IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-6, Issue-5, May 2018 E-ISSN: 2347-2693

Resource Allocation in Cognitive Cellular Hybrid Network Using Particle Swarm Optimization

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Available online at: www.ijcseonline.org

Accepted: 15/May/2018, Published: 31/May/2018

Abstract— Time slot allocation concept for cognitive cellular hybrid network (CCHN) is proposed in this paper. It has been addressed an efficient resource allocation scheme by mitigating interference problem in CCHN. A combination of hybrid underlay-overlay network is introduced to overcome the limitations of underlay and overlay cognitive network. We have adopted an opportunistic cooperative sensing based spectrum access scheme to allocate resource as available time slots among multiple cognitive radio (CR) users. Particle swarm optimization (PSO) algorithm has been implemented to optimize transmitting parameters such as antenna size, modulation index, transmission rate, SNR. In order to achieve the maximum network capacity and proper distribution of time slots beam forming concept of PSO has been utilized. As a result, a new scheme for time slot allocation in cognitive hybrid networks has been adopted. A mathematical model and emulated results have been presented to justify the proposed scheme. The graphical analysis reviles the improvement of throughput performance, system efficiency, transmission rate and the quality of service (QoS) for both the primary and secondary users.

Keywords— Cognitive radio, Cooperative sensing, Hybrid network, PSO, Outage probability.

I. Introduction

A cognitive radio (CR) [1] [2] is the key technology that allows a cognitive wireless terminal to access the available spectral opportunities dynamically. Dynamic spectrum access (DSA) network design has increased due to high demand of spectrum for new applications [1] [3]. A cognitive radio (CR) user or secondary user (SU) is allowed to use only unused spectrum opportunistically to prevent interference or collision with the primary users (PUs). In traditional underlay network [4] simultaneous primary and secondary transmission possible only if the interference caused by the secondary transmitter at the primary receiver below some acceptable threshold [5]. Determining the exact interference is a biggest challenge in that case. Whereas, in overlay network [6] secondary transmitter has knowledge about the PUs' transmitted data sequence. However, sharing the PUs' private data sequence information with SU is not secure always due to the presence of various malicious attackers. In both cases primary and secondary users maintain transmit power level within a predefined threshold for simultaneous transmission. On the other hand, Inter-wave approach [4] requires the detection of PUs in one or more of the space-time-frequency dimension. However PU activity and location changes overtime. Therefore, Inter-wave users avoid simultaneous transmission with primary users. Hybrid scheme, using all these ideas, has a great potential to improve the efficiency of spectrum sharing [7].

The idea has extended by considering a TDMA scheme for successful implementation of a hybrid scheme by traffic control and simultaneous transmission. A cooperative communication network has been investigated where fusion center (FC) broadcast available timeslot for CR users. Cooperative local sensing technique has been used to detect sudden appearance of PUs in [17]. The spectrum sensing and signal localization have also been studied in [8] [9]. On the other hand joint beamforming and power control using weighted least square algorithm have been introduced in [10]. Beamforming can be implemented either at the transmitter or at the receiver. Transmitter beamforming concentrates the transmission signal on a certain direction in order to minimize interference with other users. Receiver beamforming is usually useful for signal localization or for taking advantage of spatial diversity. A power control in a randomly time varying environment has been studied by employing particle swarm optimization (PSO) algorithm [11]. A PSO based efficient timeslot allocation scheme with high transmission efficiency and minimum interference has been investigated for multiuser cooperative transmission [12].

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In this paper, we have proposed a PSO based intelligent method to access the channel timeslot efficiently, which are broadcasted by FC for cognitive radio users. Multiple primary and cognitive radio users are allowed to access the broadcasted timeslot within a specified transmission power. In this proposed scheme, beamforming concept has been applied to serve multiple CR users with higher throughput performance. The basic goals of our work are focused on time slot allocation in a time division multiplexing access mode, to maximize the transmission rate and to minimize the transmission power of the secondary users in a randomly time varying environment.

The remainder of the paper is organized as follows: Sec. 2 explains the detailed functional strategy of proposed hybrid network. A mathematical model based on PSO algorithm has also computed in this section to establish efficient time slot allocation mechanism. The proposed network performance has been analyzed through simulations in sec. 3. Sec 4 concludes the paper.

