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Develop of A Particle Swarm Optimization Based Routing Algorithm for Cognitive Radio Network

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Abstract

A Cognitive Radio is a radio that can change its transmitter parameter based on interaction with its environment in which it operates. It has the potential to effectively address the problem of spectrum scarcity in the telecommunication industry. Ineffective routing solution in cognitive radio networks result in a number of problems such as congestion problems at the radio access layer and then at the service layer of the wireless system. For optimal benefits, routing problem in cognitive radio has to be optimally addressed. In this thesis particle swarm optimization (PSO) was used to tackle the cognitive radio routing problem. The cognitive radio routing problem was formulated as an optimization problem in which the objective function was path cost minimization. The case study network was modeled using the Cisco networks packets tracer software, using data obtained from MTN Nigeria network service provider. For the simulation carried out, the performance of the proposed PSO algorithm was compared with that of the existing dynamic source routing (DSR) algorithm. Results from simulation carried showed that the PSO method outperformed the DSR method by 33.15% in average network throughput. Evaluation showed that more delay was encountered with the DSR algorithm than with the PSO method. The proposed PSO achieved an average reduction in delay of 52.91% from that of the DSR method. A spectrum utilization improvement of 11.52% was achieved by the PSO technique over the DSR technique. With the PSO technique secondary users require an average sensing power of 25.13 watts whereas with the DSR secondary users require an average sensing power of 33.50 watt

Keywords: cognitive radio, particle swarm optimization (PSO), dynamic source routing.

I Introduction

Cognitive Radio Networks (CRNs) can operate in the licensed frequency band to improve its utilization with the coexistence of the Primary Users (PRs) or licensed users. PRs have the main rights over the licensed band in which they are operating.

Radio frequency (RF) is an important resource that people use all around the world for many services i.e. safety, communication, employment, and entertainment [1].The dedicated frequency band is allocated to the paid user that uses this frequency for specific service. Thus the RF band allocated can be vastly underutilized. Recent studies show that only 5% of the spectrum from 30 MHz to 30 GHz is used in the US [2] . The Federal Communications Commission (FCC) of United States of America found that spectrum usage is a more significant problem than the actual physical availability of RF spectrum[3]. The spectrum availability problem arises due to the currently deployed static spectrum allocation policy that limits the usage of the licensed RF band only to the licensed user or primary user. These findings need more efficient methods for utilization of the RF resources and the Cognitive Radio (CR) technology is envisioned as new mechanism for flexible usage of the RF spectrum. This technology enables the secondary users or unlicensed users to operate in the licensed band with the coexistence of the licensed users or primary users. Secondary users have the ability to identify and utilize the available channels in the RF spectrum. The ability of a secondary user to change its frequency of operation is commonly referred as dynamic spectrum access (DSA). Dynamic Spectrum Access (DSA) is introduced to solve spectrum usage inefficiency problem. DSA introduced policy based intelligent radios known as Cognitive Radios.

Cognitive radio is an emerging technology, which is used to solve the problem of scarce spectrum resource utilization. Ad hoc networks are self – organizing and adaptive, i.e. it can take different forms [4], whereas the cognitive radio networks can change its transmitter parameters according to the interactions with the environment in which it operates[5][6]. Cognitive network can be defined as an intelligent network since it automatically senses the environment and current network conditions, and adapts the necessary communication parameters accordingly.

In Cognitive radio network, two forms of users exist. They are the primary user and the secondary user. Primary users (PUs) have high priority than the Secondary Users (SUs) in the utilization of the spectrum [7]. The Cognitive radio [5] enables the unlicensed (secondary) users to sense the unoccupied spectrum portions which are not used by the licensed (primary) users for a specific amount of time.

