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PSO-Based Resource Allocation in Cognitive Radio Ad-Hoc Network

Manuvarthi Mounisha[$], V. Krishna Vamsi[$], Vivek Rajpoot[$,*], R. Anil Kumar[#] and Ramesh K. Verma[!]

[$]Department of Communication Engineering, Vellore Institute of Technology, Vellore – 632 014, India
[#]Department of Electronics and Communication Engineering, Aditya University, Kakinada – 533 437, India
[!]Department of Computer Science and Engineering, IMS Engineering College, Ghaziabad – 201 015, India
[*]E-mail: vivek.rajpoot@vit.ac.in

ABSTRACT

Increasing demand for spectrum causes the emergence of technologies like Cognitive Radio (CR). Resources like bandwidth and energy are primarily shared by the primary and secondary users in the CR network. Resource utilization depends on the number of nodes, topology dimension, packet generation rate, and time of channel utilization. Therefore, optimizing resources in CR is a need of the hour. In the presented paper, a PSO-based resource allocation scheme is implemented. The input parameters like the number of secondary user nodes, packet generation rate, dimension of the network, and simulation time are targeted to get optimum results of packet delivery ratio, average throughput, average delay, and energy consumption. To implement CR, NS-2 is used. The fitness equations are obtained by varying the input parameters in a given range. Curve-fitting software is used to get fitness equations. These fitness equations are then used in the PSO algorithm, which is implemented in MATLAB. With implementing a PSO-based resource allocation scheme, the performance of packet delivery ratio, throughput, delay, and energy consumption increased by 22.15 %, 22.15 %, 67.83 %, and 32.18 %, respectively.

Keywords: Cognitive radio; Communication networks; Particle swarm pptimization; Resource allocation; Primary user; Secondary user

NOMENCLATURE

CR	: Cognitive radio
DSA	: Dynamic spectrum allocation
PU	: Primary user
SU	: Secondary user
PSO	: Particle swarm optimization
Pbest	: Personal best
Gbest	: Global best
SNR	: Signal to noise ratio
QoS	: Quality of service
RMSE	: Root mean square error
NS-2	: Network simulator version 2
CRAHN	: Cognitive Radio Ad-hoc Network

1. INTRODUCTION

Cognitive radio (CR) networks are one of the most demanding and exciting fields of wireless communication networks in recent times[1]. The CR is a key technology of dynamic spectrum allocation (DSA). The DSA is required due to the limited spectrum availability for wireless technologies. In the CR network, there are two categories of users, one being that the primary user (PU) has the highest prioritization and is licensed to utilize a spectrum. The other one is the secondary user (SU), who is subjected to being ambitious users to access the spectrum opportunistically[2]. The secondary users contend for the spectrum if PU is inactive in the spectrum. This will cause interference in both primary and secondary users. Therefore, a proper implementation of the resource allocation is the need of the hour to avoid such situations [3].

In a dynamic scenario like CR, many factors affect the resource allocation efficiency, such as transmission power, throughput, delay, routing, signal-to-interference noise ratio, etc. Further, the network's performance is also subjected to variation if there is a change in the number of SU nodes, the channel's bandwidth, packet generation rate, and even the network dimensions [4].

Therefore, this paper is being produced to find an optimum allocation of radio resources in cognitive radio networks. The optimization of radio resources was done using the particle PSO algorithm.

The organization of the remaining paper is as follows. A brief state-of-the-art resource allocation and research methodology is presented in section II. In section III, the cognitive radio scenario is discussed. Section IV covers details of the PSO algorithm. The proposed scheme is discussed in section V. In section VI, details of the obtained simulation results are mentioned. At last, the conclusion is given in Section VII.

2. METHODOLOGY

To implement the proposed pso-based resource allocation scheme in crn, the research methodology is as follows:

- Creating a cr ad-hoc network scenario by taking fixed values of input parameters: No of nodes, network dimension, packet generation rate, and channel bandwidth.

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- Decide a range of variations for each input parameter (swarm space)
- Take one parameter at a time and vary it while keeping other parameters fixed to get the results regarding packet delivery ratio, average packet delay, average throughput, and total energy consumption.
- Repeat the same for all parameters and note down the results.
- Generate a fitness function that can relate the variation in input parameters and output results.
- Select swarm size, dimensions, and iteration of pso.
- Implement pso to get optimum values of input parameters (pbest and gbest) through fitness equations.
- Provide optimized input to the cr network and check the results.

