Optimization of Cost Function of LAN Using Particle Swarm Optimization and Genetic Algorithm

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Abstract— **Under network planning and optimization, the size of service area of a network has to be estimated to minimize the total cost. In this project work we consider the cost function of wired network of telecommunication switching station, which is applied for wired LAN. The function contains both fixed and variable cost with respect to size of the network and does not provide sharp minima on multidimensional plane hence steepest descent method could not solve the cost function. To overcome the situation, we applied PSO Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) to acquire the optimum size of the network. The theoretical, PSO and GA provides very closed results shown both in table and graph.**

Index Terms— **Optimal Area, Demand Density, Network size estimation, incremental cost and contour plot.**

I. Introduction

Before innovation of mobile cellular network, the main communication network of urban area was wired telephone network. A big city was covered by multiple interconnected switching center (telephone exchange) in star or mesh topology. Network infrastructure optimization is crucial for both cost effective and reliable communication. Researchers have explored various techniques, including machine learning algorithms like PSO and GA, optimize the cost of both small and large area network. This paper proposes an optimization model that incorporates consumption intelligence to optimize network coverage area.

In [1], authors introduced a search and rescue application under PSO using small swarm robot. As the convention of the algorithm authors used four components: current direction, random direction, direction toward the GBP, and direction toward to the PBP. The time vs. the number of convergence robot on the target zone are plotted, which took around 80 seconds.

A comparison of the performance three well-known metaheuristic algorithms: Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Simulated Annealing (SA) on benchmark functions has been shown. PSO outperformed GA and SA in achieving the highest minimum fitness, but performance can be influenced by parameter settings or operations within each method found in [2]. The paper showed all the four algorithms on section II of the paper and used 10 functions to test the algorithms. The results are shown in tabular form in the result section with the search range and global minima as the parameters.

In power system the main challenge is to maintain the demand and generation of power in blanch condition. In [3] new approach to solve the generation maintenance scheduling problem is proposed, utilizing a Hybrid PSO-GA and PSO-Evolutionary Programming methodology and compared with other techniques and tested on a 32 generating unit system.

The proposed mode shows its superiority in terms of solution quality, robustness, cost-effectiveness, reserve margin, and computing time.

A new algorithm called IMPSO is proposed in [4] as an improved PSO method, for optimizing RBF neural network parameters. The combination of two methods called IMPSO-RBF algorithm demonstrates superior solution in searching and faster convergence compared to other approaches.

In [5], The authors propose the SCEPSO algorithm for retrieving high utility item-sets in data mining. It outperforms existing GA and PSO algorithms in terms of time and memory usage. Benchmark datasets are used to evaluate the performance of the SCE-PSO algorithm. This method is particularly effective in mining profitable products considering both quantity and profit.

The vertical displacement minimization of a 3-bar truss system is considered as the goal functions in [6], where both Genetic Algorithm and Particle Swarm Optimization are used for optimization. Results show that the Genetic Algorithm outperforms Particle Swarm Optimization in terms of processing speed, quality, and optimal value.

In [7], an enhanced genetic algorithm is proposed for the design optimization of an electromagnetic relay, considering energy reduction, cost reduction, and improving mechanical and electrical performance as the constraints.

In [8], an enhanced genetic algorithm is utilized to enhance automatic transfer functions, where the proposed method improved optimization and precision compared to conventional methods. The modified genetic algorithm reduces the search time for the transfer function to approximately 13.35 seconds.

The combination of GA and RBF neural network of [4] is also found in [9] for image classification. Several individual machine learning algorithms: SVM, OMP, PCA, RBF and LDA are compared with proposed scheme and found the best result.

In [10], the proposed method utilizes a GA to optimize equalizer tap length in DFE for frequency selective and underwater acoustic channels. Different crossover techniques are employed to achieve a low BER using QPSK signals and other optimized types.

The ultra-dense heterogeneous network uses base station of low power consumption to serve different types of network devices. In [11] a modified GA is proposed to optimize energy efficiency and increases survival of nodes of the network.

In [12] authors combined GA with SNN to acquire learning process of non-holonomic robots against a target attraction. The performance of the system is measures by the profile of number of recognized targets against change in frequency of sensory neural region.

