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Whale Optimization Algorithm for Transmit Antenna Selection in MIMO Cognitive Radio Systems

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Abstract—For performance enhancement of wireless communication systems, MIMO systems are used and have become an essential component of modern wireless communication networks. Different types of MIMO systems are used according to the application such as massive MIMO (mMIMO), millimeter wave MIMO (mmWave MIMO), distributed MIMO (D-MIMO), cooperative MIMO such as cognitive radio based MIMO, etc. In this paper, Whale Optimization Algorithm (WOA), a metaheuristic technique is used for solving the optimization problem of performing transmit antenna selection (TAS) i.e., selecting the best set of antennas at transmitter side for an overlay cognitive radio (CR) based hybrid MIMO system. Due to their capacity to intelligently utilise the priceless electromagnetic spectrum, CR communication systems prove to be an effective strategy for current and future wireless communication networks. The Bit Error Rate (BER) versus Signal to Noise Ratio (SNR) graphs show the results of the proposed network.

Keywords-Transmit Antenna Selection;WOA; MIMO; Cognitive Radio

I. Introduction

Any kind of communication system's fundamental goal is to deliver information in such a way that the receiver, which is situated at a specific distance from the sender, is able to correctly decode it [1]. MIMO systems are used to increase wireless communication's dependability and assist in providing error-free transmission [2]. With MIMO systems, higher data rates and longer transmission distances are feasible without using additional bandwidth or transmitting power. Additionally, there are a number of significant advantages to using cognitive radios (CR) in MIMO wireless networks, which can further improve the network's performance and effectiveness [3]. They allow for adaptive modulation and coding, reduce interference, make it easier for dynamic channel allocation, and enable optimal spectrum utilization. Cognitive radios are a key component of the future generation of wireless communication systems because they improve the performance, capacity, and dependability of MIMO wireless networks [4].

In this research paper, a new hybrid CR-based MIMO system that can surpass current systems is described. The word "hybrid" refers to the use of a combination or hybrid of different MIMO technologies, including transmit antenna selection (TAS) employing meta-heuristics, spatial modulation (SM), and non orthogonal multiple access (NOMA).

In order to improve upon current systems and meet the needs of next-generation communication, multiple approaches are combined. SM and NOMA both make use of the spatial domain and power domain respectively whereas CR aids in the effective use of the spectrum, a limited bandwidth resource [5], [6]. The TAS scheme, which is an antenna diversity scheme, gives the system the benefit of diversity gain [7]. Additionally, this method minimizes the number of radio frequency (RF) component chains needed, lowering the resources used. It aids in cost reduction and reduces the need for bulky components used in RF chains.

The remainder of the paper is organized as follows. In the next section, the working of the Whale Optimization Algorithm (WOA) is detailed. After that, in the following section, for further improvement of the proposed model, the usage of a metaheuristic technique, Whale Optimization Algorithm for solving the TAS optimization problem in the hybrid CR-based

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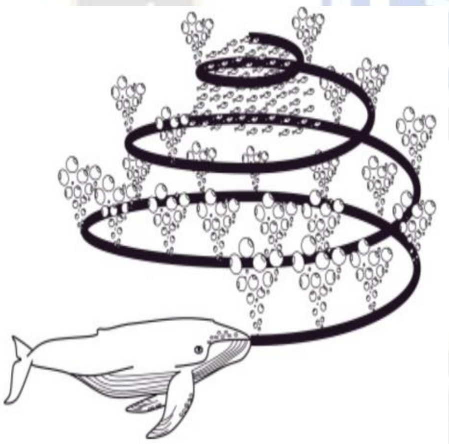
MIMO system has been described. Then the results are discussed in the succeeding section, followed by the conclusions and future scope in the next section.

II. WHALE OPTIMIZATION ALGORITHM (WOA)

A metaheuristic optimization algorithm called the Whale Optimisation Algorithm (WOA) was developed in response to humpback whales' hunting strategies. It was put up as an optimization method inspired by nature by Seyedali Mirjalili in 2016 [8].