2.1 A Brief State-of-the-Art Resource Allocation in CRN

The optimization algorithms can be implemented at multiple levels in the CR network. The swarm-based PSO is one of the popular algorithms for this purpose. There are few research papers available that have already implemented PSO-based resource allocation in CR networks. Table 1 provides some important papers that implement PSO in resource allocation in CR networks. In the available literature, throughput, delay, energy, and handoff are the main parameters optimized through PSO.

The novelty of the presented paper lies in the number of parameters as it optimizes four parameters: packet delivery ratio, throughput, delay, and energy consumption.

Table 1. State-of-the-art PSO-based optimization in CR Networks

Paper id	Type of n/w	Optimize parmeter	Comment
[6]	Hybrid	Throughput, channel allocation	Along with pso, genetic algorithm is also used
[7]	Hybrid	Throughput	Along with pso, the black widow algorithm is used
[8]	Distributed	QoS and transmit power	The energy consumption is reduced significantly
[9]	Hybrid	Optimal resource allocation and delay optimization	Snr weight algorithm psos and pso are compared.
[10]	Centralized	Throughput and energy	A modified pso is used for resource allocation and performance compared with the Pso.
[11]	Centralized	Handoff	Maximum improvement of 92 % at snr with pso.
[12]	Hybrid	Spectrum handoff	Total service time is shortened by 25 % compared to the random scheme.
[13]	Distributed	Throughput QoS	The qos is improved significantly
[14]	Cluster	Power throughput	Sensing duration, frame duration, detection threshold, and transmission power are Optimized
[15]	Hybrid	Power allocation	Total power is reduced to around 4–6 dbm compared to the sdma framework.

3. COGNITIVE RADIO NETWORK

In the proposed CR network, the ad-hoc scenario is considered. In an ad-hoc network, every node can autonomously communicate with other nodes. It is assumed that there are 10 SU nodes and 1 PU node available in the network. The PU remains active in the channel for a random duration of time. Further, all the nodes are randomly distributed in the dimensions 500*500 m^2 of the scenario. These SU nodes want to communicate with each other. The SU nodes will con- tend for the free channel when the PU node is inactive. The packet generation rate for SU nodes is also kept fixed at 50 packets/second. All the essential parameters to create the CR network are given in Table 2.

Table 2. Parameters for Proposed CRAHN

Parameters	Values
No. of SU nodes	10
No. of PU nodes per channel	1
No. of Channels	10
Bandwidth of each channel	10 MHz
Dimension of the network	500*500 m^2
Packet generation rate	50 packets/sec.
Simulation time	20 Sec.

4. PARTICLE SWARM OPTIMIZATION ALGORITHM

PSO is a nature-inspired optimization method that replicates the behavior of flocks of birds or schools of fish. In 1995, the algorithm was developed by J. Kennedy and R. Eberhart. The algorithm is very popular in problem-solving space due to its simplicity, efficiency, and effectiveness. PSO is based on the paradigm of swarm intelligence. In PSO, the particles try to search for an optimal solution by moving through a multidimensional search space. Each particle represents a possible solution, and their movements are impacted by their own experiences (personal best- Pbest) as well as the collective experiences of the swarm (global best- Gbest)[5].

The movement of the particles in the solution space is influenced by their current velocity, position, Pbest, and Gbest. Each particle updates its positions and velocity in the known solution space as given in equation (1) and (2). The process begins with randomly creating a particle population within the search space and assigning initial velocities. Velocities and positions are then adjusted based on these bests. This iterative process continues until a termination condition, such as a maximum number of iterations or a satisfactory solution, is met. The equation for updated velocity is given in Eqn (1).

$$v_i(t+1) = w * v_i(t) + c_1 * rand(P_{best}(t) - x_i(t)) + c_2 * rand(G_{best}(t) - x_i(t)) \quad (1)$$

Here, (t) and $x(t)$ represents the velocity and position of the particle in the solution space. Further, w represents weight function, c_1 and c_2 are the constants and $rand$ reprsents the random function. The position of the particles are updated by using Eqn. (2).

