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Research Article

Optimized Low-Powered Wide Area Network Within Internet of Things

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The Internet of Things is rapidly becoming an integral part of everyday life. Low-powered wide area networks are capable of providing reliable connectivity even in low-density areas and devices consuming low amounts of energy. The exponential increase in the use of Internet of Things applications across the globe will continue to generate more and more data traffic within the Internet of Things network. Thus, end devices within the Internet of Things network in the near future will rise up to billions of devices operating across the Internet of Things network, generating a necessity for more correct and reliable energy conservation Internet of Things technology. This prompted the research work on optimized low-powered wide area networks. The experiment has been carried out in various stages: firstly, running a simulation over a wireless sensor network without optimization using MATLAB Simulink and obtaining the following result of 6.3997e-17 joules power consumption; secondly, the authors tested the network with power optimization using particle swarm optimization algorithms and obtained a better result of 2.5230e-17 joules. The Long Range energy consumption is reduced by 60%. Lastly, different simulation tests of Long Range Wide Area Network protocols were conducted with respect to some network communication parameters such as throughput, packet loss, delay, data transmission, buffer size, and network density.

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1. Introduction

Background to the Study

The Internet of Things (IoT) is a transformative technology designed to establish connections among diverse devices through Radio Frequency Identification (RFID) tags, sensors, actuators, mobile phones, and other means, enabling them to collaborate in achieving specific tasks. This technological paradigm encompasses three key parameters: Things orientation, referring to objects within the IoT context; Internet orientation, facilitating communication across various nodes; and semantic orientation, regulating data traffic among communicating devices within IoT networks (Arslan *et al.,* 2019).

The Internet of Things represents an innovative approach that leverages the power of the internet to facilitate communication between tangible items or entities. These tangible entities encompass a broad spectrum, including commercial equipment and household appliances. Through the integration of sensors and communication networks, these entities generate valuable data, paving the way for a diverse range of services for individuals. For example, strategically managing building energy consumption can lead to significant reductions in energy costs (Motlag *et al.,* 2020).

The majority of IoT-based systems consist of battery-operated devices such as smart sensors, radio frequency identification (RFID) tags, home appliances, surveillance cameras, smartphones, and various other items. However, the rapid proliferation of these devices has given rise to challenges related to energy efficiency, attracting considerable attention in the process (Adul-Qawy *et al.,* 2020).

Research indicates varying levels of performance in terms of energy power consumption, range, coverage, and latency within the LPWAN sector. This technology is marked by low-power operating devices, cost-effective network components, and broad coverage. Various protocol versions operate under the LPWAN environment to fulfill the domain characteristics across unlicensed free bands. Notably, LoRaWAN stands out as one of the leading protocols in LPWAN technologies, competing for the establishment of large-scale IoT networks. LoRaWAN is anticipated to play a crucial role in connecting billions of devices in the future (Ramli *et al.,* 2021).

The widespread adoption of LoRaWAN technology can be attributed to its strong backing by the LoRa Alliance, a non-profit association comprising over 500 member companies. This work places emphasis on LoRaWAN due to its popularity in the IoT landscape. In the LoRaWAN network's star-of-stars architecture, messages traverse between end devices (EDs) and the central network server (NS) via gateways (GWs). These gateways establish connections with the network server through conventional IP connections, acting as transparent bridges by converting RF transmissions to IP packets and vice versa. LoRaWAN devices utilize the Pure ALOHA media access control (MAC) protocol for communication channel access. Through ALOHA, devices can broadcast packets directly to the communication channel without the need for carrier or collision detection. The simplicity of this protocol contributes to reduced transmission costs, overhead, and, significantly, the power consumption of transmitting devices (Ramli *et al.,* 2021).

When evaluating four wireless technologies, namely WiFi, BLE, Zigbee, and LoRaWAN, it becomes evident that WiFi consumes the highest amount of power, making it unsuitable for applications reliant on battery power (Sadowski and Spachos, 2018). In contrast, more suitable options for energy-efficient systems, especially in the energy sector, include low-power wide area network communication technologies such as LoRa, Sigfox, and LTE M. These technologies operate in unlicensed bands, offering reliable, cost-effective, low-power, long-range, and last-mile solutions for smart energy management (Motlagh *et al.,* 2020).

IoT applications span areas such as transportation and logistics, utilities, smart cities, smart buildings, consumer electronics, industry, environment, and agriculture. With increasing demand and the vast potential within the IoT ecosystem, LPWANs are anticipated to witness more advanced applications in the future, expanding into domains like remote healthcare, traffic safety and control, smart grid management, complex industrial processes, as well as applications in manufacturing, training, and surgery. Consequently, the increasing demands in these diverse domains underscore the need for LPWANs to exhibit high reliability, availability, and low latency. The batteries of End Devices (EDs), such as sensors, cannot be easily charged or replaced after prolonged use, impacting the network's operational lifespan and hindering its ability to accomplish tasks within the expected time frame, especially given the generated data traffic (Boulogeorgos *et al.,* 2016).

The anticipated rapid increase in EDs within IoT networks in the future, reaching into the billions across public, industrial, and personal networks, emphasizes the need for more accurate and reliable energy conservation technology. Addressing this challenge, the research proposes a technical solution using the particle swarm optimization algorithm to appropriately assign spreading factors to various end devices at the gateway. This optimization aims to facilitate efficient data traffic across the network, ultimately reducing the power consumption of end devices. The remaining parts of the research will cover related work, framework, IoT network simulation, results, and discussion. The following are the contributions of this study to the body of knowledge:

1. Optimized the LoRaWAN protocol by appropriately allocating spreading factors using the PSO algorithm.
2. Minimized the power consumption of end devices over a Low Power Wide Area Network.
3. Performed an evaluation of the proposed model using the following metrics: throughput, number of nodes, packet loss, data transmission, and buffer size.

2. Related Work

The research investigates a multitude of prior studies concerning low-power wide area networks (LPWANs), focusing on topics such as the energy efficiency and power consumption of Internet of Things (IoT) devices. The examination encompasses an overview of LPWAN technology, exploring design technologies, and delving into both proprietary and standard aspects of LPWANs. Additionally, the research involves a comparative analysis of LPWANs using various algorithms, specifically evaluating their energy efficiency. Furthermore, the study addresses challenges faced by LPWANs in the IoT domain and outlines potential future directions in this field.