Routing is the process of selecting paths in a network along which to send network traffic. It is the process of moving a packet of data from source to destination. The routing process usually directs forwarding on the basis of routing table which maintains a record of the routes to various network destinations. Thus, constructing routing tables, which are held in the router's memory, is very important for efficient routing. Most routing algorithms use only one network path at a time. Multipath routing techniques enable the use of multiple alternative paths. In CRN routing the spectrum (channel) as well as node will change in the routing process, channel mobility and the nodes will change here. The process of moving packets across a network from one host to another host is called as routing. Cognitive network routing is different from wireless network routing. In cognitive radio network, routing is combination of traditional routing and spectrum management since spectrum availability varies from node to node with respect to time and location. Spectrum availability is also affected by the primary user activities. The following are major challenges of routing in cognitive radio network (CRN):

- Spectrum availability: Routing module must be aware of spectrum availability which is achieved by monitoring spectral environment.
- Primary User Activity Awareness: Cognitive radio network topology is affected by primary user activities as well as by route quality measurements such as delay, bandwidth, throughput, energy efficiency which should be considered with spectrum availability.
- Route Maintenance: Primary user activities may results in frequent route rerouting which in turn will degrade the network performance. Thus effective signaling procedures are required for convenient routing in cognitive radio network.

- Lack of Common Control Channel (CCC): In traditional routing protocols, specific functionalities such as neighbour discovery, route discovery and route establishment are done through local or global broadcast messages. In cognitive radio network, due to lack of CCC broadcasting becomes a major problem.

Intermittent Connectivity: In cognitive radio network, due to spectrum availability and primary user activities reachable nodes may change frequently. Thus, network connectivity in cognitive radio network depends on spectrum availability. This challenge can be solved by using time and space based solutions with respect to channels

A wireless mesh network is a communication network that consists of a number wireless nodes organize in mesh topology. This work addresses the problem of routing in cognitive radio mesh network based on spectrum aware routing optimization using particle swarm optimization.

II **Literature review**

Author [8] proposed on demand routing and spectrum assignment in cognitive radio networks. Their work used metric Delay for evaluating the effectiveness of routes. The work is based on obtaining cost effective path based on spectrum demand. The evaluation carried used the technique achieved some marginal reduction in end-to-end delay. However, when the network is subjected to frequent spectrum re-assignment to primary users, the network throughput seriously degrades.[9] proposed an integer linear programming (ILP) technique for traffic routing in cognitive radio networks. In the work the cognitive radio routing problem is formulated as linear integer programming problem by defining a binary variable which is equal to 1 if the number of secondary users returning spectrums to primary users is below a threshold value. The impact of the proposed technique is increase in delay rate provided inter-symbol interference can be avoided; the ratio of secondary users to primary users is stable and the need for frequent traffic re-routing is below a threshold. Limitation of this approach is that the technique computes less effective routes which lead to poor spectrum utilization, dropped packets and excessive sensing energy usage in the event of channel variation secondary/primary users variation and reduced signal to noise ratio (SNR). It was reported that this limitation is because the technique used linear objective functions in its formula.[10] proposed a distributed joint channel-assignment routing technique for cognitive radio network in this approach the route cost is determined based in its average channel assignments as determined by all mesh routers in the network. The result from the work shows that cost effective traffic route is obtained in fairly stable network environment where there are less change in the availability of the number of mesh routers. However in situation where the rate at which mesh routers go offline is burst, the computed routes become more costly and routing delays increase. The shortcomings of these techniques mainly stem from poor adaptabilities of the routing algorithms to the changing network environment in terms of variation of secondary and/or primary users mesh router variation spectrum availability.

To mitigate the weakness of these approaches to routing in cognitive radio networks, this work proposed particle swarm optimization approach. The PSO is an optimization technique that is based on swarm intelligence. This is able to adapt to variation in the network environment (as swarms of insects adapt to changes in the physical environment in order to adapt naturally) in order to always determine the optimal path to route traffic through the network in order to maintain the quality of service even in the event of disruption in the spectrum environment.

