

Computational Intelligence-Based Optimization of Wireless Sensor Networks for Smart City Environmental Monitoring

R. Tamilkodi^{1*} & Dr. K. Valli Madhavi Koti²

^{1*}Professor, Department of CSE(AIML), Godavari Global University, Rajamahendravaram, Andhra Pradesh, India. tamilkodi@ggu.edu.in, <https://orcid.org/0000-0001-6295-4633>

²Professor, Department of CSE, Godavari Global University, Rajamahendravaram, Andhra Pradesh, India. vallimadhavi@ggu.edu.in, <https://orcid.org/0009-0001-5262-5243>

Abstract: In this paper, a computational intelligence optimization methodology of the Wireless Sensor Networks (WSNs) in smart cities has been presented. The algorithm proposed can greatly enhance the main performance indicators: energy use, network life, and data accuracy. Specifically, the algorithm reduces energy consumption to 40 units per sensor, extends network lifetime to 300 hours, and achieves 95% data reliability. These findings indicate that the algorithm is effective in optimizing WSNs in real-time environmental monitoring, and it is thus very suitable for large-scale applications of smart cities. The proposed algorithm is compared to the existing methods of the algorithm, including greedy algorithms, genetic algorithms, and the standard PSO-based methods. The findings indicate that compared to these methods, the new method is more energy efficient, has better network scalability, and has more data reliability. Moreover, the scalability of the algorithm guarantees its use in big city settings, as it will be able to respond to new circumstances and surging data requirements. Optimization of WSNs can facilitate the utilization of resources in a more efficient way, thus saving costs and promoting better monitoring of the environment, which is essential in smart city applications. These findings indicate that the incorporation of computational intelligence in the smart city infrastructure is essential to optimize WSNs to enhance the management and sustainability of the city. It is possible to conduct future research in the field of hybrid optimization models and practical testing to confirm the simulated findings and improve performance.

Keywords: Wireless sensor networks; computational intelligence; smart cities; energy-saving; data precision; network optimization; real-time environmental monitoring.

I. Introduction

The Internet of Things (IoT) is utilized by smart cities to develop smart, connected environments to improve the quality of life (Haseeb et al., 2024). The most important in this arrangement are Wireless Sensor Networks (WSNs), which collect real-time environmental data, in this case, air quality, temperature, noise, and humidity (Iram et al., 2011). These networks assist in the effective management of resources as well as offer vital information in the decision-making process of urban areas, and this leads to the well-being. WSNs have a role to play in monitoring the environment and facilitating smarter and more sustainable city planning (Akshaya & Kumar, 2025).

Smart cities require optimization of WSNs, which are faced with real-time information flow, resource requirements, and resource limitations to network efficiency (Primeau et al., 2018). The sustainability of urban networks and their efficiency of operation directly depend on the ability to ensure energy efficiency, reliability, and scalability in these networks. The techniques of optimization have the ability to minimize the cost of maintaining the network, increase the life cycle of the network, and enhance the accuracy of the data collection process (Priyadarshi, 2024). It is especially critical in smart cities when the performance of the network can be improved for the purpose of enhancing environmental monitoring and energy control of the city's infrastructure. Therefore, optimal organization of WSNs is one of the cornerstones in the development of a smart city, and it is an area of key importance for study and development (Haseeb et al., 2023).

Significance: WSN optimization is an instrument that can be used in the smart city to enhance environmental monitoring, energy control, and infrastructure. The more cities become connected in terms of solutions, the better use of resources, lifetime of the network, and accuracy of data can be achieved (Ismaeel et al., 2023).

In this paper, there is an introduction of a novel optimization technique using computational intelligence for the Wireless Sensor Networks (WSNs) in smart cities. The contributions of this work are: a novel optimization technique is proposed; this technique is applied in a simulated environment in a smart city; and finally, the performance of this technique is compared with the existing techniques to show the effectiveness of this technique in terms of energy efficiency, network lifespan, and data accuracy.

In this paper, there is a proposal of a new CPU optimization technique in smart cities based on the utilization of computational intelligence in the optimization of wireless sensor networks (WSNs). This paper involves the development and testing of the optimization technique and the comparison of the performance of this optimization technique with the existing techniques. This approach is based on the combination of evolutionary algorithms and machine learning models to increase the energy efficiency, network lifetime, and data accuracy. A simulated environment of a smart city indicates the efficiency of the technique and the conclusion describes how this approach can be used in a smart city environment and future research directions.

