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SPECTRUM SHARING USING SOCIAL SPIDER OPTIMIZATION BASED STACKELBERG GAME THEORY

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ABSTRACT

The spectrum sharing technique aids telecom operators in sharing the electromagnetic spectrum by allowing unlicensed users to use the licensed user spectrum. By this, the operators can continuously provide services to users in 4G or 5G networks without any intervention. Here, Stackelberg's game theory (SBGT) is used to facilitate spectrum sharing between the primary and secondary users based on the concept of Game Theory. It provides a better solution with the help of social spider optimization (SSO) by optimizing the cost and band usage. The proposed method is implemented in the frequency range between 800 MHz and 1800 MHz which is used for high-speed 4G and 5G connections. With the use of SBGT, the performance is higher i.e. the efficiency of the spectrum sharing and allocation is higher than others. The basic spectrum sharing is performed after windowed kurtosis spectrum sensing using a threshold method that determines the idle spectrum in the band. Users with low arrival rates affect the performance of a network. Herein we use the SSO method to mitigate the users with low arrival rates to avoid interference and then to determine the rewards of band utilization SSO is combined with SBGT. By using this optimized game theory approach, the users of the licensed band and unlicensed band with low arrival rates are awarded minimum rewards and are avoided for a better quality of service.

Keywords: *Spectrum Sensing, Spectrum Sharing, Windowed Kurtosis, Social Spider Optimization, Game Theory.*

1. INTRODUCTION

In today's 4G and 5G mobile networks scenario, there is an enormous proliferation of unlicensed users of wireless technologies, competing for the available licensed spectrum band. This has motivated an effective spectrum allocation method and the development of novel sharing methods to suit 4G and 5G wireless users. The limited available radio frequencies are to be allocated to mobile industries and other sectors of communication and it is very essential to be done efficiently and effectively. In a communication scenario, users are categorized as licensed or primary users and unlicensed or secondary users. It has been found that most of the licensed frequency spectrum remains unused and this wastage of spectrum can be avoided by spectrum sharing methods so that the deficiency of the limited spectrum can be improved. Firstly, the unused spectrum bands or spectrum holes are to be identified, and then these frequency bands are allocated to the users who are in need of it. Herein the users are assumed to use the limited band of frequencies between 800 and 2400 MHz. The frequency range is based upon the operators and their operating frequency range. Previously, this frequency range was enough to establish voice and text communication. The operators could give reliable communication within this frequency range. With the development of the internet and as mobile networks started to provide their users with multimedia messaging, the traditional bandwidth became insufficient. To compensate for this scarcity, various methods of spectrum sharing have been developed and used to provide the services to the users. In the future, the same is to be utilized to improve the communication networks in 5G for high-speed data, voice, and VoIP transmission. The methods and techniques of spectrum sharing are being used widely in countries like the US, UK, Japan, etc., in their 5G networks.

However, in India, inter-band sharing is not allowed. This means that the 800 MHz band (824-844 MHz/869-889 MHz) and 2100 MHz bands (1920-1980 MHz/2110-2170 MHz) which are used for high-speed connections are not allowed to share their spectrum and these results in the delay of the deployment of 5G networks [1]. But definitely, the ever-increasing user demand would make the deployment of 5G networks inevitable. Owing to the rapid development of mobile Internet and IoT, 5G systems will face new requirements and challenges in Wider-Coverage, Massive-Capacity, Massive-Connectivity, and Low-Latency for application scenarios of today [2]. Furthermore, these new requirements cannot be met in 4G and pre-generation technology. In order to address the challenges posed by differentiated performance indicators in diverse application scenarios, the network would have to change radically in terms of new spectrum exploration, dynamic spectrum usage, and higher energy efficiency.

Dynamic spectrum usage is possible via spectrum sharing. Spectrum sharing can be implemented for the unused or rarely used channels that are to be identified by the secondary or unlicensed users. The idle channel is to be sensed and identified by the secondary users through spectrum sensing techniques like the energy detection method, matched filter, Eigen value-based spectrum sensing, and windowed kurtosis method [4-6]. In this paper, an inter-band sharing concept is modeled between 800 MHz and 1800 MHz bands which are used for high-speed connections [1].

