JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 12(4), DECEMBER, 2024
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com.ng

Optimization of Signal to Noise Ratio and Power Consumption of Cognitive Radio Systems using Enhanced PSO Algorithm

Josephine Unachukwu, Evans C. Ashigwuike
Department of Electrical and Electronic Engineering,
Faculty of Engineering, University of Abuja, Nigeria.

ABSTRACT

This paper demonstrated the importance of interdisciplinary collaboration, combining knowledge from telecommunications, optimization algorithms, and engineering principles. It underscores the need for adaptable and intelligent cognitive radio engines that dynamically adjust to varying network conditions, ensuring efficient spectrum utilization and reliable communication services. Cognitive Radio (CR) is basically focused on building a flexible and reconfigurable radio guided by intelligent sensors. The sensors are responsible for sensing the cognitive radio environment, learning from previous experience and knowledge and adopting this information and its transmission parameters such as transmit power, modulation type and modulation index for enhanced spectrum usage. The CR engine then coordinates these sensor, and optimizes the routine for learning and efficient decision-making. The major challenges of CR are real-time adoption of transmission parameters, along with the environmental information such as transmission distance, noise power and available spectrum. Through the optimization process, we have uncovered Pareto-optimal solutions that represent the best compromises between these objectives. These solutions provide a valuable resource for designers and engineers to make informed decisions, selecting the most appropriate radio engine configurations that align with their specific requirements and operational environments. The performance analysis of the enhanced Particle Swarm Optimization shows ePSO's potential to tackle the intricate optimization tasks associated with cognitive radio design, establishing a foundation for more dependable and versatile wireless communication systems.

ARTICLE INFO
Article History
Received: September, 2023
Received in revised form: November, 2023
Accepted: December, 2024
Published online: December, 2024

KEYWORDS
PSO, ePSO, CRC, QoS and optimization.

INTRODUCTION

The electromagnetic spectrum is one of the most important resources required for radio communications. Spectrum utilization is regulated worldwide so that essential services can be provided and protected from harmful interference. Spectrum governance across the world traditionally tended toward static long-term exclusive use of spectrum, assigning a license to a specific operator on a certain frequency band, thereby, giving them the exclusive right to operate on the licensed band [1,2]. This static spectrum allocation strategy has led to many successful applications like broadcasting and mobile communication and it has also led to almost the entire prime available spectrum being assigned for various applications [2]. It may thus seem that there is little or no spectrum available for emerging wireless products and services. Several studies and reports over the years showed that the statically allocated spectrum was in fact vastly underutilized [3].

Cognitive radio (CR) is the enabling technology for the implementation of dynamic spectrum access (DSA) which happened to be one of the most potent remedial measures for the fixed spectrum allocation which has led to spectrum scarcity [2,5]. A CR is an aspect of the software-defined radio (SDR) that has the ability to analyze its surrounding radio environment and decide on how best to re-configure itself to

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 12(4), DECEMBER, 2024
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com.ng

suit operations without causing harmful interference to the licensed user [3,6]. The CR has the ability to identify any opportunities that exist in the spectrum band of interest and utilize them without causing any interference to the primary users (PUs). These opportunities are in the form of spectrum holes or white spaces. A spectrum hole is the part of the spectrum that is devoid of the primary licensed user [6]. Figure 1 shows the four-operation principle of CR in a closed cycle stages of Observe-Decide-Act-Learn [20].

Figure 1: Cognitive Radio Cycle [20].

As shown in Figure 1, the cognitive radio can observe its environment and make decision about action of reconfiguration and learn from previous experience to provide desired Quality of Service (QoS). A cognitive-radio device operates in either the “interweave” or the “underlay” mode for better spectrum efficiency [4]. In both types of operation, the unoccupied parts of the spectrum referred to as white spaces or spectrum holes. The generic architecture of the cognitive radio is illustrated in Figure 2. The cognitive engine is a separate system within the total solution which relies on information from the user, radio and policy domains for instructions on how to best control the communication system. The communication system is a simplified protocol stack, showing the independence of the cognitive engine from the overall system [7]. There are three input domain that concerns the cognitive radio they are defined as follows [7].

