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Fair, efficient, and power-optimized spectrum sharing scheme for cognitive radio networks

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Abstract

The cognitive radio network (CRN) is a promising solution to the problem of spectrum scarcity. To achieve efficient spectrum utilization, cognitive radio requires a robust spectrum sensing and spectrum sharing scheme. Therefore, spectrum sharing scheme plays a key role in achieving the optimal utilization of the available spectrum. The spectrum sharing in CRN is more challenging than traditional wireless network. The main factors besides throughput and fairness which need to be addressed in spectrum sharing of CRN are primary user (PU) activity, transmission power, and variations in the radio environment. In this article, we propose fair, efficient, and power-optimized (FEPO) spectrum sharing scheme that will incorporate all critical factors mentioned above to maximize the spectrum utilization. Simulation results show that FEPO scheme outperforms in terms of transmission power by reducing the number of retransmissions and guarantees required level of throughput and fairness. Moreover, periodic monitoring helps to reduce the number of collisions with PUs.

Keywords: cognitive radio, spectrum sharing, primary user arrival activity, licensed user, FEPO

1. Introduction

Current static spectrum management schemes allocate fixed spectrum to each existing wireless network. These schemes assign a block of the spectrum band to a particular radio access-network standard, which is further divided for spectrum allocations into individual operators of this access technology. However, in recent years, wireless network technology grows exponentially especially in the domain of low-cost wireless applications that utilize the unlicensed spectrum bands. These growing applications have raised the issue of spectrum scarcity for upcoming wireless services and stirred the researchers to find new techniques for the efficient utilization of the available spectrum. On the other side of the picture, the Federal Communication Commission has reported that existing spectrum utilization is very sparse at any given time and space [1,2] as shown in Figure 1a.

It shows the variations in power spectral density (PSD) across the radio spectrum from 0 to 6 GHz. Although there is a dense spectrum utilization from 0 to 2 GHz yet there is a very sporadic spectrum utilization between 3 and 6 GHz. To deal with the problem of the inefficient spectrum utilization, a new concept is evolved called dynamic spectrum access (DSA) or opportunistic spectrum sharing (OSS) [1-3]. The DSA employs cognitive radio (CR), a potential technology to reform the mechanism of spectrum utilization. The DSA architecture consists of two main entities: licensed user (LU) or primary user (PU), which has the legal rights to use the spectrum and CR user or secondary user (SU); CR has temporal rights to utilize the spectrum band of PUs on a negotiation basis. For example, in Figure 1b, there are five PUs and four SUs operating in a cell with single active PU at a given instant.

To avoid harmful interference with PU and to maximize efficiency of the spectrum utilization, CR should periodically sense the radio environment and opportunistically accesses the spectrum hole by dynamically adjusting its transmission parameters like power level, modulation scheme, and coding scheme. There are four major stages of the CR: (1) spectrum sensing, (2) spectrum management, (3) spectrum sharing, and (4) spectrum mobility [3]. The prime objective of CR is the reliable detection and the optimal sharing of spectrum holes among CR users.

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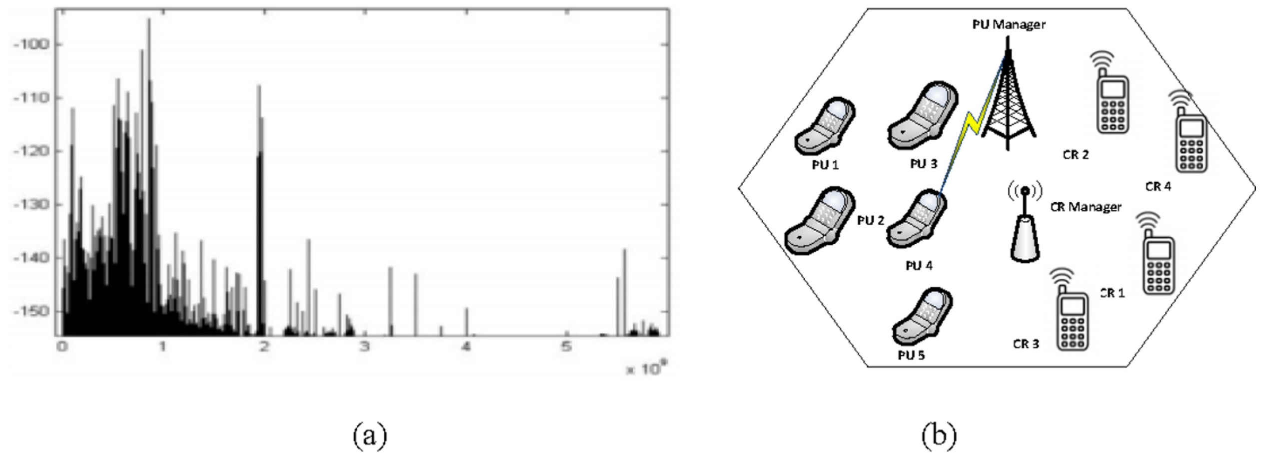

(a) (b)

Figure 1 (a) Spectrum utilization chart 0 to 6 GHz [1]. **(b)** Operation of CR in similar cell.