The WOA algorithm imitates humpback whales' social behavior and hunting techniques, in which the entire colony works together to find prey. The population of alternative solutions in the algorithm is referred to as "whales," and each whale represents a potential solution to the optimization issue. Foraging behaviour of humpback whales using bubble nets, surrounding prey, and searching for prey are all simulated by WOA using three operators. The bubble-net feeding method is the name for the unique hunting technique used only by humpback whales. Hunting krill or tiny fish in schools near the surface is preferred by humpback whales. This foraging has been seen to include the formation of characteristic bubbles along a circular or '9'-shaped route, as depicted in Figure 1 [9].

Figure 1. Humpback whales using bubble-net feeding method for foraging of a school of tiny fish.



The working of the WOA is described in detail with the help of a flowchart in Figure 2 [10]. Humpback whales can find and circle their prey when they are engaged in hunting. Since the position of the optimal value in the search space is unknown a priori, the WOA technique assumes that the best candidate solution at this time is either the target prey or extremely close to it. Adjustment of location of the remaining population of search agents is done in such a way that they move toward the best search agent after the greatest search agent has been identified.

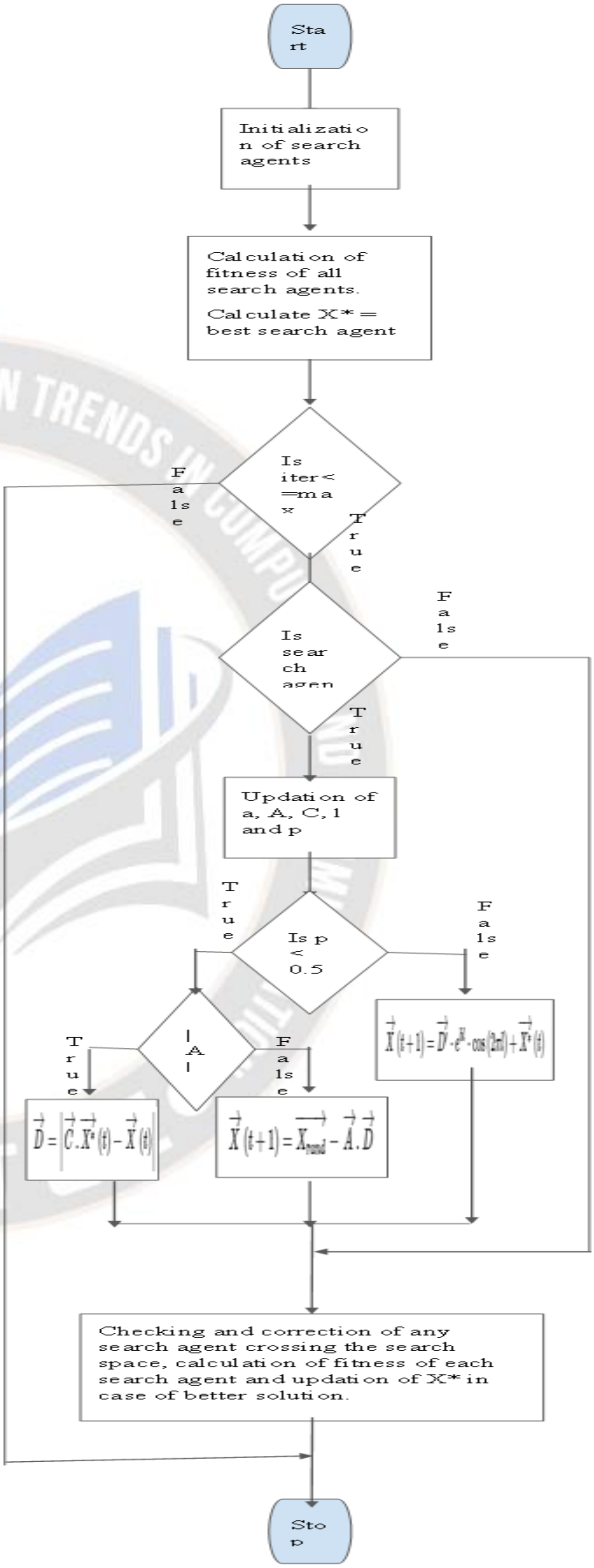


Figure 2. Flowchart of WOA

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In the flowchart, 'p' which is a random no. in [0,1], determines whether the humpback whale (solution) will move i.e., update its position in a shrinking encircled path or in a spiral motion. The probability that either of the movement occurs is chosen to be fifty percent. Hence, p is chosen to be 0.5 and if p is less than fifty percent, shrinking encircling motion occurs else spiral motion occurs, as described by the equations in the flowchart. Here, 't' denotes iteration number that is currently being processed and $\vec{X}$(t) vector represents the current location of solution. Also, $\vec{X}$(t+1) vector represents updated location for next iteration. The vector $\overrightarrow{X^*}$(t) symbolizes the optimal solution or prey towards which remaining solutions move. For following the spiral path, when $p \geq 0.5$, the equation is represented in the flowchart where $D' = \left|\overrightarrow{X^*}(t) - \vec{X}(t)\right|$ represents the distance between the current solution and optimal solution. The constant 'b' denotes the logarithmic spiral path's shape while the random number 'l' lies in the range of [-1.1]. There are two coefficient vectors which are used in the equations that control how the search is carried out and are given as follows, in equations 1 and 2 respectively. Here, $\vec{a}$ goes from two to zero, linearly, as the iterations increase and the random vector $\vec{r}$ lies in the range of [0,1].