In [13], Authors propose an anycast routing algorithm based on GA and PSO, combining their benefits to solve the ARP. The method achieves superior QoS performance, faster convergence, and finds the global optimum, making it an effective solution for the anycast routing problem.

Determination optimum topology of multicell and multi-hop wireless network is an NP-hard problem. Authors propose a sequential genetic algorithm to solve the problem which improves efficiency in terms of throughput, power consumption, and delay in [14]. In [15], Authors discuss constraint management strategies for particle swarm optimization (PSO) in solving problems with multiple constraints. Dynamic penalty functions outperform other approaches in terms of efficiency and consistency.

Lot of works are found against cost function optimization of different system under different MLs but none of them are relevant to the coverage area of network. Within the scope of the paper, we have integrated machine learning algorithms with the cost function of wires network.

The rest of the paper is organized as: section II gives theoretical analysis of 2 ML algorithms, section III provides methodology of the paper, section IV deals with results based on sections II and III, finally section V concludes the paper with some future works.

II. Theoretical Analysis

A. Particle Swarm Optimization and Genetic Algorithm

The Particle Swarm Optimization (PSO) algorithm was introduced by Eberhart and Kennedy, which uses combined effort of a group of entity called particle. The algorithm mostly used in optimization of cost function of several independent variables. Each particle possesses a velocity that is governs by its own gravity, called the velocity of inertia. Each particle keeps the record of its own best location (nearest to the target field) till its journey, called local best position LBP. The best location of the particle among the group is called global best position GBP is also stored by all the particles. On each iteration, a particle has three components of velocity: (i) own velocity due to inertia (ii) velocity component along LBP and (iii) velocity component along GBP. These three components are added to get the new location of the particle.

Updating Velocity of i^{th} particle:

$$v_{k+1} = wv_k^i + c_1 r_1 (p_k^i - x_k^i) + c_2 r_2 (p_k^G - x_k^i) \quad (1)$$

Here,

v_{k+1} = Updated velocity of i^{th} particle; wv_k^i is the current velocity of i^{th} particle and $w < 1$ is the weighting factor of current velocity called inertia weight; p_k^i = PBP of i^{th} particle; p_k^G = GBP of a particle inside the entire society; x_k^i = Current Position of i^{th} particle. Two random values: c_1= Acceleration factor related to LBP and c_2= Acceleration factor related to GBP in eq. (1) makes tradeoff between exploration and exploitation. The components of eq. (1) is shown in fig.1.

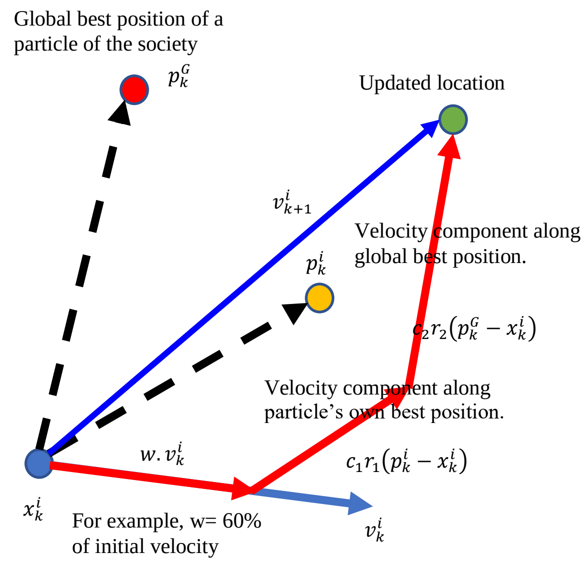


Fig.1 Explanation of updating velocity and position of a particle

B. Genetic algorithms (GAs)

Genetic algorithms (GAs) are a subset of evolutionary algorithms that use an adaptive heuristic search strategy. Genetic algorithms are based on the principles of natural selection and genetics. The algorithm stars with a set of initial population called chromosomes. Each chromosome is an array of binary or real number. The numerical value of the cost function is determined using chromosome as the independent variable, called fitness value. The chromosomes provide the fitness value above a threshold is preserved as the population of next generation. The chromosomes are modified by crossover and mutation on each iteration then fitness value is evaluated again to select the chromosomes of better fitness. This algorithm can avoid local optima but the entire process is slow.