Sharing schemes provides a way for spectrum allocation and multiplexing at the data packet level. Moreover, congestion and admission control mechanisms are directly dependent on sharing schemes. Many sharing schemes capable of ensuring required level of QoS in wireless networks have been proposed in the literature. However, these schemes cannot be directly applied to cognitive radio network (CRN) because of the variation in the capacity and quality of wireless channels across space and time and PU arrival activity. Currently, it is an urgent need to develop new spectrum sharing schemes at medium access control (MAC) layer for providing required level of QoS and operate under tolerable interference limit. Moreover, it is also desirable that the sharing scheme keeps track of the changes occur in the condition and capacity of available wireless channels. Among all other technical issues need to be addressed, spectrum sharing is one of the important issue. In this article, we propose a robust spectrum sharing scheme that will consider all important factors discussed earlier and allocates the available sensed spectrum holes among competing CR users in an optimal way.

The main contributions of this article are summarized as follows:

(i) We formulate the problem of spectrum sharing in a centralized intra CRN using a slotted structure and considering all relevant metrics and requirements of both SU and network. We provide an in-depth analysis of existing spectrum sharing mechanisms and challenges faced in designing such schemes. This is valuable for future research in this direction.

(ii) We propose a framework for dynamic spectrum sharing in CRN, which incorporates the PU activity as well as changes occurring in the channels due to the fluctuating behavior of the available spectrum in time and apace. To provide a required level of throughput and maximum fairness to the competing CR users, an optimized spectrum sharing strategy is introduced.

(iii) We propose a dynamic framing process at MAC layer, which makes variable size frames depending upon the quality of channel.

(iv) Finally, we compare our proposed scheme with the MMF scheme given in [4] in terms of power consumption to serve the CR users.

The rest of this article is organized as follows. Section 2 briefly presents the previous study related to the spectrum sharing. Section 3 describes the problem formulation process. In Section 4, the impact of PU activity is discussed. The algorithm of the proposed scheme is discussed in Section 5. Simulation results are demonstrated in Section 6. Finally, Section 7 covers the conclusion of the article.

2. Related study

Most of the ongoing research in CRN is focused either on physical or MAC layer. The basic aim of the CRN is to provide a way for the efficient utilization of the existing spectrum [5-7]. The CR finds vacant spaces in the licensed band called spectrum holes for opportunistic access [3]. The CRN employs the sensing scheme to detect the presence or absence of the PUs. Spectrum sensing schemes either detector the primary transmitter or receiver. These schemes can also be classified as local or cooperative [3,8,9]. In the local spectrum sensing each CR individually decides about the presence of PU, whereas in the cooperative spectrum sensing multiple CR users collectively decide about the presences of PUs on the particular spectrum band. After locating the pool of spectrum holes, these are shared among CR users. In [10], spectrum allocation algorithm is described based on the call request control mechanism. The probability of call blocking is reduced significantly because of the call request control mechanism. In [11], another spectrum allocation algorithm is proposed for multi-user OFDM system to maximize the overall capacity of the system. The proposed multi-user algorithm provides better results in terms of capacity and fairness, but it is limited to fully connected networks. A survey of the spectrum sharing scheme in the CRN is presented in [12]. The authors have classified the sharing schemes in three major classes of open, hierarchical, and dynamic exclusive.

The advantages and challenges of each model are also discussed. In [13], the authors present a comprehensive analysis and description on MAC protocols for CRN. It explains the issues related to spectrum sensing, and latest challenges at physical and MAC layers are also discussed in detail. The author categorizes the MAC protocol in three main classes of random access, time slotted, and hybrid protocols. In [14], the authors classify the sharing schemes as centralized or distributive. In the centralized approach, a central entity called a spectrum server or a spectrum broker, which is responsible for sharing the available spectrum band among the CR users while in the distributive method, each CR user participates in the sharing decision. They exchange the information about the sensed spectrum and then collectively share the spectrum among them according to their requirement. Another classification based on architecture is presented in [15] where the sharing schemes are classified as underlay or overlay. The underlay model seems to be the best case as far as the CR operates under the interference level with the PUs but it requires a complex hardware system. In [4,16-18], various centralized spectrum allocation schemes are proposed. In these schemes, each CR user exchange control-information (CI) with the central server to compete for sensed spectrum holes. The CI contains the sensed information, synchronization information, and power level. Based on this exchanged information, the spectrum server forms an optimal schedule for sharing the spectrum holes among competing CR users. Other random access protocols such as ALOHA and CSMA are presented in [19-21]. The authors propose and simulate a system for the sharing of spectrum holes among CR users, but these techniques are limited to the sharing of a single channel.

In [22] a spectrum sharing scheme based on the interference and power control mechanism is proposed. The author introduces a variable rate and power allocation scheme where each CR user on different channels has the different amount of transmission power and data rate. The author utilizes multilevel quadrature amplitude modulation to achieve throughput efficiency. The concept of soft sensing information is introduced to get the information about the PU activity and channel state information with respect to the quality of channels. This scheme allocates the available channels under the constraints of bit error rate, and averages transmit power. Although it is an optimal scheme in terms of throughput, but it lacks in providing fairness among CR users that is also an important factor for an optimized sharing scheme.