Due to the constant rise in demand for high data rate services, the wireless Radio Frequency (RF) spectrum is extremely congested. When the primary/licensed user is not transmitting on a channel for an extended period of time, Cognitive Radio (CR) enables secondary/unlicensed users to use that portion/slice of the licenced spectrum, known as a channel [14]. Due to the development and evolution in Cognitive Radio Networks (CRNs), the performance of Transmission Control Protocol (TCP) over CRN has become a crucial factor. TCP ensures the reliable end-to-end delivery of data, which is very important for the quality of service (QoS) requirements. TCP performance is severely affected by channel switching and channel availability in CRNs [15]. Due to the fact that ISM channels were overcrowded, cognitive radio networks (CRNs) technology was created in order to more effectively use wireless licenced channels. With the use of Cognitive Radio (CR) technology, unlicensed users, also known as Secondary Users (SUs), are given the ability to transmit while their corresponding licenced users, also known as Primary Users, are not using the channel (PUs) [16]. Cognitive radios adapt their settings based on their surroundings to improve communication efficiency. Fuzzy inference systems make it possible to replicate the nonlinear and unpredictable interactions between many variables, which presents a significant prospect for advancement in cognitive radios [17]. Long Term Evolution (LTE) subscriber growth and data consumption demand have compelled Third Group Partnership Project (3GPP) to create a traffic data growth solution [18]. The main difficulty with wireless communications is maintaining Quality of Service (QoS) while dealing with a variety of environmental constraints and maximising resource use at the same time. Because wireless channels are unpredictable, it is challenging to support QoS in wireless communication [19].A hybrid crypto-system with long-distance communication capabilities that encrypts picture data sent between a swarm of unmanned aerial vehicles (UAVs) and a ground control station (GCS) at a high rate of speed [20].

Existing spectrum sharing methods are analyzed in section 2. Interband sharing has been analyzed and herein an optimized spectrum sharing method is detailed in section 3 in the context of game theory to optimize the rewards of bands to the users with respect to their user arrival rates. The implementation and discussion of the proposed method are further elaborated in section 4. Finally, in section 5, the conclusions and future work are discussed.

2. Sensing and sharing methods

Spectrum management functions include spectrum sensing, sharing, mobility function, and decision-making function [2]. Spectrum can be used efficiently if the unused channels could be allocated and enabled to be shared by the unlicensed users. To identify these spectrum holes, the channels have to be monitored continuously and this is called spectrum sensing. The basic model for spectrum sensing is initially developed by us using a simple windowed kurtosis-based spectrum sensing utilizing a predefined threshold and is implemented in MATLAB [4]. The same is based on a conventional energy-based technique [5]. The implementation is such that the unused channel is sensed based on its kurtosis threshold value [4]. Different sensing methods in software-defined radio are implemented and the comparative results of the energy detection method, correlation detection method, and eigenvalue-based detection method are presented [6]. Spectrum sensing takes place in the physical layer and sharing in the data link layer. In all seven layers, the spectrum mobility functions and spectrum decision functions take place. The details of how the secondary user transmits the information through the sensed power spectrum of the primary user are discussed [7]. To overcome the interference problem between the primary and secondary users, the dual decomposition method is used which helps to improve the ergodic capacity along with fewer interference problems. There are many game theory (GT) approaches available for spectrum sharing. One of the GT approaches is that it deals with the bidding of secondary users to share the licensed spectrum with the primary user [8]. The GT approach also proposes a dynamic updating algorithm to determine the Nash equilibrium state for the individual secondary users. Here, only the cost of the spectrum is under consideration in the analysis [9]. Commonly, used game theory approaches for spectrum sharing is follows.

- Cournot Model
- Auction based Model
- Bertrand Model
- Cheat Proof Model

These approaches failed to provide a solid solution for spectrum sharing due to low efficiency and poor matching of spectrum resources to the users. The spectrum sharing between Long term evolutions (LTE) using the game theory approach is performed in [10]. Here spectrum utilization can be maximized with the help of a decision tree learning algorithm. Even though the utilization efficiency is improved, as the number of secondary user's increases, the time required for training and learning the environment of the secondary users also increases. The utility function represents the degree of satisfaction of users and is represented by the rate allocated by the cellular network. A Cooperative cognitive radio framework has been framed in which the primary user is aware of the nature of the secondary users and leases out a portion of its spectrum holes. The model is formulated based on Stackelberg game theory in which both users target at maximizing their utility functions in terms of their transmission rate and revenue [11]. The cooperative model and the payoff function considered in this paper are similar to the cooperative cognitive radio framework and utility function [11] & [12], but here the rewards are optimized to enhance the spectrum efficiency. The problems of spectrum sensing and sharing are listed as follows,

- How do sensing control and how do identify the PUs?
- How do characterize the spectrum and how reconfigure the spectrum?
- How do sense the spectrum and how do spectrum access?
- How do allocate the resources through optimization techniques?

