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Optimized Low-Powered Wide Area Network within Internet of Things

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ABSTRACT

The Internet of Things (IoT) is rapidly becoming an integral part of everyday life. LPWANs have been introduced to support the billions of internet-connected devices and the data they produce. LPWANs are capable of providing reliable connectivity even in low-density areas and devices consuming a low amount of energy. The exponential increase in the use of IoT applications across the globe will continue to generate more and more data traffic within the IoT network. Hence, it will increase device battery usage that may reduce the battery life expectancy limits. Thus, End Devices (EDs) within the IoT network in the near future will rise up to billions of devices operating in public, industry, and personal networks, generating a necessity for more correct and reliable energy conservation technology. This prompted the research work on an optimized low-powered wide area network within IoT. This paper focuses on three different strategies: LoRa power consumption model design, simulation of IoT wireless sensor networks, and implementation of SF allocation across the wireless sensor network and results analysis. 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 test the network with power optimization using particle swarm optimization algorithms and obtained a better result of 2.5230e-17 joules. The LoRa energy consumption is reduced by 60%. Lastly, different simulation tests of LoRaWAN protocols with respect to throughput, packet loss, delay, data transmission, buffer size, and network density. The results presented on the graph showed that the proposed model outperforms the existing models. Hence, appropriate spreading factor allocation has increased the power efficiency of LoRa end device battery.

Keywords: Internet of Things, Low-Powered Wide Area Network, Long Range, Long Range Wide Area Network.

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1. INTRODUCTION

The Internet of Things (IoT) is a technology that focuses on connecting various devices, which communicate with one another via RFID tags, sensors, actuators, mobile phones, etc., to accomplish tasks. IoT is composed of three parameters: “Things oriented,” referring to objects within the IoT context; “Internet oriented,” which enables communication between various nodes; and “semantic oriented,” which regulates data traffic of communicating devices within IoT networks [3]. The Internet of Things is a novel technology that utilizes the internet to facilitate communication between physical items or things. Physical devices include, among others, commercial equipment and home appliances. By utilizing appropriate sensors and communication networks, these devices are capable of producing important data and enabling the delivery of a variety of services for individuals. For instance, strategically managing building energy consumption can help reduce energy costs [25]. The majority of IoT-based systems consist of battery-operated devices, including smart sensors, radio frequency identification (RFID) tags, home appliances, surveillance cameras, smartphones, and other items. Energy efficiency challenges have emerged due to the exponential expansion of such gadgets, attracting considerable attention [1].

Recent advancements in IoT communication technologies have led to the emergence and triggering of low-power wide area networks (LPWANs), which are wireless technology standard protocols within the IoT platform with low cost, low power consumption, and wide coverage that connect multiple heterogeneous devices within a continuous network [14]. Research has revealed that there are varying degrees of performance with respect to energy power consumption, range, coverage, and latency within the LPWAN sector. LPWAN is a technology triggered within the IoT that is characterized by low-power operating devices, less expensive network devices, and wider coverage. Different protocol versions operate under the LPWAN environment to realize the domain characteristics across unlicensed free bands; hence, LoRaWAN is one of the leading protocols in LPWAN technologies competing for the formation of large-scale IoT. LoRaWAN is expected to provide a solution for connecting billions of devices in the future [28].

The LoRaWAN technology currently enjoys greater popularity because it is supported by the LoRa Alliance, a non-profit association of more than 500 member companies. It is for this reason that this work focuses on this technology. Through gateways (GWs), messages are routed between end devices (EDs) and the central network server (NS) in the star-of-stars architecture of the LoRaWAN network. Gateways connect to the network server via conventional IP connections. By converting RF transmissions to IP packets and vice versa, they serve as transparent bridges. LoRaWAN devices use the Pure ALOHA media access control (MAC) protocol to access the communication channel. ALOHA allows devices to broadcast packets directly to the communication channel without first performing carrier or collision detection. The simplicity of this protocol lowers transmission costs, overhead, and, most importantly, transmitting device power consumption [33].

Wi-Fi technology does not suit the energy efficiency of Low-Powered Wide Area Network (LPWAN) due to its high power consumption. Better options for use in the energy sector include low-power wide area network (LPWAN) communication technologies like LoRa, Sigfox, and LTE M that operate in unlicensed bands, as well as established LPWAN technologies like ZigBee, Bluetooth low energy (BLE), and narrowband IoT (NB-IoT). Due to the ability to provide dependable, low-cost, low-power, long-range, last-mile technology for smart energy management solutions, LPWAN technologies are becoming increasingly prevalent [25].

