International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I10P109

Volume 72 Issue 10, 85-89, October 2024

Original Article

Optimizing Energy Efficiency in Wireless Sensor Networks: Integrating Bluetooth M-LPN System with ABC Algorithm

H. S. Mohammed[1], Omer A. Abdulkareem[2], A. Ahmad[3], Captain Samuel Dowse[4]

[1]*Melbourne Institute Technology, School of Information Technology and Engineering, 154-158 Sussex St, Sydney NSW 2000, Australia.*
[2]*Senior Product Engineer, Insituform Technologies-Azuria water solutions. 63005 Chesterfield, MO, USA.*
[3] *School of Computing, College of Art and Sciences, University Utara Malaysia, Malaysia.*
[4]*Australian Defence Force, Canberra, Australia.*

[1]*Corresponding Author : halmuslehi@academic.mit.edu.au*

Received: 20 August 2024 Revised: 04 September 2024 Accepted: 29 September 2024 Published: 25 October 2024

Abstract - *In the evolving landscape of sustainable technology, optimizing energy efficiency is increasingly critical. Bluetooth Low Energy (BLE) has emerged as a pivotal technology for energy-efficient communication, particularly in the Internet of Things (IoT) and healthcare sectors. This study explores the integration of BLE with the Artificial Bee Colony (ABC) algorithm to enhance the efficiency of Bluetooth M-Low Power Node Wireless Sensor Networks (M-LPNWSNs). The ABC algorithm, inspired by the foraging behavior of honeybees, excels in optimizing energy consumption in Wireless Sensor Networks (WSNs) through a mesh topology, which ensures robust and efficient data transmission. This paper examines the synergy between BLE and the ABC algorithm, focusing on the advantages of mesh networks and low-power nodes in reducing power consumption. Through detailed simulations and comparative analyses, the effectiveness of the ABC algorithm in improving energy efficiency in Bluetooth M-LPNWSNs is demonstrated. Key results highlight the algorithm's superiority over traditional methods, such as Genetic Algorithms (GA), in minimizing power usage. This research provides valuable insights into developing more sustainable and efficient WSNs, offering a practical framework for integrating BLE with advanced optimization techniques.*

Keywords - *Bluetooth low energy, ABC algorithm, Wireless sensor networks, Energy efficiency, Mesh topology.*

1. Introduction

In the contemporary drive toward sustainable technology, energy efficiency has become a cornerstone of innovation. With the proliferation of connected devices, particularly in the Internet of Things (IoT) and healthcare sectors, optimizing energy consumption is crucial. Bluetooth Low Energy (BLE) represents a leading technology in this domain, offering significant advancements in energy-efficient communication [1]. BLE's low power consumption and broad applicability make it ideal for a variety of applications, from smart homes to medical devices [2]. This paper investigates the integration of BLE with the Artificial Bee Colony (ABC) algorithm to enhance further the efficiency of Bluetooth M-Low Power Node Wireless Sensor Networks (M-LPNWSNs) [3]. The ABC algorithm, inspired by the foraging behavior of honeybees, is a robust optimization technique designed to improve energy efficiency in Wireless Sensor Networks (WSNs) [4]. It operates on a mesh topology, which facilitates effective data transmission over extended areas and ensures network resilience [5]. By employing beacon signals for initiating data transmission and adopting a "listening" mode, the ABC algorithm minimizes unnecessary transmissions, thus conserving energy [1].The integration of BLE and the ABC algorithm promises significant advancements in network efficiency. The mesh topology of the ABC algorithm enables efficient communication between nodes, while BLE's low-power characteristics align with the energy-efficient objectives of this system [3]. This paper details the benefits of combining these technologies, focusing on how low-power nodes and optimized data transmission paths contribute to reduced power consumption [6]. The methodology involves defining energy efficiency as the ratio of useful data transmitted to the total energy consumed, establishing a baseline for evaluating improvements. Moreover, the paper presents detailed simulations to compare the ABC algorithm with other optimization techniques, such as Genetic Algorithms (GA) [7]. The results illustrate the superior performance of the ABC algorithm in minimizing power consumption, emphasizing its potential for enhancing energy efficiency in Bluetooth M-LPNWSNs. By integrating BLE with the ABC algorithm, this research contributes a novel approach to developing sustainable and efficient wireless sensor networks, offering a practical framework for future advancements in this field.