From the recent research works carried out and reported above, it is observed that the research is based either on pricing or power constraints. We observe that for the proper spectrum sharing, both pricing and utilization are important factors. We have formulated a social spider optimization based on Stackelberg game theory (SSO-SBGT) for spectrum sharing arrived at after optimizing and mitigating the low arrival rates by identifying the interference region of both the operators and awarded the appropriate rewards for the secondary users.

3. PROPOSED METHODOLOGY

The main objective of the current work is to improve the utilization factor of the spectrum for the secondary users and to award the users with an appropriate reward and thus enhancing the spectrum efficiency. In this case, the optimization of the primary user spectrum is performed with the help of social spider optimization. The optimization process is done to optimize the price and spectral efficiency. The game theory maximizes the spectrum utilization efficiency with minimal blocking probability with the help of the optimization process. The flow chart for the spectrum sharing is shown in Fig.1.

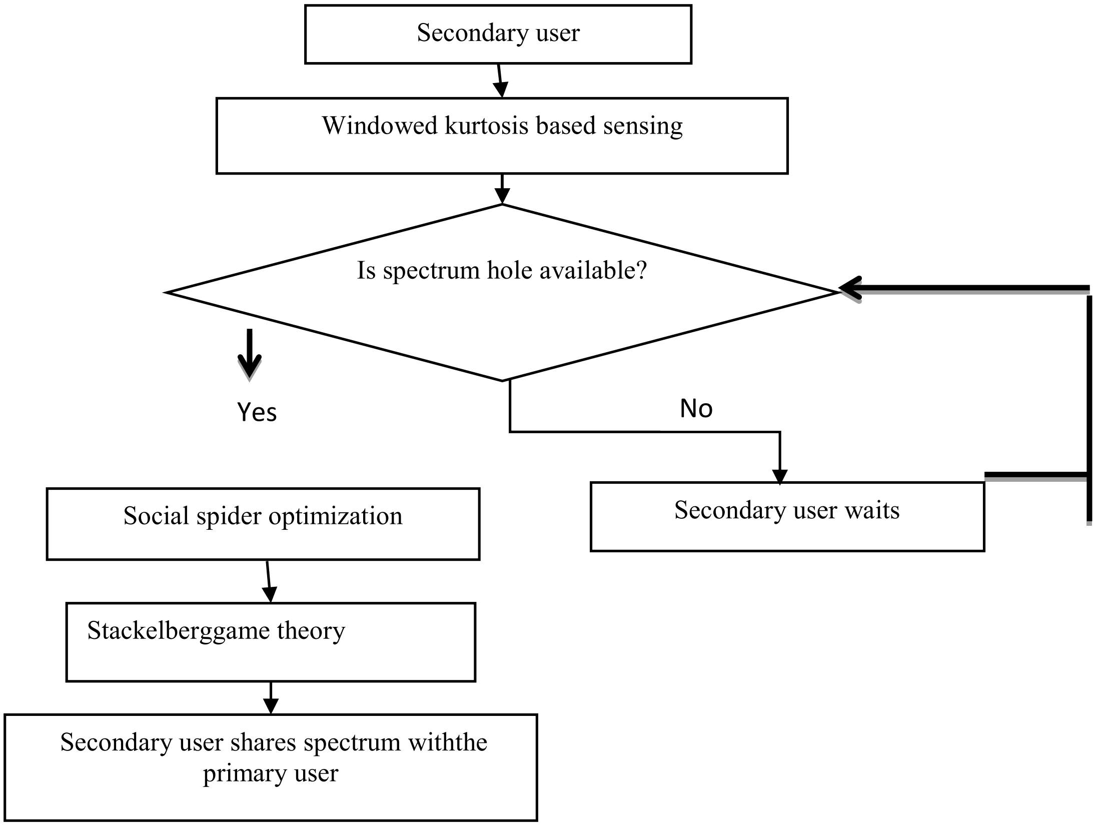

Fig.1.Flow chart of the proposed methodology

The flow chart of the proposed methodology is presented in figure 1. From the figure, it is observed that the spectrum sharing takes place after the identification of an idle primary user using a windowed kurtosis scheme [4]. The spectrum sharing involves two main processes as follows:

- Social spider optimization (SSO)
- Stackelberg game theory (SGT)