LPWANs are suitable for massive IoT applications such as transportation & logistics, utilities, smart cities, smart buildings, consumer electronics, industry, environment, and agriculture. Due to an exponential demand increase and potentials in the IoT ecosystem, there will be more advanced applications of LPWAN in the future in various domains such as remote health care, traffic safety and control, smart grid control applications, complex industrial applications, as well as manufacturing, training, and surgery. Therefore, they have very high demands for reliability, availability, and low latency [5].

The exponential increase in the use of IoT applications across the globe will continue to generate more and more data traffic within the IoT network. Hence, it will increase device battery usage that may reduce the battery life expectancy limits. Thus, End devices (EDs) within IoT networks in the future will rise up to billions of devices operating in public, industry, and personal networks in the next few years, generating a necessity for more correct and reliable energy conservation technology. This prompted the research work on optimized low-power wide area networks within IoT.

1.2 Motivation of the Study

Feasibility, power-efficient conservation, and a wide range triggered the evolution of LPWAN technology within IoT. The exponential increase in end devices across the network led to network density that consumed more energy within the network, reducing the power efficiency of LPWAN standards. [3] mentioned that the correct assignment of spreading factor (SF) values is a key parameter for the energy efficiency of (LoRaWAN) systems and thus requires further investigation towards improved solutions. Energy conservation is among the important components in an embedded system within the IoT domain as the battery provides electrical current for end device functionality, which is normally designed to be used for a long period of time; it can neither be charged nor replaced easily.

1.3 Statement of the Problem

The exponential increase in IoT applications thus triggered a request for improved energy performance of LoRaWAN. This attracted attention to carrying out these studies on an optimized Low-Powered Wide Area Network within the IoT domain. The research gap stated in the journal of [38] is that appropriate spreading factor allocation is crucial for the energy efficiency of the LoRaWAN protocol; this triggered the proposed research work. Referring to the research gap mentioned above, the proposed research solved a problem stated in the journal of [35] with respect to the energy efficiency of the LoRaWAN protocol by appropriately assigning spreading factors at the gateway using Particle Swarm Optimization Algorithm (PSO) through the MATLAB environment. Based on the experiment carried out, the solution provided is an improvement to the work of [38].

1.4 Aim and Objectives of the Study

The thesis aims to use spreading factor techniques for energy conservation of the low-power wide area network standard protocol within the Internet of Things. The objectives are to:

i. Develop a framework for the implementation of the proposed model.
ii. Perform an evaluation of the proposed model using a suitable tool.
iii. Simulate spreading factor allocation using a suitable tool.

1.5 Significance of the Study

The continued growth of nodes in the IoT domain, as a result of cost efficiency, power efficiency, and wider network coverage, leading to its high popularity and acceptance in some parts of the world, has led to data traffic generation. Thus, this requires complex computation for the manipulation of IoT devices communicating within its domain. Therefore, appropriate allocation of spreading factors will reduce data traffic generation that would consume more energy within an IoT environment.

1.6 Scope and Limitation of the Study

The study will focus on Long Range (LoRa), which is a proprietary LoRaWAN protocol used across the IoT domain, specifically in LPWAN. LoRa devices have the following characteristics: cost-effectiveness, good power management, and larger network coverage. LoRa is a physical layer based on chirp spread spectrum modulation techniques that use wireless communication technology.

2 RELATED WORK

To address the energy efficiency of IoT devices, [37] considers the optimization of network traffic management for energy power-saving management in computer networks using a centralized control framework and a hierarchical control framework on both small and medium-sized networks. The authors utilized an energy-aware state concept over computer networks, whether wired or wireless. They examined the power status of network devices and their components in two phases. The first phase involves a state where some network devices go to sleep when they are idle, while the second phase involves a state where network devices remain active even if they have no function to handle. The researchers explored the effect of network topology on power management in a computer network. The journal further stated that the hierarchical control framework is more resistant to inaccurate forecasting than the centralized control framework, based on the results of the simulation. Additionally, it is suitable for networks with high variability of devices compared to the centralized control framework. The author adopted the Heuristic algorithm control framework; this algorithm is used for calculating the power status of a network device. Thus, it is a method of power conservation over a computer network and optimal routing resource management and duty cycling.