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (2)$$

The weight function is defined in equation (3). Here, w_f is the final weight, and w_{in} is the initial weight. The weight function also depends upon the number of iterations. The weight function's value is updated with every iteration. Therefore, $iter$ represents the current number of iterations, and max_{iter} represents the total number of iterations.

$$w = w_f - (w_f - w_{in}) * (iter/max_{iter}) \quad (3)$$

4.1 PSO Algorithm

The steps followed to implement the PSO algorithm are mentioned as follows.

Step 1: Initialization- Create a population of particles at random within the search space. Assign the particles beginning velocities.

Step 2: Evaluation- Based on the goal function, assess the fitness of each particle.

Step 3: Update Pbest and Gbest- Update each particle's personal best and global best

Step 4: Update Positions and Velocities- Based on Pbest and Gbest, update the velocities and locations of each particle.

Step 5: Criteria for Termination- Repeat steps 2 to 4 until a termination condition, either maximum iterations or satisfying solution, is achieved.

5. PROPOSE PSO-BASED RESOURCE ALLOCATION IN CRN

5.1 Range of Input Parameters

The input parameters of the network are varied to implement the proposed scheme of PSO-based resource allocation in CRN. The four input parameters are considered for optimization: number of nodes, network dimension, packet generation rate, and channel bandwidth. Only one parameter varies at any time, while other parameters are fixed to their reference values, as shown in Table 2. The details of the variation are given in Table 3. Suppose the number of SU nodes varies from 6 to 15 with a step size of 1. The network results are tested with 6 SU nodes while keeping other parameters fixed, as in Table 2. Then, the number of SU nodes is increased by 1 step size, and the network results are tested with 7 SU nodes. Therefore, ten different results are obtained by varying SU nodes from 6 to 15. The same process is repeated for other input parameters and the given range in Table 3.

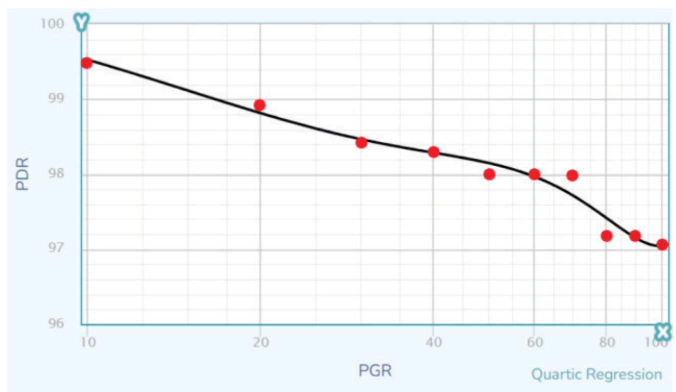
Table 3. Range of parameter variation

Parameter	Min. value	Max. value	Step size
No. of SU nodes (in numbers)	6	15	1
Dimension of the network (m^2)	100*100	1000*1000	100*100
Packet generation rate (pkt/sec)	10	100	10
Channel Bandwidth (MHz)	5	12	1

An example of the simulation result for the number of node variations is given in Table 4. Here, the number of nodes varied from 6 to 15, and the corresponding results for packet delivery ratio, average throughput, average delay, and energy consumption are shown.

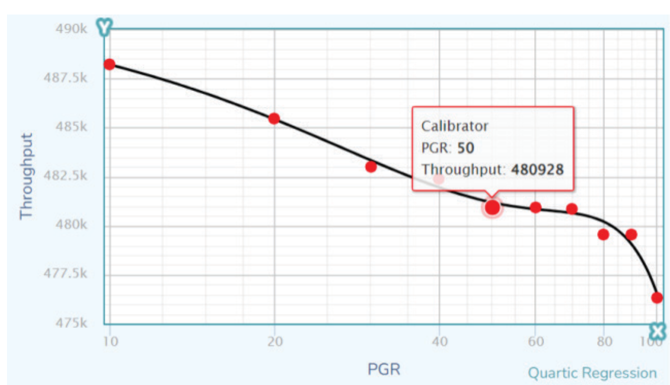
Table 4. Example of obtained results when SU nodes are varied