3. a. Social Spider optimization

The optimization used in this paper is inspired by [13] which describe the spider optimization process for solving non-linear problems. The algorithm is designed based on the operations of a spider; viz. building the web, mating process, and social communication between the spiders web colonies. All these processes are done with the help of male and female spiders on the web. The Social Spider Optimization (SSO) algorithm determines the minimum spectrum band which gives the lowest profit for both leader and follower in the Stackelberg game theory. It is achieved by the spiders' living nature. The search space is formulated as a spider web for the problem of optimization. The web acts as a vibration generated in the transmitting media for the spiders. Every position on the web gives a feasible solution for the optimization problem. As soon as a spider transfers to a new location, a vibration is produced this propagates through the web. The vibration comprises the spider's information, and when the vibration is transmitted other spiders will receive the information. The vibrations depend on the weight and distance of the spider which has generated them. In order to reproduce this process, the vibrations are modeled as per the Euclidean distance between two spiders. Every spider includes a memory that stores the preceding individual information. The algorithm models involve two search spiders: male and female. In this context, the primary users are the female spiders and the secondary users are the male spiders. Let ED be the Euclidean distance between the primary and secondary users. Once the vibration value is estimated, the mating process will take place with the help of the dominant male and female spiders. Here the dominant female spider is the primary user with a spectrum hole and the dominant male spider is the user with an appropriate vibration function. Once the offspring are produced from a spider, that spider will not be used in the mating process again. Perform the mating process; it determines the dominant spider based on the population and weight of the male and female spider. Once it completes its iteration, it comes out of the colony and produces the worst user rate and its minimum rewards. The algorithm for the social spider optimization used for spectrum sharing is described in Table 1.

Table 1: SSO Algorithm Description For Spectrum Sharing

Algorithm of SSO used in spectrum sharing for boundary values of user arrival rate [12].	
Step 1:	Start
Step 2:	Initialize the number of users: The number of primary users are randomly selected in the range of 65%-90% and the number of secondary users are calculated from the below equations. $N_{sfl} = 0.65$ $N_{sfu} = 0.9$ $N_{sfa} = (N_{sfl} + N_{sfu}) * rand$ $N_{sf} = round(N * N_{sfa})$ $N_{sm} = N - N_{sf}$ Where N is the total number of spiders; these are the users. N_{sfl} and N_{sfu} are the lower and upper bounds for the primary user percentages. N_{sf} and $N_{sm}$are the primary and secondary spider values.
Step 3:	Evaluate the fitness function for primary user and secondary user separately. It is used for calculating the weights of the spider which correspond to the solution quality of the total population or's' users. The weight of the spider is calculated as follows: $F_{sf} = fitness(N_{sf})$ $F_{sm} = fitness(N_{sm})$ $F_s = [F_{sf}\ F_{sm}]$ $W_s = \frac{F_s - \max(F_s)}{\min(F_s) - \max(F_s)}$ The fitness function determines the rewards for the users at each user rate speed.
Step 4:	Based on the weights, the vibration of the spider is calculated with the help of Euclidean distance between them. $V_s = W_s . e^{ED^2}$ Where *ED* is the Euclidean distance between the spiders. Those secondary users which are far from the primary user and those with minimum arrival rates are reduced through the evaluation of fitness function and vibration values.

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Step 5:	The vibration functions of all those secondary users which are in need of spectrum are checked. Once a secondary user's fitness function is checked, the algorithm removes the secondary user form the population and checks the fitness function of other secondary user. The fitness function and vibration values are iterated to produce the worst user rate and its minimum rewards.

3. b. Stackelberg Game theory:

In Stackelberg's game theory, both participants get advantages only if the follower observes the leader move, otherwise, the benefits will be reduced. In this case, the licensed user is the leader and the unlicensed user is the follower. Therefore, the follower will observe the leader's absence in the spectrum to enable communication in that spectrum. There is some initial assumptions have been fixed in the SGT model as (1). Linear demand, (2). Constant Marginal Cost, and (3). Identical Firms Produces Homogeneous Products.

Here, two bands are considered as players. One is the 800 MHz band user as a leader (L) and the other is the 1800 MHz band user as a follower (F).

Game theory concentrates on the three principles as follows:

- Net data rate of the users.
- Price of the sharing spectrum.
- Time taken for the hand-off between the licensed and unlicensed users.