III Methodology

For the design carried out in this work, routing in cognitive radio network will be modeled as an optimization problem solved using particle swarm optimization (PSO) technique. Simulation will be used to evaluate the performance of the proposed routing algorithm. The case study network used for this work is the MTN Nigeria high-end dynamic radio access network (i.e. a cognitive radio network infrastructure). This case study network is a mesh network having 5 mesh routers and 20 mesh clients. Out of which 10 are primary users (PUs) and 10 are secondary users SUs. The case study cognitive radio network data used is obtained from the network service provider MTN Nigeria as a snapshot of the network traffic structure extracted from one of the mesh routers(each mesh router has a copy of the traffic statistics and log of the network). To carry out performance evaluation of the proposed cognitive radio routing algorithm, the digital model of the case study network is created using CISCO packet Tracer 7.0 software. The CISCO packet Tracer is a network modeling and simulation program for the design and simulation of network infrastructure. The Dynamic Source Routing (DSR) algorithm will be used to benchmark the performance of the proposed PSO routing scheme. Key performance metrics to be used to evaluate the performance of the proposed routing scheme are network throughput, end-to-end delay, spectrum utilization and spectrum sensing power requirements.

The most challenging issue for a routing protocol in cognitive radio network (CRN) is the effective utilization of the available spectrum. The PSO routing strategy developed in this work is to opportunistically route data packets, across paths with under-utilized spectrum, avoiding congested (in terms of spectrum availability) areas. To achieve this goal, the proposed spectrum aware routing technique must be optimal in distributing traffic according to the available spectrum resources. The proposed PSO routing problem is formulated as a minimization of the spectrum utilization between every pair of nodes (i, j). The optimal route design concept adopted is established on the basis that the routes which minimize spectrum utilization (optimal routes), can be reproduced as minimum cost (shortest) paths.

The design considers an underlying distributed cognitive radio architecture where physical layer(PHY) and media access control(MAC) layer platforms work in concert to provide collaborative spectrum sensing and adaptive management and sharing mechanisms. Using collaborative sensing mechanisms cognitive radio users exchange messages about their local view of the spectrum, and they can more effectively detect the primary users. Adaptive spectrum management and sharing mechanisms dynamically adjust the available spectrum blocks to the unlicensed users.

IV Characterization of the routing operation of this case study mesh network in MTN dynamic access metropolitan area.

The digital model of the case study computer radio network was created using the Cisco packet tracer 7.0. The Cisco packet tracer is a network modeling and simulator program for the design and simulation of network infrastructure (wired or wireless) it has the facilities to emulate enterprise network devices, protocols and algorithms.

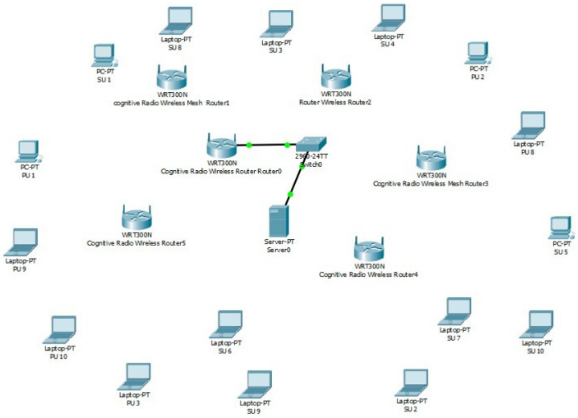


Fig 1: Digital model of the case study computer radio network

Figure 1 shows the case study cognitive radio mesh network created using the Cisco packet tracer software. The model consists of 5 mesh routers and 20 mesh clients (PUs and SUs). Of the 20 mesh clients 10 are PUs and the other 10 are SUs. The program allows configuration of the routers radio characteristics, the parameters of the layer 2 switches and the mesh clients. In the packet tracer environment the radio network parameters such as number of channels, transmit power, burst (slot) duration are configurable in order to properly setup the simulation. Data used for the setup and configuration of the simulation environment is shown on table 3. In the packet tracer network model of figure 1, cognitive radio wireless router 0 is setup as the mesh controller.

V. To develop a particle swarm optimization based routing algorithm for optimal traffic routing in a cognitive radio mesh network.