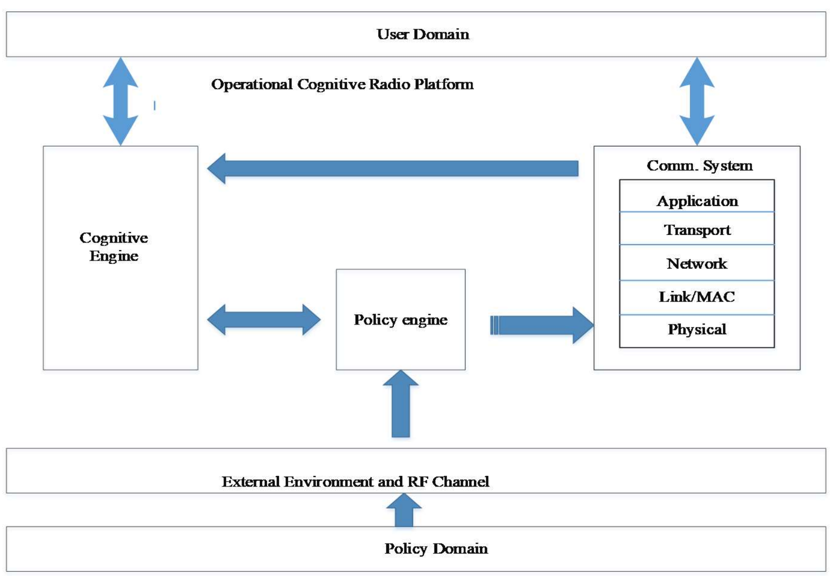

Figure 2: Generic Architecture of Cognitive Radio [4].

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 12(4), DECEMBER, 2024
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com.ng

Asadi et al. [8] developed a scheme that was aimed at demonstrating the fact that a CRE with meta-abilities can choose the learning technique that is best suited for each application scenario. The work firstly characterized different wireless scenarios such as high/low SNR, available bandwidth, and primary user activity) and performance of each CRE technique. By using these characterizations, the scheme was able to evaluate the effectiveness of each learning technique in terms of the characterized scenario. Saha and Roy [9] proposed a binary particle swarm optimization for dynamic channel allocation in wireless networks. In the work, Particle Swarm Optimization (PSO) was used to find an optimum solution of channel assignment problem. Also binary PSO algorithm was used to test the maximization of the spectrum utilization function and to solve the channel assignment problem in cognitive network. Simulation results showed that the proposed algorithm had a superior performance over the conventional methods in terms of maximum spectrum utilization. BPSO gave a better solution when the numbers of radios were equal to the number of available channels for allocation. AlQerm and Basem, [10] proposed an adaptive multi-objective optimization scheme (AMOS) for CR network with multiple subcarriers to improve spectrum operation and network performance. The proposed optimization technique was applied in the optimization phase of CRs decision-making engine using six objective functions. It relied on adapting radio transmission parameters to environmental parameters using optimal performance metrics and objective weights. AMOS used Genetic Algorithm (GA) that was adaptive in terms of its parameters and objective weights as the vehicle of optimization The performance objective functions included minimizing power consumption, minimizing bit error rate (BER), delay and interference. The environmental parameters from the TCP/IP stack layers and quality of service requirements were extracted using cross-layer optimization approach. Simulation results showed that AMOS outperformed other meta-heuristic searching algorithms in a multicarrier environment by achieving the highest score, fastest convergence and feasibility. The Cross-layer optimization method adopted was an ultimate approach to extract environmental parameters and QoS requirements.

APPROACH METHODS

Optimization of the developed objective function model was achieved using the developed PSO algorithm. The success of this process depends on proper parameter tuning for the PSO algorithm, the quality of your objective function, and understanding the problem to optimize.

It is a good practice to perform sensitivity analysis to assess how changes in the parameters of the objective function model affect the optimization results.

In order to design the proposed cognitive radio engine [6], the following steps were adopted.

a. Perceiving the environment information.
b. Inputting the cognitive radio parameters, and perform multi-objective optimization
   i. Input the cognitive radio parameters and perform multi-objective optimization.
   ii. Calculate the fitness value and the crowding distance of the individuals.
   iii. Update the memory library and judge whether the termination condition is met.
   iv. Perform crossover and mutation with probability, *P*.
   v. Calculate the fitness and crowding distance of all the individuals
c. Selecting a set of parameters from the Pareto-optimal set according to the communication requirements and optimize the objective function using PSO

The development of multi-objective optimization model for cognitive radio engine was carried out using the following steps:

i. All the environmental and transmission parameters (such as modulation index, modulation type, transmit power, noise power, transmission distance, channel loss, battery life etc.) required to calculate the objective function were defined.
ii. The mathematical model for maximizing the data rate was developed using the established parameters.
iii. The model for minimizing power consumption was developed and.