The sharing schemes in CRN differ from the traditional cellular networks channel sharing techniques because of the capricious nature of the spectrum band in space, time, and quality. This becomes even more challenging if we consider the arrival activity of the PUs as well. Most of the research efforts in CRN are focused to find a way to cater with the interference problem with PUs. There are two main methodologies to deal with the problem of interference with the PUs. In first approach, a predictor forecasts the idle time for the available channels [23-26]. In second approach, interference can be avoided by taking on the fly channel eviction decision. This will degrade the QoS for the SU, but it requires simplified structure as compared to the former approach. In this article, we adopt the latter approach to avoid the interference with the PUs in a centralized intra CRN.

3. Problem formulation

In this section, we present the methodology for the formulation of our problem. First, we present the network model, and then proposed the framework of our system. We also present the frame format that we have considered for our system.

3.1 Network model

We consider a network with $p = 1, 2, 3, ..., P$ PUs and $c = 1, 2, 3, 4, ..., C$ CR users operating in similar pattern as shown in Figure 1. Each CR user performs sensing operation on $n = 1, 2, 3,..., N$ primary channels of same cell and forward this measurement to the central entity known as CR base station. The primary channel can be modeled as an independent continuous-time Markov process [27]. The transmission on nth channel for CR user c using can be modeled using the Markov process as $S_n^c(t)$. The $S_n^c(t) = 0$ represents the idle state, whereas $S_n^c(t) = 1$ indicates the busy state of channel. The CR can transmit only during the idle state of the channel. We assume the slotted structure for the CR transmission with slot length λ as shown in Figure 2. The slot length λ is divided into three subslots. The symbol τ indicates the sensing time consumed by a particular CR user, ε represents the channel eviction time period, and t_{d} represents data transmission period. Mathematically, the slot length is

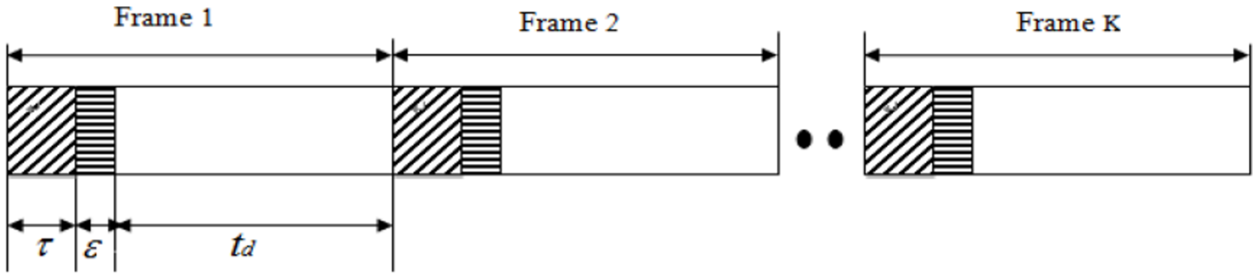

Figure 2 Frame format (τ: sensing time, ε: eviction/switching time and td: actual data transmission time).

$$\lambda = \tau + \varepsilon + t_d \quad (1)$$

$$t_d = \lambda - \tau - \varepsilon \quad (2)$$

$$\varepsilon << \tau << t_d \quad (3)$$

We assume that the channel eviction time is very small as compared to the sensing time while the actual data transmission time is significantly larger than the sensing time for a given time slot as shown in Figure 3. Moreover, the allocation is performed after every time slot, and we assume that the environment remains same for the duration of a given time slot.

3.2. The proposed framework

Monitoring the PU activity over channels helps significantly to reduce interference with the PUs by vacating/evicting the channel. Figure 3 represents the proposed framework design for fair, efficient, and power optimized (FEPO) scheme. The general steps can be listed as follows.

Step 1: The PU arrival monitor (PAM) block gathers the statistics about the arrival of PUs on different frequency channels through the spectrum sensing.

Step 2: The PAM analyzes the current spectrum sensing results and sets the value of the channel status flag (csf) for each currently in use frequency channel. If the PU arrives on the same channel, then PAM sets csf = 1 for that particular channel.

Step 3: The eviction controller (EC) block observes the csf flags of different channels and preempts/evicts CR users accordingly. For example, if csf of a particular channel is set to 1, then EC triggers the eviction of CR user from that channel and at the same time informs the spectrum allocator (SA) about this observation.

Step 4: The SA is the central entity that is responsible for sharing the spectrum among CR users. The SA consists of four elements: (1) channel quality indicator (CQI), (2) user database, (3) a first in first out (FIFO) queue, and (4) a scheduler.

