



Optimizing IoT Wireless Sensor Networks: A Comparative Analysis of Particle Swarm Optimization (PSO) and Genetic Algorithms (GA)

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Abstract

The IoT can be defined as a system of various types of computing and digital devices, machines, objects, animals, and humans that are connected through networks to send data without the need for direct person-to-person or computer-to-person interfaces. Every component in this structure is given a unique identity. While under the domain of IoT, WSN serves as a wireless sensor network that does not have an established infrastructure but consists of many wireless sensors for surveillance over systems, the environment, and the physical world. Because of its versatile usage like surveillance and environmental monitoring, Wireless Sensor Networks (WSNs) are vital in many applications. The performance of these networks is largely dependent on how sensor nodes are distributed across the area to provide good coverage and connectivity. In this paper, we propose a new method for node placement optimization in WSNs, which tries to solve the problem of coverage holes at the stage of initial deployment. Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) are implemented using MATLAB to deal with the problem's complex and non-linear nature. These algorithms help find optimal node positions, thus improving coverage while ensuring no coverage gaps occur. A way to achieve this is through iterations, which involve fitness evaluation, selection of promising solutions, and genetic operators like crossover and mutation or position updates for PSO to investigate and improve the final solution. The simulation results mentioned in this paper demonstrate the usefulness of those methods, displaying major increases in coverage and the removal of all gaps that could appear in the initial deployment. This research contributes to the field of wireless sensor network optimization, specifically addressing coverage issues using GA and PSO algorithms ...

Keywords: IoT; WSN; Genetic Algorithms; Particle Swarm Optimization; MATLAB

1. Introduction

According to the text, Internet of Things (IoT) can be considered an important regional structure similar to normal systems where data can be transported and exchanged easily. Sometimes also called the "Internet of Everything," the IoT is a new paradigm in which information technologies like RFID, personal computers, the internet, embedded systems, communication technologies, and other devices are integrated to connect virtual and physical worlds [2], see Figure 1. What makes IoT so versatile is its readiness to adapt to almost every software part, hardware component, or sensor connected to its system.

In the first place, the IoT plays a critical role in data and security management; it operates as an international channel linking people and things. Its usage is wide-ranging, starting from smart cities to quick medical support systems, smart buildings, and rapid transport response systems [3]. The possibility to eliminate multiple sensors by incorporating their functionalities into one simpler sensor exists within current IoT platforms [4]. This method requires an infrastructure-free wireless network called Wireless Sensor Network (WSN). WSN includes

several wireless sensors that are placed strategically for tracking environmental, physical, and system variables [5].

The regional control and monitoring are achieved by sensor nodes possessing integrated CPUs, while these sensor nodes are associated with a central Base Station that acts as the WSN system's processing center. The base station links up to the Internet so that data can be shared [6].

In the realm of the IoT world, WSN applications are widespread and cover various sectors. Some of these areas involve security monitoring, surveillance, threat identification, military use cases, as well as environmental measurements which may include factors like air pressure, humidity, or temperature. WSNs provide significant value in different domains including patient monitoring in medicine, agriculture, and landslide detection. Nevertheless, adopting WSN comes with challenges such as limited power and energy resources; also security threats and QoS maintenance. These issues need to be addressed in order to fully exploit the potential of WSN within the larger context of IoT. [7], [8].

