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Original Article

Energy Efficiency Optimization of Multiuser Cognitive Radio Network

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Abstract *- With the increasing demand for wireless devices in present times, the need for cognitive radio networks has risen. This increases the importance of the energy efficiency of the cognitive radio system. This work investigates the energy efficiency optimization of a multi-user single relay cognitive radio system. Collisions between data packets from numerous secondary users happen in a cognitive radio network, significantly reducing the throughput of the network, which causes a reduction in energy efficiency. This research presents a novel analytical energy efficiency model for the multi-user cognitive radio network. The proposed model makes it easy to formulate an optimization problem in such a way that the energy efficiency can be optimized by maintaining the collision probability within the permissible limit. As a result of this, an improvement in energy efficiency as well as the preservance of reliability of the system in the Cognitive Radio Network (CRN) is obtained. The energy efficiency optimization of the multiuser cognitive radio network is performed using optimization techniques like Particle Swarm Optimization (PSO), Human behavior based Particle Swarm Optimization (HPSO), and Aging Leader and Challengers Particle Swarm Optimization (ALCPSO). The simulation results demonstrate that, in comparison to alternative optimization methods, the optimized systems based on ALCPSO deliver higher energy efficiency. Additionally, a comparison is presented between the proposed method and the existing method for the multi-user cognitive radio system's possible energy efficiency. It is proved by the simulation results and analysis that the scheme proposed here improves the cognitive radio network's energy efficiency.*

Keywords *- Energy efficiency, Aging leader and challengers particle swarm optimization, Multi user cognitive radio network, Secondary user, Transmission power.*

1. Introduction

In recent times, with the growing demand for wireless devices has caused a shortage of spectrum in the radio frequency range. According to the Federal Communication Commission (FCC) study, under the static spectrum allotment, spectrum utilization is only 5% to 15% on average [1]. The issue of spectrum underutilization is addressed by the proposal of Dynamic Spectrum Assignment (DSA) methods. Cognitive radios [2] based on intelligent networks policy are used to implement DSA.

A Cognitive Radio (CR) is a radio or system that senses its operational electromagnetic environments and can dynamically and autonomously adjust its radio operating parameters to alter system operations. Due to their exceptional spectrum efficiency, these networks have received a significant amount of interest in the wireless communications field. If the spectrum in such networks is not being used by the licensed or main user (PU), then an unlicensed or Secondary User (SU) may be able to access it. To check for spectrum availability to use by SUs, spectrum sensing methods are used by Cognitive Radio Networks (CRN). Numerous spectrum sensing methods have been put out thus far. These methods include energy detection-based sensing, cyclostationarity-based sensing, waveform-based sensing, radio identification-based sensing, etc. [3]. To achieve high energy efficiency effective spectrum utilization is necessary for the cognitive radio network. Energy-efficient cognitive radio system design, which also maintains network reliability, is a new area of research. A mathematical formula for the attainable secondary user throughput was derived by Liang et al. [4], and it was shown that the maximum throughput for the cognitive radio network may be achieved at an optimal spectrum sensing time. In [5], they presented a CRN system which offers a superior trade-off between sensing and throughput and also simultaneously senses spectrum and transmits data.

A Particle Swarm Optimization (PSO)-based strategy was presented by Rashid et al. [6] to solve the trade-off between SU throughput and sensing time. By using that method, throughput is significantly increased as opposed to using a non-optimal sensing scheme. The relays receive source nodes' signals and retransmit the signals after it is amplified to the destination node in relay-based wireless networks. Cognitive radio network uses relays to increase SU throughput and improve the reliability of spectrum sensing [7-12].

An equal power allocation strategy for spectrum sensing in a relay-based CRN that is energy-efficient was reported in [9]. An optimal power allocation plan was put out by Huang et al. [10] to maximize SU throughput in cognitive relay networks while taking sensing reliability and power limits into account. In order to enhance throughput and energy efficiency, [11] a cognitive relay system was proposed by Song et al. and it simultaneously optimizes signal-to-noise and sensing time. For use in multi-relay CRN, a method is proposed in [12] and found that the consumption of energy during the process of data transmission is minimal.

In order to improve the data transmission delay [13], they tried to minimize the contention probability in the multi-user CRN and found satisfactory results. The trade-off between the amplify-and-forward relay scheme's sensing performance and data transmission energy was examined in [14], taking into account both the situation of constant and variable amplifying strength. The analysis states that there is an optimal amplification gain that balances energy usage and sensing performance. In [15], the issues of interference to primary user minimization and route lifetime maximization were jointly examined in outage-constrained cognitive radio networks. A study was conducted in [16] to optimize the cognitive radio network throughput while considering interference temperature constraints. The throughput optimization in (EH) relay based interweave/underlay CRN is carried out in [17].

Wu et al. [18] presented a global assessment of the distribution of video based on restricted observation and demonstrated the effect of the size of video on a realistically distributing video in a mobile Device-to-Device system. In [18], it was observed that there was a licensed spectrum for Device-to-Device Communication. Zhao, YC. et al. [19] did throughput optimization by allocating spectrum in CRNs. Here cross-layer throughput optimization solution is proposed, which is based on a measurement-assisted SINR.