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 12(4), DECEMBER, 2024
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com.ng

iv. Minimizing BER model and error probability was also developed.

The deployment of the Enhanced Particle Swarm Optimization algorithm was implemented by adopted the following steps:

i. Initialization of the population size and each particle of the population was considered as a candidate solution to the objective function.
ii. Evaluation of each particle's position using the fitness function.
iii. Up gradation of particle current position. The current value of the particle new position gbest was set.
iv. Choose particle with the best fitness value in the population as gbest.
v. Calculation of the particle velocity.
vi. Update the particle new position.

Simulation was performed in MATLAB R2017a and validation by comparing with the work of [6] using BER, energy consumption and data rate as performance metrics.

The algorithm's convergence was monitored by checking whether the maximum number of iterations has been reached or a satisfactory solution is found. The optimization process was ended, as the termination condition was met. The selected design solutions were implemented and thoroughly tested for their performances under various conditions to ensure they meet the desired goals.

RESULTS AND DISCUSSIONS

Creating a multi-objective optimization model for cognitive radio engine design using the Enhanced Particle Swarm Optimization (EPSO) algorithm involves formulating the problem, setting objectives, constraints, and implementing the optimization process.

Comparison of PSO and ePSO Based on SINR

The Signal to Noise Ratio (SINR), which quantifies the quality of the received signal relative to interference and noise, is a key determinant of communication performance. As depicted in the Figure 3, there is an evident inverse relationship between SINR and interference power. Higher SINR values correspond to a stronger signal, resulting in superior communication quality, higher data rates, and enhanced reliability. Conversely, as interference power increases, SINR decreases, leading to reduced performance and the potential for communication issues.

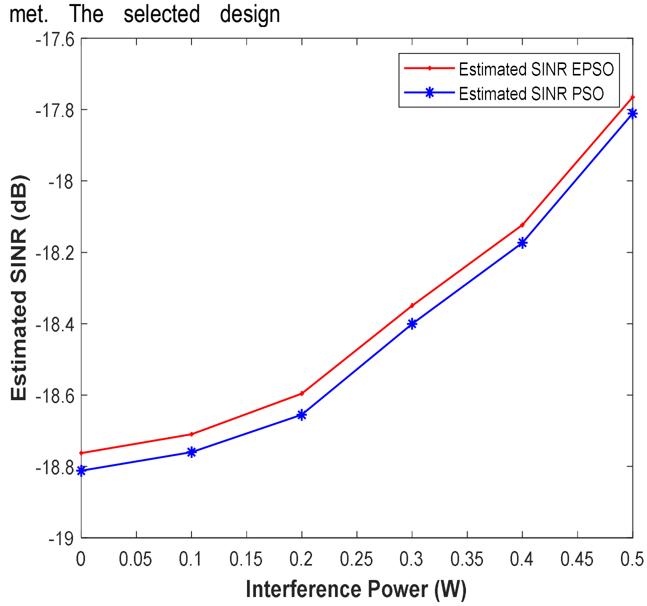

Figure 3: Estimated SNR (dB) vs. Interference power.

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.

The significance of these results lies in their implications for cognitive radio engine design and optimization. Cognitive radio systems, designed to adapt to dynamic and congested wireless environments, play a pivotal role in managing interference and enhancing SINR. The multi-objective optimization model developed in this project offers a versatile approach to address this trade-off. By optimizing various parameters such as frequency band selection, power allocation, and dynamic spectrum access, cognitive radio engines can efficiently enhance SNR while considering multiple objectives, including spectral efficiency, energy consumption, and interference mitigation.

From a practical standpoint, the findings have direct relevance to a range of applications, including 5G, Internet of Things (IoT), and public safety communications. In such applications, where dynamic and crowded spectrum environments are common, effective management of SNR is vital for reliable and efficient communication. These results inform the ongoing development of cognitive radio technology and its application in next-generation wireless networks. However, it is important to acknowledge the complexity of optimizing SNR and managing interference in real-world scenarios, which may involve challenges related to hardware limitations, regulatory constraints, and the need for advanced interference mitigation techniques.

Comparison of PSO and ePSO Based on Estimated Signal Power

As shown in the Figure 4, signal power decreases as interference power increases. Lower signal power signifies a diminished ability to transmit and receive data effectively, often leading to communication degradation.