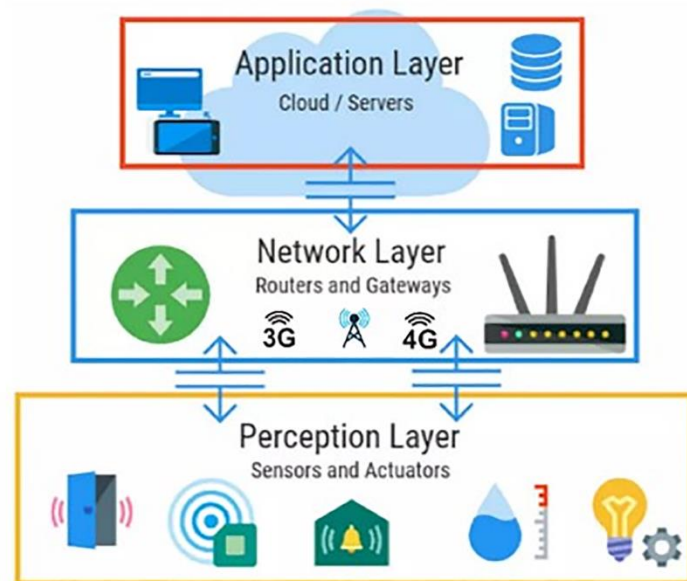


Figure 1: General IoT topology

WSNs and the IoT have been explored extensively in the literature. The research by S. W. Nourildean et al. evaluated the energy-efficient ZigBee WSNs, their routing topologies along with an investigation on applications and security issues of IoT-enabled WSNs [9]. On a separate note, V. Rishiwal et al. proposed a novel routing protocol and algorithm considering QoS factors to improve network performance within an IoT-based environment [10]. An important contribution to the field was made by T. Brito et al. when they proposed a novel encoding and decoding process to optimize communication in wireless sensor networks, which has been rarely addressed in the literature. Their approach was not merely theoretical; it was applied and validated in the practical context of a wildfire detection system [11]. Another notable study by A. Seyyedabbasi et al. honed in on the challenge of resource efficiency in wireless sensor networks and decentralized IoT-based systems. In response, they introduced two novel energy-efficient routing methods, namely I-GWO and Ex-GWO, leveraging metaheuristic algorithms to discover optimal paths. The primary objectives of these methods include minimizing traffic, enhancing fault tolerance, improving reliability, and extending the overall network lifespan [12].

These diverse contributions underscore the multifaceted nature of research in this field, ranging from theoretical considerations to practical applications, and from energy-efficient routing protocols to novel metaheuristic algorithms designed to optimize various aspects of WSNs and IoT systems.

The paper organization can be presented as follows: Section 2 presents the proposed research methodology, Section 3 exhibits the definition for the GA, Section 4 exhibits the general definition for PSO and its mathematical expression, Section 5 exhibits a general introduction and definition for the objective function, Section 6 demonstrates the obtained results and discussion for the established work, finally, Section 7 illustrates what concluded after carry out the proposed methodology.

2. Research Method

This work established an IoT wireless sensor network with randomly generated node positions. It calculates the link margin (the difference between received power and the required Signal-to-Noise Ratio (SNR)) for all node pairs, assessing the network's performance. GA and PSO are used to optimize node positions to minimize transmitted power while maintaining the necessary SNR.

3. Genetic Algorithm

The principles of natural selection and genetics have been harnessed to formulate GAs, characterized as universal search techniques randomly selected. These algorithms incorporate recurring methods that find widespread application in addressing optimization challenges across various fields of research and technology. Diverging from earlier approaches, this methodology considers a set of responses that characterize populations or individuals at each iteration or generation, rather than focusing solely on a single point within the search space. Evaluation is then based on the quality of the solutions offered by each individual [13].

GAs have proven to be highly effective in resolving a myriad of issues, including but not limited to the traveling salesman problem, graph partitioning, filter design, and power electronics. Furthermore, their utility extends to adaptive control, dynamic control systems employing learning principles, and machine learning applications [14]. Figure 2 provides a graphical representation of the GA process.