Hosseinzadeh *et al,.* (2022) examine the most significant issue facing the IoT infrastructure today: a deficiency of available energy in nodes. A clustering approach was used by the researchers for maximum efficiency in terms of both power consumption and network longevity. The authors used Hybrid Aquila Optimizer and FireFlow Algorithm approaches for IoT clustering and routing operations in their study. Proving effective, the suggested technique has been found to improve system energy usage by at least 18% and increase the packet delivery ratio by at least 25%. According to the authors, in the future, researchers may choose to systematically relocate a system's base station, cluster head node, and cluster member node in order to better understand how such changes affect network operation.

Szynkienwicz *et al.,* (2015) consider an energy-aware state to reduce network energy consumption within an IoT-based heterogeneous wireless sensor network. The energy state of network devices plays an important role in the design, development, and management of computer networks. In relation to our current area of research, the authors used heuristic algorithm optimization techniques to reduce network power consumption within IoT at the network device control level. Moreover, the authors used a central control framework and a hierarchical control framework on both small and medium-sized networks for network energy consumption optimization. The authors stated energy consumption on wired and wireless computer networks as an issue of consideration across IoT networks.

Iwendil *et al.* (2021) worked on A Metaheuristic Optimization Approach for Energy Efficiency in the IoT Network in order to minimize the energy consumption of sensors in the IoT network as well as extend network lifetime. The authors used a hybrid whale optimization algorithm (WOA) with simulated annealing (SA). Researchers compared hybrid meta-heuristic algorithms with other algorithms where the meta-heuristic algorithm outperforms state-of-the-art optimization algorithms like the artificial bee colony algorithm, the genetic algorithm, the adaptive gravitational search algorithm, and the whale optimization algorithm.

Pau (2015) carried out research on power consumption reduction for wireless sensor networks using a fuzzy approach such as a Fuzzy Logic Controller (FLC), which can be used in such a way as to further reduce the energy consumption in a WSN. In fact, the fuzzy-based approach presented in their work dynamically changes the sleeping time in order to increase the battery duration of the sensor devices. Simulation results demonstrate that using the proposed FLC, a substantial reduction in energy consumption is obtained compared to simulations carried out with fixed sleeping times. The results have been obtained using Gaussian membership functions because an improvement of 30% has been achieved compared to the approach without FLC.

Abdul-Qawey (2020) carried out a study on the classification of energy-saving techniques for optimum utilization across the IoT heterogeneous wireless sensor network. The co-authors work toward energy-saving techniques within the IoT domain for proper network management with respect to efficient power consumption. Abdul-Qawey *et al*. (2020) mentioned in their work that realizing energy efficiency in heterogeneous wireless sensor devices becomes a key challenge and extends the system's life. The researchers considered the current operating conditions of network devices, such as active, idle, and sleeping states. According to the authors, upcoming developments will focus on the design and implementation parts of the IoT.

According to Ismail *et al*. (2019), LPWAN (Low-Power Wide-Area Network) emerged as an enabling technology for Internet of Things applications. The authors conducted a study on low-power wide-area networks with respect to opportunities, challenges, and future directions within the IoT domain. Ismail and colleagues discussed the characteristics of current low-power wide-area network (LPWAN) technologies, which enable them to provide long-range connectivity, low-power communication, and low deployment costs for a large number of devices. The researchers mentioned in their journal that, due to the increase in demand within the IoT network, several competing technologies are being developed, including LoRa, SigFox, IQRF, RPMA, DASH7, and Weightless. The authors have stated future research in LPWAN as follows: future scalability and coverage, technology coexistence, inter-technology communication, real-time communication, support for control applications, support for mobility, support for data rate, and security.

Bouguera *et al*. (2018) presented an improved energy model for sensor nodes. Various LoRaWAN modes and scenarios based on LoRaWAN Class A were examined for a particular Internet of Things application. The authors also looked into LoRaWAN scenarios to figure out how much power the sensor node would consume. The created model enables analysis of how choices in hardware and software affect the autonomous behavior of the node under study. The authors demonstrated through numerical results that the amount of energy consumed varies depending on the LoRa/LoRaWAN parameters used, which include spreading factor, coding rate, payload size, and bandwidth, in order to reduce the energy consumption of the sensor node. Our research adopted some of these parameters for the formulation of the power consumption model.

Zanaj and colleagues (2021) carried out a survey and analysis of short- and wide-area IoT technologies to ascertain the energy efficiency and consumption characteristics of LPSAN and LPWAN technologies. The characteristics of the most important Internet of Things technologies—low-power wide-area networks (LPWAN) and low-power short-area networks (LPSAN)—have been thoroughly studied by the writers. In the end, the most often used methods for increasing energy efficiency could be categorized into multiple broad categories: methods for data reduction, radio optimization, sleep/wake, energy-efficient routing, and method evaluation across multiple technologies were all taken into consideration. Among Low Power Wide Area Network (LPWAN) standards, LoRaWAN has become a prominent protocol, as they have discussed in their journal.

Motlagh *et al.* (2020) conducted an investigation into the existing literature on the application of the Internet of Things in energy systems in general, and smart grids in particular. Many IoT techniques are studied by the researchers. The paper also examines some of the challenges associated with implementing IoT in the energy sector, such as privacy and security, and some of the potential solutions, such as blockchain technology. The authors worked on the application of the Internet of Things in the energy sector and consider the Internet of Things to be a platform that promotes energy conservation, specifically efficient energy use, through the use of various LPWAN protocols such as LoRa, Sigfox, and others; thus, it formed the basis of using the LoRa protocol in our study.

Lansky *et al*. (2022) carried out a study on a lightweight centralized authentication mechanism for the Internet of Things driven by fog. The authors developed a lightweight centralized authentication mechanism for IoT using cryptographic techniques and asymmetric cryptographic techniques for the fog network. For the authentication between the gadget and the fog, lightweight encryption algorithms are employed, and asymmetric procedures are implemented for the identification system between the fog and the cloud server. For future work, there is a need for more modification to be made to use this method in various contexts such as BLE or Zigbee.