2. ABC Algorithm: Nature-Inspired Optimization for Energy-Efficient WSNs

The ABC algorithm, inspired by the foraging behaviour of honeybees, is a nature-inspired optimization technique initially designed for numerical problem-solving but has found application in WSN networks to enhance energy efficiency [7]. Operating on a mesh topology, nodes in the network are interconnected, allowing for efficient data transmission over a broad area. The algorithm employs beacon signals emitted by each node to initiate data transmission, triggering communication among neighboring nodes6. Through a collective decision-making process informed by received beacon signals, the network determines the optimal path for data transmission, minimizing energy consumption. The algorithm includes a "listening" mode, enabling nodes to actively monitor the network for incoming data packets and respond only when necessary, reducing unnecessary transmissions and lowering energy usage [8]. Inspired by bee foraging behaviour, this adaptive and dynamic approach contributes to developing a robust and energy-efficient wireless communication network. An illustrative example in an agricultural field monitoring scenario demonstrates how the ABC algorithm optimizes communication paths, conserves energy through listening modes, and ensures effective data transmission in WSNs, showcasing its practical application and benefits in real-world scenarios [9].

3. Optimizing Energy Efficiency: A Mesh-Based Bluetooth M-LPNWSN System Integrated with ABC Algorithm

Integrating the Bluetooth M-LPN system and the ABC algorithm offers a compelling solution for an energy-efficient WSN network. This proposed system leverages the benefits of a mesh topology, where interconnected nodes facilitate efficient and resilient data transmission, aligning seamlessly with the energy-efficient communication objectives of Bluetooth Low Energy [10]. Introducing Bluetooth Low-Power Nodes enhances energy efficiency, proving ideal for medical, healthcare, home automation, and security systems applications. The ABC algorithm optimizes energy consumption by strategically determining optimal data transmission paths. Its applications in the IoT, medical monitoring, and industrial settings underscore its versatility. Meticulous simulations demonstrate the ABC algorithm's superiority over Genetic Algorithms, emphasizing its potential to enhance energy efficiency in Bluetooth M-LPNWSN networks. This integration presents a robust and versatile solution for sustainable and efficient wireless sensor networks [3]. This study presents a novel approach to optimizing energy efficiency in WSNs by integrating the Bluetooth M-LPN system with the ABC algorithm. The methodology involves several key steps, each contributing to the formulation of an energy-efficient model tailored to the unique demands of WSNs. The first step in our methodology involves defining the Energy Efficiency of the WSN [1]. Energy efficiency is expressed as the ratio of useful data transmitted to the total energy consumed within the network. This ratio is crucial as it quantifies the effectiveness of energy usage in maintaining network operations [1, 11].

$$EE = \frac{D_{transmitted}}{E_{total}} \tag{1}$$

Where:

- ✓ $D_{transmitted}$ represents the total amount of useful data transmitted by the network nodes.
- ✓ E_{total} denotes the total energy consumed by the network during the data transmission process.

This formula serves as the baseline for assessing improvements in energy efficiency resulting from the integration of the Bluetooth M-LPN system and the ABC algorithm.

4. Bluetooth M-LPN System Contribution

The Bluetooth M-LPN system is incorporated to leverage its low-power features, which are critical for minimizing energy consumption in WSNs4 [12, 13]. The system's contribution is modeled through the reduced power consumption associated with its low-power modes and optimized packet transmission.

$$P_{M-LPN} = \frac{E_{\boldsymbol{active}} + E_{Sleep}}{T_{cycle}} \tag{2}$$

Where:

- ✓ P_{M-LPN} represents the power consumption of the Bluetooth M-LPN system.
- ✓ $E_{active}\ and\ E_{Sleep}$ are the energy consumption during active and sleep modes, respectively.
- ✓ T_{cycle} denotes the total operational cycle time.