$$\overrightarrow{A} = 2\,\overrightarrow{a}.\,\vec{r} - \vec{a} \qquad (1)$$

$$\vec{C} = 2.\vec{r} \qquad (2)$$

On the other hand, for shrinking encircling movement, i.e., when $p < 0.5$, there are two possibilities depending on the value of A which is the magnitude or absolute value of $\overrightarrow{A}$. For the value of A being less than 1, local exploitation occurs while it being greater than 1 implies exploration which is described by the corresponding equations in the flowchart. In the equations, a random vector is chosen from the existing search agents and is denoted by $\overrightarrow{X_{rand}}$. Since WOA metaheuristic technique performs both local exploitation and global exploration, it is able to find out global maxima and minima.

III. WOA For TAS In Hybrid MIMO Cognitive Radio System

By utilizing a combination or hybrid of the various MIMO techniques such as TAS, SM, and NOMA, a new hybrid MIMO system based on Cognitive Radio networks is depicted in [11]. The novelty of this research work is the usage of the WOA metaheuristic algorithm for the optimization of TAS in the system. The multiple MIMO techniques and their advantages are described ahead.

SM involves the transmission of bits via the active antenna index along with the actual bits transmitted. The active antenna is chosen according to the best channel conditions and results in a gain of $log_2(N_t)$ in spectral efficiency, where N_t denotes the number of transmitting end antennas [12]. Also, non orthogonal, correlated, or dependent signals are used in NOMA. Under NOMA, several users can share the same time and frequency resources while using various power levels and/or modulation techniques. The usage of NOMA further increases spectral efficiency, reduces latency, and provides massive connectivity and better quality of service (QoS) for cell-edge users.

TAS is a closed-loop MIMO technology that feeds CSI back to the transmitting end utilizing a very low data rate channel. Each transmitting antenna broadcasts a set of pilot sequences in order to identify which is the best-transmitting antenna for the connection. This information is used to select the antenna corresponding to the best channel conditions. TAS helps in lessening of the number of bulky RF chains required in the MIMO system [13]. Further, by the usage of the metaheuristic technique or TAS, there is a reduction in Bit Error Rate (BER). Above all, CR helps in resolving the spectrum scarcity versus under-utilization dilemma of the conventionally deployed fixed spectrum allocation. Non-cognitive users educate cognitive users about their signal codebooks and messages on the overlay CR network. Therefore, the main users, or non-cognitive users, assist the secondary users, or the cognitive users, rather than clashing for access to the spectrum [14]. The MIMO overlay cognitive radio model utilizing the hybridization of techniques, such as NOMA, SM, and TAS is shown in Figure 3.