Lavric and Popa (2018) carried out an experiment on the performance evaluation of LoRaWAN communication scalability in large-scale wireless sensor networks. The authors specifically found out the number of nodes that can be handled by a given gateway so as to reduce collision. Lavric and co. (2018), from their obtained results, concluded that the configuration with the lowest transfer rate ensures the highest level of collisions. Because the airtime of the packet is a few seconds, it is prone to collisions that can negatively influence the capacity of the communication channel. Based on their evaluation results on collision reduction over the LoRa network, they found out that collision will be minimized using ADR algorithms and by limiting the maximum number of transmission packets over the network.

Raj and Basar (2019) designed a gateway that enables connection establishment using simple fuzzy rule-based neural networks clubbed with clustering to have a proper exploitation of energy, evading the wastage caused during the selection of the head and the patterning of the cluster. The learned system enables cluster patterning and routing to make optimized choices on the selection of the nodes for conveying and affords a delay-less, energy-aware, and less failure-prone proposed system for transmission. The performance analysis is done with regard to the packet delivery ratio, energy consumption, sensor network lifetime, and delay to evidence its perfect functioning. According to the authors, performance evaluation of the proposed system compared to the preceding methods proves that the proposed system is highly adept.

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Mechanism	Approach	Advantage	Weakness
Hosseinzadeh et al., (2022)	Hybrid Aquila Optimizer and Firefly algorithms	Reduction of power consumption and extended network lifetime	Relocation of experiment parameters, for example
Szynkienwicz et al., (2015)	Centralized and Hierarchical control framework for energy-saving management.	Formulation of Meta-heuristic Algorithm	Fails to account for large size networks.
Iwendi et al., (2021)	Meta-heuristic approach: Whale Optimization algorithm-Simulated Annealing	Minimization of power consumption and extended network lifetime	Fails to account for delay, node density, link lifetime, etc., for performance metrics in the selection of cluster head within IoT wireless sensor networks
Pau, (2015)	Fuzzy logic controller	Reduction of power consumption and increase in network lifetime.	Further validation of the model by multiple runs of simulation and in contexts characterized by real-time constraints.
Abdul-Qawey (2020)	Classification of energy-saving techniques for IoT base	Appropriate classification of energy-saving techniques.	Design and implementation aspects of the IoT-based system to provide energy-aware green products.
Ismail et al., (2019)	Review of Low Power Wide Area Network	Explores opportunities and challenges in Low Power Wide Area Network across the IoT domain.	Future scalability and coverage, technology coexistence, inter-technology communication, real-time communication, support for control applications, and support for mobility.
Zanaj et al., (2021)	Power Model	Explores power consumption model for wireless sensor networks	Fails to account for spreading factor allocation.
Mechanism	Approach	Advantage	Weakness
Lansky et al., (2022)	Cryptographic and asymmetric cryptographic technique	Development of lightweight authentication mechanism	More modification of the proposed method needed to be used on BLE and Zigbee
Lavric and Pova, (2018)	ADR algorithms	Performance Evaluation of LoRaWAN Communication Scalability in Large-Scale Wireless Sensor Networks	N/A
Raj and Basar, (2019)	Clustering with neural and simple fuzzy rule based	Optimization of energy-efficient routing in IoT wireless sensor networks	N/A

Table 1. Summary of techniques mentioned.

3. Framework of the Research

The research framework was developed in alignment with the stated objective of the research project. The proposed methodology outlines the implementation of spreading factor allocation to various end nodes, utilizing the network simulator MATLAB to simulate the IoT network based on the LoRaWAN protocol. The spreading factor allocation is designed to be applied across the IoT network to optimize its performance. The parameters utilized in this framework were adopted from the studies conducted by Kim *et al*. (2020) and

Kalifeh *et al.* (2021). The visual representation of the research framework is depicted in the figure below.

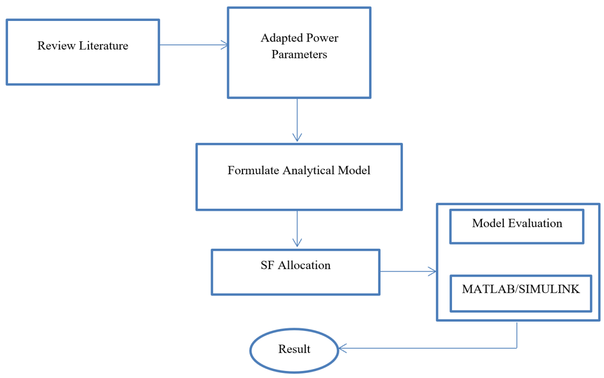

Figure 1. Framework for the Proposed Model

The framework of the proposed study can be described as depicted in Figure 1 as follows: Review of literature is the first part of a research work where related articles are reviewed for understanding, guidance, and focus on the proposed work. This is followed by the adaptation of power parameters from the related literature to be used in the research experiment. The formulation of the analytical model is a level where the power consumption model is derived from the related literature. The spreading factor is a level where the spreading factor is allocated to end devices across the simulated wireless sensor network at the gate. MATLAB is the platform where the wireless sensor network is simulated, the power consumption model is evaluated, and results are obtained.

IoT Architecture

Based on design considerations and network architectures for low-power wide-area networks by Chaudhari and Borkar (2020), IoT architecture has four layers, which are: LPWAN nodes, LPWAN Gateways, network server, and application server, as depicted in Figure 2 below.