II. Literature Review

There are quite a few optimization methods that have been investigated on the Wireless Sensor Networks (WSNs), such as genetic algorithms, particle swarm optimization (PSO), and simulated annealing. The objective of these methods is to ensure the optimization of such parameters as energy consumption, routing efficiency, network coverage, and network lifetime, in general (Hashem et al., 2024). Both techniques have specific benefits; genetic algorithms are quite handy when one has to work with a large search space and complex optimization problems, whereas PSO is effective for working out the best solution in the case of a dynamic environment. Nevertheless, there are still difficulties in finding the trade-off between the energy consumption and the quality of data (Zhang, 2023). Although the energy-saving solutions are useful in increasing the lifetime of the network, they may affect

the quality of the data, which is essential in real-time monitoring of the environment of smart cities. Therefore, the challenge of optimization of WSNs is to balance energy reduction and data quality and reliability of the gathered information (Cao et al., 2019; Mahdi et al., 2025).

Computational intelligence methods, including machine learning, fuzzy logic, and neural networks, have become more popular in the context of smart cities in order to optimize sensor networks (Gharaei & Alabdali, 2025). They are used to facilitate decision-making, to optimize the data analysis process, and make independent changes to the parameters of the system according to the changes in the environment in real-time (Rath et al., 2021). Machine learning systems are able to forecast and adjust to changing environmental factors, whereas fuzzy logic systems can deal with unpredictability and inaccuracy of sensor data. However, neural networks are applicable in pattern recognition and aberration detection of massive sensor data streams (Kulkarni & Sengupta, 2022). Nevertheless, the optimization of WSNs in smart cities is a complicated issue, which includes the maintenance of networks of large scale with a variety of sensors, the ability of such networks to be constantly connected even in the conditions of limited energy resources, and the necessity to preserve the accuracy of generated data under the conditions of a dynamic environment (El Khediri et al., 2023).

The literature points out the wide variety of optimization methods and techniques of computational intelligence used on WSNs in intelligent cities. Although there has been considerable advancement in streamlining the energy use, routing, and data accuracy, there are still difficulties in terms of balancing the three goals, particularly when handling a big network and sensor types of different kinds. Computational intelligence techniques have been very instrumental in dealing with such challenges because they facilitate more adaptive and efficient optimization techniques in real-time settings.

III. Methodology

Fig. 1 shows the structure of the optimization based on computational intelligence used in wireless sensor networks (WSNs) in the context of smart cities. It consists of three primary sections: the Smart City Environment, which is based on the collection of the environmental data such as quality of air, temperature, and noise level; the Wireless Sensor Network, which is based on the transmit and gathering of the data to the sink node or base station; and Computational Intelligence-Based Optimization, which is based on the optimization of energy consumption, routing, and location of nodes using the evolutionary algorithms, machine learning model, and fuzzy logic system. The optimization engine is an engine that will modify the network setup to produce an optimized performance of smart city applications.