For content sharing between two devices, Zhou [20] presented a content-sharing mode selection strategy depending on the socially aware rate. Many devices shared the spectrum in [20], preserving the network's connection quality. Wang Y et el. [21] proposed a Multiuser Time Power Resource Allocation algorithm (M-TPRA). First, by including slack variables, M-TPRA converts non-convex optimisation problems into convex ones. Second, the problem of optimisation is split into two smaller problems, they are power control and time allocation-using the concept of hierarchical optimisation. Thirdly, unary linear optimisation is used to acquire time allocation, while sub-gradient descent is used to obtain power control. Furthermore, Wang et el. in [22] solved the optimization of Energy Efficiency (EE) for a multi-user CRN in which they also consider Interference Channels (ICs) of Multiple-Input- Multiple-Output (MIMO). They use non-cooperative game techniques to formulate the problem of optimization of EE. Again, Kaleem Arshid et al. [23] offered a second priority user transmission system that detects available channels using cooperative spectrum sensing. Energy efficiency is enhanced by optimising the energy utilisation of the sensing process through the use of energy-detecting techniques.

In [24], improvement of energy efficiency by optimizing transmitting time and sensing time is done and a suboptimal iterative search algorithm performs it. Due to the collision between SU data packets in a cognitive radio network, the user's throughput and the energy efficiency of CRN may deteriorate. In cognitive radio networks which use a relay, an outage at the secondary destination is caused by a low value of amplifying gain, and a large amplifying value causes the primary network's interference. Therefore, it is important to determine the optimal range for the amplifying gain in order to maintain the interference and outage probability below a certain threshold. Moreover there are very few works on energy efficiency optimization of multiuser CRN is done. The following are the contributions made by this work:

At first, the development of a mathematical model of energy efficiency of the multiuser cognitive radio network is proposed and collision probability between packets of multiple SUs is also considered in formulating it. The model is helpful for energy efficiency optimization, and it also helps in maintaining collision probability between SUs data packets below a predetermined threshold.Secondly, the determination of the optimal range of relay amplifying gain has been performed such that the outage probability's effect and effects of interference can be maintained within allowable limits. Moreover, the optimal limits for the transmission power of PU are also kept within allowable limits.

Furthermore, the false alarm probability is kept less than equal to the, threshold value of false alarm probability and also, the probability of activeness of the PU in the sensed channel is kept greater than equal to the threshold value of PU being active. Moreover, in this paper, four constraints, i.e. amplification gain of the relay, probability of false alarm, probability of PU being active, and transmission power of PU, are considered in the optimization process. Thirdly, the energy efficiency optimization of the system is carried out by PSO [25, 26], HPSO [27] and ALCPSO [28], which are based on swarm intelligence-based optimization techniques which also maintain the reliability of the system, which was not done in earlier works of energy efficiency optimization.

The algorithms based on swarm intelligence techniques of optimization are employed because this gives fast convergence time and is free of derivative terms.

Furthermore, this makes the complexity of computational time easy [25-31]. From the results it is seen that the energy efficiency of cognitive radio networks is improved than that of the other optimization methods. The structure of this paper is given as follows. Section 2 describes the model of the system. In Section 3, the energy efficiency formula is developed, whereas the optimal limits for Amplify-and-Forward (AF) relay amplifying gain and optimal limits for transmission power of PU are discussed in Sections 4 and 5, respectively. Sections 6 and 7 present the problem formulation and description of the optimization process. Section 8 describes the results and discussions, and Section 9 finally summarizes the conclusion.

2. Model of the System

Figure 1 demonstrates the model of the system, which comprises a primary network and an infrastructure-based multi-user single-relay cognitive radio network. The Amplify-and-Forward (AF) relay, Fusion Center (FC), Secondary Base Station (SBS), and m numbers of Secondary Users (SUs) make up the cognitive radio network. The primary network is made up of a Primary User (PU) and a Primary Base Station (PBS). Data is sent from the PU to PBS in the primary network. Only in the absence of data transmission across the channel by the PU, the SUs are permitted to send data. The transmission of data between SU and the base station is done via the AF relay. Here, the signals from the SUs are enhanced primarily by the AF relay, although there is a distance between SUs and SBS. The cognitive radio network operates on a frame-by-frame basis, meaning that SUs are allotted a channel for a time period T. As seen in Figure 2, the time frame is divided into two sections namely data transmission and sensing, respectively. SUs sense the channel to check if PU is present during the sensing time T_s.

In the sensing process, if the Primary User (PU) is not present on the channel being sensed, then SUs will transmit data for the remainder of the time duration, i.e.,(T-T_s). The SUs communicate with the AF relay by sending signals during data transmission. The amplified form of the signals received is sent to the SBS by the relay. During the transmission process, the AF relay puts interference to the Primary Base Station and the dotted line is used to denote it as shown in Figure 2.

The SBS sends various users' signals to the appropriate destinations after receiving the signals of various SUs. The cooperative spectrum sensing technique [8], which is based on energy detection, is employed for sensing purposes. The scheme involves the individual sensing results from each SU being forwarded to the Fusion Center (FC) via a common control channel. The FC uses the combined sensing results from the SUs and the OR fusion rule and it is used to determine the presence of PU in the sensed channel. If the fusion center determines that there is no PU signal, then SUs are permitted to use the channel for the transmission of the signal.