No. of SU nodes	Packet delivery ratio	Average throughput (bps)	Average delay (sec)	Energy Consumption (Jule)
6	98.1769	481784	0.1622	54.107
7	72.0197	353422	0.2073	80.2863
8	69.5759	341430	0.1677	82.2629
9	86.0357	422203	0.1794	78.9664
10	80.7732	396378	0.1607	80.1774
11	79.1958	388637	0.205	113.645
12	45.8624	225061	0.3914	45.8624
13	98.1381	481593	0.1501	67.2696
14	38.0657	186800	0.4495	136.146
15	44.3774	145737	0.3567	157.2033



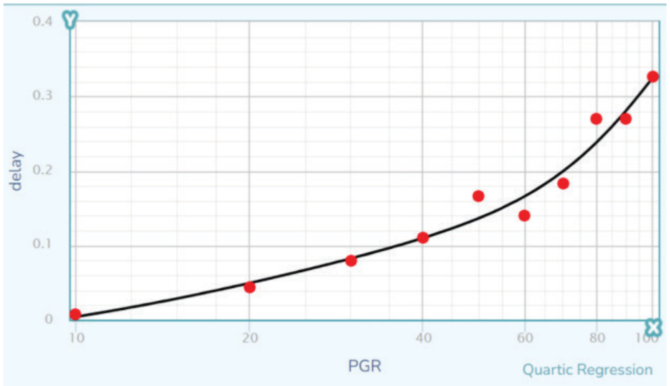
(a)

$$PDR = 100.84 - 0.171\,PGR + 4.465 * 10^{-4}\,PGR^2 - 5.353 * 10^{-5}\,PGR^3 + 2.22 * 10^{-7} PGR^4 \quad (4)$$



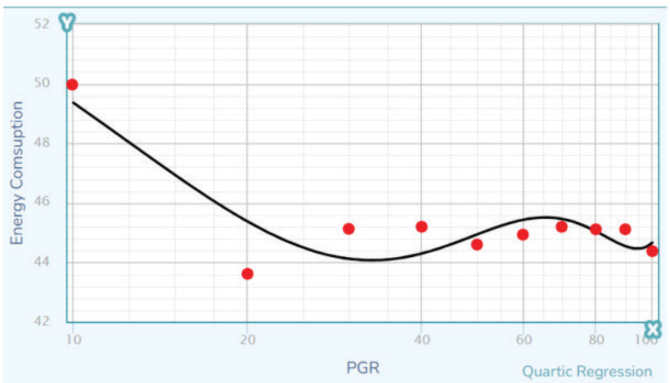
(b)

$$Throughput = 49.156 * 10^3 - 360.74\,PGR + 1.943\,PGR^2 + 4.302 * 10^{-2}\,PGR^3 - 4.147 * 10^{-4}\,PGR^4 \quad (5)$$



(c)

$$Delay = -6.094 * 10^{-2} + 7.849 * 10^{-3}\text{PGR} - 1.475 * 10^{-4}\,PGR^2 + 1.7121 * 10^{-6}\,PGR^3 - 6.3476 * 10^{-9}\,PGR^4 \quad (6)$$



(d)

$$Energy\ Consumption = 57.723 - 1.116\,\text{PGR} - 3.151 * 10^{-2}\,PGR^2 + 3.549 * 10^{-4}\,PGR^3 - 3.549 * 10^{-6}\,PGR^4 \quad (7)$$

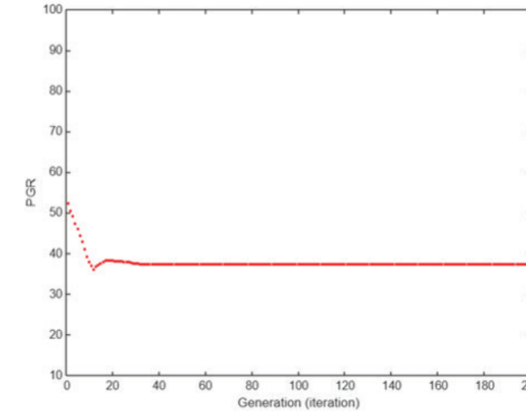
Figure 1. (a), (b), (c), and (d) shows graphs obtained on the curve- fitting tool w.r.t. packet generation rate.