[12] conducted a study to determine the performance of the Orthogonal Variable spreading Factor (OVSF) code on flat fading and frequency selective fading channels with respect to Bit Error Ratio (BER) and Energy bit per noise (Eb/no). The simulated result showed that the performance of the OVSF sequence is influenced by the number of multipath components and length of the code. The result ascertains that the OVSF has bad performance seen from the autocorrelation function. However, the OVSF code has good performance seen from the cross-correlation function. Comprehensively, the authors analyzed the effect of multipath channels on the variation of several multipath components: 4, 8, 12, and 16, and the corresponding orthogonal spreading factor codes: 16, 8, 4, both on flat fading channels and frequency-selective channels. The authors used two parameters (BER) and (Eb/no) with respect to the performance evaluation of multipath fading channels. Based on the experiment conducted by the authors, the result proved that the OVSF code length 16 is better than the OVSF length of 8 and 4. The code length 16 has a BER value of 0.0197, while the BER values for code length of 8 and 4 are 0.0421 and 0.0828, respectively, meaning the larger the code length the better the channel, vice versa. The researchers also noticed that the influence of multipath components in relation to BER. The more the number of multipath components on both the two considered channels, the higher the number of BER, as shown on the graphical representation of activity. Data aggregation management is

another energy conservation technique that combines data coming from different sources into one packet to avoid redundant transmission. Media Access Control (MAC) control protocol describes the rules to transmit frames across the network.

[24] explored various approaches of power conservation techniques within the IoT domain as follows: Node activity management, which is an approach that schedules activities of various nodes across the network in terms of sleeping scheduling and on-demand node management. The Media Access Control protocol is another technique that describes the rules of sending frames across the IoT network. Routing and topology management are additional energy conservation techniques discussed by the authors in their journal. The researchers further stated the rudiment of power conservation and IoT. The authors have offered an overview of the importance of sensors in the context of the Internet of Things, as well as several paradigms for energy-efficient IoT systems. In addition, different stages of the IoT system architecture are examined from the standpoint of energy conservation.

The rapid expansion and wide-scale deployment of IoT-based wireless devices has resulted in enormous energy dissipation. As a result, there is a pressing need to research new methods and approaches that can assist in saving energy and increasing the life of battery-operated gadgets. [1] investigated this issue in IoT-based heterogeneous WSNs and offered a new taxonomy of various energy-saving techniques recently developed for traditional WSNs and IoT-based systems in this study. The authors began by reviewing some of the important research papers in the literature that provide a classification of power conservation techniques, discussing their main focuses, and pointing out certain essential parameters that are mostly dependent on some connected parameters and classification targets. The authors presented their proposed grouping, which gives a generic and common classification that brings everything together in a current and thorough classification. According to the studied articles, the authors sought to incorporate the importance of energy-saving measures introduced recently. Upcoming developments will work on the design and implementation parts of the IoT.

[23] developed a universal framework to model wireless network device energy usage at the system level. All of the components that play a critical role in realistic industrial applications are included in the model, including conventional networking, sensing and acquisition components, and processing technologies. The authors' method bridges the gap between theoretical analysis and actual applicability by employing a simple method for predicting a few critical parameters linked to the platform's technology and the operating conditions of a specific application. The approach's value is demonstrated in two case studies, in which the model's validity and suitability for real-world applications and platforms are demonstrated by the consistency between experiments and predictions. It also demonstrates that determining a set of application-specific characteristics is sufficient for obtaining accurate power consumption estimates. All of these advantages have led to the development of a new framework for investigating and assessing energy life-cycles in applications. The methodology is accurate enough to be used for other purposes, despite the fact that the researchers concentrated solely on its practical usefulness. According to the authors, application developers can use this model to predict how different application parameters affect power consumption and to understand the system's tolerance margins and tradeoffs. Furthermore, they can do so even before the application is fully implemented, such as during the pre-dimensioning, pre-deployment, or pre-production stages.

[25] 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 researcher. 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. LoRa was judged to be the most advantageous LPWAN protocol in terms of low cost, low power consumption, wider coverage, security, and privacy, according to the journal's research on the protocols. They identified big data management, connectivity issues, integration of subsystems, security and privacy concerns, energy requirements of IoT systems, standardization, and architectural design as future directions in their research on the challenges of applying IoT in the energy sector.

[15] conducted an experiment on the spatial and temporal correlation of the generated traffic in wireless sensor networks (WSNs), and the findings were used to determine whether the networks could be used as factors in lowering the energy consumption of continuous sensor data collection. The authors employed energy-saving strategies called dual prediction (DP) and data compression (DC). The DP technique, which lowers traffic between cluster heads and sink nodes, benefits both cluster nodes and cluster heads, whereas the DC scheme lowers traffic between sink nodes and cluster heads. For both methods, a variety of algorithms were looked at and evaluated in terms of accuracy, delay, and the amount of transmission decrease. Neural networks (NNs) and long short-term memory networks (LSTMs) are suggested as models to use in order to create predictions for the DP approach. This is crucial because the DP scheme calls for the NNs and LSTMs to be trained online. The effectiveness of the methodology will be evaluated in

comparison to well-known least-mean-square techniques. We also analyzed and compared the principal component analysis, non-negative matrix factorization, truncated-singular value decomposition, and discrete wavelet transform with the DC scheme and examined the effects of transmission decrease on bandwidth, energy, and congestion in WSNs in a real-world test-bed. Implementation of DP and DC schemes at different network layers is stated as part of the future work presented in their journal.