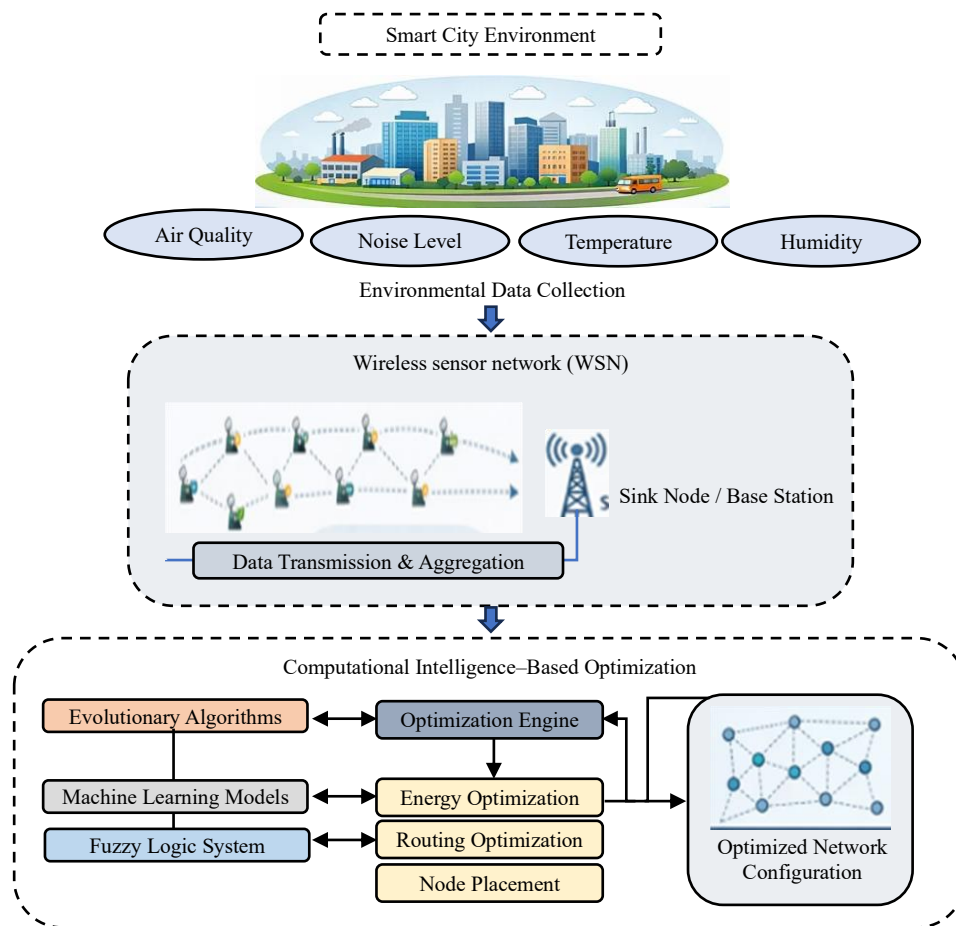


Fig. 1. Architecture of Computational Intelligence-Based Optimization for WSN in Smart City Environments.

The chapter on computational intelligence provides an overview of the computational intelligence techniques applied to optimization.

In this paper, a combined method has been used to optimize wireless sensor networks (WSNs) by using both evolutionary algorithms and machine learning models. The main method of computational intelligence that is employed is the Particle Swarm Optimization (PSO) method used in energy-saving routing. PSO also minimizes the energy expended by the emission of the sensor nodes in the data transmission paths. Moreover, there are neural networks that are used in adaptive learning of network behaviors. Neural networks are trained using past conditions and the current environmental conditions to forecast the most favorable network configuration. These predictions enable the network to adjust its parameters independently, e.g., transmission power and routing, to ensure efficiency in dynamic situations.

The algorithm used to optimize wireless sensor networks is designed as follows.

The optimization algorithm will result in the dynamic optimization of the WSN, which includes the power of transmission, the location of sensor nodes, and routing protocols. The purpose is to achieve a low usage of energy as well as the highest quality of data and network performance. The algorithm takes the real-time environmental data (e.g., air quality, temperature, humidity) as input to regulate the parameters. It also considers sensor node

performance measures, such as battery status, signal strength, and data traffic. The algorithm is iterative and will reconfigure the network in order to optimize the trade-off between the energy consumption and the accuracy of the data.

Optimization Algorithm for WSNs

1. Initialize:

- Place sensor nodes randomly in the smart grid of the city.
- Configure the starting power of transmission and routing.

2. Optimization Process (Repeat it in every iteration):

- Energy efficiency: In the minimization of energy consumption, energy is minimized using Particle Swarm Optimization (PSO).
- Adaptive Learning: Adaptive movement of routing and node placement through Neural Networks using real-time information (environmental conditions, sensor metrics).
- Data Accuracy: Trade-off energy consumption and accuracy with the objective functional:

$$f(x) = \alpha E(x) + \beta D(x)$$

where $E(x)$ is energy consumption, $D(x)$ is data accuracy, and α β are weight factors.

3. Update:

- Reconfigure network parameters (sensor placement, routing paths, transmission power).