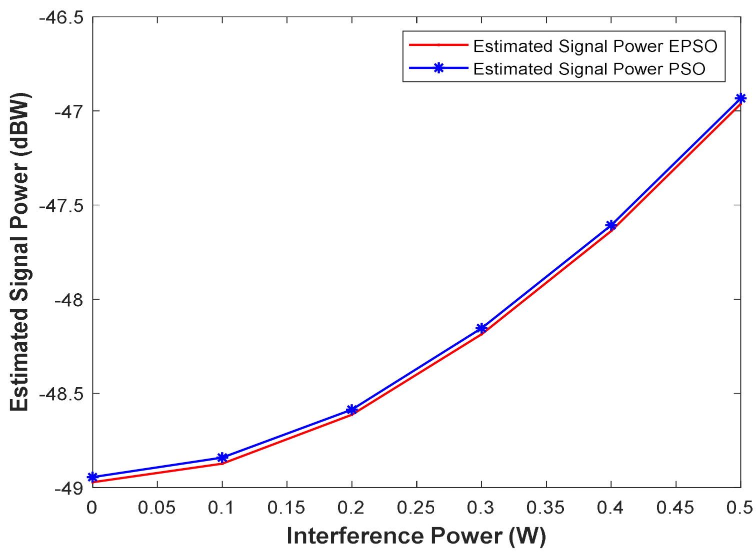

Figure 4: Estimated signal power (dBW) vs. Interference power

Conversely, lower interference power corresponds to stronger signal power, which is vital for enhancing communication quality, data throughput, and overall system reliability. These findings underscore the paramount importance of cognitive radio engine design in managing interference, allocating resources judiciously, and optimizing signal power. The multi-objective model developed in this project offers a robust approach to addressing this trade-off by considering various objectives such as spectral efficiency, energy consumption, and interference mitigation. This graph's significance extends to practical applications, including 5G, the Internet of Things (IoT), and public safety communications, where dynamic and congested spectrum environments demand efficient interference management and signal

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.

power optimization. Nonetheless, it's vital to recognize the complexity of optimizing signal power and handling interference in real-world scenarios, including hardware limitations, regulatory constraints, and advanced interference mitigation strategies.

Performance Evaluation of PSO and ePSO based on BER

As depicted in Figure 5, both enhanced Particle Swarm Optimization (ePSO) and Particle Swarm Optimization (PSO) exhibit iterative improvements in BER, with ePSO consistently outperforming PSO. This trend indicates that the enhanced version of the algorithm, ePSO, demonstrates superior convergence characteristics, resulting in lower BER values and improved communication reliability.

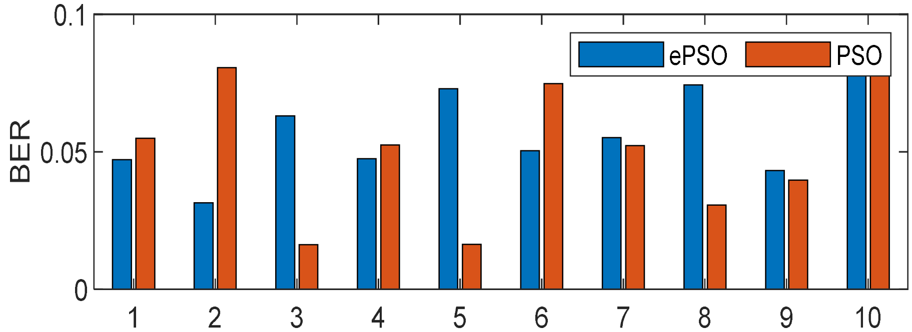

Figure 5: BER Convergence Comparison: ePSO vs. PSO in Cognitive Radio Optimization

The significance of these results lies in the potential for ePSO to play a pivotal role in the design and optimization of cognitive radio engines, where minimizing BER is of paramount importance for ensuring efficient and robust wireless communication. This performance analysis underscores the practical utility of ePSO in cognitive radio systems and opens up avenues for further exploration in cognitive radio design, especially in the face of dynamic and interference-prone wireless environments.

Also, both ePSO and PSO exhibit iterative convergence towards an optimal power solution, with ePSO consistently surpassing the performance of the standard PSO algorithm, as shown in the Figure 6. The results emphasize that ePSO's enhanced features lead to more effective and rapid convergence, resulting in lower power consumption and more efficient resource allocation.