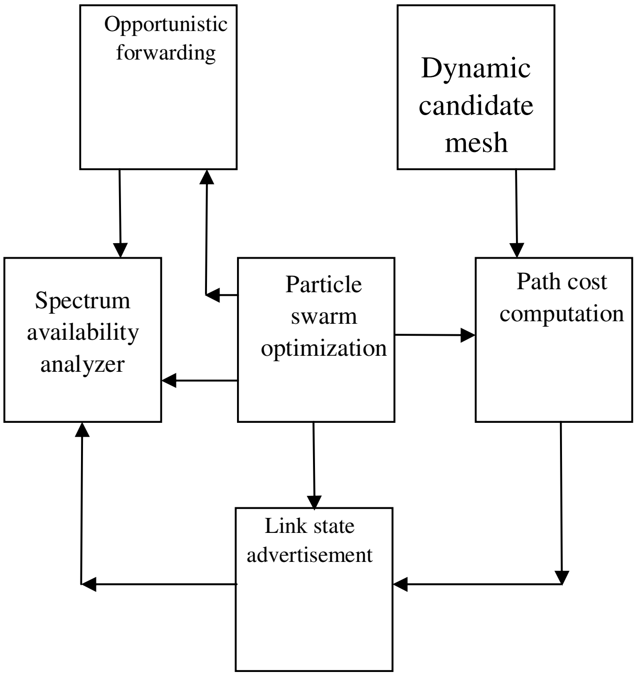


Fig 2: Block diagram of the proposed system

The block diagram of the proposed system shows the modules of the algorithm. The spectrum analyzer checks for the availability of free spectrum for opportunistic access based on the link state advertisement from the link state advertiser module. The path cost computation module invokes particle swarm optimization to find the minimum path from source to destination based on the link state advertisement from the link state advertiser. The opportunistic forwarder computes the parameter that allows the opportunistic forwarding of traffic across the links with the highest spectrum availability (spectrum availability as computed by the spectrum availability analyzer).

(PSO Algorithm for the solution of the cognitive radio routing problem)

```
for each $k \epsilon \{1,2,\ldots..\eta\}$ do
    if $t > 0$ then
        $X^t{}_k \leftarrow X^{t-1}{}_k$ , and calculate its fitness $f(X^t{}_k)$
        $V^t{}_k \leftarrow V^{t-1}{}_k$
    else
        initialize particle $k$'s position $X^t{}_k = (x^t{}_{k1}, x^t{}_{k2}, \ldots\ldots\ldots, x^t{}_{k(2n)})$ randomly where $x^t{}_{k(2i-1)} \sim U(0,W)$ and $x^t{}_{k(2i)} \sim U(0,H)$ for each $i \in \{1,2,\ldots\ldots.,n\}$, and calculate its fitness $f(X^t{}_k)$
        initialize particle $k$'s velocity $V^t{}_k = (v^t{}_{k1}, v^t{}_{k2}, \ldots\ldots\ldots, v^t{}_{k(2n)})$ randomly where $v^t{}_{k(2i-1)} \sim U(0,W)$ and $x^t{}_{k(2i)} \sim U(0,H)$ for each $i \in \{1,2,\ldots,n\}$.
    end if
    $P^t{}_k \leftarrow X^t{}_k$ and $f(P^t{}_k) \leftarrow f(X^t{}_k)$
    if $f(P^t{}_k) > f(P^*)$ then
        $P^* \leftarrow P^t{}_k$ and $f(P^*) \leftarrow f(P^t{}_k)$
    end if
end for
repeat
    for each $k \in \{1,2,\ldots,\eta\}$ do
        update particle $k$'s velocity $V^t{}_k$ by equation (3.14).
        $\forall i \in \{1,2,\ldots,2n\}, v^t{}_i$ is truncated if violating Constraint(3.10)
        update particle $k$'s position $X^t{}_k$ by equation (3.15)
        $\forall i \in \{1,2,\ldots,2n\}$, $x^t{}_i$ is truncated if violating Constraint(3.10)
        calculate $f(X^t{}_k)$.
        if $f(X^t{}_k) > f(P^t{}_k)$ then
            $P^t{}_k \leftarrow X^t{}_k$ and $f(P^t{}_k) \leftarrow f(X^t{}_k)$
            if $f(P^t{}_k) > f(P^*)$ then
                $P^* \leftarrow P^t{}_k$ and $f(P^*) \leftarrow f(P^t{}_k)$
```

```
25:            end if
26:         end if
27:       end for
28:   until{the maximum iteration $\tau$ is reached or $f(P^*)$ exceeds a threshold}
29:   output $f(P^*)$ as the solution at the $t-th$ key time point.
```