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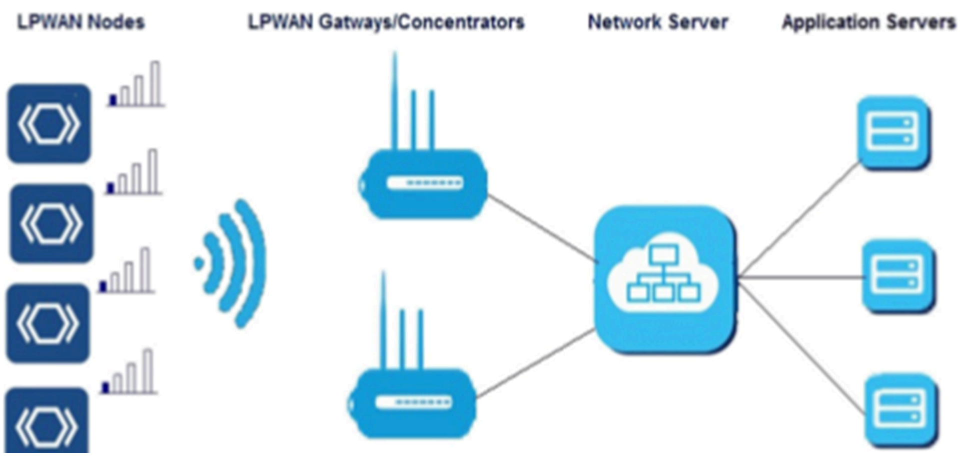

Figure 2. Typical LPWAN entities

Parameters for the Implementation of Proposed Model

The parameters for the implementation of the proposed model comprise both generic and specific parameters. They were adopted to address the pressing challenge of connecting and networking different computer systems due to the rapid development of information technology (Li et. al., 2015). However, IoT has its own network architecture, which corresponds to each layer of the OSI reference model. Generic parameters were considered part of the design based on the perception of Li *et al.,* (2015) that there is a conventional standard for heterogeneous devices to participate in a network in general called the Open System Interconnection (OSI) reference model. While specific parameters were adopted from the journals of Kalifeh *et al.* (2021) and Kim *et. al.* (2020), which are carrier frequency, transmission power, spreading factor (SF), bandwidth (BW), and code rate,

Data

The default spreading factor runs from 7 to 12, provided the data that we used. LoRa employs multiple orthogonal spreading factors ranging from 7 to 12. SF provides a tradeoff between data rate and range. The choice of a higher spreading factor can increase the range but decrease the data rate, and vice versa. Each symbol is spread by a spreading code of length 2^{SF} chips. At the transmitter, the spreading code is subdivided into codes of length $2^{SF}/SF$. Then each bit of the symbol is spread using the subcode, so it takes 2^{SF} chips for the spreading of one symbol (SF bits × 2^{SF} = SF). The substitution of one symbol for multiple chips of information means that the spreading factor has a direct influence on the effective data rate. At the receiver, the spreading code is multiplied by the received bits to regenerate the input data. (Noreen *et al.*, 2017).

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S/NO	Parameters	Values
1.	Carrier Frequency	433 MHz
2.	Transmission Power	20 mW
3.	Spreading Factor	SF7-SF12
4.	Bandwidth	125KHz
5.	Coding rate	4/8
6.	Duty cycle	1%

Table 2. Simulation Parameters

Procedures for Wireless Sensor Network Simulation

The processes for wireless sensor network simulation can be described as follows: the network will consist of 50 nodes, and an Area of Interest (AoI) of 20m by 30m is used as justified in the journal of Al-Fuhaidi *et al.,* (2020). Using a small number of nodes and a small AoI for wireless sensor network simulation gives better performance in terms of coverage, cost, and accuracy. MATLAB software is used for the simulation of wireless sensor networks using MATLAB Simulink, as well as for the implementation of spreading factor allocation across the wireless sensor network using the particle swarm optimization algorithm. Spreading factor

Spreading factor (SF)

Proposed Energy Model

The first approach consists of an active mode, that is, the duration during which the sensor nodes are active, and a sleep mode. All the gadgets are powered by 3.3V, with the exception of the sensor unit, which requires a power supply of 2V to operate. The quantity of power the sensor uses could change as a result of the energy used in this mode. Thus, it is necessary to take into account the sleep mode consumption. The total energy used by the end node is given by equation (1).

$$E_{Total} = E_{Sleep} + E_{Active} \qquad (1)$$

Where E_{Total} is the total energy used by the end nodes within the wireless sensor network, E_{Sleep} is the energy used when the end node is in sleep mode, and E_{Active} represents the energy used when the end node is in the on state. Therefore, E_{Sleep} is given by equation (2):

$$E_{Sleep} = P_{Sleep} * T_{Sleep} \qquad (2)$$

P_{Sleep} represents the sleep state, and T_{Sleep} represents the time taken in the sleep state. E_{Active} is given by equation (3.3):

$$E_{Active} = E_{SU} + E_m + E_{proc} + E_{WUT} + E_{Tr} + E_R \qquad (3$$

E_{SU} is the energy used for the sensor startup, E_m represents data measurement, E_{proc} represents microcontroller processing, E_{WUT} is the wakeup of the LoRa transceiver, E_{Tr} is the energy used by the transmission mode, and E_R is the energy used at the reception mode of the packets in the network. The model above depicts the total energy consumption of a wireless sensor network (Bouguera et al., 2018).

Steps for Allocation of SF using PSO

1. Define the problem
2. Initialize the Swarm
3. Evaluate particles
4. Update particle's best position
5. Update Swarm Global position
6. Update Particle's Velocity and Position
7. Repeat Steps 3-6
8. Output the Solution

4. Simulation of IoT Network

The first part of the experiment started with a simulation of a wireless sensor network in a MATLAB environment. The network consists of wireless sensors, microcontrollers, and the gateway. The sensors were randomly positioned using a random function in the MATLAB working environment. In addition, the experimenter keeps packet loss, delay, and throughput at the same level throughout the experiment. Below is a graph depicting the simulated LoRa network, showing wireless sensors at random point locations on the farm.