The steps of the GA are:

a) Select initial population or chromosomes randomly

b) Evaluate fitness value of the cost function

c) Apply crossover and mutation on the chromosomes

d) Select chromosomes of better fitness value

e) Continue steps b, c and d until termination criteria is fulfilled.

f) Show the optimum solution

III. Methodology

A. Cost Function of Service Area

In the service area of a local telephone exchange (switching center) a lot of components are involved. For example, cost of land, construction of building of the exchange, equipment cost, wiring cost, end equipment cost etc. The total cost of per subscriber includes both fixed cost (cost of land, building, power supply etc.) and variable cost. This section deals with a mathematical model based on demand density and cost (fixed and variable) of different components for calculating the optimum service area of a wired network like [16].

Let, the service area of a network is circular with radius of *r*.
ρ = demand density of users (number of users per unit area)
D = unit cost of subscriber's line in TK.
A = fixed cost of central switching station in TK.
B = incremental cost of switching per user in TK/sub (capacity increment cost).
∴Total number of subscribers,
N_r = Demand density × area = $\rho \times \pi r^2 = \pi\rho r^2$
Now the exchange cost,
C_E = Fixed cost + Variable cost = *A*+*Nr*.*B*
The incremental area at a distance x from the center=$(2\pi x)dx = 2\pi x dx$
The incremental demand at a distance *x* = incremental area×demand density = $(2\pi x dx)\rho = 2\pi\rho x dx$

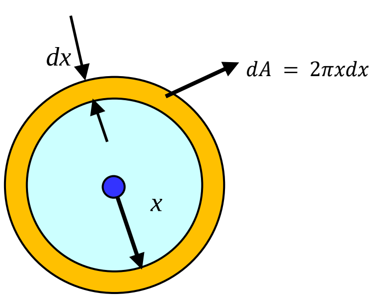


Fig.1 Incremental area of a LAN

The incremental total length of subscriber lines at a distance *x* is,

dL = incremental area × demand density × distance
= $2\pi\rho x^2 dx$ (2)

The incremental total cost of subscriber lines at a distance x is,

dC=incremental length × unit cost of line=$2\pi D\rho x^2 dx$ (3)

The total cost of subscriber lines in the service area,

$$C_L = \int_0^r 2\pi D\rho x^2 dx = \frac{2}{3}\pi D\rho r^3 \quad (4)$$

Total cost,

$$C_T = A + N_r.B + \frac{2}{3}\pi D\rho r^3 \quad (5)$$

Total cost per subscriber,

$$c_t = \frac{C_T}{N_r} = \frac{A + N_r B + \frac{2}{3}\pi D\rho r^3}{\pi\rho r^2} = \frac{A}{\pi\rho r^2} + \frac{2}{3}Dr + B \quad (6)$$

Exchange area can be optimized taking the minima of eq. (6),

$$\frac{dc_t}{dr} = -\frac{2A}{\pi\rho r^3} + \frac{2}{3}D = 0$$

$$\therefore r_{opt} = \sqrt[3]{\frac{3A}{\pi\rho D}} \quad (7)$$

So, the cost function to be optimized is,

$c_t = \frac{A}{\pi\rho r^2} + \frac{2}{3}Dr + B$ and the theoretical optimum radius will be $\therefore r_{opt} = \sqrt[3]{\frac{3A}{\pi\rho D}}$.

Now, the cost function has four variables: *r*, *D* and *B*. We will set the upper and lower bound of these variables and then we will feed these values in PSO algorithm. The PSO algorithm will determine the optimum result from the set of parameters. Then we will plot the variation of cost function against the radius *r*.