The CQI is responsible for measuring the quality of each unused frequency channel by computing its signal-

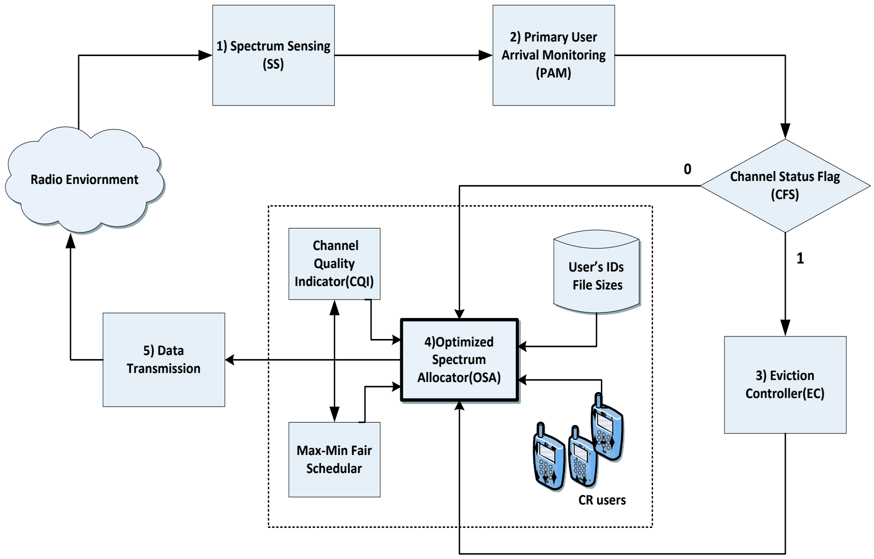

Figure 3 Proposed framework.

to-interference ratio (SIR). A user database contains the information such as the identifier of CR users, the file size, and the minimum data rate required for each CR user. The FIFO queue maintains the list of CR users competing for channel availability. The spectrum scheduler (SS) forms an optimal schedule by incorporating the observations and calculations from different components within the spectrum allocator with the prime objective of interference avoidance (eviction/silence) with PU and transmission power reduction. We incorporate MMF scheduling algorithm given in [4] to achieve global fairness among CR users. However, if there is a need to vacate a channel on arrival of the PU, then SS will update in-service users with the observation made by EC block.

Step 5: The CR users perform the transmission on the allocated channel and then return to step 1 for sensing.

4. PU arrival activity

The CRN utilizes the spectrum band of PUs in an opportunistic manner on the lease basis. From the view point of PUs, it is an important factor that whenever PU needs a spectrum band, CR should vacate the channel to avoid the interference and reduce the number of retransmissions.

Figure 4 represents the on-off activity of PUs on three different channels that we consider for our simulation results. Initially, all three channels are in idle state, i.e., $S_n^c(t) = 0 \ \forall \ n$ and available for CR communication. A PU arrives on channel 1 during the slot number 2, the status of channel gets change from idle to busy state, i.e., $S_n^c(t) = 1$ for $n = 1$. During sensing interval, CRs sense the arrival activity of PU and vacate the channel immediately by performing channel eviction/vacation activity with the help of EC block.

5. Algorithm

This section describes the algorithm that we have considered for our approach. The details about the different notions and equation are also discussed in this section.