5.2 Curve-Fitting and Fitness Equations

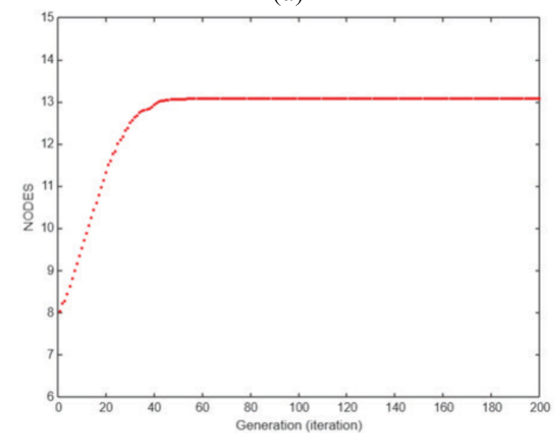
Once all the results are tabled, the fitness equations for every output are obtained for the input parameter. Curve-fitting tools are used to get the fitness equation that relates output to input. Fig.1 (a), (b), (c), and (d) shows graphs obtained on the curve-fitting tool and relate the output parameters such as packet delivery ratio, throughput, delay, and energy consumption to the input parameter packet generation rate. The corresponding fitness equations are given in Eqn. (4-7). This is one case; similarly, the relationship between each input and output parameter is obtained to get the fitness equation. Since

Table 5. Parameters to Implement PSO in MATLAB

Parameter*s*	Values
Particle population size	70
Dimensions	4
No. of iterations	200
Constant C1	2
Constant C2	2
(Initial weight) win	0.9
(Final weight) Wf	0.4



(a)



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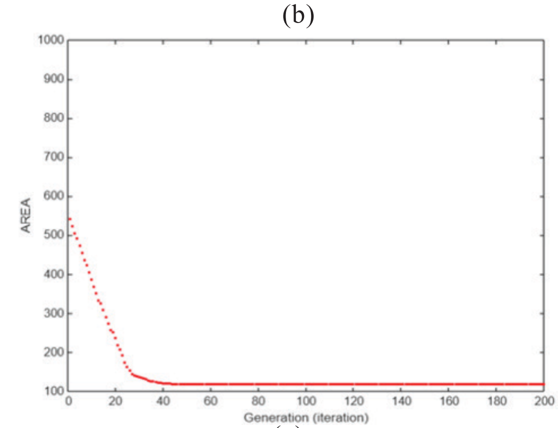

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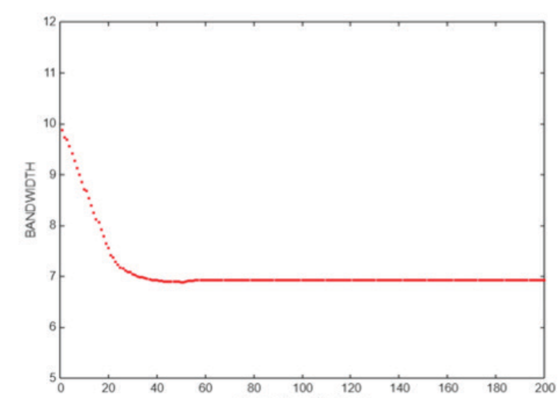

(d)

Figure 2. Gbest value obtained for the number of nodes, packet generation rate, dimension of the network, and bandwidth w.r.t. iterations.

four input and four output parameters are considered, 16 fitness Eqn. are formed[5].

5.3 Fitness Function

A root mean square error-based fitness function is created to implement the abovementioned equations in the PSO. If E_i is representing the root mean square error function for i^th^ program, then it can be given as mentioned in Eqn. (8).

$$E_i = \sqrt{\frac{1}{n}\sum_{j=1}^{n} P_{ij} - T_j} \tag{8}$$

In the above equation, the value P_{ij} is the predicted value for i^{th} program's j^{th} case in total n fitness cases. The value T_j is the target set by the user. The equation will perfectly fit if E_i=0. An RMSE-based fitness function is created for our PSO program using the above-generalized fitness function. The generalized fitness function is given by Eqn. (9).