The above three are considered in designing the game theory for sharing the spectrum which won't cause any loss to both the players. A game is denoted by G. The benefits of the players are P1 and P2. The maximum reward R for the band [8] is given by

$$R = \sum_{j=1}^{8} N_j \, \pi_{Nj} S_j(N_j, B_j) - SP_j - BP_j$$

(1)

Where, $N_j N_j$ implies the number of users in the cell. $\pi_{N_j} \pi_{N_j}$ denotes the steady state probability of the users and its value is 0.8. $S_j(N_j, B_j)$ $S_j(N_j, B_j)$ is the satisfaction of the users in the cell in the free blocks of the band. $B_j B_j$ indicates the total spectrum pool of 2700 MHz which includes the reserved 100 MHz for the emergency purpose. $SP_j SP_j$ denotes the spectrum price and $BP_j BP_j$ denotes the blocking penalty. According to the reward values, spectrum sharing is implemented and also the value of reward must be higher for sharing the spectrum. Depends upon the number of primary users and secondary users in the radio environment, and the available spectrum the performance of reward might be varied.

4. IMPLEMENTATION AND DISCUSSIONS

The proposed methodology is implemented with the help of the Matlab R2018a version in the Windows 10 environment. For the practical simulation, two bands are considered - 800 MHz and 1800 MHz - for spectrum sharing using the optimized game theory. In this, the social spider optimization is performed to determine which band will give the least benefits to the players. The game theory is performed on these two bands with the following initializations mentioned in Table 2.

Table 2: Parameters For The Game Theory

Parameters	Values
Band frequency	800 MHz and 1800 MHz
Data speed	2 Mbps
Active users	80 %
Total band	2700
Total data rate	7.93

The social spider optimization process finds the minimum payoffs for both the frequency bands for the parameters in Table 2 with 50 spiders and processes for 50 iterations. The outputs for the 1 & 50 iterations are shown in the following Fig.2 & Fig. 3 with the convergence marked out.

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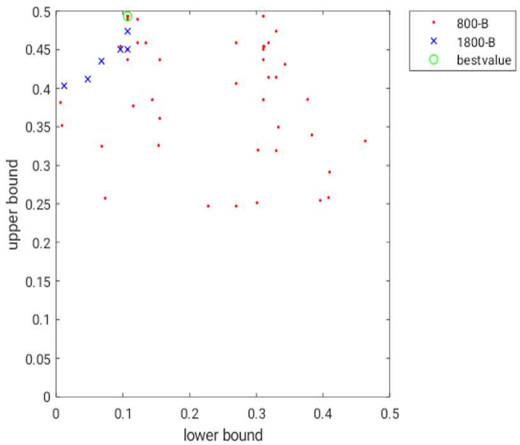

Fig.2: At Iteration 1

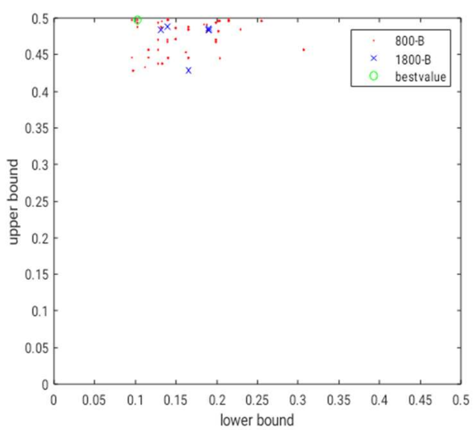

Fig.3: At Iteration 50

The overall optimization based on the fitness value and user data rate is plotted in Fig.4, the fitness value is 1.436889 e4 and the value is consistent only for a data rate of 3.4 bits/sec.

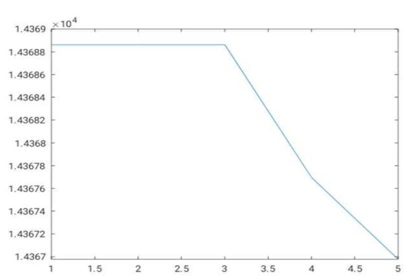

Fig.4: Convergence Curve Of SSO

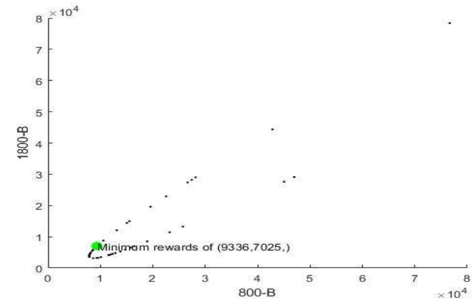

Fig.5: Minimum Rewards By SSO-Based Game Theory

From Fig.5, it is clear that the minimum rewards achieved by 800 MHz and 1800 MHz users should be avoided to improve the spectrum sharing as well as to avoid interference between the users. Hence, the proposed SSO-based game theory determines the exact interference region and improves the spectrum sharing. Under the collision condition, the performance of SSO increases as the number of user increases, and their low spectrum availability.