Algorithm: FEPO spectrum sharing scheme

```
Input: n_user, n_ch, $d_{min}[i]$ and $d_{max}$ [i] for (i = 1, 2, 3, ..., C) n_user:number of CR user
user_serv←0, Temp←0, csf ←0; Initialization
    While (user_ser = = 0) do
        for n = 1 to N
            If PU[n] = = 1 PUs arrival
                csf[n] = 1;
                Temp = 0;
            else
            call CQI; calculate channels quality
                call max-min fair; call max-min fair function
                Temp = ch_data[n];
            d_u[n] = d_u[n]- Temp; ch_data from max-min fair

            If user serve completely
                n_user = n_user-1;
                bring new user;
            end
        end
            if (n_user = = 0) all user get served
                user_serv = 1;
            end
        end
    end
csf   channel status flag
dmin   minimum data rate requirement of CR
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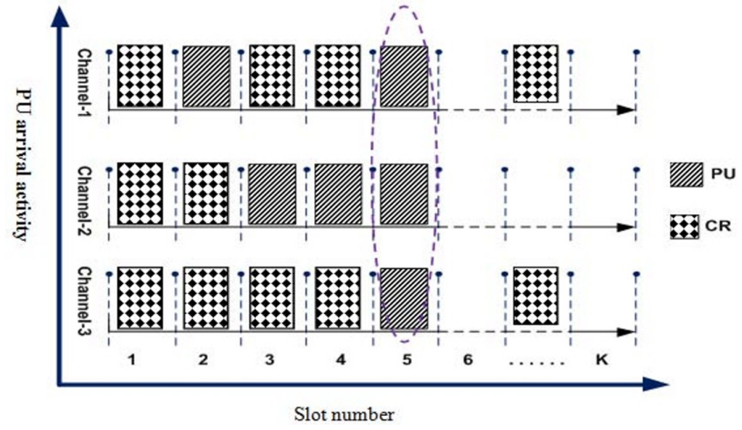


Figure 4 PU's arrival activity.

dmax *max data file size of CR*
d_u *user data record variable*
d_ch *data rate on a channel*

In the given algorithm of FEPO, csf represents the channel status flag of nth channel in the given time slot. The CQI indicates the channel quality identifier which expresses the quality of channels in terms of SIR. The quality of free channels can be computed by the expression given in [4] as

$$\Psi_n^m = \frac{t_n^m G_{nn} P_n}{\sum_{i \neq n} t_m^i G_n^i P_i + \sigma_n^2} \tag{4}$$

where G_{nn} is the channel gain, P_n is the power by which CR transmits data on channel n, t_n^m indicates the on-off pattern of a particular channel, and σ_n^2 represents the noise variance. The subscript m indicates the transmission mode. The terms with superscript i represent the effects of the interference from other active CR users on the on the user operating on nth channel. As the CR users increase in number, this factor gets increase and hence it will decrease the overall SIR ratio. The data rate on the channels can be calculated using the expression presented in [4] as

$$d_n^m = \log(1 + \Psi_n^m) \tag{5}$$

where d indicates the capacity of the channel n under certain transmission mode m. For the simplicity, we consider the transmission mode in which all the available channels are in active state in a given time slot. In order to achieve fairness, we incorporate MMF scheme discussed in [4] which allocate the equal data rate to all CR users. The proposed scheme also maximizes the throughput while fulfills the minimum data rate requirement ($d_{\min}$) of each CR user.

6. Results and analysis

In this section, we quantify the performance of our proposed scheme and present simulation results. The simulation program is implemented in Matlab. Although the simulation results are true for more general cases, yet we perform analysis for some specific case to illustrate our outcomes. Our approach is different from the previous studies in terms of taking into account the sharing of the spectrum inconsistency because of irregular PU activity and the changes occur in the radio environment. Moreover, we compare the performance of our proposed technique with previous study in terms of power consumption for the transmission of the CR user's data file. We also incorporate the dynamic framing process within the SA to make the variable frame size. The parameters used for simulation are mentioned in the Table 1.

Table 1 Simulation parameters

Parameter	Values
Slot length	1 s
Transmission period	0.9 s
Sensing period	0.08 s
Channel eviction period	0.02 s
Number of channels	3
CR user pairs	2
Channel gain	0-1
Noise variance	0.2-0.7
Minimum data requirement	[0.5, 0.7, 0.8]
Transmission power	30 dB

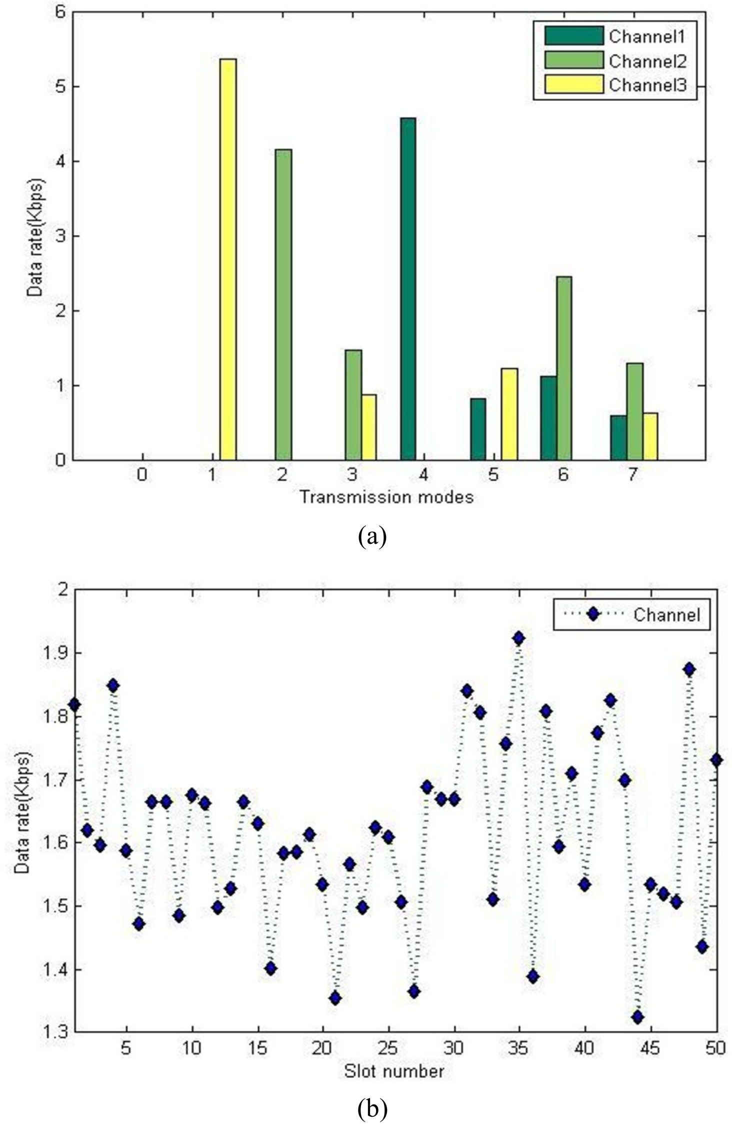
6.1. Impact of selecting transmission the modes and variations in the channel condition on data rate