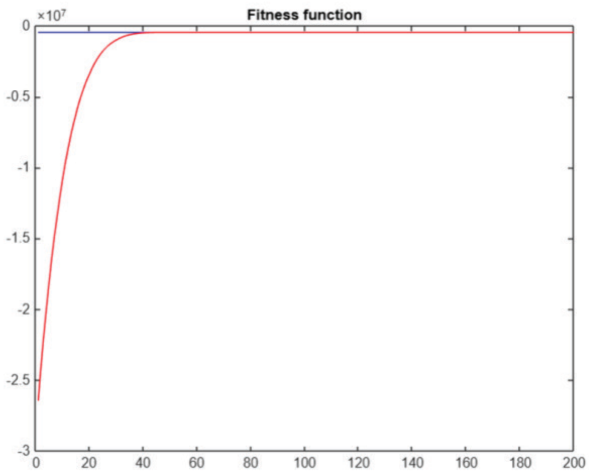

Figure 3. Minimized RMS curve for 'a', 'b,' 'c,' and 'd' each has equal values of 0.25.

Table 6. PSO-optimized CRN

Parameters	Values to design conventional CRN	PSO-optimized Gbest values
No. of SU nodes	10	13.26 ≈ 13
Dimension of the network	500*500 m^2	132.79*132.79 m^2
Packet generation rate	50 packets/sec.	37.84 packets/sec.
Channel bandwidth	10 MHz	6.92 MHz

Table 7. Comparison of result

Parameters	Conventional CRN	PSO-optimized CRN	Improvement in the result (%)
Packet delivery ratio	80.7732	98.6682	22.15
Average throughput	396378	484195	22.15
Average delay	0.1607	0.0517	67.83
Energy consumption	80.1774	54.3723	32.18

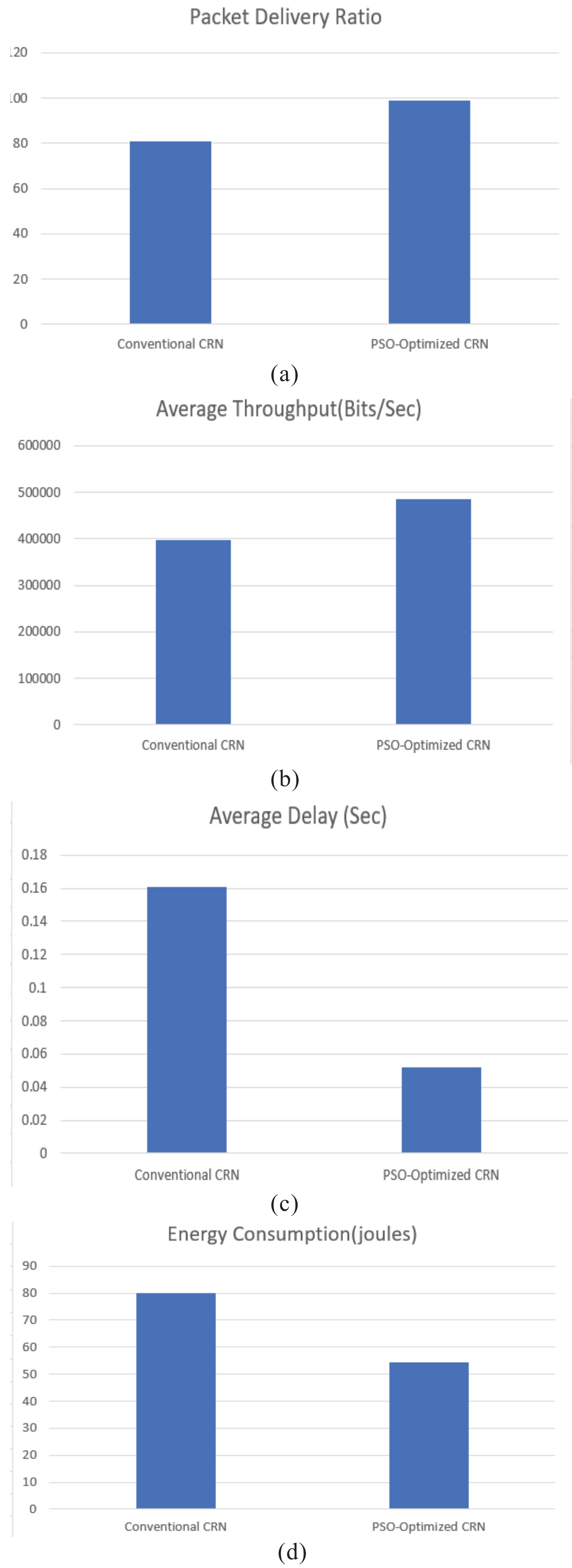

Figure 4. Comparison of output parameters packet delivery ratio, average throughput, average delay and energy consumption between conventional CRN and PSO-optimized CRN