This equation illustrates how the Bluetooth M-LPN system contributes to overall energy efficiency by reducing energy use during both active communication and idle periods.

5. ABC Algorithm Contribution

The ABC algorithm is integrated into the methodology to optimize node selection and data routing within the WSN. The ABC algorithm enhances energy efficiency by minimizing energy consumption per node, which is captured in the following equation:

$$E_{ABC} = \sum_{i=1}^{N} \frac{E_{node_i} \cdot P_{selection}(node_i)}{N} \tag{3}$$

Where:

- ✓ E_{ABC} represents the total energy consumption as optimized by the ABC algorithm.

- ✓ E_{node_i} denotes the energy consumption of node i.
- ✓ $P_{selection}(node_i)$ is the probability of selecting node i for data transmission.
- ✓ N is the total number of nodes in the network.

This step emphasizes the role of the ABC algorithm in distributing network load efficiently, thereby extending the network's operational lifetime.

6. Integration into a Unified Energy Efficiency

The final step involves integrating the contributions from the Bluetooth M-LPN system and the ABC algorithm into a unified formula that provides a comprehensive measure of the optimized energy efficiency for the WSN.

$$EE_{optimized} = \frac{\sum_{i=1}^{N} D_{transmitted}(node_i)}{E_{total} + P_{M-LPN} + E_{ABC}} \quad (4)$$

Where:

- ✓ $EE_{\boldsymbol{optimized}}$ is the optimized energy efficiency of the WSN.
- ✓ $D_{transmitted}(node_i)$ represents the useful data transmitted by node i.
- ✓ $E_{total} + P_{M-LPN} + E_{ABC}$ are as defined in the previous steps.

This formula integrates the low-power benefits of the Bluetooth M-LPN system with the optimization capabilities of the ABC algorithm, resulting in a comprehensive model for enhancing energy efficiency in WSNs. The methodology is adaptable and can be expanded or refined based on specific network requirements or environmental conditions, making it a robust solution for energy management in modern wireless sensor networks.

Here is a table that provides a summary of the key parameters and their descriptions used in a code related to the implementation of a Mesh-Based Bluetooth M-LPNWSN system optimized by the ABC algorithm. Each parameter in the table plays a specific role in the algorithm's operation and overall system simulation, as shown in Table 1.

Table 1. Summary of parameters and descriptions used in the code for Mesh-Based Bluetooth M-LPNWSN system with ABC algorithm

Parameter	Description	Value/Range
nNodes	Number of nodes in the network.	100
nScoutBees	Number of scout bees in the ABC algorithm.	10
nEmployedBees	Number of employed bees in the ABC algorithm.	20
nOnlookerBees	Number of onlooker bees in the ABC algorithm.	20
MaxIt	Maximum number of iterations for the ABC algorithm.	500
nBees	Total number of bees (scout, employed, and onlooker).	50
networkSize	Size of the network area.	1000 x 1000
dataRate	Data transmission rate.	1 Gbps