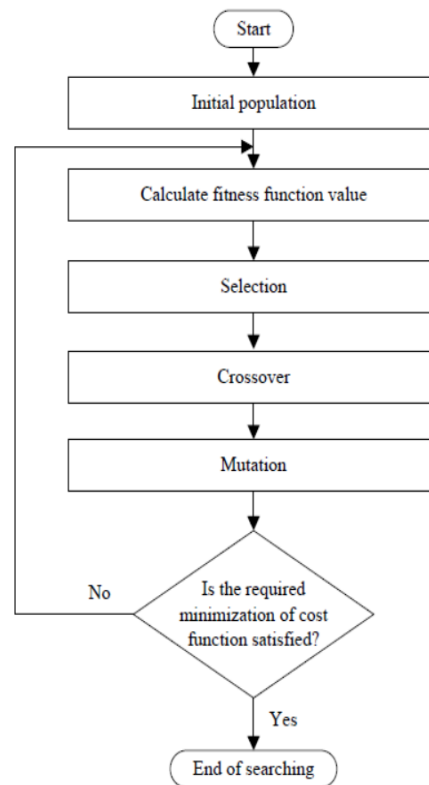


Figure 2: Flowchart for the GA operation

4. Particle swarm optimization

The PSO method represents a stochastic optimization algorithm based on population dynamics. The fundamental idea behind PSO involves propelling each particle towards its P_best (previous best position) and G_best (global best position) locations, utilizing a random weighted acceleration at every time step. The particle's velocity and position undergo adjustments according to the following velocity and position equations, respectively [15]:

$$v_i^{t+1} = q \times v_i^t + c_1 \times U \times (X_i^b - X_i^t) + c_2 \times U \times (X_i^g - X_i^t) \quad (1)$$

$$X_i^{t+1} = X_i^t + X_i^{t+1} \tag{2}$$

Where v_i^t describes the particle velocity, X_i^t describes the current for the describes the particle position, q is describes the inertia weight, X_i^b is describes the best value, X_i^g is describes the global best value, U is describes the random function between in the range of 0 and 1, c_1 and c_2 describes the learning factors. Figure 3 provides a visual representation of how the PSO process unfolds graphically.

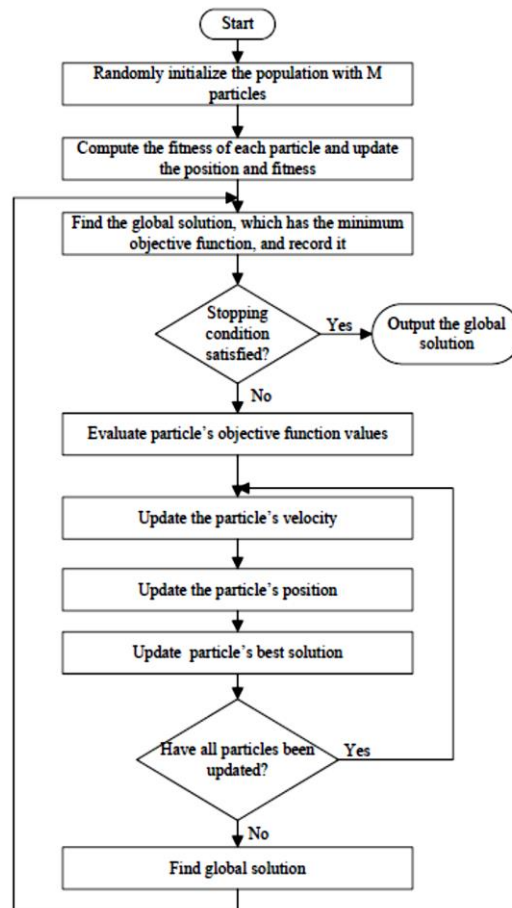


Figure 3: Flowchart for PSO operation.

5. Objective function

In an optimisation problem, the objective function, also referred to as the fitness function or cost function, is a mathematical expression that needs to be optimized. It serves as a metric, gauging how closely a solution aligns with the objectives outlined in the problem [16].

The objective function utilised in this work mathematically describes the coverage area based on the sensor node positions, in mathematical form can be expressed as follows [17]:

Let x be a vector representing the positions of sensor nodes, where $x = [x_1, y_1, x_2, y_2, \dots, x_N, y_N]$ for N sensor nodes.

The deployment area is given by $area=[L_x, L_y]$, where L_x and L_y are describe the lengths for the deployment area in the x and y directions. The transmission range of each sensor node is denoted as "Trange." The objective function for the coverage area is defined as follows

$$Coveragearea(x) = \frac{1}{\frac{num_covered_points}{total_points}} \tag{3}$$

Where num_covered_points is describes the number of randomly distributed points within the deployment area that are covered by at minimum one sensor node and total_points is describes the total number of randomly distributed points.

The determination of a point's coverage involves assessing whether the Euclidean distance between the point and any given sensor node is within or equal to the designated transmission range, denoted as Trange [18].