B. Steps of operation

a) Set the parameters of cost function

b) Determine optimum radius of service area theoretically using eq. (6)

c) Design chromosome and fitness function of GA

d) Determine optimum radius using GA under Matlab 18

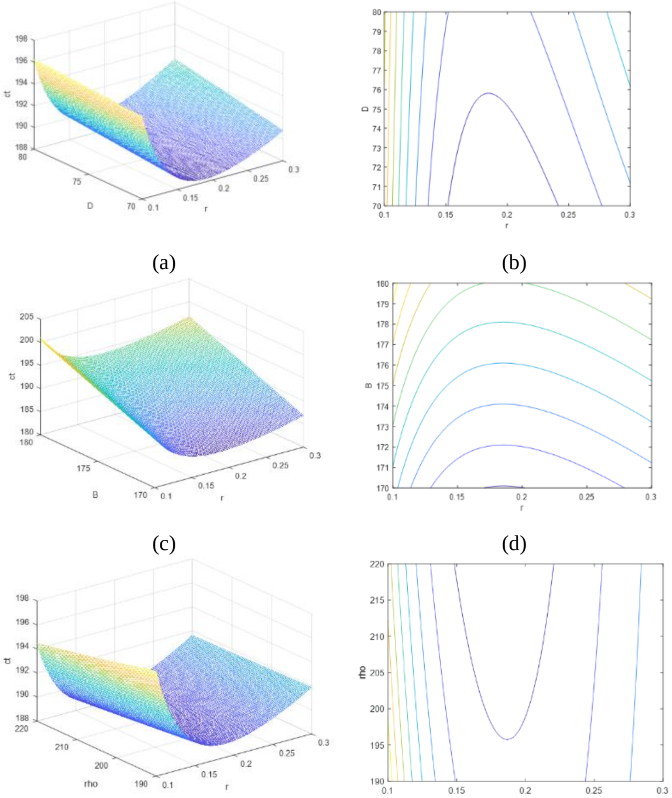
e) Set the parameters of PSO

f) Determine optimum radius using PSO under Matlab 18

g) compare the results of steps: b, d and f

IV. Result

The cost function, $c_t = \frac{A}{\pi\rho r^2} + \frac{2}{3}Dr + B$, has four variables: ρ, *r*, *D* and *B*. The function $c_t(D, B, A, r, \rho)$ is plotted (mesh and contour) against two parameters and keeping other two fixed like in fig.6. The Fig. 6(a) and (b) shows mesh and contour plot considering *D* and *r* as the variables, Fig. 6(c) and (d) consider *B* and *r* as the variables, and Fig. 6(d) and (e) consider *r* and ρ as the variables. No sharp minima are found hence gradient descent method cannot provide the minima of cost function.



(a) (b)

(c) (d)

(e) (f)

Fig. 6 Variation of parameters of cost function

In this paper five experiments are made under PSO on Matlab 18, as the second step. In experiment 1, the lower and upper bound of four parameters are taken as: $\rho \to [50, 200]$, $r \to [0.1, 0.4]$, $D \to [75, 100]$, $B \to [175, 200]$. Running the Matlab code, the numerical value of the parameters to achieve a sharp minima is found as: ρ =200, r = 0.2375, D = 75, B = 175. Taking above parameters, the variation of cost function against the radius r is plotted, which is shown in fig. 4(a).

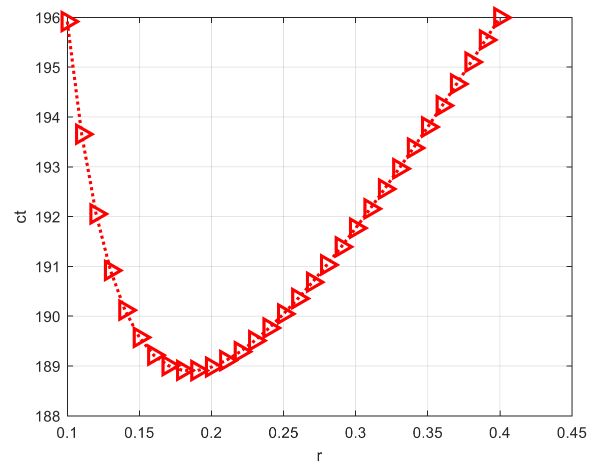
In experiment-2, the range of variables are taken as, $\rho \to [50, 220]$, $r \to [0.1, 0.4]$, $D \to [60, 100]$ and $B \to [150, 200]$.

The PSO provides the values as, ρ =220, r = 0.2452, D = 60, B = 150. The profile of cost function for above parameters is shown in fig. 4(b).