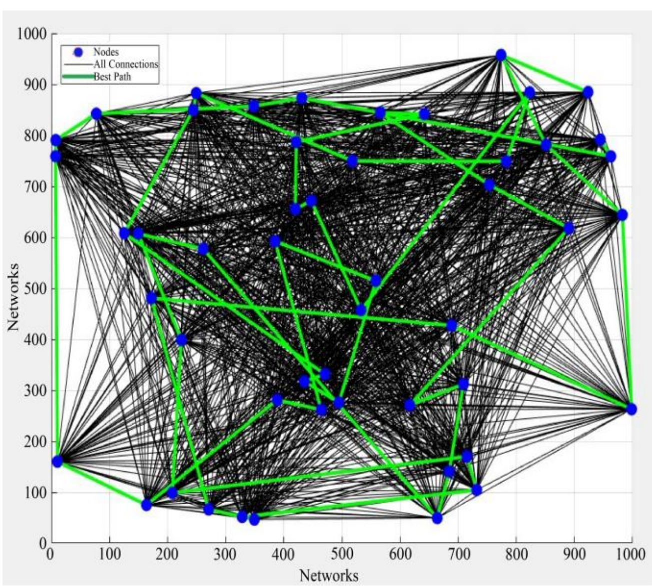

Fig. 1 Simulation of a Bluetooth M-LPN with WSN using ABC algorithm

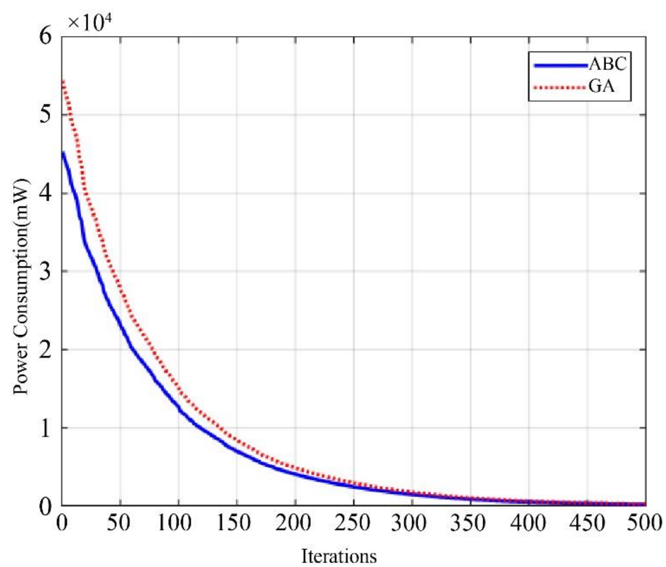

Fig. 2 Comparison of power consumption optimization between the ABC algorithm and GA in a Bluetooth M-LPNWSN

The simulation depicted in Figure 1, conducted using MATLAB R2024a, models a Bluetooth M-LPN using WSN with 100 nodes distributed in a 1000 x 1000-meter area and runs through 500 iterations. Key parameters include 10 scout bees, 20 employed bees, and 20 onlooker bees, all part of the ABC algorithm used to find the best paths for data transmission and optimize node configurations.

Each node plays a vital role in data collection, transmission, and energy consumption. The dynamic optimization process, driven by these parameters, is designed to enhance network performance and energy efficiency, with Figure 1 illustrating how the nodes' interactions and configurations evolve through iterative optimization.

Figure 2 illustrates a comparison between the ABC algorithm and GA in optimizing power consumption within a Bluetooth M-LPNWSN system. It shows that after 500 iterations, the ABC algorithm achieves significantly lower power consumption than the GA algorithm, indicating its superior effectiveness in minimizing energy use. The GA algorithm, serving as a benchmark, records higher power consumption, underscoring the ABC algorithm's efficiency. This outcome highlights the ABC algorithm's potential for enhancing energy efficiency in low-power networks, offering valuable insights for researchers and practitioners seeking optimal solutions for such systems.

Figure 3 illustrates the convergence trajectories of power consumption and network lifetime across 500 iterations with 100 nodes in the WSN. The curves reveal that the ABC algorithm demonstrates superior convergence dynamics that showcase its efficacy in optimizing both power consumption and network lifetime. The ABC algorithm's performance highlights its precision and effectiveness, establishing it as a leading method for enhancing convergence in Bluetooth M-LPN WSN networks.

Applying the ABC algorithm to Bluetooth M-LPN WSN system applications has yielded significant results in power consumption efficiency over 500 iterations. As shown in Figure 4, the ABC algorithm outperforms other methods, achieving notably lower power consumption. This demonstrates its effectiveness in optimizing energy efficiency within Bluetooth M-LPN WSNs. The results underscore the potential of the ABC algorithm to enhance power efficiency in low-power communication networks, offering valuable insights for researchers and practitioners seeking optimal solutions in this domain. The application of the ABC algorithm to Bluetooth M-LPN WSN system scenarios has demonstrated noteworthy improvements in power consumption efficiency over 500 iterations. As depicted in Figure 5, the ABC algorithm outperforms alternative methods in minimizing power consumption, underscoring its effectiveness in enhancing energy efficiency within Bluetooth M-LPN WSNs.