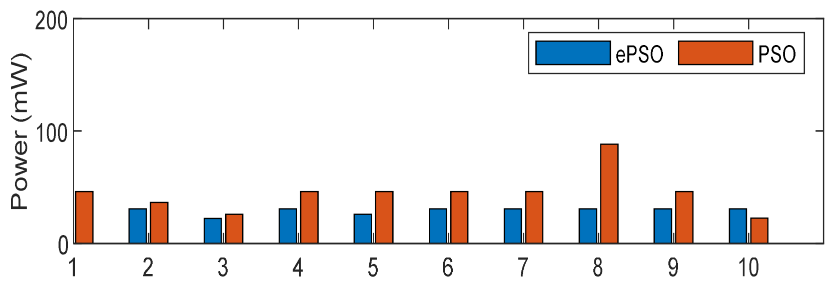

Figure 6: Power Optimization Progress: ePSO vs. PSO Iterations in Cognitive Radio Design

In the context of cognitive radio engine design, where power optimization is a critical objective to prolong battery life and minimize energy consumption, these findings hold significant implications. The superior performance of ePSO highlights its potential for application in the development of energy-efficient and sustainable cognitive radio

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 12(4), DECEMBER, 2024
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com.ng

systems. This performance analysis underscores the practical advantages of ePSO in cognitive radio optimization and its potential for contributing to the advancement of next-generation wireless communication networks. However, it is evident that ePSO exhibits a more rapid and effective attenuation reduction, surpassing the performance of the conventional PSO, as shown in the Figure 7.

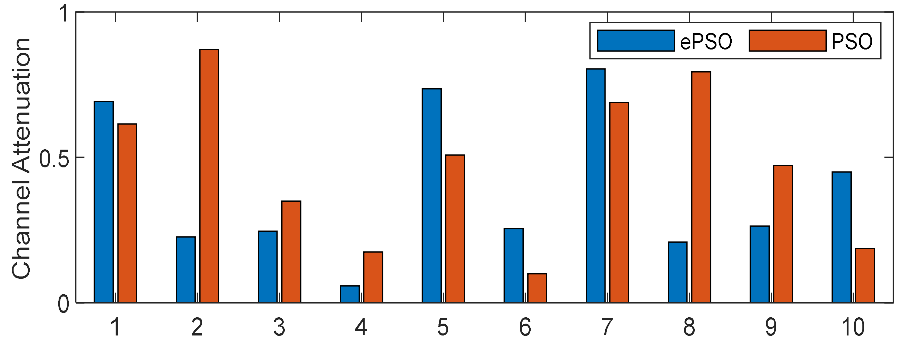

Figure 7: Channel Attenuation Convergence Analysis

These results underscore the superior convergence capabilities of ePSO, which is paramount for reducing channel attenuation and enhancing signal quality in cognitive radio systems. In practical terms, efficient channel attenuation reduction is crucial for mitigating signal losses and optimizing communication reliability, especially in dynamic and challenging spectrum environments. These findings hold substantial implications for the potential application of ePSO in cognitive radio engine design, facilitating more reliable and resilient wireless communication systems. This performance analysis highlights the promising role of ePSO in advancing the development of cognitive radio networks and underscores the potential for addressing critical communication challenges.

Performance of PSO and ePSO Based on Fitness Value

As depicted in Figure 8, both ePSO and PSO display iterative improvements in fitness values; however, ePSO consistently outperforms traditional PSO. This finding underscores ePSO's advanced convergence capabilities, leading to superior optimization results. In the context of designing cognitive radio engines, where the need to balance multiple conflicting objectives is paramount, and the advantages of ePSO's performance are highly significant.

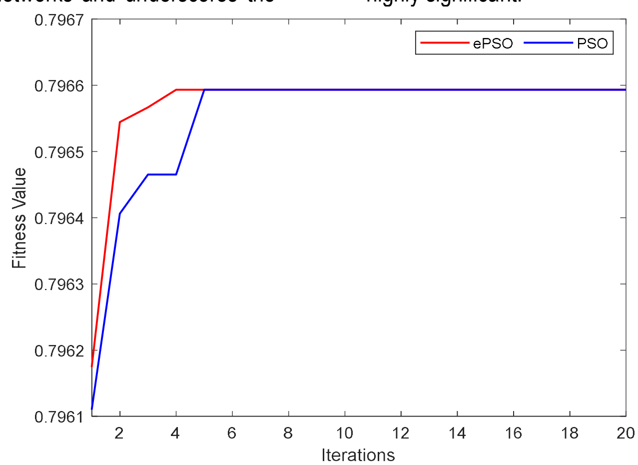

Figure 8: Fitness Value Evolution: ePSO vs. PSO Iterations in Cognitive Radio Optimization

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 12(4), DECEMBER, 2024
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com.ng

By enabling rapid and effective optimization across various parameters, such as spectral efficiency, energy consumption, and interference management, ePSO holds promise for advancing cognitive radio systems. These outcomes suggest a practical use of ePSO in creating adaptable and efficient cognitive radio networks, offering a potential solution to the challenges presented by dynamic and crowded spectrum environments.