Figure 5a shows the impact of selecting different transmission modes (TM) on the throughput. The TM describes the on-off pattern of available channels. Here, we consider only three channels with eight possible TMs from 000 to 111 as defined in [4]. For example, for TM 001 channel 3 is the best quality channel and has a data rate of 5.39 kbps, whereas channel 2 is poor quality with data rate of 4.17 kbps for TM 010. The data rate reduces significantly when two or more channels are active in a given time slot. This reduction in data rate is because of the co-channel interference among CR users. It can be seen that the co-channel interference is the maximum when all the three channels are active under transmission mode 111, but it provides fairness among CR users. As the CR is utilizing the spectrum band of PU on lease basis and accessing opportunistically, there is a significant variation in the channel condition (data rate) across time and frequency during the transmission in each time slot. Figure 5b depicts the variation in the data rate achieved for different time slots. As mentioned earlier, the MMF scheme is used to provide same data rate on all available channels. Hence, we plot the variations only for single radio channel in Figure 5b.

Initially, the data rate on the given channel is 1.82 kbps but data rate decreases during second and third time slots. This decrease in data rate is because of the poor channel condition. The data rate increases again to 1.85 kbps during time slot number 4 because of the significant improvement in the channel condition as compared to the slot number 3. The maximum data rate of 1.94 kbps and minimum data rate of 1.2 kbps are achieved during time slot numbers 35 and 44, respectively. Hence, the achievable data rate on a channel depends on its condition.

6.2. Channel eviction activity, sum rate, and channel sharing pattern

Figure 6 shows the channel eviction behavior and impact of PU activity on the throughput of CR using



(a)

(b)

Figure 5 Impact on data rate. **(a)** Change in transmission modes [4], **(b)** Change in nature of spectrum.

the PU arrival pattern depicted in Figure 4. In this case, we consider three CR users with different file sizes of 10, 5, and 10 kb, respectively. Initially, in the first time slot all primary channels are in the idle state. Therefore, these channels can be used for CR communication. In slot number 2, a PU arrives on channel 1. In this case, the PAM block sets the csf = 1 for channel 1 and inform the SA about the arrival of PU at this time slot. The SA evicts CR from channel 1 by triggering the channel eviction mechanism. This may lead to slight degradation in CR user's throughput operating at the cost of interference avoidance. During time slot numbers 3 and 4, a PU arrives on channel 2, the CR which is currently using channel 2 immediately evicts the channel and switch to channel 1 for its future communication. Lastly, if all the channels are being occupied by PUs then the csf flags of all the channels are set to 1 and SA evicts/preempts all CR users from transmission in order to avoid interference and reduce the power used in retransmissions. This situation happens during slot number 5 as shown in Figure 4. There is a slight variation in the behavior of CR at channels 2 and 3 during time slot number 7. This variation is due to the *early service effect* (ESE). The ESE indicates that the remaining file size of CR user is less than the data capacity of channel, and it is serviced fully at the given time slot. The same argument is true for the small data usage on channel 1 during time slot number 8.

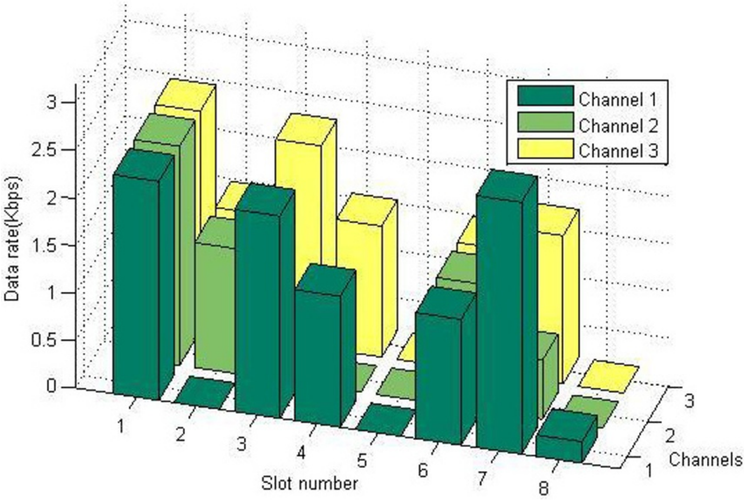


Figure 6 Channel eviction behavior of CR.

The effect of channel eviction on the sum rate is illustrated in Table 2. The sum rate is the sum of data rates achieved on all channels by all CR users. For example, in current case, we consider three channels and the sum rate is equal to the addition of available data rates on all channels. The results show that the optimal sum rate is achieved for the case in which more channels are available for CR users. The sum rate is maximum during slot number 1 as all channels are being used for CR transmission. In this case, there is no activity of PU on these channels. The sum rate declines significantly during slot numbers 2, 3, and 4 because of the arrival of PU on the channels 1 and 2.