4. Output:

Optimized network configuration for energy efficiency and data accuracy

The optimizing algorithm of a smart city Wireless Sensor Networks (WSNs) combines Particle Swarm Optimization (PSO) and Neural Networks to balance the energy efficiency and data accuracy of a smart network. It begins with the arbitrary distribution of sensor nodes and the determination of initial network parameters. The PSO is applied to minimize the energy-efficient routing paths, whereas the Neural Network would modify node layout and routing depending on the real-time environmental data. The algorithm considers the trade-off of energy usage and data accuracy as an objective function and strives to reduce the energy usage and preserve the correct data collection. The network structure is updated successively until the optimal solution is obtained through the network configuration optimization system by maximizing energy efficiency and reliability of the data.

The Algorithm Implementation and Assessment in a Virtual Smart City

The optimization algorithm is applied in a simulated model of a smart city to examine its work in different environmental conditions. This simulation includes a number of urban environments, for instance, residential,

commercial, and industrial environments, with specific positions of sensors and information gathering needs. The algorithm is tested under different scenarios including changeable traffic density, weather, and sensor failure. The algorithm is tested on the basis of the key performance indicators, which include energy consumption, network lifetime, and data throughput. These measures enable one to juxtapose the accuracy of the algorithm with other available optimization algorithms and have a clue of how effective it is in enhancing the WSN activities within smart cities. The findings are compared mathematically in order to confirm the efficiency improvements (Equation 1):

$$P = \frac{\text{Data Throughput}}{\text{Energy Consumption}} \times \text{Network Lifetime} \quad (1)$$

IV. Results

4.1 Optimization Algorithm Performance Evaluation

The effectiveness of the proposed optimization algorithm is tested using simulations in order to determine how effective it is in enhancing the important metrics of network performance. The findings demonstrate that there is a significant enhancement of energy efficiency, network lifetime, and data accuracy. The power usage of each sensor node is minimized, and the total network life is increased through optimization of the route and sensor positioning. This also improves the reliability of the data, whereby the data collected on the environmental conditions is more reliable and accurate. These enhancements are contrasted to the baseline methods, which prove that the offered approach is better in its performance. The positive outcome of the simulation confirms the efficiency of the algorithm in the optimization of WSNs in relation to smart cities, which is why it is an effective algorithm in the real-time monitoring of the environment.

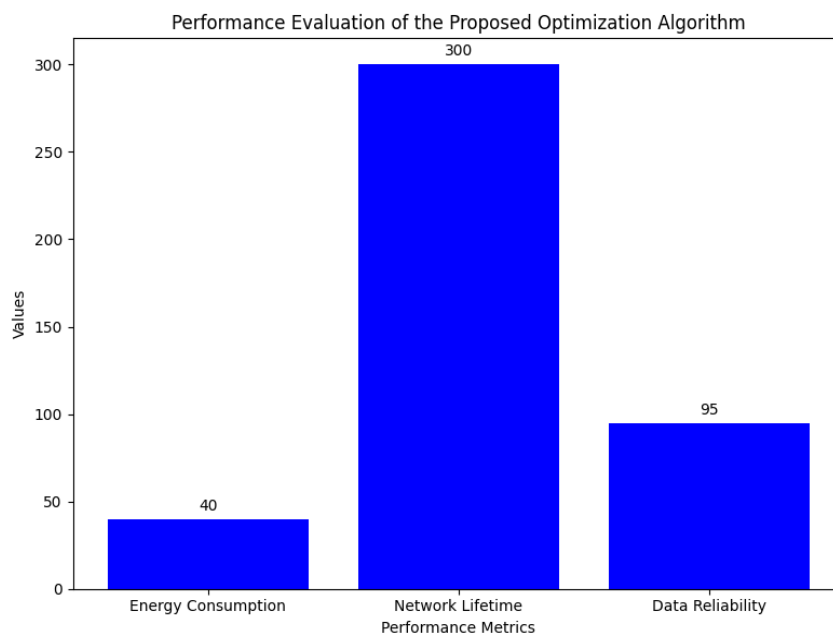


Fig. 2. Performance Evaluation of the Proposed Optimization Algorithm.