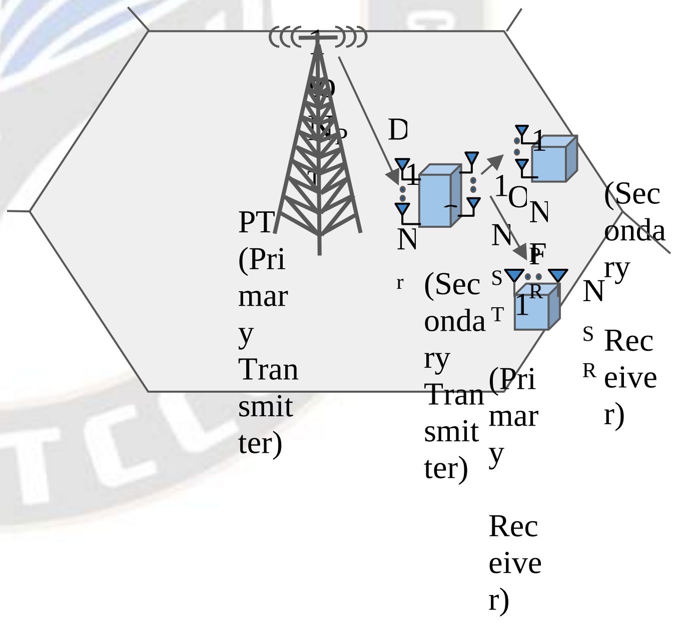

Figure 3. System Model of Overlay CR Network

The base station (BS) is the main or primary transmitter (PT), employing a licensed frequency spectrum band to broadcast data to its main customers. Let's suppose that there is a primary receiver (PR) near the cell edge and that the channel between the PT and the PR is very weak, preventing the PT from receiving any signals. Because it is now using the PT's

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spectrum for communication, the Secondary Transmitter (ST), which is the CR device in this scenario, may assist the ST by serving as a relay between the ST and SR and transmitting its own data to its secondary user (SU). As a result, both the primary and secondary networks gain. The channels between PT and ST, ST and SR, and ST and PR are denoted by D, O and F respectively. Here, N_{PT} and N_{ST} denote the transmitting antennas at PT and ST respectively. Also, N_r, N_{PR} and N_{SR} denote the receiving antennas at ST, PR and SR respectively. The ST works as a relay by performing reception of signal from PT and sending it to PR while performing simultaneous information transmission to SR as well by using NOMA and SM. In addition, TAS is performed at ST to boost the performance of the PR.

For further improvement of the proposed model, metaheuristics have the potential to be used. Metaheuristics offer better solutions with less complexity as compared to traditional TAS approaches. The whale Optimization Algorithm is one such metaheuristic that is demonstrated in this paper. The goal of this research study is to implement the WOA method to find the best-optimized weights for antenna selection under restrictions such as how much power is consumed along with how much minimization of error is possible in order to overcome these problems. In the proposed MIMO cognitive radio model, the problem of allocation of power constitutes an important aspect in TAS for providing fair power allocation to each user in NOMA and thus increasing the capacity. To decrease the Mean Square Error (MSE) of the Secondary Transmitter, i.e., the cognitive radio having N_{ST} antennas and to reduce the power of the Primary Transmitter (P_{PT}) is the objective of this research work. The MSE and power consumption of the selected antenna must be as low as practical in order for the system to obtain maximum antenna gain with the least amount of noise. Here, the problem's objective function is given in equation 3 as follows:

$$ob = mean[min(MSE_1, MSE_2, MSE_3, \ldots, MSE_n)] + P_{PT} \quad (3)$$

where, $MSE_1 = (Y_{NST1} - Y'_{NST1})^2$

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$MSE_2 = (Y_{NST2} - Y'_{NST2})^2$

$MSE_n = (Y_{NSTn} - Y'_{NSTn})^2$

In the above equation, Y_{NSTn} and Y'_{NSTn} represent the actual symbol and the estimated symbol at the nth secondary user. WOA algorithm is utilized for calculating the optimized values of antenna selection under power consumption and minimization of error constraints.