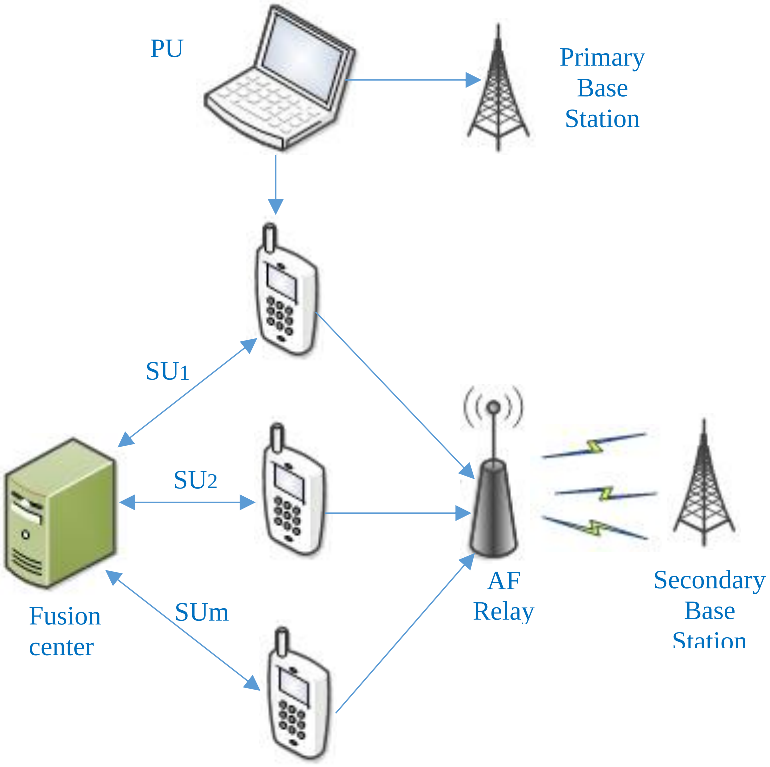

Fig. 1 System model

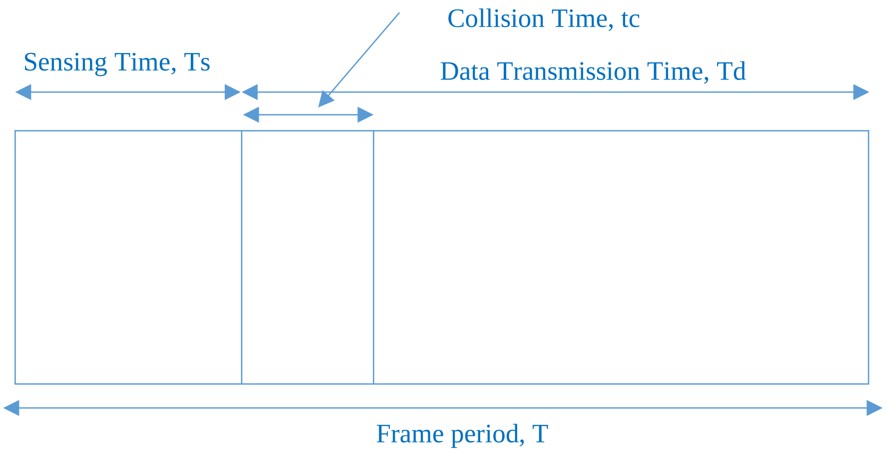

Fig. 2 Time layout of the cognitive radio network

3. Energy Efficiency in Cognitive Radio Network

The cognitive radio network's Energy Efficiency (EE) can be defined as the ratio of throughput (bits per sec per hz) and transmission power (in watts). Mathematically, EE is defined as

$$Energy\ Efficiency = \frac{Throughput}{Transmission\ Power} \tag{1}$$

The derivation of EE expression for multi-user cognitive radio networks is done as follows.

In the sensing process, the detection probability (P_{di}) and the false alarm probability (P_{fi}) are estimated by different SUs in the network. In this case, (P_{di}) is the probability of correctly determination of existence of the primary user by the ith SU and (P_{fi}) is the probability of wrongly determination of signals of the primary user although it is not present in the channel sensed by SU. These two probabilities can be written as [4].

$$P_{f_i} = Q\left(\left(\frac{\varepsilon}{P_n} - 1\right)\sqrt{N}\right) \tag{2}$$

$$P_{d_i} = Q\left(\left(\frac{\varepsilon}{P_n} - 1 - \gamma_i\right)\frac{\sqrt{N}}{2\gamma_i + 1}\right) \tag{3}$$

In this case, γ_i is the Signal-to-Noise Ratio (SNR) of the PU at the i th SU during the data transmission period and the N is used to denote the sensing sample number. Furthermore the detection threshold is represented by ε. The Fusion Center (FC) collects the SU's detection probabilities.