$$F(x) = \sqrt{a(P-P_t)^2 + b(T-T_t)^2 + c(D-D_t)^2 + d(E-E_t)^2} \quad (9)$$

In the above equation, P_t, T_t, D_t and E_t are the target values for packet delivery ratio, average throughput, average delay, and energy consumption, respectively. We can set the targets at the desired values of the outputs. Further, 'a, 'b,' 'c,' and 'd' are biasing constants that provide the weight. Compared to the other constants, if a higher value is provided to one of these constants, then this will bias the fitness function toward that parameter. It means that if the parameter 'a' is kept high compared to 'b,' 'c,' and 'd', the fitness function will try to give more emphasis on minimizing the error between P and P_t and to get a better Gbest value for the packet delivery ratio.

6. SIMULATION RESULTS

To implement the proposed scheme, the simulation has been done through Network Simulator version 2 (NS-2)[16]. The NS-2.31 version is specifically used with the Cognitive Radio Ad-hoc Network (CRAHN) patch. The conventional network is created using the parameters in Table 2 in NS-2.31. Then, the input parameters are varied in the range specified in Table 3, and the results are obtained in NS-2.31. The fitness equations are developed with the results obtained after implementing input parameter variations. The curve-fitting tool is used to get fitness equations. The PSO algorithm is implemented in MATLAB-R2023a[17].

6.1 MATLAB Results

Some important simulation parameters, such as particle population size, dimension of each particle, number of iterations, constants, and weights for implementing the PSO algorithm in MATLAB, are given in Table 5. The optimum result or global best (Gbest) values are obtained for every input parameter after the simulation in MATLAB. Fig 2 shows the Gbest value obtained for the number of nodes, packet generation rate, dimension of the network, and bandwidth w.r.t. the number of iterations.

The curves are plotted w.r.t. the number of iterations. It is also observed that the curves are not stable in the initial phase. Therefore, it is essential to use sufficient iteration to obtain values. The notable point in Fig 2(c) is that if the 'y' axis represents 100, it means area 100*100 m^2 and 200, which means area 200*200 m^2 likewise.

The graph shown in Fig. 4 represents the minimization of the root mean square error curve for parameters 'a', 'b,' 'c,' and 'd', each having equal values of 0.25.

Table 6 shows a comparison of parameters that were initially taken to design the conventional network and the Gbest values obtained from PSO. We can observe that all the input parameter values have been changed significantly.

Finally, a new CR network is designed with the Gbest values obtained. The results for packet delivery ratio, average throughput, average delay, and energy consumption are obtained. Table 7 compares the results obtained with those of a conventional CR network and the proposed PSO-optimised CR network. The same results are plotted as bar graphs and shown in Fig. 4(a), Fig. 4(b), Fig. 4(c), and Fig. 4(d).

The result mentioned in Table 7, 'PSO-optimized CRN,' is obtained by taking the weight parameters 'a' 'b,' 'c,' and 'd' fixed at 0.25 each. These weight parameters can also change to give more emphasis on any one of the output parameters. Therefore, Table 8 mentions the obtained Gbest values for the input parameters by varying the weights 'a', 'b,' 'c,' and 'd'. The Gbest values for the no. of nodes are rounded off in the table to calculate the optimized output parameters, as mentioned in Table 9.