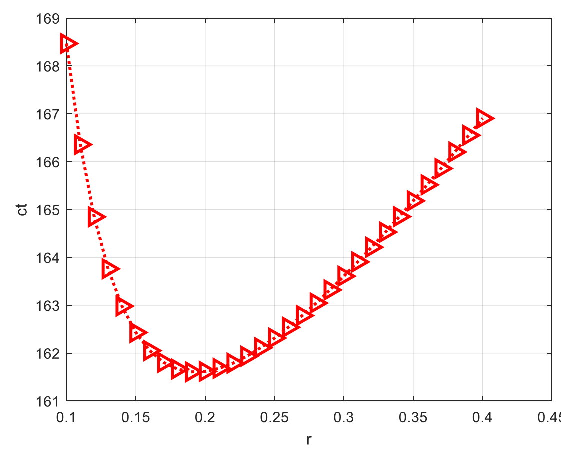
In experiment-3, the ranges are considered as, $\rho \to [50, 250]$, $r \to [0.1, 0.4]$, $D \to [30, 100]$ and $B \to [120, 200]$. The edxact values of the parameters as: ρ =250, r= 0.2825, D = 30 and B =120. The profile of cost function for above parameters is shown in fig. 4(c).

In experiment-4, the ranges are changed as, $\rho \to [50, 250]$, $r \to [0.1, 0.4]$, $D \to [20, 100]$ and $B \to [100, 200]$. The corresponding numberical values are: ρ =250, r= 0.3126, D = 20 and B =100. The profile of cost function for above parameters is shown in fig. 4(d).

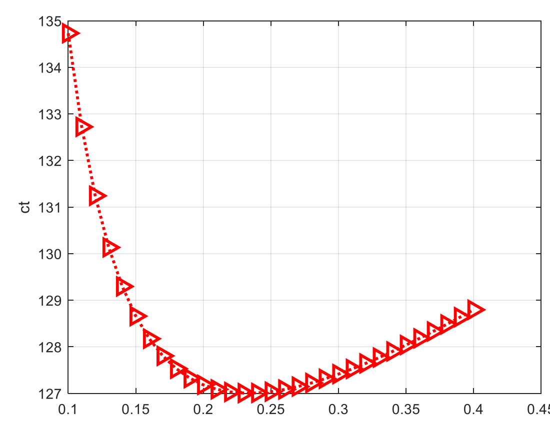
In experiment-5, the ranges of variables are, $\rho \to [50,300]$, $r \to [0.1, 0.4]$, $D \to [10, 100]$ and $B \to [80, 200]$. The numerical values of them are found as, ρ =300, r= 0.3552, D = 10 and B =80. The profile of cost function for above parameters is shown in fig. 4(e). Changing the parameters of cost function, the minima point is sifted at the same time the sharpness of minima is also changes visualized from the figures 4(a)-(e).