The blocking probability and intensity utilization are calculated based on the lambda and the number of users per cell.

The lambda value for the SSO based spectrum sharing is linspace(0,1.5,2000)and the maximum number of users is 8. By substituting this value in the erlang-b formula,

$$P_b = \frac{\frac{E^n}{n!}}{\sum_{i=0}^{n}\frac{E^n}{i!}} \quad (2)$$

Where E=lambda*D. D is the call rate which is 200 secs in this paper.

The intensity utilization function is determined from the inverse erlang. The utilization of bandwidth 2700 for a single block of spectrum size 52.9412 by 8 users is shown in figure 6.

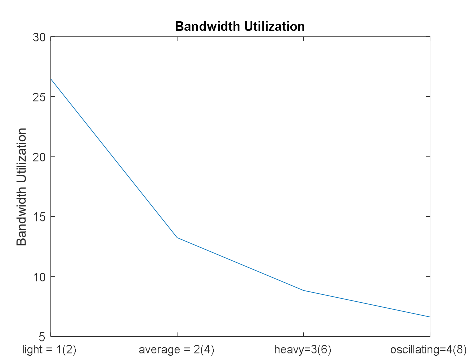

Fig.6: Bandwidth Utilization

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Both bandwidth utilization and intensity utilization in figs 8 and 9 discuss the utilization rate for the channel in terms of intensity and bandwidths.

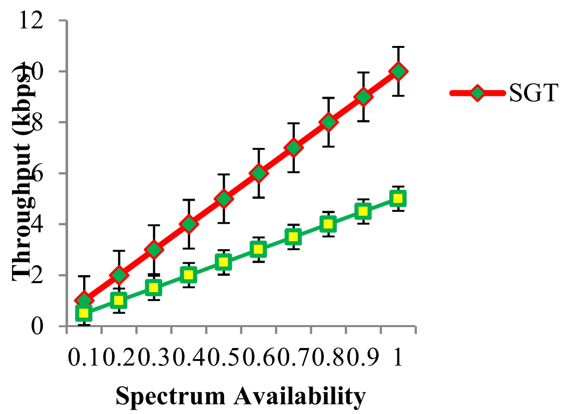

Fig.7. Spectrum Availability Vs. Throughput

Fig 7 discusses the comparison of the proposed SGT and also the traditional GT. From that analysis, it is confirmed it provides better performance than the conventional GT approach.

5. CONCLUSION

A population-based algorithm called the Social Spider Optimization (SSO) mimics the social spider's cooperative nature. SSO takes into account both male and female search agents (spiders). Depending on the gender, each individual is run through a distinct set of evolutionary operators that imitate certain cooperative behaviours that are frequently observed in a colony. With this specific categorization, it is possible to lessen serious faults like inappropriate exploration-exploitation balance and early convergence that are found in many SI techniques. Since its debut, the SSO has demonstrated its ability to tackle a wide range of engineering issues, outperforming other well-known algorithms with which it is compared in terms of the quality and accuracy of the overall solution. Many users today access the spectrum that is available in 4G and 5G communication networks at high data rates. In order for the spectrum to be used effectively, it must be shared between the primary and secondary users. Primary users are allotted licenced spectrum, while secondary users must share the licenced spectrum with the primary user since the unlicensed spectrum band is constrained and congested. Here, the idle spectrum has been detected using the windowed kurtosis method, leading to the development of a unique spectrum sharing technique based on SSO optimization and Stackelberg game theory. The utility function for modelling the Stackelberg game theory approach for the sharing strategy has been determined using the SSO optimizer.It is discovered that the awards given to the secondary users are optimised without changing the rewards given to the prime users. The greater data rate and power estimation that could be a gauge for potential energy harvesting will be included in the future.

Declaration:

Ethics Approval and Consent to Participate:

No participation of humans takes place in this implementation process

Human and Animal Rights:

No violation of Human and Animal Rights is involved.

Funding:

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Conflict of Interest:

Conflict of Interest is not applicable in this work.

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