In the mathematical terms, the coverage checks for a point (x_i, y_i) and a sensor node at position (x_j, y_j) can be expressed as [19]:

$$\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \leq \text{Trange} \quad (4)$$

The objective is to find the configuration of sensor nodes x that maximizes the coverage area, i.e., maximizes coverage area (x) . Optimization algorithms aim to find the optimal values for x that achieve this maximum coverage, Table 1 illustrate the parameters that used in simulation.

Table 1: Selected simulation parameters

	Parameter	Value
Deployment Parameters	Number of nodes	10
	Area	[10m, 10m]
	Trange	2
	Lambda	0.125
	nodes. major	2
	nodes. minor	0.25
	redundant No	1 (calculated as round $(10 * N / 100)$)
GA Optimization Parameters	Population Size	20
	Max Generations	100
	Lower bounds for decision variables	0
	Upper bounds for decision variables	10
PSO Parameter	Swarm Size	40
	Max Iterations	100
	Inertia Weight	0.8
	Lower bounds for decision variables	0
	Upper bounds for decision variables	10

6. Results and discussion

In Figure 4, the initial arrangement of nodes is illustrated, each denoted by a red dot, and surrounded by a circular fill indicating its transmission range. The red dots represent sensor nodes, and the filled circles around them delineate the extent of their transmission capabilities.

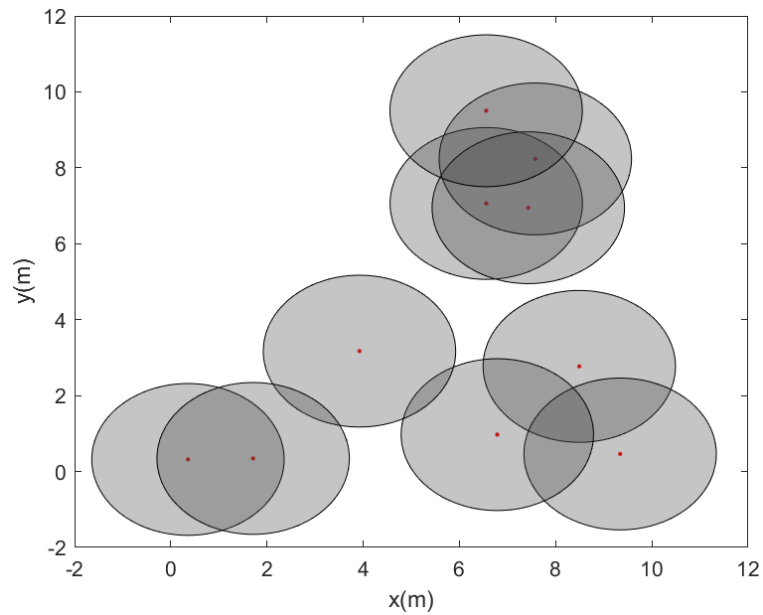


Figure 4: IoT WSN initial placement.

In Figure 5, the initial positioning of nodes is depicted, featuring circular transmission ranges. Notably, the figure includes an overlay of the Delaunay triangulation, connecting nodes to form triangles. This triangulation serves the purpose of hole detection in the network

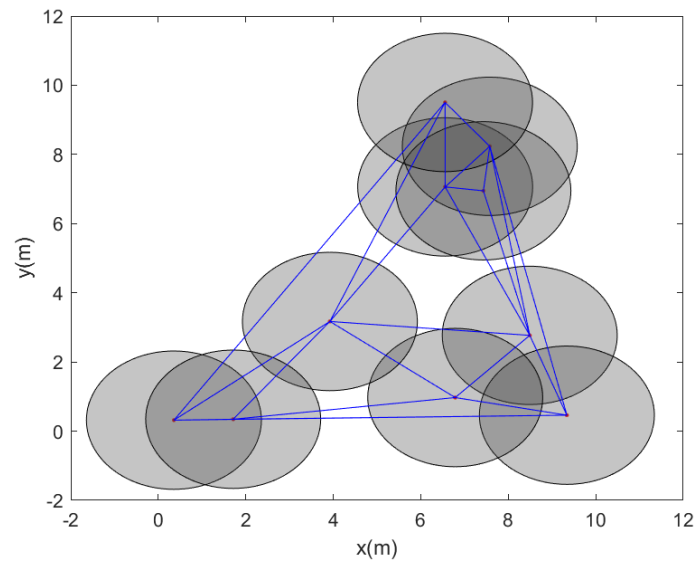


Figure 5: Coverage hole in initial position of nodes.