7. CONCLUSIONS

The paper proposed a scheme of PSO-based resource allocation in the CR network. The input parameters like no. of secondary user nodes, packet generation rate, dimension of

Table 8. Comparison of result (Gbest) values of I/P parameters in MATLAB

Parameters	**Conventional CRAHN**	**PSO-optimized Gbest values (a=b=c=d=0.25)**	**PSO-optimized Gbest values (a = 0.6 & b=c=d=0.2)**	**PSO-optimized Gbest values (b= 0.6 & a=c=d=0.2)**	**PSO-optimized Gbest values (c=0.6 & a=b=d=0.2)**	**PSO-optimized Gbest values (d=0.6 & a=b=c=0.2)**
No. of SU nodes	10	13.26 ≈ 13	14.13 ≈ 14	13.01 ≈ 13	12.98 ≈ 13	8.5 ≈ 9
Dimension of the network (m^2)	500*500	132.79*132.79	154.64*154.64	142.64*142.64	187.11*187.11	149.50*149.50
Packet generation rate (Pkt/sec.)	50	37.84	17.41	35.20	32.62	32.29
Channel bandwidth (MHz)	10	6.92	6.87	9.87	10.50	7.71

Table 9. Comparison of result (O/P parameters in NS2)

Parameters	**Conventional CRAHN**	**PSO-optimized (a=b=c=d=0.25)**	**PSO-optimized (a = 0.6 & b=c=d=0.2)**	**PSO-optimized (b= 0.6 & a=c=d=0.2)**	**PSO-optimized (c=0.6 & a=b=d=0.2)**	**PSO-optimized (d=0.6 & a=b=c=0.2)**
Packet delivery ratio	80.7732	98.6682	99.4311	98.5518	98.6553	98.6553
Average throughput	396378	484195	487938	483624	484131	484131
Average delay	0.1607	0.0517	0.0198	0.0985	0.0871	0.0871
Energy consumption	80.1774	54.3723	81.9361	54.0397	54.36	54.36

the network, and simulation time are optimized to get the best results in terms of packet delivery ratio, average throughput, average delay, and energy consumption of the network. First, a conventional CR network is implemented, and its input parameters vary in a specified range. For each variation, the simulation results are obtained. These results are then used to create a fitness equation. The fitness equations are used in the PSO algorithm to get the optimum values of input parameters. With the obtained Gbest values of the input parameter, the performance is improved by 22.15 % for packet delivery ratio, 22.15 % for average throughput, 67.83 % for average delay, and 32.18 % for energy consumption.

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CONTRIBUTORS

Mrs Manuvarthi Mounisha is a BTech student in the Department of Communication Engineering, School of Electronics Engineering, at VIT University, Vellore, India. Her research interests include: Optimization algorithms and wireless networks.
Contirbution in the current study is developing the Particle Swarm Optimization (PSO) algorithm in MATLAB. Further, she has developed the fitness equations.

Mr Veluvali Krishna Vamsi is a BTech student in the Department of Communication Engineering, School of Electronics Engineering, at VIT University, Vellore, India. His research interests include: PSO algorithms and cognitive radio networks.
Contirbution in the current study: He contributed by creating a cognitive radio network in NS2. He carefully configured the network scenario, defined key input parameters, and collected performance data, which led to the overall conceptualization of the research,

Dr Vivek Rajpoot obtained PhD from Motilal Nehru National Institute of Technology Allahabad, Prayagraj and working as an Assistant Professor in the Department of Communications Engineering, SENSE, VIT, Vellore, Tamil Nadu, India. His research interests include: Cognitive radio networks, WSN, 5G and 6G communication, optimization algorithms, and microstrip antenna design.
In this paper, he played a critical role in refining the manuscript, improving the discussion, and validating the results.

Dr R. Anil Kumar obtained his PhD from JNTUK University, Kakinada and working as an Associate Professor in the Electronics and Communication Engineering department at Aditya College of Engineering Technology, Surampalem. His areas of interest include: Wireless communications, signal processing, and ML and DS.
In the presented paper, he contributed by developing the Adhoc network setup for cognitive radio and its input parameter selection.

Dr Ramesh Kumar Verma obtained his PhD from AKTU Lucknow, Uttar Pradesh, India and working as an Assistant Professor in the Department of Computer Science and Engineering at IMS Engineering College Ghaziabad. His areas of interest include: Antenna design and particle swarm optimization (PSO) Algorithms also optimizing the microstrip patch antenna with PSO and curve fitting.
In the presented paper, he contributed to getting the fitness equation through the curve fitting method. He also analyzed the PSO’s global best (Gbest) solutions, comparing them to conventional CRN setups to demonstrate the effectiveness of the proposed approach.