II. PROPOSED SCHEME

Space diversity access which is also known as secondary users' access scheme divides the available time slots among multiple secondary users to access the channel. Primary network leases portion of channel access time to the SUs for their transmission using particle swarm optimization (PSO) algorithm. PSO algorithm is implemented to optimize the QoS parameters such as transmit power, transmission rate of SUs, SU outage probability, system efficiency of the Cognitive radio system which results in an enhanced utilization of the electromagnetic spectrum.

2.1 Hybrid cognitive cellular network

We have designed a hybrid network, where simultaneous primary and secondary transmission is possible using time slot allocation mechanism. Time frame is divided into slots for control channels and data transmission. When no SUs present in the network, PU uses their allocated time slot for data transmission. An entity is known as fusion center (FC), is connected with the multiple cognitive radio (CR) clusters as shown in the figure1. FC coordinates sensing and detection operation of licensed and unlicensed spectrum and broadcast reliable time slots information among the inter-cellular CR users. FC collects all the available resource statistics from spectrum sensing results to generate control decisions for optimizing the performance of the CR users within a cluster. It also provides roaming services to the cognitive users as a value added service feature. A global network controller (GFC) can be used as interconnected entity between two adjacent FCs to support the intra cellular cognitive users roaming and resource sharing. The registered SUs can make request for time slot allocation to the network controller or FC. FC must be informed about the occupied time slot by the particular SU. However, FC continuously broadcast the available time slots information within a network. Only registered SUs are allowed to access the available broadcasted time slots. Any SU can join the network by proper registration process to access the available time slots. If the registered user number increases over the maximum limit then the excess number of SUs has to wait for some period of time to access the network. On the other hand, if owner of that time slot suddenly appear during SU's transmission, then probability of interference has raised. However, by cooperative sensing operation, SU and FC already know about the PU's sudden appearance from PU base-station. Therefore, without wasting any time FC broadcast this information along with new available time slot to switch immediately on that new channel to continue data transfer operation. In case of unsuccessful transmission, new available time slot is also broadcasted by FC after getting request for new slot. Cooperative sensing is essential operation for CR node and FC to detect PUs within a network.

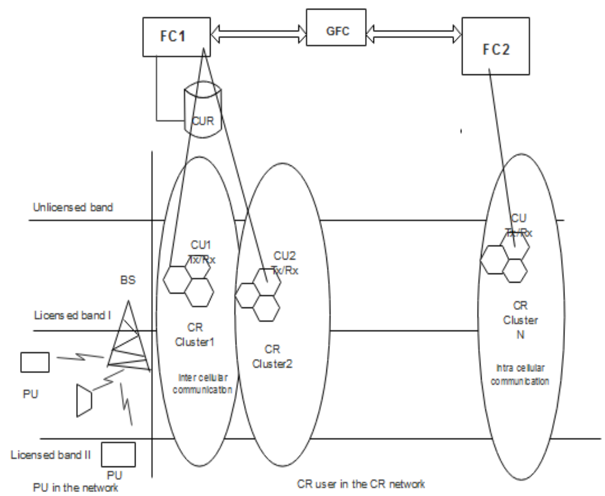

Figure 1: System nodel for cooperative communication

2.2 Cooperative sensing

In CR, cooperative spectrum sensing occurs when multiple CR user terminal share the sensed information. When multiple primary and secondary user simultaneously active in a network, cooperative sensing is necessary to avoid interference with the primary user. This provides an efficient usage of spectrum. In our proposed network we have used the concept of centralized cooperative sensing operation.

In centralized approach of cooperative spectrum sensing, there is a master node within the network that collects the sensing information from all the sense nodes or radios or user terminals within the network. It then analyses the information and determines the spectrum that can and cannot be used.

The CR central node or FC can organize the various sensor nodes to undertake different measurements at different times. In this way it is possible to undertake a number of different sense actions at the same time. For example, some nodes may

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be instructed to detect on channel signal levels, while others may be instructed to measure levels on adjacent channels to determine suitable alternatives in case a channel change is required or PUs sudden appearance occurs. In our proposed network, sensing information of all cognitive radio user terminals is transmitted towards FC which takes the final decision. Each new CR user requests for spectrum through registration process and FC broadcast available spectrum information. Each and every individual cognitive node does local sensing operation to reduce interference with PUs' and determine sudden appearance of PUs. The goal of spectrum sensing is to decide between the following two hypotheses:

$H1$: PU is absent.