The optimized locations of sensor nodes after the PSO algorithm are illustrated in Figure 6. The red dots demonstrate the final tuned positions of the nodes, and the circular fills around each node depict their transmission ranges

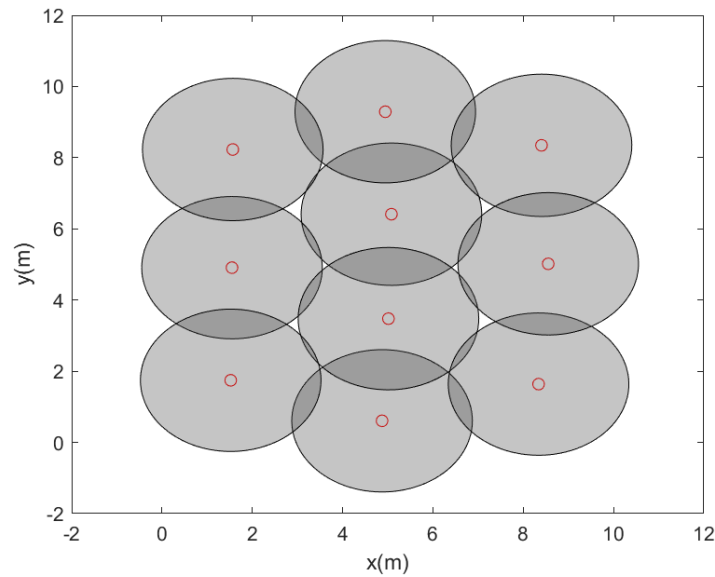


Figure 6: Optimized location of nodes with circular transmission range (PSO).

The optimized positions of sensor nodes post-GA optimization are showcased in Figure 7. Once more, the concluding fine-tuned positions are denoted by red dots, and the surrounding circular fills illustrate the respective transmission ranges

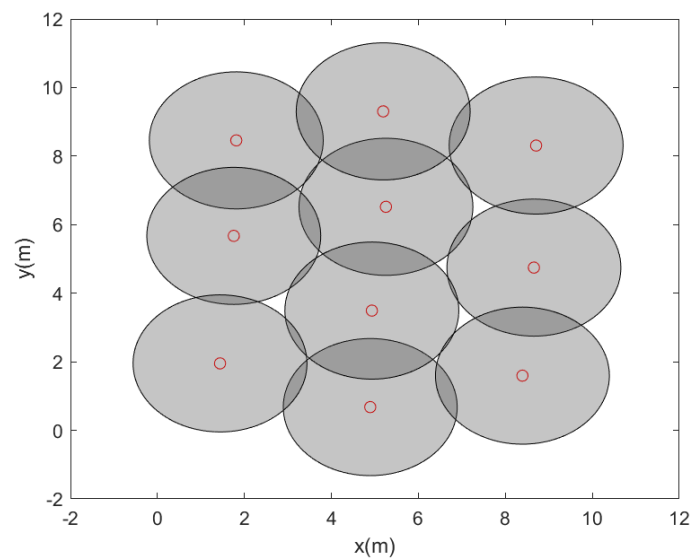


Figure 7. Optimized location of Nodes with circular transmission range (GA).