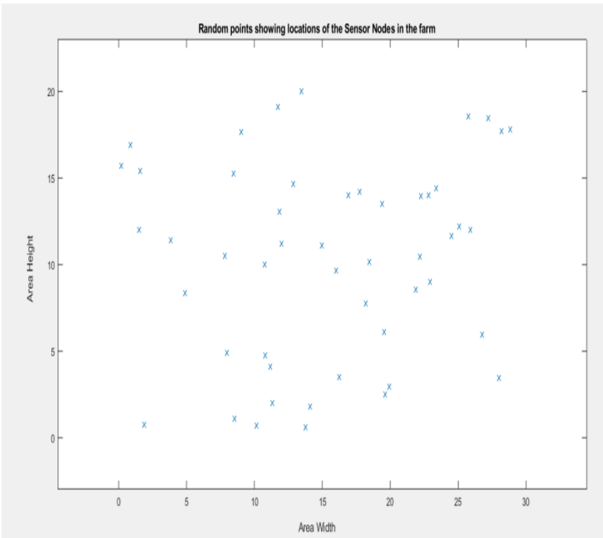

Figure 3. Wireless sensor network

Experiment Scenario 1

In Experiment Scenario 1, a spreading factor was implemented without optimization across the wireless sensor network (Figure 4). Scenario 1 has the following results:

- Network Energy Consumption without optimization = 6.3997e-17 Joules
- Delay1 (ms) without Optimization = 1.2574
- Throughput without optimization (kbps) = 0.4004
- Packet Loss without optimization = 0.5499

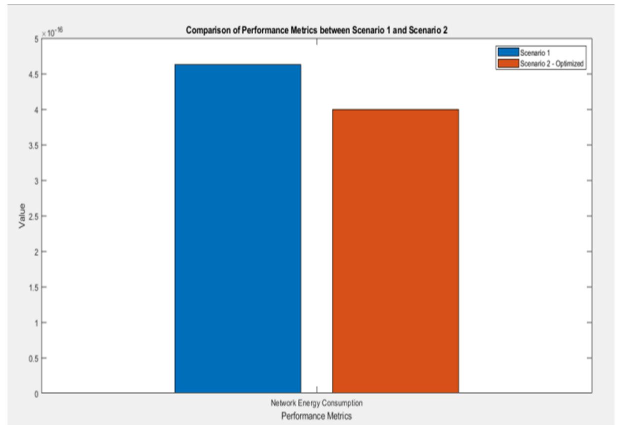

Figure 4. Experiment without optimization

Experiment Scenario 2

The experiment was conducted with optimization, meaning the spreading factor was implemented across the wireless sensor network using particle swarm optimization algorithms, and we came up with the following results:

- Network Energy Consumption optimized = 2.5230e-17 joules
- Delay optimized (ms) = 1.2574
- Throughput optimized (kbps) = 0.4004
- Packet Loss – Optimized = 0.5499

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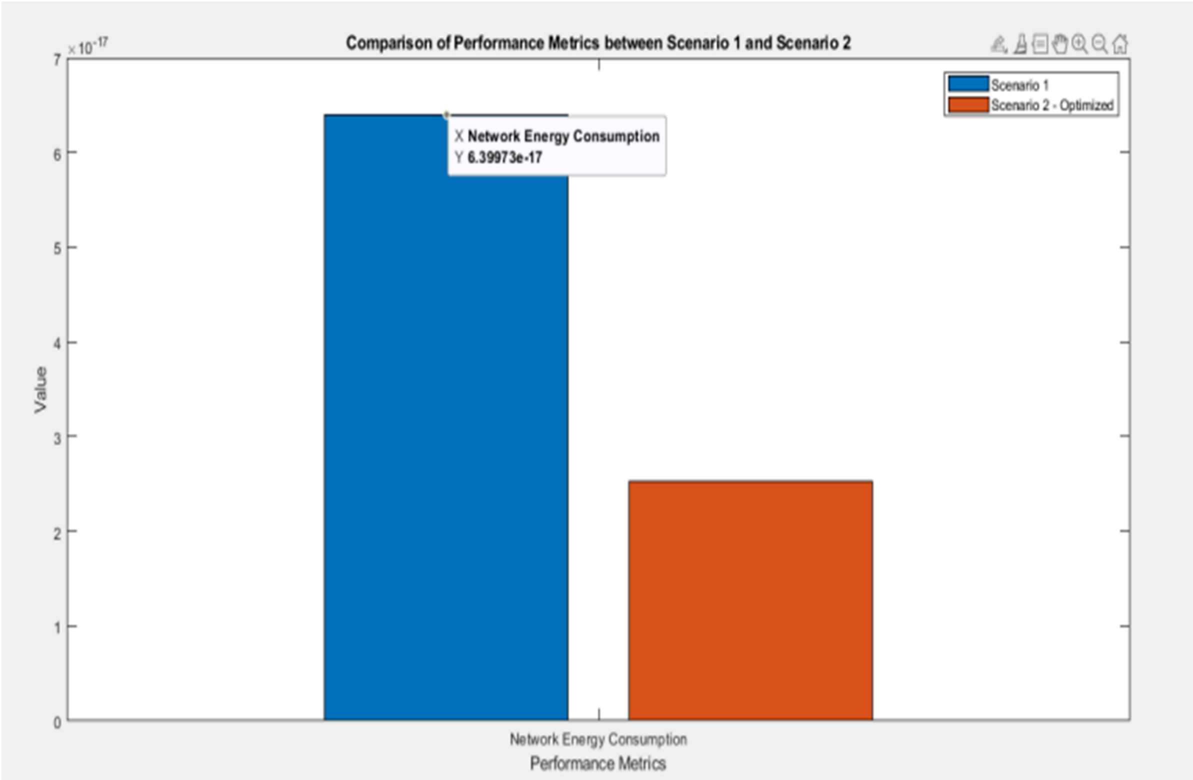

Figure 5. Scenario 2 optimized

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Experiment	Result
Experiment 1 network power consumption	6.3997e-17 joules
Experiment 2 network power consumption	2.5230e-17 joules
Improvement Percentage of the power consumption	60%

Table 3. Total results

Table 4 is the experimental result obtained from the phase 1 simulation experiment, where experiment 1 network power consumption indicates the running of simulation across the wireless sensor network without optimization, maintaining the same delay of 1.2574 ms, packet loss of 0.54994 kbps, and throughput of 0.4004 bit/sec throughout the first experiment. After the simulation without optimization, we obtained a power consumption of 6.399e-17 joules.

Experiment 2 network power consumption from Table 4 was obtained after running the simulation again with optimization, maintaining the same throughput, packet loss, and delay as the first experiment. The result of power consumption obtained after the simulation is 2.5230e-17 joules. Finally, the percentage was calculated by subtracting the power consumption of experiment 2 from experiment 1, dividing the difference by experiment 1, and multiplying by 100%. We arrived at reducing power consumption by 60% compared to the work of Bouguera *et al.* 2018 280 LoRaWAN probe setting, which uses only 44% more energy than the optimal setting.