OR fusion rule is used to integrate each SU's sensing results, and at FC, the cooperative probability of false alarm (P_f) and the cooperative probability of detection (P_d) of the network were computed. These two probabilities are expressed as [4],

$$P_f = 1 - \prod_{i=1}^{m}(1 - P_{f_i}). \tag{4}$$

$$P_d = 1 - \prod_{i=1}^{m}(1 - P_{d_i}) \tag{5}$$

Here, m is used to represent the number of SUs in the system. Different users use Time Division Multiple Access (TDMA) in a multi-user cognitive radio system to access the channel in an unused state. During data transmission time, the SNR (γ_r) of the SUs received at SBS is written as,

$$\gamma_r = \frac{\sum_{i=1}^{m} \alpha G_{rb} G_{s_i r} P_{s_i}}{\sum_{i=1}^{m} \alpha G_{rb} P_n + P_n} \tag{6}$$

Here, the amplification gain of the relay is denoted by α, P_n is noise power, P_{si} is the transmission power of the *i* th SU in the network and G_{rb} is the channel gain between the AF relay and the SBS and G_{sir} is the gain of the channel between ith SU and the AF relay respectively. The AF relay average transmission power is given by

$$\begin{aligned}\overline{P}_t &= P(H_1)\alpha\left(\sum_{i=1}^{m} G_{s_i r} P_{s_i} + G_{pr} P_p + P_n\right) + (1 - P(H_1))\alpha\left(\sum_{i=1}^{m} G_{s_i r} P_{s_i} + P_n\right) \\ &= \alpha\left(\sum_{i=1}^{m} G_{s_i r} P_{s_i} + P(H_1) G_{pr} P_p + P_n\right)\end{aligned} \tag{7}$$

Here, P_p represents the PU transmission power, G_{pr} is the gain of the channel between the PU and the relay and $P(H_1)$ is the probability that the PU signal is present in the sensed channel.

If the cognitive radio network's total transmission power budget is P_{max}, then it can be found that,

$$\sum_{i=1}^{m} P_{s_i} + \overline{P}_t \le P_{max} \tag{8}$$

The network made use of its whole power budget, and each Secondary User's (SU) transmitted power was the same, i.e. $P_{s1} = P_{s2} =$ ---------- $= P_{si} = P_s$. So P_s, from (7) and (8) is,

$$P_s = \frac{P_{max} - P(H_1)\alpha G_{pr} P_p}{m + \alpha \sum_{i=1}^{m} G_{s_i r}} \tag{9}$$

From (6) and (9), the SNR at SBS can be written as,

$$\gamma_r = \frac{\alpha \sum_{i=1}^{m} G_{s_i r} G_{rb} \left(P_{max} - P(H_1)\alpha G_{pr} P_p \right)}{\left(\alpha \sum_{i=1}^{m} G_{rb} P_n + P_n \right)\left(m + \alpha \sum_{i=1}^{m} G_{s_i r} \right)} \tag{10}$$

The throughput *R* of the CRN can be defined as,

$$Throughput(R) = P(H_0)(1-P_f)\frac{T_d}{T} log_2(1 + SNR(\gamma_r)) \tag{11}$$

Where, $P(H_0)$ is the probability that the PU signals are absent in the sensed channel furthermore, the false alarm probability is denoted by P_f, the data transmission time is denoted by T_d and T is the frame period respectively. From (10) and (11), the throughput at the SBS becomes,

$$R = P(H_0)(1-P_f)\frac{T_d}{T} log_2 \left(1 + \frac{\alpha \sum_{i=1}^{m} G_{s_i r} G_{rb} \left(P_{max} - P(H_1)\alpha G_{pr} P_p \right)}{\left(\alpha \sum_{i=1}^{m} G_{rb} P_n + P_n \right)\left(m + \alpha \sum_{i=1}^{m} G_{s_i r} \right)} \right) \tag{12}$$

Using (1), (7) and (12), the EE for a multi-user cognitive radio network can be obtained as,

$$Energy\ Efficiency\ (EE) = \frac{P(H_0)(1-P_f)\frac{T_d}{T} log_2 \left(1 + Z \right)}{\alpha \left(\sum_{i=1}^{m} G_{s_i r} P_s + P(H_1) G_{pr} P_p + P_n \right)} \tag{13}$$

Where, $$Z = \frac{\alpha \sum_{i=1}^{m} G_{s_i r} G_{rb} \left(P_{max} - P(H_1)\alpha G_{pr} P_p \right)}{\left(\alpha \sum_{i=1}^{m} G_{rb} P_n + P_n \right)\left(m + \alpha \sum_{i=1}^{m} G_{s_i r} \right)}$$

If the sensed channel is absent of PU signal, then multiple SUs may try to transmit a signal through the channel at the same time which results in collision between data packets. Considering the collision probability, the total duration of the time frame is given by

$$T = T_s + \frac{m t_c}{\sqrt{2P_c}} \tag{14}$$

As shown in Figure 2, here T is the frame period, T_s is the sensing time and t_c is the collision time, and the collision probability between SUs is P_c, respectively. Now the T_d/T can be written as,

$$\frac{T_d}{T} = \frac{\frac{m t_c}{\sqrt{2P_c}}}{T_s + \frac{m t_c}{\sqrt{2P_c}}} = \frac{m t_c}{m t_c + \sqrt{2P_c} T_s} \tag{15}$$

So, the Energy Efficiency (EE) is given by,

$$Energy\ Efficiency(EE) = \frac{P(H_0)(1-P_f)\frac{m t_c}{m t_c + \sqrt{2P_c} T_s} log_2 \left(1 + Z \right)}{\alpha \left(\sum_{i=1}^{m} G_{s_i r} P_s + P(H_1) G_{pr} P_p + P_n \right)} \tag{16}$$

Where, $$Z = \frac{\alpha \sum_{i=1}^{m} G_{s_i r} G_{rb} \left(P_{max} - P(H_1)\alpha G_{pr} P_p \right)}{\left(\alpha \sum_{i=1}^{m} G_{rb} P_n + P_n \right)\left(m + \alpha \sum_{i=1}^{m} G_{s_i r} \right)}$$

4. Derivation of Relay Amplifying Gain's Optimal Limits

An AF relay is used in the cognitive radio network, such that the system is efficient in terms of throughput. Relay amplifying gain values should be carefully selected so that the interference cannot affect the primary network in the system and an acceptable value of throughput can be achieved at the same time.

