variables will be generated based on some optimization parameters. Therefore, the genetic algorithm parameters are used in simulation preferred the population size about 20 for simplicity and process time. The maximum number of generation is equal to 100. Constraints depending on mutation, uniform selection and cross over functions are used with cross over fraction reached to about 0.8 and stopping criteria is the Function tolerance with value reached to $10^{-6}$.

5 SIMULATION RESULTS

![Figure 4. Sum rate for all SU in CRN with maximum transmit power for GFDM and OFDM.](image)

Figure 4. Investigates the total throughput for all SUs in the downlink CRN with the total transmit power at AP using two different modulation techniques GFDM and OFDM. By increasing the total transmit power at AP, the throughput will be increased until it reached to saturation (maximum and constant level). Also this Fig. shows that the improvement in the total rate for all SUs using GFDM based on GA reached to 19.6% over OFDM under the same optimization technique at saturation. Under the effect of cyclic prefix at 5 dB, the total throughput reduced by 3.5% in GFDM but in OFDM, the reduction reached to 19%. This means that the improvement in GFDM using minimum number of cyclic prefix reached to approximately 15% rather than OFDM.

![Figure 5. Sum rate for all SUs in CRN with maximum transmit power at AP for GFDM under different level of σ and £.](image)

Figure 5. Studies the effect of roll off and noise factors on the total throughput in down link CRNs based on GFDM system. From this Fig., we conclude that by increasing the roll off factor, the overlaps between
subcarrier will be increased. Therefore, the noise level will be increased, and consequently the total throughput will be reduced. At transmit power equal to 5 dB, the roll off factor increases from 0.1 to 0.9 with incensement in noise factor from 0 dB to about 3 dB. Therefore throughput reduced from 2% to 17.9%.

Figures 6 and 7 show the performance of the total throughput under different number of PUs using two different modulation techniques. The total throughput will be improved in the GFDM technique than using OFDM. Furthermore, by increasing the number of active PUs in the system, the total throughput will be reduced. In fact, the system reached to the fully utilized which means that all PUs becomes active and the total throughput reduced by about 58%.
Figures 8, 9. Show the performance under increasing the number of SUs. If increasing the number of SUs, the total throughput improves, but at the saturation level due to increasing the number of SUs, the saturation level will be reduced because the interference from SUs on each other on each subcarrier will be increased based on its number. Figure 10 and 11. Show that by increasing the total number of subcarriers for each SU, the total throughput will be improved. If the number of subcarrier increases to double, this improve the total throughput by about 58% in OFDM system and by about 67% in GFDM system. Figure 12. Shows that the total throughput under different noise levels which at low noise level, the total throughput will be high and by increasing the noise level, the total throughput will be reduced until the noise level will be high and the total throughput will be destroyed. Moreover, GFDM system improves the total throughput by approximately 20% over OFDM system.
Figure 12. Sum rate for all SUs in CRN with noise level.

6 CONCLUSIONS

Proposed technique was suggested for Power allocation strategies to maximize the total throughput of underlay CRN. This proposed technique based on genetic algorithm under both interference and power constraints which is not clarified until now. Furthermore, this proposed technique based on two different multicarrier modulation systems OFDM and GFDM. Beside them, some OFDM problems in CRNs were solved. Moreover, the performance of the system under using different number of PUs, SUs, subcarriers, and fully utilized system under maximum transmit power and interference constraints was studied.

REFERENCES