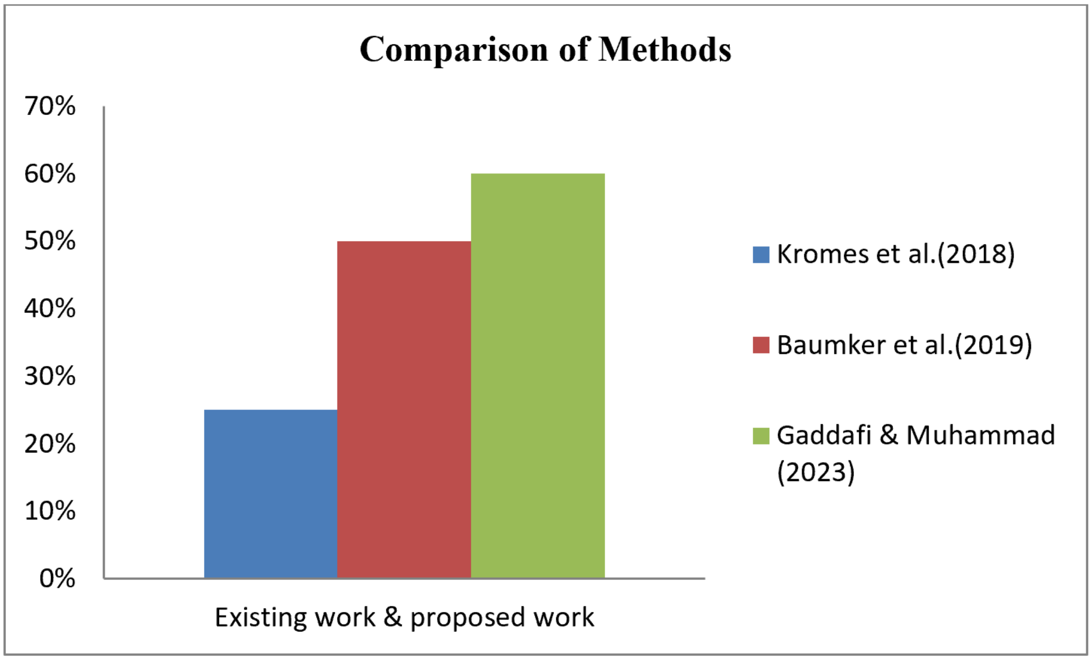

Figure 6. Methods

Figure 6 depicts the comparison of results between the proposed study and existing work. The work of Kromes *et al.* (2018) was carried out with respect to the received window (RX_1) from the Things Network (TTN) server. Their effort includes testing the power consumption of both RX_1 and RX2, where the result proved that the power consumption of RX_1 is reduced by 25% as compared to RX_2. Baumker *et al.*, (2019) found that the result of their experiment lowered the power consumption by 50% using the new generation configuration of the transmitter SX1262. The proposed work used the spreading factor allocation technique to lower power consumption by 60%. Based on the figure above, the proposed work outperformed the existing work.

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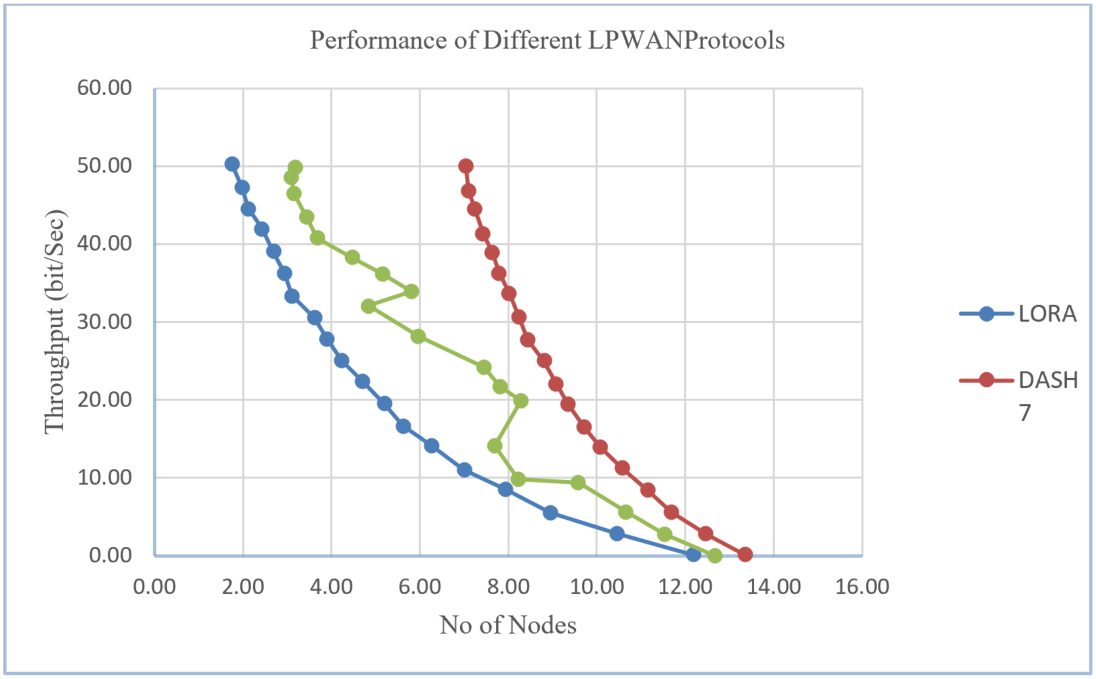

Figure 7. Performance of different LPWAN protocols

The graph above presents the performance between LPWAN protocols; the proposed protocol used LPWAN protocols in relation to the number of nodes and throughput. Figure 7 shows that with a decrease in the number of nodes, there is an increase in the throughput of the proposed protocol. Based on an evaluation of the energy consumption of LPWAN technologies by Rajab *et al*. (2021), it was found that DASH7 and LoRaWAN protocols are more power-efficient than Sigfox. However, the experiment above proved that the LoRaWAN protocol is the most energy-efficient as compared to the DASH7 and Sigfox protocols.