In this section, the optimal limits for AF relay's amplifying gain are looked into. In order to obtain these, minimization of the two effects which are not desirable is considered, i.e., the effect of interference at PBS and outage probability at SBS.

4.1. Interference to PBS

As was previously stated, the relay may interfere with the PBS throughout the transmission process. To increase the efficiency of the system, the interference effect should be minimized. The effect of interference between the AF relay and PBS is shown by the dotted line in Figure 1. The power due to interference is given by,

$$I = P(H_1)(1-P_d)\alpha\left[\sum_{i=1}^{m} G_{s_i r}P_s + G_{pr}P_p + P_n\right]G_{rpb} \quad (17)$$

Here, G_{rpb} is used to denote the gain of the channel between the relay and the PBS. The interference power has to be kept below the I_{th} known as threshold value and is predefined for improving the cognitive network efficiency i.e.,

$$P(H_1)(1-P_d)\alpha\left[\sum_{i=1}^{m} G_{s_i r}P_s + G_{pr}P_p + P_n\right]G_{rpb} \le I_{th}$$

$$or, \alpha \le \frac{I_{th}}{P(H_1)(1-P_d)\left[\sum_{i=1}^{m} G_{s_i r}P_s + G_{pr}P_p + P_n\right]G_{rpb}} = \alpha_{max} \quad (18)$$

In (18) α_{max} is used to denote the upper limit for the relay's amplifying gain. Thus, in order to maintain the interference power to the PBS below a predetermined threshold $\alpha \le \alpha_{max}$.

4.2. Outage Probability

When the destination node SNR in the cognitive radio network is not greater than or equal to a predefined threshold, an outage occurs [14]. The outage probability at SBS is written as,

$$P_{out} = Pr(\gamma_r \le \gamma_{th}) = 1 - Pr(\gamma_r \ge \gamma_{th}) \quad (19)$$

The distribution of received SNR of the cognitive radio network is exponential with a probability distribution function $f_{\gamma r}(\gamma)$ and is written as,

$$f_{\gamma_r}(\gamma) = \frac{1}{\gamma_r} exp\left(\frac{\gamma}{\gamma_r}\right) \quad (20)$$

From (19) and (20),

$$P_{out} = 1 - \int_{\gamma_{th}}^{\infty} \frac{1}{\gamma_r} exp\left(\frac{\gamma}{\gamma_r}\right) = 1 - exp(\frac{-\gamma_{th}}{\gamma_r}) = 1 - exp\left(\frac{-\gamma_{th}\alpha\sum_{i=1}^{m} G_{rb}P_n + P_n}{\alpha\sum_{i=1}^{m} G_{rb}G_{s_i r}P_s}\right) \quad (21)$$

The outage probability is to be lower than $\bar{P}_{out}$ the predefined threshold value to make the transmission in CRN to be reliable, i.e.,

$$1 - exp(\frac{-\gamma_{th}}{\gamma_r}) = 1 - exp\left(\frac{-\gamma_{th}\alpha\sum_{i=1}^{m} G_{rb}P_n + P_n}{\alpha\sum_{i=1}^{m} G_{rb}G_{s_i r}P_s}\right) \le \bar{P}_{out} \quad (22)$$

$$or, \alpha \ge \frac{P_n}{ln(1-\bar{P}_{out})^{-1}\sum_{i=1}^{m} G_{rb}G_{s_i r}P_s - \gamma_{th}\sum_{i=1}^{m} G_{rb}P_n} = \alpha_{min} \quad (23)$$

In (23), α_{min} denotes the lower limit for the AF relay's amplifying gain. So, in order to maintain the outage probability below $\bar{P}_{out}$, α_{min}, ie, $\alpha \ge \alpha_{min}$.

5. Optimal Limits for Transmission Power of PU

The throughput of PU is,

$$R_P = log_2\left(1 + \frac{G_P P_P}{P_n}\right) \ge \bar{R}_P \quad (24)$$

Here $\bar{R}_p$ represents throughput's threshold value, G_p is the channel gain of PU.

Since P_{max} is the maximum power budget of the CRN, so the optimal limits for transmission power of PU is within the range,

$$\frac{(2^R - 1)P_n}{G_P} \le P_p \le P_{max} \quad (25)$$

6. Formulation of Optimization Problem

In the CRN model used here, which is multi-user, the SU data samples may collide with each other, and this causes a decrease in the system's throughput and it results in a decrease in the energy efficiency of the system. This paper's primary goal is to maximize the multi-user cognitive radio network's energy efficiency in a way that the chance of a collision between an SU's data packet should be less than a certain threshold. During the optimization process, the relay's amplifying gain is kept within an optimal range to prevent undesired effects like interference to the primary base station from exceeding permissible limits and also outage probability should also be less than permissible ranges. Formulating the optimization problem as,

$$max\ EE = \frac{P(H_0)(1-P_f)\dfrac{mt_c}{mt_c+\sqrt{2P_cT_s}}log_2\left(1+Z\right)}{\alpha\left(\sum_{i=1}^{m} G_{s_ir}P_s + P(H_1)G_{pr}P_p + P_n\right)}$$

$$\begin{cases} P_f \le \bar{P}_f,\ P(H_1) \ge \bar{P}(H_1) \\ \alpha_{min} \le \alpha \le \alpha_{\max} \\ \dfrac{(2^R-1)P_n}{G_P} \le P_p \le P_{max} \end{cases} \tag{26}$$