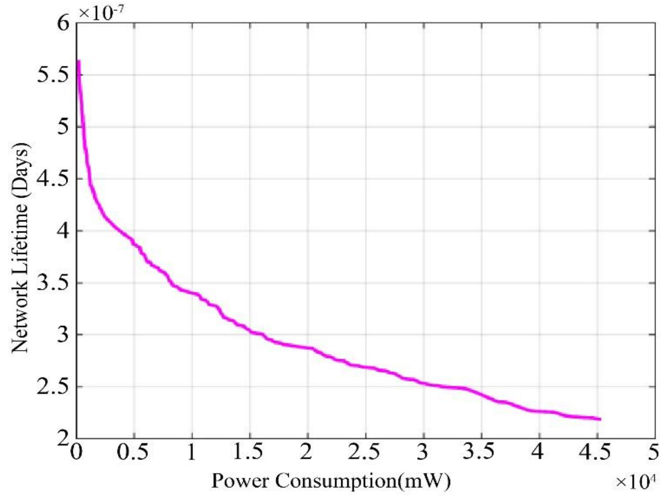

Fig. 3 Comparative convergence curves for power consumption and network lifetime in a Bluetooth M-LPNWSN

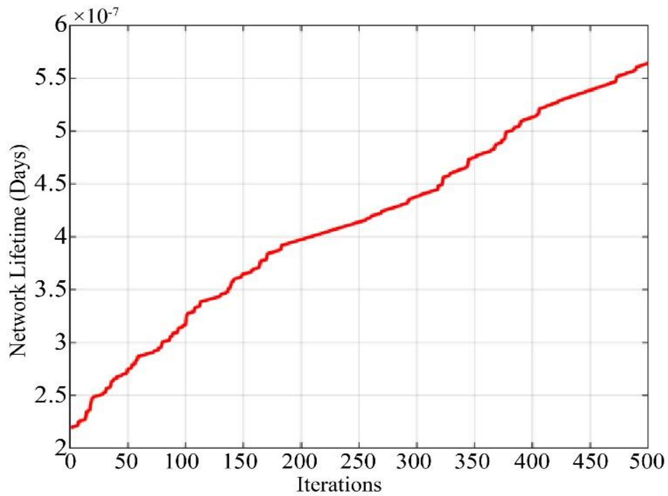

Fig. 4 Power consumption versus iterations efficiency in Bluetooth M-LPNWSN using the ABC algorithm

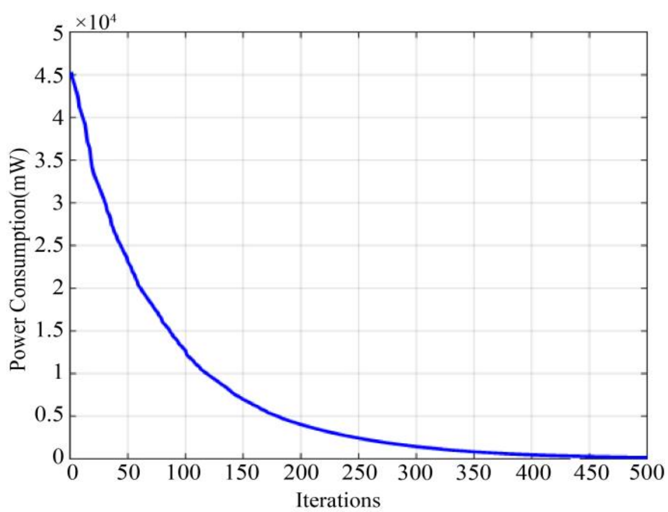

Fig. 5 Power consumption versus iterations efficiency in Bluetooth M-LPNWSN using the ABC algorithm

These findings emphasize the ABC algorithm's potential to significantly boost power efficiency in low-power communication networks, providing crucial insights for both researchers and practitioners in search of optimal solutions.

7. Conclusion

The integration of BLE with the ABC algorithm represents a significant advancement in optimizing energy efficiency in WSN. This study demonstrates how combining BLE's low-power capabilities with the ABC algorithm's robust optimization techniques can lead to substantial improvements in network performance and energy conservation. The mesh topology enabled by the ABC algorithm ensures efficient data transmission across the network, while its adaptive "listening" mode reduces unnecessary power consumption. Simulations conducted in this study reveal that the ABC algorithm outperforms traditional methods, such as the GA algorithm, in achieving lower power consumption and extending network lifetime.