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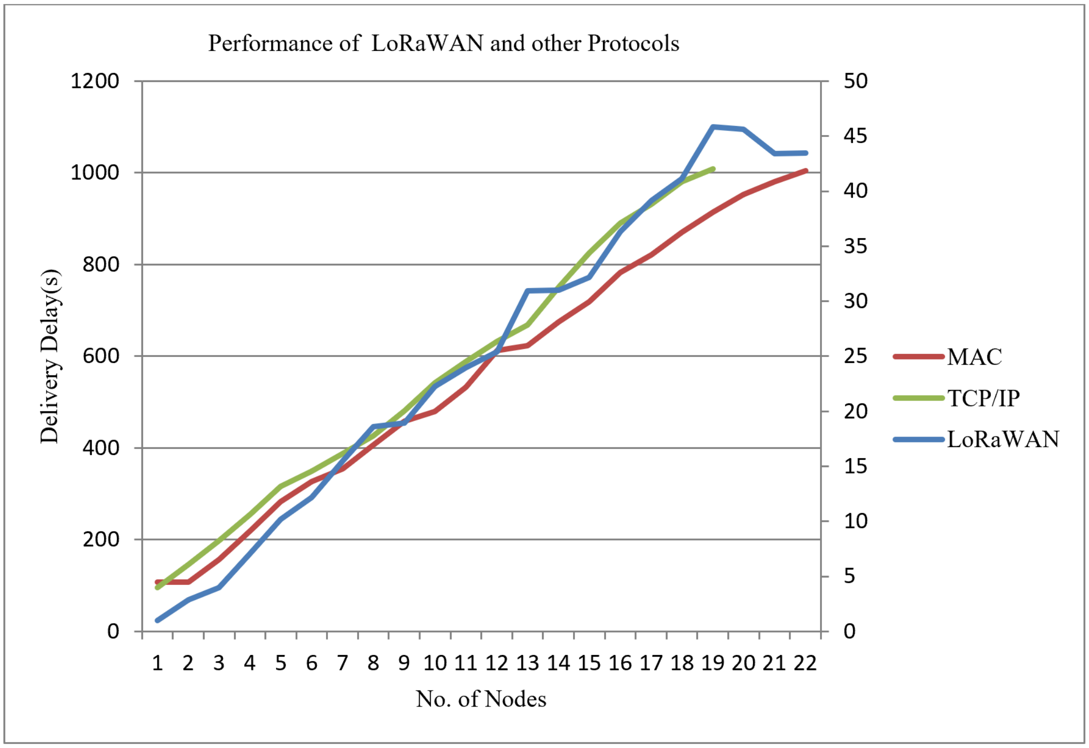

Figure 8. Delay Delivery with Respect to No. of Nodes

The graph above depicts the performance of the LoRaWAN protocol with respect to delivery delay and number of nodes. The results indicate that with an increase in network density, there is an associated increase in delay in delivery, which corresponds to the delivery delay of other routing protocols, as stated in the journal of Khan *et al*. (2013). The authors revealed that with an increase in the number of nodes, there is also an increase in delay.

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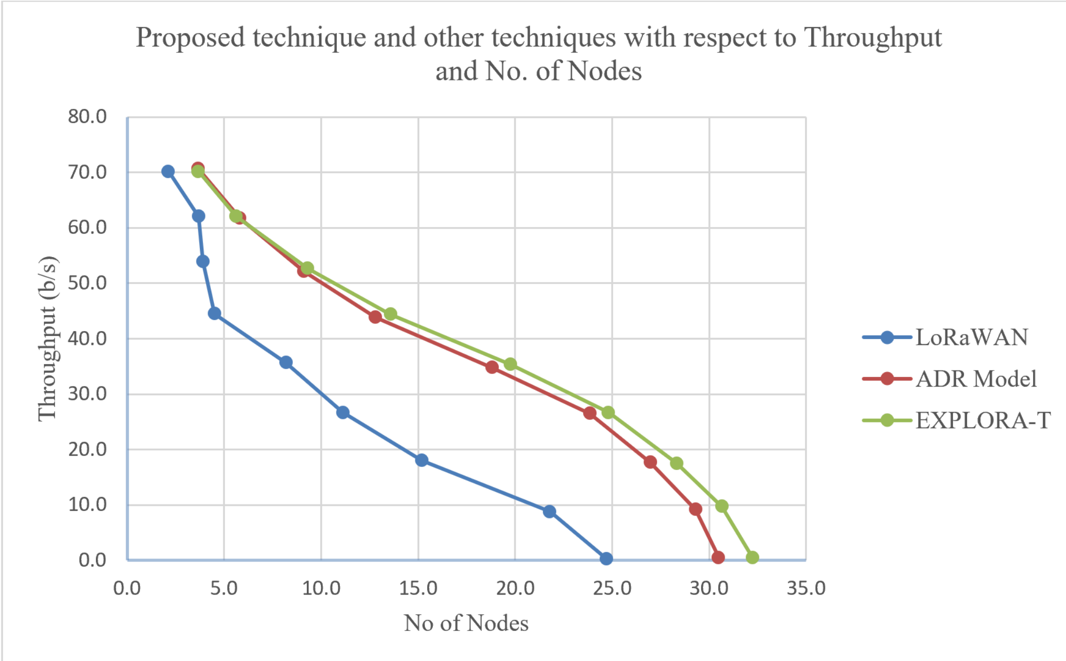

Figure 9. Proposed Techniques and other

Based on Figure 9, the proposed technique and other techniques were tested with respect to the number of nodes and throughput. Figure 9 shows that with a decrease in the number of nodes (density), there is an increase in throughput, and vice versa. The proposed system has maximized throughput to minimize the network density so as to reduce the packet loss of the proposed model. As stated in the journal]. Coumo *et al.*, 2017with a low packet rate, EX-PLoRa-T performs better, and with a high packet rate, EX-PLoRa-T performs better, meaning with a low number of nodes," thereby reducing packet loss in the proposed model. As noted in the journal Coumo *et al.* 2017, systems with a low packet rate perform better, and in the case of high packet rates, ExploRa-T performs better. This indicates that with a low number of nodes, the throughput increases.