The channel sharing pattern of the proposed scheme is also shown in Table 2. We consider six SUs with three transmitters and three receivers. We assume that all SU transmitters are the same power, i.e., 30 dB. The file size and user's ID of SU are managed through a small database. The proposed scheme selects the SUs from FIFO queue and assigns the available channel. The framing is performed before transmission of the data, and the frames of variable size are used depending upon the capacity of channels. For example, channel 2 is assigned to the SU with ID 2 and SU_2 transmits fame of size 2.30 and 1.13 kb during slot numbers 1 and 2, respectively. Hence, OSA maximizes the capacity utilization with variable frame size.

Table 2 The sum rate and SUs activity on channels

Channels	Slot number							
	1	2	3	4	5	6	7	8
1	SU_1	PU	SU_1	SU_1	PU	SU_1	SU_1	SU_1
2	SU_2	SU_2	PU	PU	PU	SU_2	SU_2	-
3	SU_3	SU_3	SU_3	SU_3	PU	SU_3	SU_3	-
Sum rate (kbps)	6.90	2.62	4.52	2.75	0	3.97	4.82	0.22

6.3. Effect of PU arrival on SU's service time and throughput

Figure 7a, b shows the impact of PU arrival activity on the total service time and throughput of SU. In this scenario, we show the outcomes for three different file sizes and five SUs. The SUs have file size of 5, 10, and 15 kb. Therefore; the total file size for each case is 25, 50, and 75 kb, respectively.

Figure 7a depicts the delay in the service time because of the arrival rate of PU. In the first case, each SU has a file of 5 kb. All SUs get service in just 5 s. In this case, there is no PU activity on three available channels. The service time increases in linear pattern with the increase of file size. It becomes nearly double (5.9-11 s) when the total file size varies from 25 to 50 kb. Similarly, when we increase the total file size to 75 kb, the required time to serve SUs becomes almost three times (16 s). There is another significant impact on service time because of the increase in the arrival frequency of PU. For the arrival frequency equals to 20, there is an increase of 110, 63, and 43% in the service time for the file size of 25, 50, and 75 kb, respectively.

The effects of arrival activity of PU on small file size are slightly higher since in certain time slot the SU may have less amount of remaining data than the frame size. Figure 7b depicts the degradation in the SU's throughput with the increase in the arrival rate of PU. PU arrival rate is varied from 0 to 1. The fraction of throughput decreases linearly with the increase in the arrival rate of the PU for larger file size. For small file size, there is a slight variation in the behavior, this is because of the same reason given in Figure 7a.

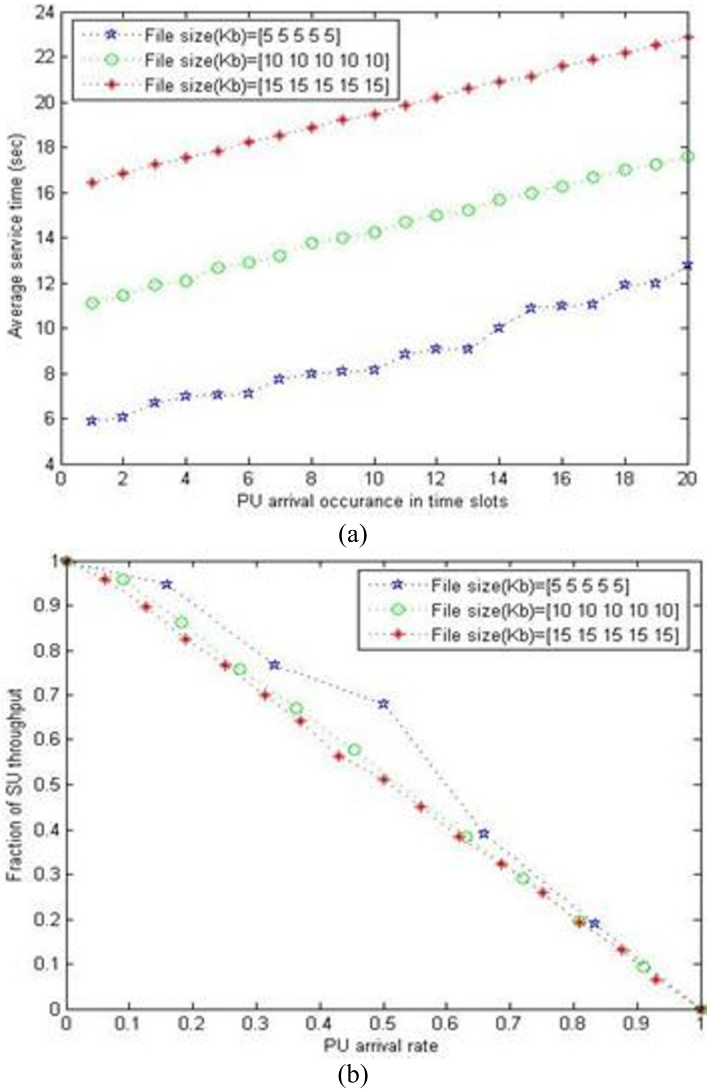


Figure 7 Impact of PU activity. **(a)** Effect on average service time; **(b)** Effect on SU's throughput.

6.4. Comparison with MMF scheme

In this section, we compare our proposed FEPO scheme with the MMF scheme in terms of transmission power. The periodic monitoring of PU activity significantly reduces the transmission power.

In this case, we consider two different scenarios: (1) varying file size and (2) varying number of retransmissions for the PU activity illustrated in Figure 4. For simplification, we assume that system consumes 1 kW to transmit 1 kB data file. In first scenario, the PU arrives six times on channels 1, 2, and 3, respectively. The FEPO scheme utilizes the PAM block to monitor the arrival activity of PU and does not transmit data when PU arrives on current in use channel and save the significant amount of transmission power. We simulate this scenario for different file sizes varying from 25 to 125 kb as shown in Figure 8a. The FEPO transmits the same data file by consuming 10-40% lower power. For example, to transmit the file size of 25 kb MMF requires 35 kW transmission power, whereas the FEPO scheme transmits the same file with transmission power of 25 kW, which is significantly lower power as compared to MMF scheme. Mathematically, the current scenario 1 for a given PU activity (see Figure 4) can be represented as follows.