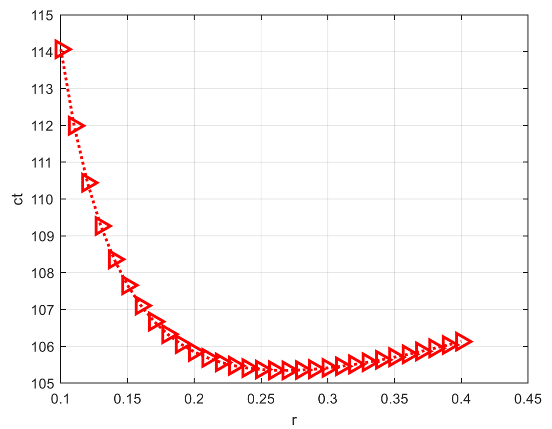
(a) ρ =200, r = 0.1853, D = 75, B = 175



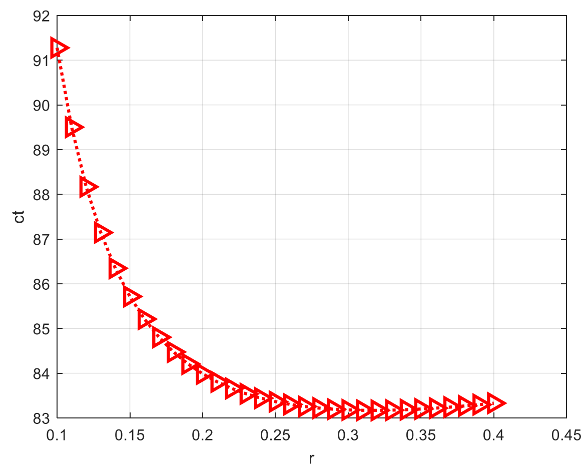
(b) ρ =220, r = 0.1934, D = 60, B = 150



(c) ρ =250, r= 0.2335, D = 30, B =120



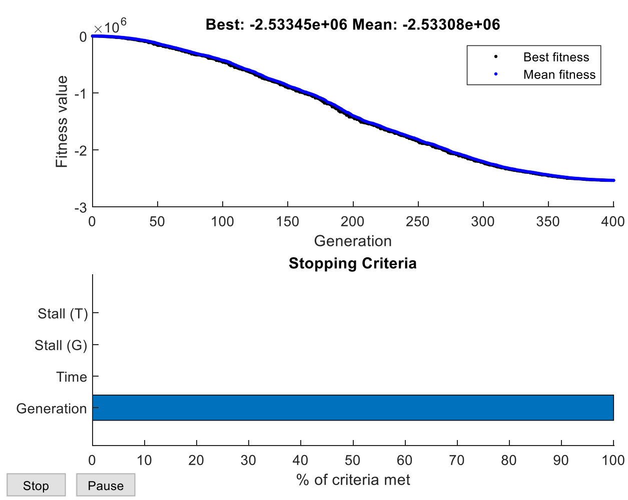
(d) ρ =250, r= 0.2673, D = 20, B =100



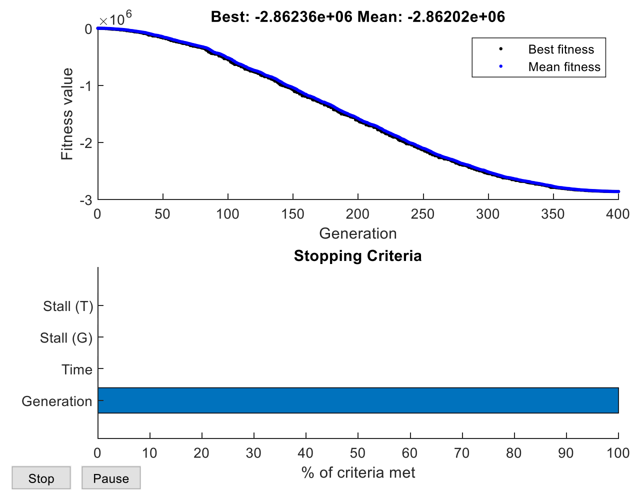
(e) ρ =300, r= 0.3169, D = 10, B =80

Fig.4. Variation of cost function against the radius of service area

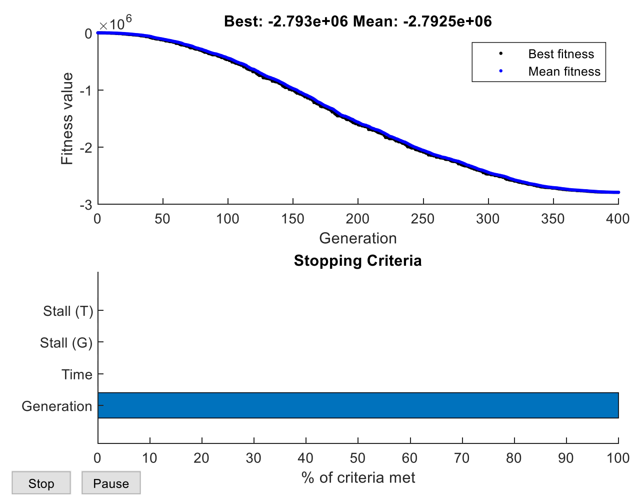
Next GA is applied on the cost function for five different range of variables like PSO. For each case the profile of the best and mean score are shown graphically against the population of each generation. For every case 400 generations were need to stabilize the fitness value and 100% criteria is meet on every experiment visualized from fig. 5(a)-(e).