IV. Results

The simulation is done on MATLAB R2020a. Two randomly generated datasets are used. The first data involves transmission of 4 lakh bits of information and the second dataset involves the communication of 6 lakh bits of information. The results are plotted in the form of BER versus SNR graphs. The SNR values are varied from -10 to +10 decibels and the corresponding BER values are plotted to obtain the graphs for performance evaluation. Investigating the effectiveness of suggested method for dataset-1 and dataset-2, corresponding to the four situations of varying transmitting antenna number, the results are graphically represented in Figures 4, 5, 6 and 7 for dataset- 1 and Figures 8, 9, 10 and 11 for dataset-2. The four figures for each dataset correspond to different cases of various MIMO configurations between the primary base station and cognitive radio base station and between the cognitive radio base station and cognitive radio receivers. Here, N_{PT} stands for no. of antennas at the primary transmitter BS, N_{SR} represents no. of antennas present at receiver of cognitive radio base station, N_{ST2} and N_{ST1} represent the antennas for trasmission allocated at cognitive radio BS for primary receiver and secondary receiver respectively. Similarly, N_{SR1} and N_{SR2} represent the receiving antennas allocated at the primary receiver and secondary receiver respectively.

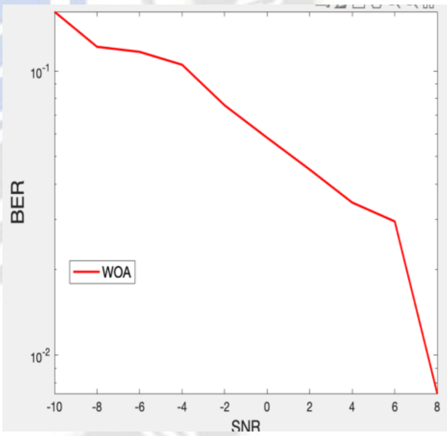

Figure 4. BER versus SNR graph for $N_{PT} = 8$, $N_{SR} = 16$, $N_{ST1} = N_{ST2} = 2$, $N_{SR1} = N_{SR2} = 4$ for dataset 1

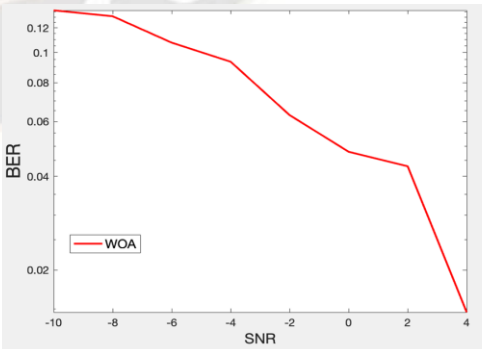

Figure 5. BER versus SNR graph for $N_{PT} = 8$, $N_{SR} = 16$, $N_{ST1} = N_{ST2} = 4$, $N_{SR1} = N_{SR2} = 8$ for dataset 1

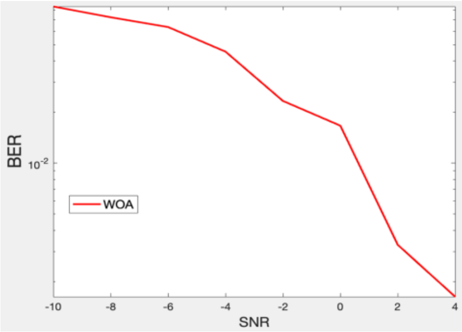

Figure 6. BER versus SNR graph for N_{PT} =16, N_{SR}=32, N_{ST1}= N_{ST2}= 4, N_{SR1} = N_{SR2} = 8 for dataset 1

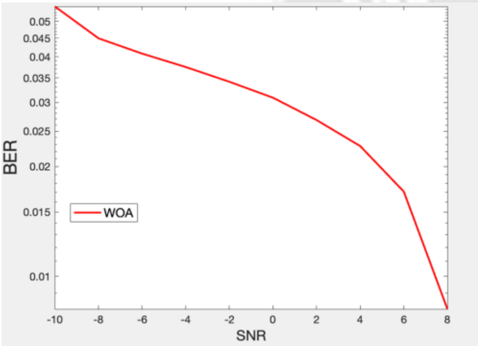

Figure 7. BER versus SNR graph for N_{PT} =16, N_{SR}=32, N_{ST1}= N_{ST2}= 8, N_{SR1} = N_{SR2} = 16 for dataset 1