$$\xi(f) = f \tag{6a}$$

$$\xi(f) = f + (\beta + \gamma) \tag{6b}$$

where $\xi(f)$ represents the power requirement for each scheme. The factor f represents the power requirement

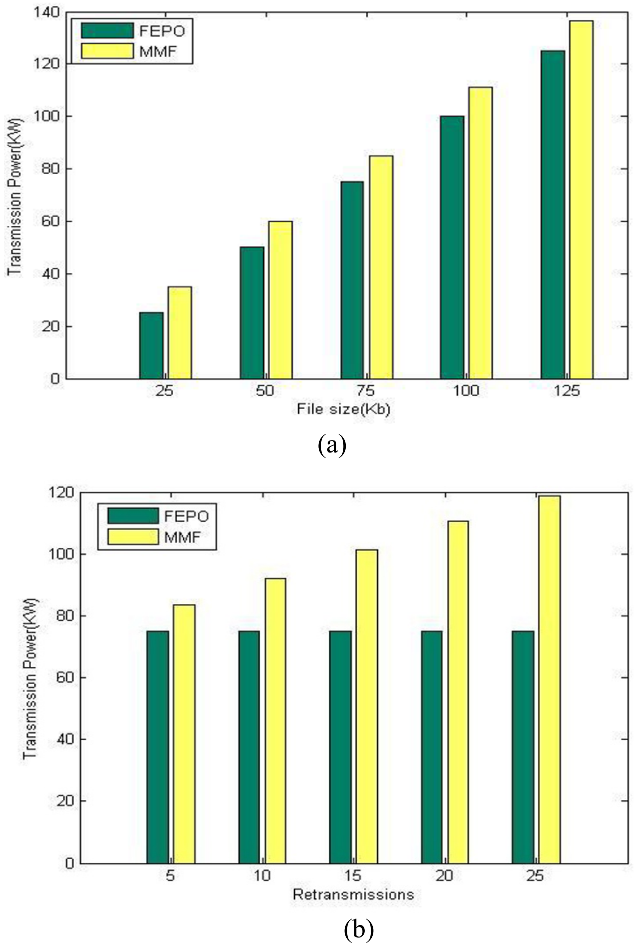


Figure 8 Comparison between FEPO and MMF scheme in terms of transmission power. **(a)** Varying file size; **(b)** Varying number of retransmissions.

of our proposed FEPO scheme. The factor $\beta + \gamma$ indicates the additional power factor for MMF scheme. The β factor has a constant value for a given PU activity. The γ factor is very small as compared to the β factor, i.e., $\gamma < <\beta$. In Figure 8a, the value of β factor is 10 and the values of γ factor are 1 and 2 for file size of 100 and 125 kb, respectively. The γ factor is zero for first three file sizes.

In second case, we show the comparison using file size of 75 kb and varying the number of retransmissions. Each PU's arrival requires a retransmission if monitoring is not considered properly. The retransmissions are varied from 5 to 25, and we measure the power consumption for each scheme. It is clear from the simulation results that MMF scheme consumes 11.5-58.5% extra power for the transmission of same files having size of 25 and 125 kb, respectively. Mathematically, the comparison of scenario 2 can be depicted using the following equations

$$\xi(r) = \alpha \tag{7a}$$

$$\xi(r) = \alpha + kr \tag{7b}$$

where $\xi(r)$ represents the power requirement of each scheme. The proposed FEPO scheme requires significantly lower power to transmit a given file. However, the power requirement of MMF scheme increases linearly with the increase in the number of retransmissions. The factor k is the slope factor and r represents the number of retransmissions. In Figure 8b, the value of α factor is 75 kW, the factor r represents the number of retransmissions and k is increasing factor, and its value is 1.82 for $r = 20$.

7. Conclusions

The spectrum sharing in CRNs is more challenging than the traditional wireless networks. Here, spectrum band varies continuously across the space and time in terms of both availability and quality. This varying nature of spectrum demands for a radio environment-aware optimized spectrum allocation mechanism. In this article, we present a spectrum sharing scheme that schedules the sensed spectrum holes among cognitive radio (CR) users by considering the changes occur in the radio environment as well as the PU's activity on current in use channels. In the proposed framework, we assume slotted structure where each CR performs sensing operation at the start of each slot. The CR monitors the in-use channel for PU activity. If the channel is still idle, it will perform the transmission on the same channel otherwise it looks for some other channel for transmission or remains silent during the entire time slot to avoid interference with PU.

We also propose a dynamic framing process at MAC layer, which can form variable size frames depending upon the capacity of available channels. The simulation results show that our proposed scheme outperforms in saving the transmission power while ensuring required throughput and fairness. Moreover, we compare the service time and throughput of CR user against different file sizes. The PU arrival activity on the available channels degrades the performance of the CRN but in our scheme, the periodic monitoring significantly enhances the performance by reducing the number of retransmissions.

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Competing interests
The authors declare that they have no competing interests.

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