$H0$: PU is present.

Lots of sensing technique like energy detector, matched filter detection, feature detection, collaborative spectral detection has been studied [17]. The energy based spectrum sensing and detection is the simplest method for detecting PUs in the network. Cognitive node measures radio frequency energy in the channel or received signal strength indicator (RSSI) to determine whether the channel is idle or not. If the energy detected is above threshold, the PUs' detected otherwise not detected any PUs.

Sensed information then sent back to FC, so that FC take the final decision and broadcast what alternative action should be taken.

2.3 Problem formulation and analysis

A system model consists of N number of PUs as shown in Fig1, transmits and communicates with the constant and specific transmission power. There are M secondary users present in the model. The time slot division is shown in Fig2. The secondary network processing is based on beam-forming at both the transmitter (k antennas) and the receiver (k antennas) for each SU link. In the secondary network, secondary users are considered to work in the same frequency band as the primary system. An efficient transmit beam-forming technique is proposed to maximize the total throughput.

The transmit power of secondary users are limited to a maximum value prescribed by primary users. The secondary users work as relays by dividing data transmission into frames, where duration is 1 time unit.

t_P : First fraction of time slot which is dedicated to the transmission of both primary receiver and secondary user as the cooperative relay.

$(1-t_P)$: Time unit of slot is separated into two sub-slots based on γ .

$\gamma(1-t_P)$: Relay secondary users transmit primary user's data to primary receiver.

$(1-\gamma)(1-t_P)$: Multiple secondary users also access channel in space diversity mode.

Time slot division for secondary and primary transmission,

t_p	$\gamma(1-t_p)$	$(1-\gamma)(1-t_p)$
1st part of time slot	**2nd part of time slot**	**Remaining part for cognitive user transmission**

Figure 2: Time slot division

Here the amount of access time for secondary users is related to the contribution they made in relay process. This network coexists in the same area with secondary users which are cognitive users.

In this paper, Particle Swarm Optimization algorithm is implemented to optimize the QoS parameters of the Cognitive radio system which results in an enhanced utilization of the electromagnetic spectrum. Here, it is assumed that the cognitive radio has already sensed its surrounding i.e. the RF environment & the spectrum holes are detected. The quality of service needed for the intended application is already identified through the secondary users (SUs) requests.

The objective is to minimize the transmission capacity of the primary and secondary users and to allocate time slot for an optimal transmission. In addition beam-forming of the transmitted signal from cognitive users is considered as pre and post beam-forming vectors. The received signal at the secondary users functioning as relay is obtained as follows:

$$Y_m(t) = \sqrt{P_{PU_{Tx}}}\, g_{pm} x_{PU}(t_p) + n_m \qquad (1)$$

$P_{PU_{Tx}}$, represents the transmit power of the primary base station, x_{PU} and g_{mp} are the transmitted signals of the primary base station and the channel gain between primary base station and m-th secondary user respectively. n_m is the additive white Gaussian noise. The signal received by primary receiver at the time slot $t = \gamma(1-t_p)$ is given by,

$$Y_P(t) = \sqrt{P_m}\, g_{mp} \frac{Y_m(t_p)}{|Y_m(t_p)|} + n_m \qquad (2)$$

g_{mp} and P_m represents the channel gain and transmit power of m-th secondary user respectively.

Power is constrained by a maximum transmit power limit. Here the pre and post beam-forming vector and transmit and receive beam-vector are presented. Beam vector associated with each secondary user are determined by optimizing a certain criteria to reach a specific target such as maximizing

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throughput or minimizing the interference. Assuming that the secondary users' signal is uncorrelated with zero mean, the m-th secondary user received signal at the remaining part of time slot as,

$$Y_m^{(!)} = H_{SU_{mm}} S_m + \sum_{j=1, j \neq m}^{M} H_{SU_{jm}} S_j + n_m \quad (3)$$

Where $H_{SU} \in C^{K \times K}$, a $K \times K$ complex vector of the fading path gains between secondary users. This vector is set with random complex components and obeys the Rayleigh distribution. The additive white Gaussian noise vector $n_m \in C^{K \times 1}$ is a Gaussian random process with zero mean and variance N_O on each vector component. The transmit vector S_m of size $K \times 1$ is yielded as follows:

$S_m = x_m b_m$, where $b_m \in C^{K \times 1}$, the pre beam-forming vector. x_m is the transmit sample for m between 1 and M. The m-th receiver beam former is,

$$Y_m = a_m^H Y_m^{(!)} \quad (4)$$

Where $a_m \in C^{K \times 1}$, the post beam-forming vector at the receiving secondary users'. The transmission rate for the time slot $t = \gamma(1 - t_p)$ is as follows:

$$R_{pm} = \log_2 (1 + \frac{P_{PU} g_{pm}^2}{N_O^2}) \quad (5)$$

In equation (5), g_{pm}^2 represents the gain of the channel gain between FC and secondary user.