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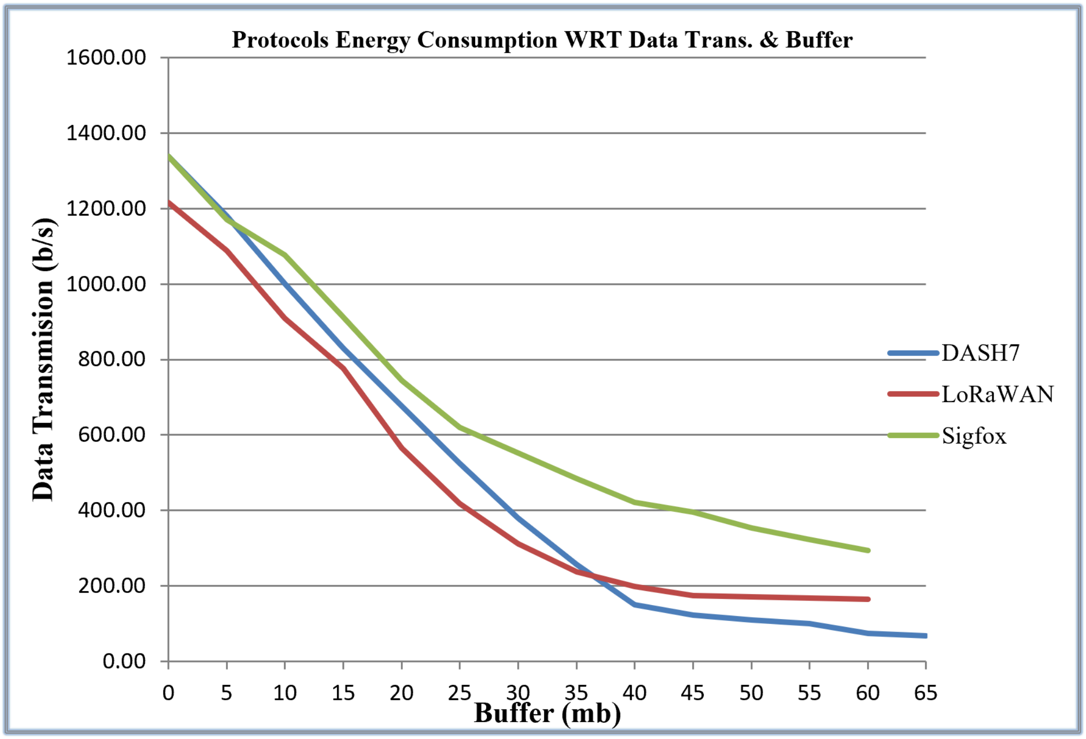

Figure 10. Protocols' Energy Consumption with Respect to Data Transmission & Buffer Size

The power consumption of LPWAN protocols as a function of buffer size and data transmission is shown in Figure 10. According to the equation above, buffer size decreases as data transmission increases, and vice versa. In comparison to other protocols, LoRaWAN is the most energy-efficient, according to the results presented in Figure 10. According to a journal article by Singh et al. 2020, Sigfox is not as energy-efficient as LoRaWAN and DASH7.

5. Results and Discussion

The experiment on battery power consumption was carried out in various stages, as follows: The experiment was implemented in a MATLAB environment; a wireless sensor network was simulated randomly using a random function in MATLAB across the measured area of 20 m by 30 m. Following the simulation of an IoT wireless sensor network, an optimization technique called particle swarm optimization was implemented by calling the PSO algorithms in the MATLAB library for the assignment of spreading factors to the end device at the LoRa gateway. Some specific key parameters, like data rate, spreading factor, throughput, network density, delay, and packet loss, were used as metrics for the validation of the model. The results of the experiment were obtained as follows: Experiment scenario 1 spreading factor was implemented without optimization across the wireless sensor network, as shown in Figure 4. Delay, packet loss, and throughput were maintained at the same level throughout the experiment. Experiment scenario 2 was obtained after implementing PSO for SF allocation across the wireless sensor network, as shown in Figure 5. Finally, the percentage of the reduced power consumption of the network was calculated by subtracting the power consumption of experiment 2 from experiment 1, dividing the difference by experiment 1, and multiplying by 100. Now, the total power consumption across the LoRa network was minimized by 60% as compared to the existing work of Krome et al. (2019), which uses the receive window (R_X) technique to reduce energy consumption by 25%, and the journal of Baumker et al. (2018), which uses the transmitter configuration method to reduce power consumption by 50%, as depicted in Figure 6. Based on Figure 6, the proposed work outperforms the existing work of Krome et al. (2019) and Baumker et al. (2018). The results of the proposed work indicate that using the Particle Swarm Optimization (PSO) algorithm for appropriate spreading factor assignment across the IoT network leads to lower energy consumption. This demonstrates the effectiveness of the PSO algorithm in

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finding an optimal spreading factor configuration that minimizes energy consumption. Based on the results of the proposed system, using the PSO in allocating spreading factors in LoRaWAN, the network can achieve a more efficient allocation of resources, resulting in reduced energy consumption. Different graphical models were tested with respect to various network communication parameters such as network density, throughput, buffer size, data transmission, packet loss, and network delay as another form of evaluating the proposed work against the existing work of the recently reviewed literature.

Limitations of the study

1. The study considers only device class A, while classes B and C are not captured for the wireless sensor network simulation.
2. Using MATLAB Simulink for wireless sensor network simulation lacks support for accurate physical modeling, which will reduce the level of accuracy of the results.
3. Lack of scalability: MATLAB Simulink may not handle large-scale wireless sensor network simulation scenarios efficiently.

6. Conclusion

The Internet of Things is a connection of various objects that communicate with each other without human intervention via radio frequency identification, actuators, etc., to carry out a task. The tremendous increase in end devices on the LoRa network led to more power consumption due to data traffic at the gateway, thus triggering the research work. The authors used the spreading factor allocation technique to reduce the data traffic at the gateway, thereby minimizing the power consumption of the end devices. The researchers carried out the experiment by simulating an IoT network and allocating spreading factors to heterogeneous devices across the wireless sensor network in a MATLAB environment. A particle swarm optimization algorithm was used as an optimization technique that reduced data traffic to minimize power consumption across the LoRa network. Thus, the experiment reduced power consumption by 60%. The researchers state that simulators like Arduino and ThingSpeak should be used for the online implementation of spreading factor allocation over an IoT cloud platform using PSO and to compare the results.

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Declarations

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