Lines 14 - 28 are the main loop of the PSO algorithm. For each iteration, Lines 15 – 27 are repeated until the total number of iterations is greater than the maximum iteration number or the best fitness value $f({P^t}_k)$ found so far exceeds a threshold value. Each iteration of the main loop considers each particle k. The velocity ${V^t}_k$ and the position ${X^t}_k$are updated respectively, in Lines 16 and 18. Since ${V^t}_k$ and ${X^t}_k$Need to satisfy Constraints (3.10), they are truncated if the constraint is violated. Once the position ${X^t}_k$ is updated, its fitness $f({X^t}_k)$ is calculated in Line 20. In Lines 21- 26, the local best position ${P^t}_k$ and the global best position P^* are updated if a better position is found; their fitness values are updated at the same time.

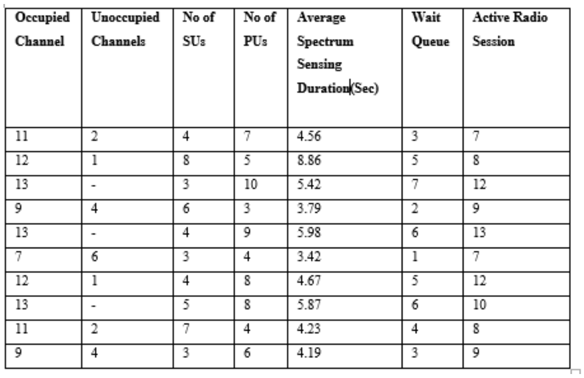
Since $f(P^*)$ stores the global best solution of each iteration, Line 29 outputs the final best solution at the end of the PSO algorithm.

VIRESULTS

In the simulation, 60 iterations were done. Each iteration lasts 60 seconds. During each iteration, its network traffic statistics is queried programmatically from the simulation trace file in intervals of 3 seconds (i.e. the network performance data sampling window is 3 seconds). From the simulation trace file the network performance statistics are extracted and plotted to evaluate the performance of the proposed network routing algorithm. From the simulation trace file performance for throughput, spectrum utility, SU sessions counts, PU session counts, End-to-End Delay, bytes transferred, spectrum sensing duration, energy usage for sensing, processor time, are extracted, tabulated and plotted.

The Java source code for the Dynamic Source Routing (DSR) algorithm for cognitive radio network is given on appendix B. The working of the DSR routing algorithm is evaluated using the same set of data to compare its performance with that of the proposed algorithm.

Table 1: Data for the case study cognitive radio mesh network used to set up the simulation



Occupied Channel	Unoccupied Channels	No of SUs	No of PUs	Average Spectrum Sensing Duration(Sec)	Wait Queue	Active Radio Session
11	2	4	7	4.56	3	7
12	1	8	5	8.86	5	8
13	-	3	10	5.42	7	12
9	4	6	3	3.79	2	9
13	-	4	9	5.98	6	13
7	6	3	4	3.42	1	7
12	1	4	8	4.67	5	12
13	-	5	8	5.87	6	10
11	2	7	4	4.23	4	8
9	4	3	6	4.19	3	9

Number of channels: 13
Channel Bandwidth: 22mHz
Transmission Power: 20W
Burst (slot) duration: 625μs

a. Throughput evaluation

For the DSR routing algorithm the variation of throughput is shown in figure 4.2 (the values are in table 4.2). Unlike in the case of the proposed PSO algorithm, the throughput rose gradually. It got to its peak value of 112.5 kilobytes/sec at about 39.4657 Kbytes/sec then it falls to 105.147 Kbytes in about 46.663 seconds and then it raised a bit to 108.3824 Kbytes/seconds in 108.3824 Kbytes/sec at about 49.3246 seconds, then it gradually tappers to 102.7941 Kbytes at about 60 seconds. This indicates that the variation in throughput with the DSR as the routing protocol is not as stable as with the proposed PSO routing algorithm.