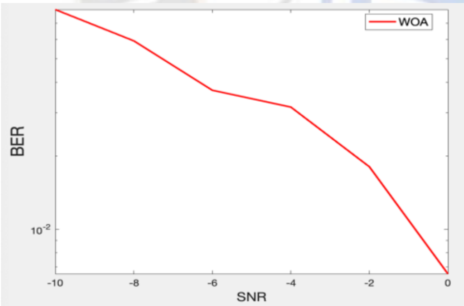

Figure 8. BER versus SNR graph for N_{PT} =8, N_{SR}=16, N_{ST1}= N_{ST2}= 2, N_{SR1} = N_{SR2} = 4 for dataset 2

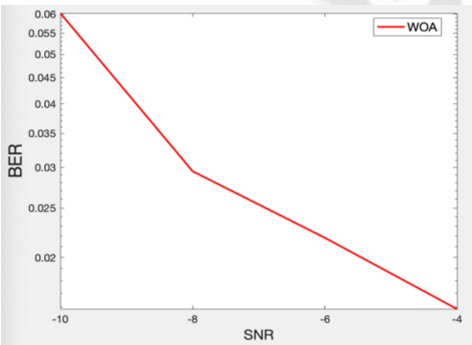

Figure 9. BER versus SNR graph for N_{PT} =8, N_{SR}=16, N_{ST1}= N_{ST2}= 4, N_{SR1} = N_{SR2} = 8 for dataset 1

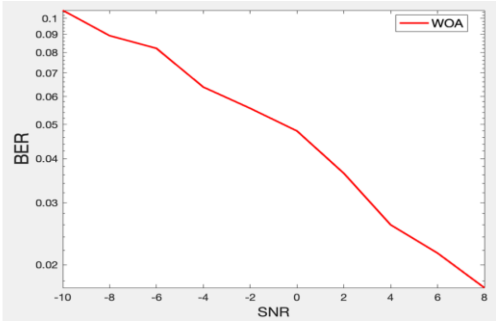

Figure 10. BER versus SNR graph for N_{PT} =16, N_{SR}=32, N_{ST1}= N_{ST2}= 4, N_{SR1} = N_{SR2} = 8 for dataset 1

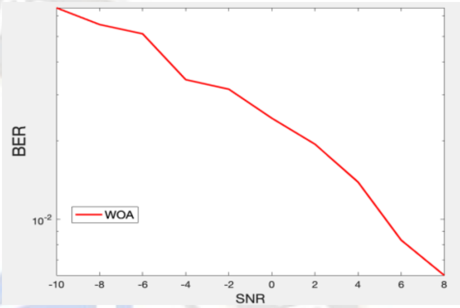

Figure 11. BER versus SNR graph for N_{PT} =16, N_{SR}=32, N_{ST1}= N_{ST2}= 8, N_{SR1} = N_{SR2} = 16 for dataset 1

Table 1 in which the added advantage of all the MIMO techniques used shows the statistical performance of the proposed WOA algorithm for TAS for both dataset 1 and dataset 2.

TABLE I. COMPARISON OF STATISTICAL RESULTS OF WOA FOR TAS ON TWO DATASETS

Statistical Measures	Whale Optimization Algorith for TAS	
	Dataset 1	*Dataset 2*
Best	3.9059	4.1714
Worst	95.868	70.839
Mean	17.889	21.795
Median	10.004	20.007
Standard Deviation	19.904	16.846

V. CONCLUSIONS AND FUTURE SCOPE

In this research work, a unique method for antenna selection optimization for overlay CR MIMO model by usage of SM and NOMA has been developed through the application of an optimization technique. The dual goal of the optimized WOA antenna selection method takes into account both the total usage of power alongwith the MSE. The MSE and power consumption of the chosen antennas must be lowered in order for the system to obtain the greatest antenna gain with the least amount of noise.

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