The data rate of direct transmission is given by,

$$R_{PU} = \log_2 (1 + \frac{P_{PU} g_{PU}^2}{N_O^2}) \quad (6)$$

In equation (6), g_{PU} denotes the channel gain between primary base station and users. Since the transmission links are serially connected at relay, the throughput equals the smaller throughput of the two links. Hence, the overall achievable primary rate of cooperative transmission equals the minimum transmission rate of two links. Then one has:

$$R_{(PU,SU)_{Coop}} = \min\{t_P R_{PU}, \gamma(1 - t_P) R_{mp}\} \quad (7)$$

Maximum efficiency,

$$\eta_{eff} = \frac{m_i R_{(PU,SU)_{Coop}} B_{min}}{B_i m_{max} R_{PU}} \quad (8)$$

Where, m_i is the no of bits per symbol, B_{min} is the minimum value of bandwidth, m_{max} is the maximum modulation index.

2.4 SNR Adaptation for unlicensed communication

The signal outage probability is fairly simple to compute if one knows the probability distribution of the fading (Rayleigh or Rician) and outage occurs if the signal drops below the noise power level. Outage probability is defined as the probability that information rate is less than the required threshold information rate. When primary and secondary, simultaneous transmission occur, transmission outage probability for secondary channel is given as,

$$\varepsilon_0 = P_r (\frac{g_{mp} P_{PU}}{g_{mp} P_m + N_O B_i}) \quad (9)$$

Where $P_r(.)$ denotes the probability.

III. SIMULATED RESULTS

In PSO, the swarm of particles contains a solution set of parameter values where each particle is a candidate solution and PSO tends to find the global minimum point of the search space. For optimization, we have set the parameter value as shown in table 1. We have set GSM band spectrum to perform simultaneous data transfer operation of primary and secondary users. The channels between the transmitters and receivers are assumed to be Rayleigh faded with mean of one. The channel gains are independent across sub-channels. The power spectral density of additive Gaussian noise is 10−8 W/Hz. We have varied primary transmitter power from 0.03 to 0.09 mW. The maximum transmit power *P*max for each secondary user is assumed to be0.0 5mW. The amounts of time slot division parameters, γ and tp, will be set during the iterations by related components Maximum number of iteration 100 is considered.

Table 1. Various Parameters

Parameters	***Optimum Value***
Available channel frequency	890-962 MHz
distance between primary and secondary units	10m
$T_X - R_X$ antenna size	0.1m
Primary users' transmit power	0.03-0.09mW
Secondary users' transmit power	0.05mW
Transmission rate	1-8Mbps
Maximum number of iteration	100

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Modulation index	1-2

Figure3 shows SU outage probability curve with respect to PU transmission power level. If secondary users transmit power level increases, then PUs outage probability will be more. Interference probability at the primary user is inversely proportional with its own transmit power. If transmit power of PUs increases then interference probability decreases. Therefore, PU always wants to increase transmit power level to reduce interference. But if PU increases its power level, then remaining power will be less for SU. So, there should be an optimum power level for co-operative transmission.

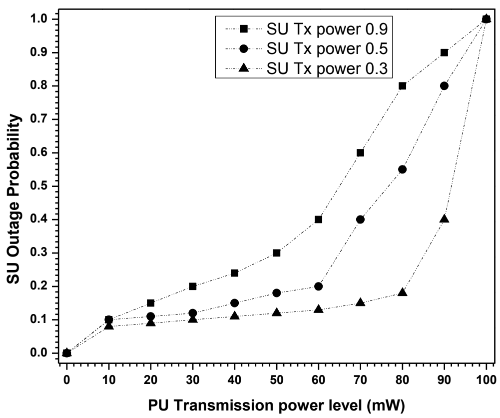

Figure 3.Characteristics of Outage Probability

Figure4 represents typical variation of transmit power of cooperative transmission with respect to number of iterations. It has been observed that the maximum transmit power is achieved only during the first iteration. As the number of users' increment within the network, results in lower power level. After 20th iteration onwards, because of cooperative transmission, it maintain predefined threshold power level for transmission.