Again, the threshold value of the probability of a false alarm is denoted by $\bar{P}_f$ and $\bar{P}(H_1)$ is the threshold value of the probability of PU being active. Moreover, Equations (18) and (23) are used to determine the maximum (α_{max}) and minimum (α_{min}) values of amplifying gain of CR, respectively. Furthermore, G_p is the gain of the channel of PU, P_n the noise power and power required for PU is denoted by P_p respectively.

7. Optimization Process

The algorithms PSO [25, 26], HPSO [27], and ALCPSO [28], which are based on swarm intelligence techniques, are employed for optimizing the energy efficiency of the system under consideration, and it also satisfy the constraints stated in (26).

The problem statement of this study is to maximize the energy efficiency for a multi-user cognitive radio network while keeping the system parameters within acceptable limits.

In order to do this, a novel analytical expression for energy efficiency that takes into account the probability of collisions between SU data packets is established, and the optimization problem is stated as (26). The swarm intelligence-based methods initialize the population for a P size population with dimensions n for solving the optimization problem.

The population's particles indicate the tentative solutions to the optimization problem. Every algorithm employs a distinct methodology to identify the optimal result for the optimization problem. Nonetheless, a common working methodology is established, based on which the algorithms are applied to solve the problem statement's objective function. Figure 3 displays the flowchart of the optimization process.

The values of constraints used in the process of optimization are listed in section 8. Furthermore, to update the position, each of the algorithms is repeated many times until the optimal solution for each algorithm is found that satisfies every constraint in the optimization problem.

The time complexity of swarm intelligence-based algorithms is O(P x cof + n x P), where n is the problem's dimension, the population size is P, and cof is the objective function's cost [24]. n x P indicates the computing of solutions for a P size population with dimensions in the complexity analysis n. The best solution is indicated by P x Plog$_2$P among the P number of solutions.

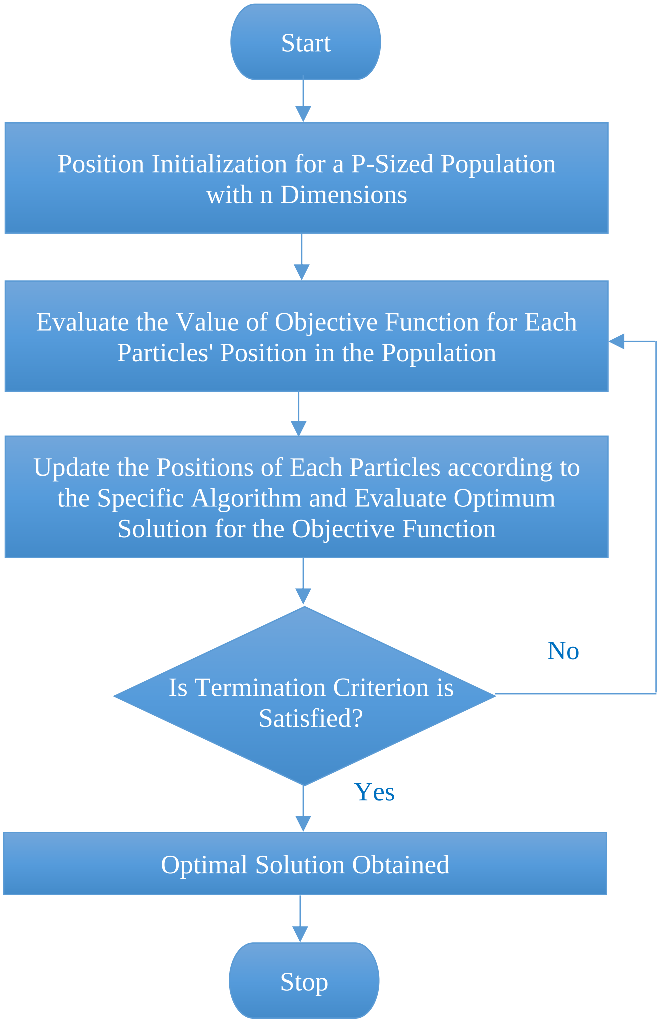

Fig. 3 Flow chart of the optimization process

8. Results and Discussion

In order to examine the proposed scheme's performance in the multi user Cognitive Radio Network (CRN) simulations, results are presented here by considering energy efficiency and other parameters of the systems.

For obtaining the improved reliability of the CRN system the parameters of the optimization problems are specified accordingly. Federal Communications Commission (FCC) standards say that, the maximum acceptable false alarm probability is considered as 10% and the setting of minimum detection probability is done as 90% [6].