The findings underscore the effectiveness of this integrated approach in enhancing the sustainability and efficiency of Bluetooth M-LPNWSNs. By optimizing energy usage and improving data transmission paths, this research provides a practical framework for developing more efficient and environmentally friendly WSN solutions. Future work could explore further refinements and applications of this approach in diverse settings, contributing to the broader goal of sustainable technology development.

Acknowledgments

The authors sincerely thank the SITE in Melbourne Institute Technology Sydney campus for their support and collaboration.

References

[1] Ado Adamou Abba Ari et al., “Energy Efficient Clustering Algorithm for Wireless Sensor Networks Using the ABC Metaheuristic,” *2016 International Conference on Computer Communication and Informatics*, Coimbatore, India, pp. 1-6, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[2] S. Jeba Anandh, and E. Baburaj, “Energy Efficient Routing Technique for Wireless Sensor Networks Using Ant-Colony Optimization,” *Wireless Personal Communications*, vol. 114, no. 4, pp. 3419-3433, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[3] Deep Kumar Bangotra et al., “Energy-Efficient and Secure Opportunistic Routing Protocol for WSN: Performance Analysis with Nature-Inspired Algorithms and its Application in Biomedical Applications,” *BioMed Research International*, vol. 2022, no. 1, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[4] Long Cheng, Lu Qu, and Yu-wei Xu, “Artificial Bee Colony Algorithm-Based Multiple-Source Localization Method for Wireless Sensor Network,” *2017 2nd IEEE International Conference on Computational Intelligence and Applications*, Beijing, China, pp. 445-448, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[5] Gordana Gardašević et al., “Emerging Wireless Sensor Networks and Internet of Things Technologies Foundations of Smart Healthcare,” *Sensors*, vol. 20, no. 13, pp. 1-30, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[6] Yijun Gu et al., “Multi-Objective Artificial Bee Colony Algorithm Based On Scale-Free Network for Epistasis Detection,” *Genes*, vol. 13, no. 5, pp. 1-19, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[7] Josie Hughes, Jize Yan, and Kenichi Soga, “Development of Wireless Sensor Network Using Bluetooth Low Energy (BLE) for Construction Noise Monitoring,” *International Journal on Smart Sensing and Intelligent Systems*, vol. 8, no. 2, pp. 1379-1405, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[8] K. Johny Elma, and S. Meenakshi, “Clustering and Coverage Using Artificial Bee Colony (ABC) Optimization in Heterogeneous WSN,” *Journal of Advanced Research in Dynamical and Control Systems*, vol. 12, no. 3, pp. 182-194, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[9] Rashmi Mishra, and Rajesh K. Yadav, “Energy Efficient Cluster-Based Routing Protocol for WSN Using Nature Inspired Algorithm,” *Wireless Personal Communications*, vol. 130, pp. 2407-2440, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[10] Naveen Muruganantham, and Hosam El-Ocla, “Routing Using Genetic Algorithm in a Wireless Sensor Network,” *Wireless Personal Communications*, vol. 111, pp. 2703-2732, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] Satyasen Panda et al., “Performance Analysis of Wireless Sensor Networks Using Artificial Bee Colony Algorithm,” *2018 Technologies for Smart-City Energy Security and Power*, Bhubaneswar, India, pp. 1-5, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[12] Huadong Wang, Ying Chen, and Shi Dong, “Research on Efficient-Efficient Routing Protocol for WSNs Based on Improved Artificial Bee Colony Algorithm,” *IET Wireless Sensor Systems*, vol. 7, no. 1, pp. 15-20, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[13] Shuai Wang et al., “Adaptive Multi-Population Artificial Bee Colony Algorithm for Wireless Sensor Network Coverage Optimisation,” *International Journal of Wireless and Mobile Computing*, vol. 25, no. 4, 2023. [CrossRef] [Google Scholar] [Publisher Link]