CONCLUSION

In conclusion, the development of a multi-objective model for cognitive radio engine design optimization represents a significant step forward in the field of wireless communication and radio spectrum management. Throughout this dissertation, we have demonstrated the power of employing cutting-edge optimization techniques, such as Enhanced Particle Swarm Optimization (EPSO), to address the complex and conflicting objectives inherent in cognitive radio engine design.

By formulating the problem, specifying objectives, and introducing constraints, we have set the stage for achieving a delicate balance between spectrum efficiency, energy consumption, and interference mitigation. The multi-objective approach acknowledges that real-world design challenges involve trade-offs and that a one-size-fits-all solution may not be optimal.

Through the optimization process, we have uncovered Pareto-optimal solutions that represent the best compromises between these objectives. These solutions provide a valuable resource for designers and engineers to make informed decisions, selecting the most appropriate radio engine configurations that align with their specific requirements and operational environments.

The performance analysis of the enhanced Particle Swarm Optimization illuminates ePSO's potential to tackle the intricate optimization tasks associated with cognitive radio design, establishing a foundation for more dependable and versatile wireless communication systems.

This dissertation has demonstrated the importance of interdisciplinary collaboration, combining knowledge from telecommunications, optimization algorithms, and engineering principles. It underscores the need for adaptable and intelligent cognitive radio engines that can dynamically adjust to varying network conditions, ensuring efficient spectrum utilization and reliable communication services.

REFERENCES

[1] E. Biglieri, L. J. Goldsmith, L. J. Greenstein, N. B. Mandayam, H. Poor and H. V. Poor, Principles of cognitive radio, Cambridge: Cambridge University Press, 2012.

[2] M. B. Weiss, w. Lehr, M. Altamimi and L. Cui, "Enforcement in dynamic spectrum access systems," *Sensors,* vol. 4, no. 2, pp. 2-12, 2012.

[3] F. Javed and A. Mahmood, "The use of time frequency analysis for spectrum sensing in cognitive radios," in *2010 4th International Conference on Signal Processing and Communication Systems (ICSPCS)*, 2010.

[4] Y. Tawk, J. Costantine and C. G. Christodoulou, "Cognitive-radio and antenna functionalities: A tutorial," in *Wireless Corner*, Antennas and Propagation Magazine, IEEE, pp. 231-243, 2014.

[5] B. Mounika, K. R. Chandra and R. R. Kumar, "Spectrum sensing techniques and issues in cognitive radio," *International Journal of Engineering Trends and Technology (IJETT),* vol. 1, no. 4, pp. 2231-5381, 2013.

[6] S. Mansuri and P. Nagaich, "Cognitive Radio Engine Design usingAdaptive MultiObjective GA and PSO," *International Journal of Digital Application and Contemporary Research,* vol. 5, no. 11, pp. 1-6, 2017.

[7] P. Kolodzy, and I. Avoidance, “Spectrum policy task force,” Federal Commun. Comm., Washington, DC, Rep. ET Docket (02-135), 2002.

[8] AlQerm Ismail and ShihadaBasem, “Adaptive Multi-Objective Optimization Scheme for Cognitive Radio Resource Management,”*IEEE*

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 12(4), DECEMBER, 2024
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com.ng

Global Communications Conference, 2(1), pp. 1-7, 2014.

[9] S. BSeshadriBehera and D.D. Seth, "Resource Allocation for Cognitive Radio Network using Particle Swarm Optimization," *2nd international conference on electronics and communication system (ICECS),* 2(4),pp. 665-669, 2015.

[10] MeiqinTang and YalinXin, "Energy efficient power allocation in cognitive radio network Using coevolution chaotic particle swarm optimization,"*www.elsevier.com/locate/comnet*, 4(6), pp. 1-5, 2016.

Corresponding author: Josephine Unachuckwu
josephineukachukwu@gmail.com
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Abuja, Nigeria.