The probability of inactiveness of PUs is considered as 80%. The collision probability is to be maintained below a predefined threshold such that the SUs throughput can be increased. The collision probability's threshold value is considered as 8%. The interference to the PBS caused by the increase in the AF relay's amplifying gain can be maintained below the predetermined threshold by maintaining the gain of amplification below the upper limit (α_{max}). Again, a lower value of the AF relay's amplifying gain causes an outage effect at SBS. Therefore, the amplifying gain value is kept above the lower limit (α_{min}) in order to avoid the occurrence of an outage at SBS. So (18) and (23) are used to determine the upper and lower limits of the AF relay's amplifying gain, respectively. This keeps interference effects and outage probability below the specified threshold levels. Table 1 provides the values of some of the parameters taken into consideration throughout the optimization process. For simulations, channel parameters considered are G_{sir} = G_{rb} = -5dB and G_{rpb} = -20dB. The maximum transmission power budget is considered as P_{max} = 0.5dBW. In the cognitive radio system, there are assumed to be 15 SUs. Each SU's and the PU's average transmission power is assumed to be 0dBW.

Table 1. List of optimization parameters

Parameters	Values	Parameters	Values
$\bar{P}_f$	10%	α_{max}	3.56
$\bar{P}_c$	8%	P_{max}	0.5*dBw*
α_{min}	1.05	$\bar{P}_{out}$	10%
$\bar{R}$	0.25bps/Hz	m	15

8.1. Energy Efficiency Optimization Using Swarm Intelligence-Based Techniques

Swarm intelligence-based strategies, as mentioned in Section 7, are applied to solve the objective function stated in (26). On an i7 processor, simulations are run in the MATLAB environment. The convergence graphs of the PSO, HPSO, and ALCPSO are presented in Figure 4. In comparison to the other optimization techniques, the ALCPSO plot converges at a higher value of energy efficiency, as shown in Figure 5. This shows that, despite PSO's superiority in terms of complexity of time, ALCPSO outperforms the other previously described algorithms in terms of energy efficiency while solving the optimization problem. Table 1 displays the optimal parameter values that were determined by using these three optimization algorithms.

Table 2. EE values for three algorithms

Algorithms	PSO	HPSO	ALCPSO
Energy Efficiency	94%	95%	97%

From Table 2, it can be concluded that energy efficiency is higher for the system optimized with ALCPSO than for the systems optimized with the other three optimization algorithms.

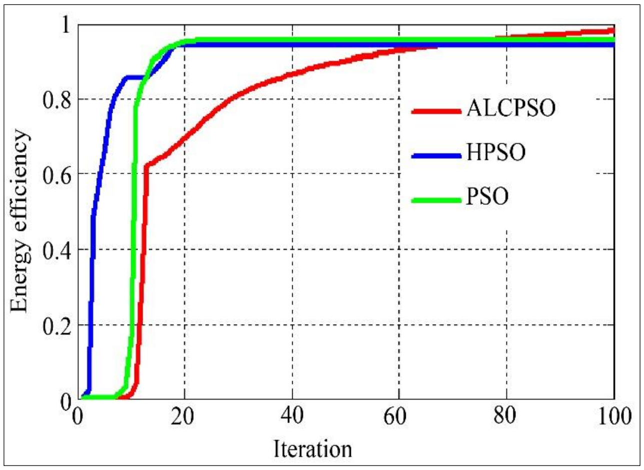

Fig. 4 Plot of convergence of the optimization algorithms

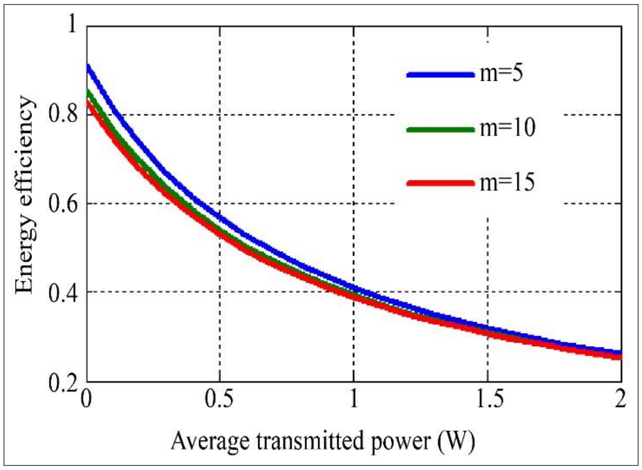

Fig. 5 The normalized energy efficiency of the network versus transmitted power of SUs by varying secondary users

8.2. Energy Efficiency Analysis of the System with Varying Parameters

The energy efficiency of the multi-user cognitive radio system for varying user counts is depicted in Figure 5 as a function of the average power of the secondary users. Also it is observed from Figure 5 that the energy efficiency of multi-user CRN decreases as the number of SU increases.

Again, also, the decrease in energy efficiency occurs as the average power of the secondary user increases. Figure 6 shows the energy efficiency of multiuser CRN with the average power of the secondary user for different values of signal-to-noise ratio. It is observed from Figure 6 that SNR values largely affect energy efficiency. EE values decrease with the decrease in the SNR values.

Figure 8 shows the energy efficiency variation of multiuser CRN using the scheme proposed by the author with SNR by varying users. Figure 8 illustrates that with an increase in the number of users, the energy efficiency value decreases.