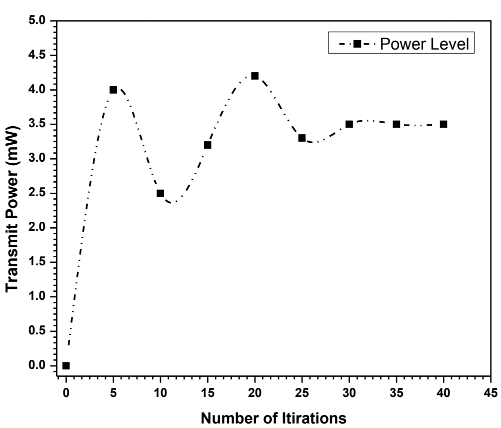

Figure 4.Cooperative Transmission Power Level

Figure5 represents the variation of co-operative and direct transmission rate with respect to number of iteration. When secondary users are not involved in data transmission operation primary users directly transmit data at its own threshold power level and it happens continuous smoothly. But when co-operative transmission operation involves then during first iteration transmission rate is high, as number of iteration increases transmission rate curve become saturated at threshold level. As in co-operative operation both primary and secondary users join in data transfer operation so it should maintain some threshold transmission rate to avoid interference with the primary and other secondary users.

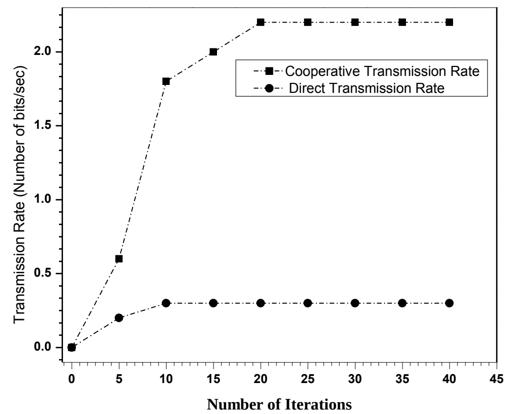

Figure 5.Characteristics of Data Transmission rate

Figure6 represents the efficiency curve for the proposed co-operative network. Maximum efficiency is achieved with the first iteration. It has been observed that efficiency decreases with the increase of number of iterations. At a certain time the network maintain a constant efficiency for co-operative transmission.

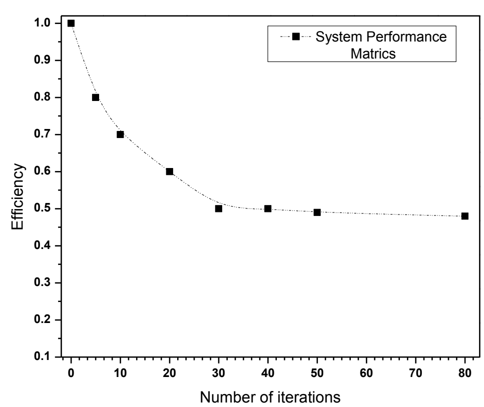

Figure 6.System efficiency

IV CONCLUSION

In this paper, resource allocation and channel interference problem of cognitive cellular network were identified. The parameters such as throughput, SNR, system efficiency, transmission rate which influence these problems are optimized by an intelligent scheme of PSO. A PSO-assisted time slot allocation strategy has been applied in our proposed

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hybrid cellular network for simultaneous transmission by unlicensed users with licensed users on the same frequency band. We have combined the concept of traditional underlay and overlay communication system and proposed a modified cognitive cellular hybrid network system to overcome the various limitations of individual communication network. Hybrid network with opportunistic cooperative sensing based spectrum sharing method has been introduced to avoid interference with PU. This improves the transmission capacity of secondary users within the primary network. The PSO aided algorithm provides improved performance by using appropriate pre- and post beam forming. The proposed technique not only improved throughput and QoS but also reduce interference probability with PUs. As per theoretical analysis, our emulated results show better transmission rate for both users with minimum transmission power level. Graphical analysis with respect to various parameters has proved this. Hence, time slot allocation scheme with hybrid network is the best possible method to achieve optimum performance in cognitive cellular network.

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