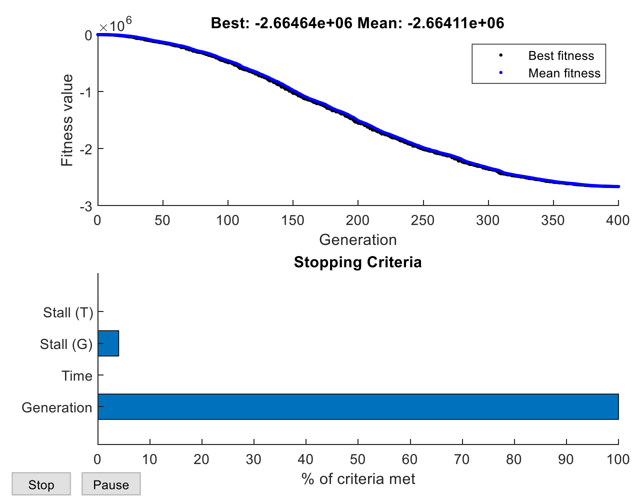
(a) Experiment 1



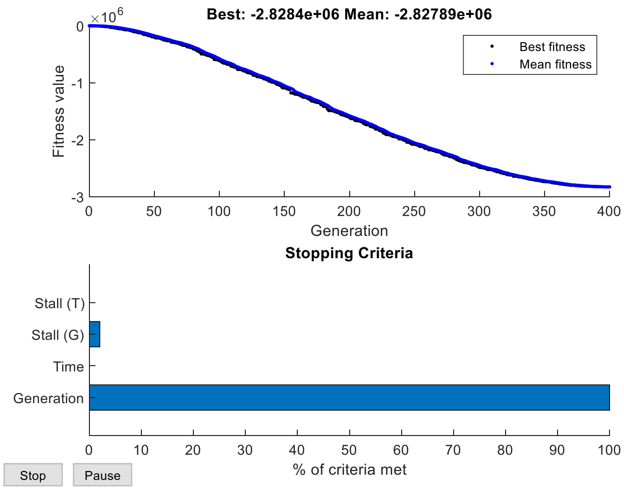
(b) Experiment 2



(c) Experiment 3



(d) Experiment 4



(e) Experiment 5

Fig. 5 Profile of fitness function against generation

Table-I
Comparison of c_t of PSO and GA

Expt.	r_{opt} (Theory)	c_t (Theory)	r_{opt} (PSO)	c_t (PSO)	r_{opt} (GA)	c_t (GA)
1	0.1853	188.900	0.1853	188.900	0.1853	188.9002
2	0.1934	161.604	0.1934	161.604	0.1934	161.6042
3	0.2335	127.005	0.2335	127.005	0.2335	127.0053
4	0.2673	105.346	0.2673	105.346	0.2673	105.3460
5	0.3169	83.1692	0.3169	83.1692	0.3169	83.1692

The numerical value of optimum radius and cost function are evaluated in three ways as discussed in subsection B of section III as: (i) theoretically (ii) PSO and (iii) GA. The results of five experiments are shown in Table I and found the same numerical value of optimum radius and cost function.

V. Conclusion

The paper compares optimum area and cost/user of a service area for three cases: theoretical, Particle Swarm Optimization and Genetic Algorithm. All the three model provides the same result. The mathematical model regarding cost function used in this paper considers uniform distribution of users. In future the model will be modified for nonuniform distribution users hence wire cost will be increased along the dense area compared other direction. Such concept will be applicable for campus wide large network. Other mathematical models, such as the Artificial Bee Colony Algorithm and the Ant Colony Algorithm, can also be employed to optimize the cost function. In the future, we will measure the convergence of each approach in context of process time.

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Biography

Rifat Ara has completed her SSC and HSC education at Safiuddin Sarker Academy and College in 2015 and 2017, respectively. Recently pursued an BSC degree in Computer Science and Engineering from Jahangirnagar University with a research focus on networking combined with machine learning. She aims to revolutionize the field by leveraging intelligent algorithms for enhanced performance, security, and efficiency. She is currently enrolled in the MSC program for Computer Science at Jahangirnagar University.

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