Table 2: Throughput realized using the DSR routing algorithm

Time interval(sec)	Throughput
3	2.7941
6	14.5588
9	25.7353
12	35.4412
15	45.7353
18	50.4412
21	62.7941
24	65.7353
27	84.8529
30	92.7941
33	98.9706
36	105.1471
39	107.5000
42	110.7353
45	111.9118
48	112.5000
51	106.9118
54	105.4412
57	108.3824
60	103.6765
Average	**77.60295**

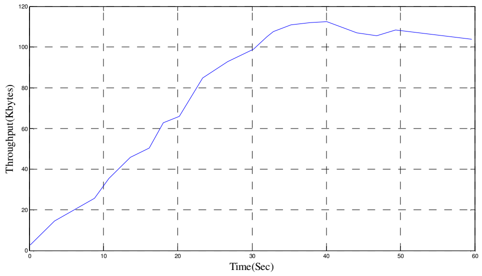


Fig 3: Variation of network throughput using the PSO routing algorithm

The variation of throughput with time using the proposed routing algorithm in the simulation is shown in figure 4.3 (the related values are given in table 4.3).

From the figure it can be seen that the throughput rises (varies) with time then almost became stabilized to 153.6765 kybes/sec at about 28.5 seconds. The increased and steady throughput indicates effectiveness in the algorithm. This also indicates increase in the ability of the SU and PU to transmit more data. Effective routing enabled, for instance, the SUs to quickly and efficiently detect available spectrums and opportunistically use them for data transfer. However, spectrum availability detection (detection of holes) does vary with traffic conditions. But in this case the throughput rose and was kept it at a fairly stable level thereafter.

Table 3: Throughput realized using the proposed PSO routing algorithm

Time interval(sec)	Throughput
3	2.6786
6	20.1786
9	41.9643
12	64.1071
15	74.4643
18	86.6071
21	102.3214
24	121.2500
27	128.3929
30	145.8929
33	153.3929
36	152.6786
39	153.3929
42	153.3929
45	153.0357
48	153.0357
51	153.0357
54	153.3929
57	153.3929
60	155.1786
Average	**116.0893**

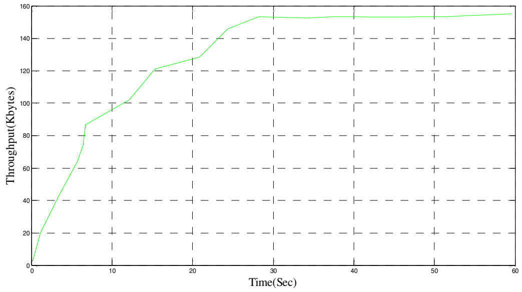


Fig 5: variation of network throughput using the proposed PSO routing algorithm for cognitive radio network.

From table 3 the average throughput with the proposed algorithm is 116.0893kbytes/sec. from table 3 the average throughput with the DSR algorithm is 77.60295kbytes/sec. This shows that the proposed PSO outperforms the DSR algorithm by 33.15%. It is clear from the combined plot given in figure 5 that PSO routing algorithm outperforms the DSR routing algorithm.

This variation is as a result of the algorithm not adapting properly to the increase to the increase in network traffic as a result of increasing opportunistic allocation and de-allocation of spectrums to secondary users. Hence its inability to adapt and compute more optimal paths to effectively transmit data results in less stable network throughput than with the case of the proposed PSO algorithm

b. System utility evaluation.

The variation of system utility (efficiency of system usage with increase in SU i.e. ratio of spectrum usage to SU) using the DSR routing algorithm is shown in figure 6 (the associated values are given in table 4). It can be seen that utility reduces with increase in the number of SUs that come online. This presents routing demands. For the DSR algorithm, the utility falls steadily from about 100% (the default) to about 25% in about 20seconds.

Table 4.: System utility with respect to SUs using the DSR routing algorithm

SU	**Utility(%)**
1	99.1964
2	94.375
3	91.1607
4	84.9107
5	79.7321
6	72.7679
7	72.0536
8	66.3393
9	63.125
10	55.0893
11	50.8036
12	49.1964
13	46.875
14	45.9821
15	44.5536
16	42.0536
17	39.9107
18	35.9821
19	30.4464
20	25.4464
Average	**59.5**

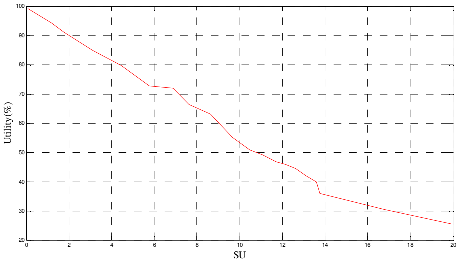


Fig 6: Variation of system utility using the DSR routing algorithm.