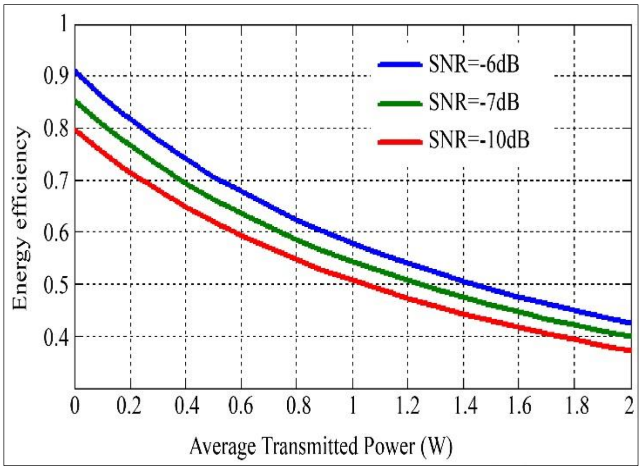

Fig. 6 The normalized energy efficiency of the network versus transmitted power of SUs by varying SNR

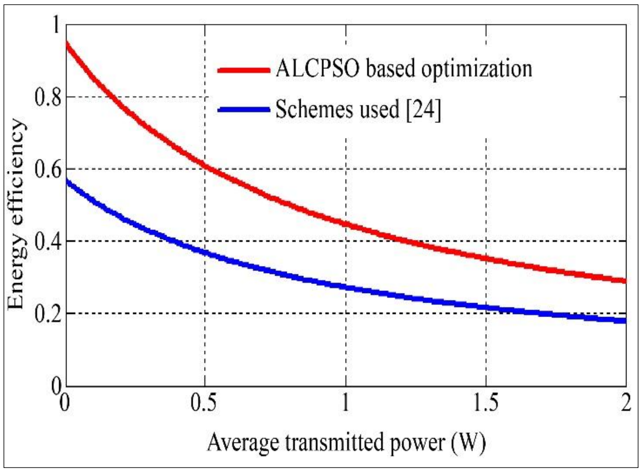

Fig. 7 Normalized energy efficiency of the network versus transmitted power of SUs

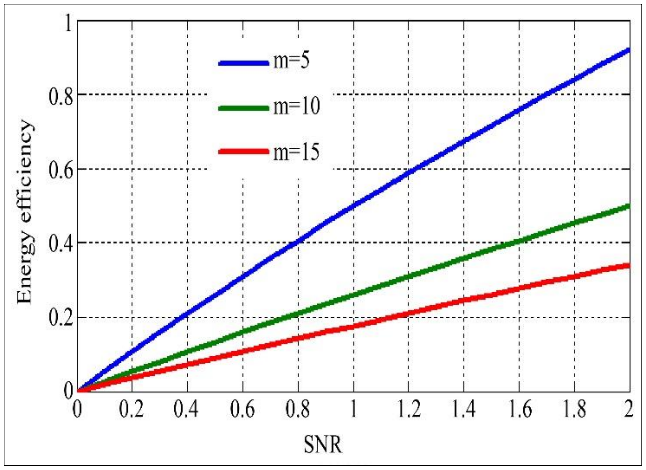

Fig. 8 Normalized energy efficiency of the network versus signal-to-noise ratio by varying secondary users

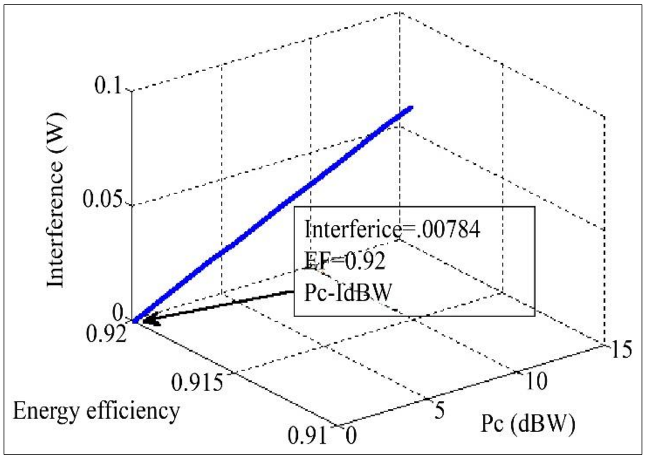

Fig. 9 Three dimensional plot between energy efficiency, interference and probability of collision

8.3. Performance Comparison

A plot between energy efficiency, interference and probability of collision for different values of transmission power of CRN is shown in Figure 9. It is seen from the plot that at the optimal point, the energy efficiency is 92%, and the interference power and collision probability are within acceptable limits. Furthermore, a comparison of the performance of the proposed ALCPSO based optimization scheme with other optimization methods [24] in terms of energy efficiency by varying SUs average transmitted power is shown in Figure 7. In [24], they used Sub Optimal Iterative Search Algorithm (SOISA). The comparative study reveals that the scheme proposed here for the CRN gives better energy efficiency as compared to the scheme used in [24].

9. Conclusion

A proposal for a mathematical model of energy efficiency in the cognitive radio network has been presented in this paper. By using this model, the optimization of energy efficiency has been attempted using modern optimization techniques. Moreover, to mitigate the negative impacts of outage probability and interference, the AF relay's amplifying gain is determined within an optimal range. In this paper, the optimization problem has been solved by using optimization algorithms like PSO, HPSO and ALCPSO and these algorithms are based on the swarm intelligent technique. The simulation results indicate that the ALCPSO-based optimized system improves energy efficiency. Also, it is seen that an ALCPSO-based optimized system improves the reliability of the multi-user cognitive radio network.

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