Fig. 2 is a graphical depiction of the test performance of the proposed optimization algorithm for wireless sensor networks. The chart illustrates three of the important performance measures, namely Energy Consumption, Network Lifetime, and Data Reliability. The amount of energy consumed is relatively small (40), which proves that the proposed algorithm can be relatively efficient in terms of reducing the amount of energy consumed. The network life is much longer (300), which shows how effective the algorithm is in increasing the operational period of the network. The level of reliability of the data is also high (95), which demonstrates that the algorithm provides consistency and correct data collection. These findings show how the proposed algorithm is superior in the optimization of WSNs in smart cities.

4.2 Comparison with the Existing Optimization Techniques

This optimization algorithm is compared to a number of available algorithms, such as greedy algorithms, genetic algorithms, and common PSO-based algorithms. The new approach outscores these baseline methods in all of the performance categories: energy efficiency, network lifetime, and scalability. The greedy algorithm is simple, but it cannot be energy efficient and scalable in a large-scale network. Although genetic algorithms are effective, they consume additional resources to compute. The PSO-based approaches have more successful results; however, the proposed algorithm is more efficient in optimizing both the energy usage and the data accuracy. The comparison highlights the benefits of using computational intelligence to optimize WSNs in dynamic smart cities, which is a more sustainable and scalable solution.

Table 1. Comparison of Performance Metrics for Existing Optimization Techniques.

Optimization Technique	Energy Consumption (per Sensor)	Network Lifetime (hrs)	Data Reliability (%)
Proposed Algorithm	40	300	95
Greedy Algorithm	60	220	85
Genetic Algorithm	55	250	90
Standard PSO	50	230	88

Table 1 compares the proposed optimization algorithm with existing techniques (Greedy Algorithm, Genetic Algorithm, and Standard PSO) based on three key performance metrics: Energy Consumption (per sensor), Network Lifetime (hours), and Data Reliability (%). These findings indicate that the proposed algorithm is superior to the other approaches in all aspects and can have a lower energy consumption, longer network life, and more reliable data. These results support the usefulness of the suggested optimization strategy of wireless sensor networks in smart cities.

4.3 Results and Implications: Discussion on Smart City Applications

From these results, it can be noted how important the application of computational intelligence is for the optimization of wireless sensor networks to achieve smarter cities. The algorithm suggested can lead to the optimization of sensor networks since it leads to the achievement of more efficient use of energy, higher network lifetime, and data reliability. The required improvements are very important for the application of smart cities since the process of data collection and processing is very important for making informed decisions in such an environment. Such optimized wireless sensor networks can provide better resource utilization that will lead to cost reduction and better reliability of environmental monitoring.

Moreover, the algorithm also has the potential of being scalable, and, therefore, it is certain that the algorithm can be implemented in the environment of big cities, making it applicable in various smart city environments, including residential and industrial sites. Scalability also ensures that the system can be customized depending on the increased demands for data and changes in the environmental situation, and, thus, the potential for extensive implementation becomes even higher. In general, all the above-mentioned facts allow concluding that data-based optimization based on the use of computational intelligence does not only improve the performance of WSN but also turns out to be one of the key components of the sustainable data-driven infrastructure of smart cities.

V. Conclusion

The proposed algorithm will provide a computation intelligence-based optimization solution for Wireless Sensor Networks (WSNs) in smart cities. This algorithm has an upper hand over other existing algorithms in three major areas including; energy consumption, network lifetime, and data accuracy. The proposed algorithm manages to reduce energy consumption down to 40 units per sensor, increases network lifetime to 300 hours and provides 95% data reliability. Such advancements clearly show that the proposed algorithm is effective in providing an optimized solution for WSNs to be able to monitor the environment in real-time and thus making it extremely useful for large scale applications in smart cities.

Potential directions for future research could be to examine hybrid optimization approaches that would combine different types of computational intelligence models to further enhance the capabilities of the WSN. This can include, for example, using machine learning approaches together with evolutionary algorithms or even other optimization approaches, such as reinforcement learning, for dynamic optimization. Furthermore, it is necessary to test the proposed approach in practice by implementing the WSN solution in a smart city environment and see how well the simulation results would be replicated in real life. Optimization of the WSNs is also vital from the perspective of scalability and sustainability of the future smart cities because of the necessity to expand the urban areas. Implementation of intelligent optimization algorithms will be crucial for making sure that the urban management processes will be sustainable and affordable in the future.

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