For the proposed PSO algorithm, the variation of utility with SUs is not as steep as that of the DSR algorithm. Figure 6 (the values are given on table 4.) gives the variation of utility with SU using the PSO routing algorithm.

From figure 6, the system utility falls from about 100% (the default value) to about 55% in 14 seconds. From then the algorithm seemed to maintain the utility at this value (it actually kept the utility slightly varying around this value). This indicates stability in usage of radio spectrum.

Table 6: System utility with respect to SUs using the proposed PSO algorithm

SU	Utility(%)
1	99.1912
2	95.9559
3	94.7794
4	91.2500
5	88.4559
6	84.0441
7	80.3676
8	77.7206
9	74.6324
10	69.0441
11	65.0735
12	59.9265
13	56.6912
14	55.6618
15	55.0735
16	54.6324
17	54.7794
18	54.0441
19	54.9265
20	54.1912
Average	**71.022065**

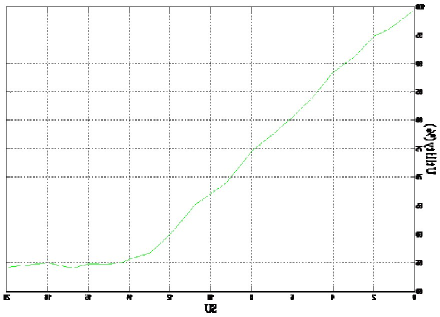


Fig 7: Variation of system utility using the proposed PSO routing algorithm.

The combined plot of the utility variations for the two algorithms is shown in figure 8 From figure 8, it can be seen that the impact on utility resulting from the pressure of SUs have greater impact for the DSR algorithm than it does for the PSO algorithm. The reduction in utility is at a greater rate for the DSR algorithm than for the proposed PSO algorithm. From table 6, the average utility of the network using the proposed PSO routing algorithm achieved a better spectrum utility (usage) than the DSR algorithm. This represents 11.52% improvement over the DSR algorithm.

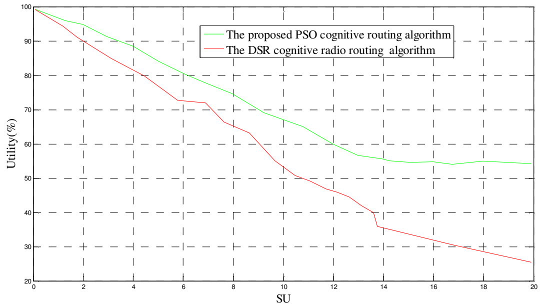


Fig 8: Comparison of the utility of the proposed PSO algorithm with the DSR algorithm.

Conclusion

This work focused on optimal routing technique for cognitive radio networks utilization. A “Cognitive Radio” is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. Cognitive radio networks provide high bandwidth to mobile users through heterogeneous wireless architectures and dynamic spectrum access techniques. Cognitive radio techniques allows users to use or share spectrum opportunistically. Cognitive Radio technology allows users to detect available portion of spectrum as well as primary user’s presence, to select best channel, to share the channel with other users and to free the channel whenever primary user is detected. Cognitive radio is an emerging technology, which has the capacity to solve the problem of scarce spectrum resource. However to fully harness the power of cognitive radio, routing function in cognitive radio network has to be optimal. In this work cognitive radio routing technique based on particle swarm optimization technique is proposed.

The PSO routing strategy developed in this work is to opportunistically route data packets, across paths with under-utilized spectrum, avoiding congested (in terms of spectrum availability) areas. To achieve this goal, the proposed spectrum aware routing technique must be optimal in distributing traffic according to the available spectrum resources. The proposed PSO routing problem is formulated as a minimization of the spectrum utilization between every pair of nodes. The formulated routing optimization problem is solved using PSO. The proposed routing algorithm is implemented in the Java programming language

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