The best function plot for each iteration is a visualization of the best fitness value achieved by the optimization algorithm at each generation or iteration. Figure 8 shows the convergence of PSO algorithm that is mean a plot of the best fitness value at each iteration during the optimization. This plot is helpful for monitoring the convergence of the algorithm. Ideally, you would observe a decreasing trend in the best fitness value over iterations, indicating that the algorithm is progressing towards finding an optimal solution. While Figure 9 shows the best fitness value for GA optimization technique in other words represents the fitness of the best individual (chromosome) in each generation

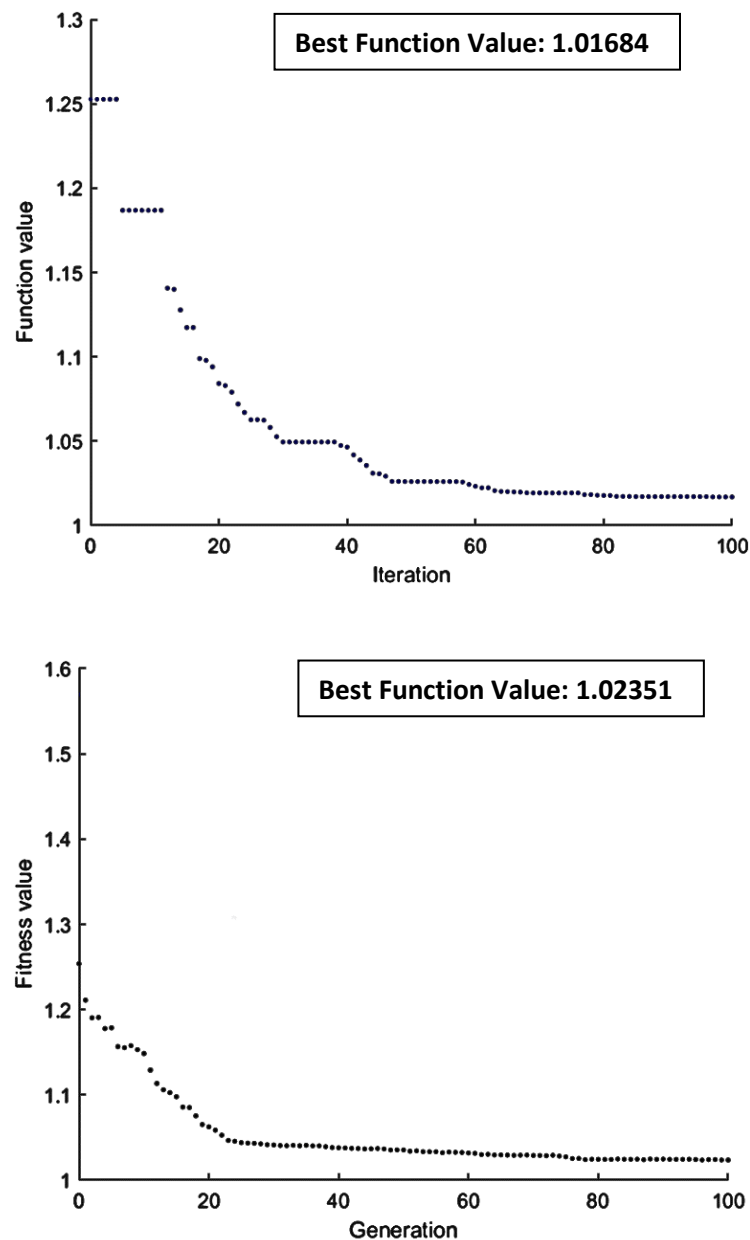


Figure 9: The convergence of GA.

The best fitness value in optimization algorithms represents the quality of the solution found by the algorithm. The PSO algorithm provides a slightly smaller best fitness value 1.01684 while GA provide 1.02351 that mean PSO has found a solution with a lower objective function value, indicating a more optimal solution for the given problem.

7. Conclusion

In this paper, we have introduced a novel approach for optimizing the placement of wireless sensor nodes within a deployment area, with a particular focus on addressing coverage holes present in the initial configuration. Our deployment strategy integrates both PSO and GA techniques, employing an iterative process to fine-tune the positions of sensor nodes. The primary objective of our method is to augment the coverage and connectivity of the wireless sensor network, thereby ensuring efficient data transmission and bolstering fault tolerance. This contribution significantly advances ongoing research in wireless sensor network optimization, specifically tackling challenges associated with coverage holes and optimal node placement. The comparative analysis between PSO and GA offers worthy insights into the distinct strengths and weaknesses of each algorithm within the context of this study

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