According to [36], a review on network optimization in the Internet of Things, a thorough review of the most important aspects of IoT communication is shown through a few of the cutting-edge methods for optimizing networks for IoT connectivity. Numerous algorithm types for multi-objective problems, robust shortest path tree problems, hierarchical sensor networks, approaches for optimizing energy efficiency in IoT, opportunistic link selection methods, and secure energy-efficient routing protocols were investigated to increase network utilization. Different Internet of Things parameters, such as routing energy conservation, congestion, heterogeneity, scalability, reliability, quality of service, and security, were discussed in detail by the authors. Scheduling schemes and energy-efficient uplink radio resources for the management of LTE-based networks are required to address the challenges that the network is facing and to improve the efficiency of wireless spectrum utilization. The following are listed as challenges within the IoT's purview, according to the authors: network routing and mobility; multicast; security; heterogeneity; interoperability; scalability; overhead and packet retransmission; and security breaches.

High energy consumption management is required for the design and implementation of communicating sensors due to the sensor's efficient energy consumption need. A sensor node using LoRa/LoRaWAN technologies is presented by [5] to actualize sensors' optimal energy usage across IoT platforms. The authors presented an improved energy model for sensor nodes. In this model, 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 the 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, it is critical that these parameters are optimized.

In order to determine the energy efficiency and consumption characteristics of LPWAN and LPWAN technologies, [38] conducted a survey and analysis. The writers carefully examined the traits of the most significant Internet of Things technologies that fall under these two categories. The researchers then present a taxonomy of metrics used to assess energy and power efficiency in Internet of Things networks, as well as a study of energy consumption models put forth in the literature. Ultimately, the most popular techniques for raising energy efficiency have been divided into several broad groups: Approaches for radio optimization, data reduction, sleep/wake-up, energy-efficient routing, and approach evaluation across several technologies were all considered. [38], Classification and analysis give a thorough overview of current and proposed energy-efficiency methods, highlighting problems and unresolved issues, and ultimately laying the groundwork for further study in the areas of correct spreading factor assignment to network end nodes, novel direct communication methods between devices and base stations, novel methods for accurate prediction, and correct assignment of spreading factors.

As discussed in the journal paper of [9], low-power wide-area networks (LPWAs) have emerged as the de facto communication standard for the Internet of Things due to their low power consumption and wide coverage. Because it is an open platform, LoRaWAN has emerged as a significant protocol among Low Power Wide Area Networks (LPWANs) standards. LoRaWAN architecture and design details were introduced by the authors, who also provided a comprehensive review of the protocols: SigFox, LoRaWAN, NB-IoT, WiFi, ZigBee, and Bluetooth, as well as a state-of-the-art of LoRaWAN protocol. According to the authors, LoRa signals can pass through walls, and receivers are capable of extracting data from extremely low-power signals. LoRaWAN is an open standard that was created to effectively moderate the network and prevent network consumption, in contrast to LoRa, which is a closed modulation. To regulate end-node energy use and medium access, LoRaWAN Classes A, B, and C introduce TX and RX policies. These policies are implemented in the LoRaWAN protocol. LoRaWAN has a number of benefits over other communication technologies, including being an open standard, having built-in security, GPS-free geolocation, being able to communicate over great distances, consuming little energy, and being able to deploy in a private setting. A comparison study was carried out by [8] between three LPWAN proprietary protocols: SigFox, LoRaWAN, and NB-IoT and conventional networks: WiFi, ZigBee, and Bluetooth, taking into consideration specific parameters such as the standard, frequency, modulation, bandwidth, and others. While not perfect, LPWAN standards have proven to be more suitable for the Internet of Things due to their lower cost, longer range, and lower power consumption characteristics. As stated by the authors, the future works in the research field are: High-density LoRaWAN deployment optimization, ADR, network management, and application and network compatibility.

LPWANs (Low-Power Wide-Area Networks) are emerging as an enabling technology for Internet of Things applications, according to a paper published by [14]. As part of their presentation, 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. Ismail and colleagues concluded their discussion by identifying four areas of potential application for LPWAN: Smart Cities, Transportation, Logistics, Agriculture, Smart Farming, and Healthcare Applications. 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 are all considered challenges and future research directions by the authors in their work.

3 METHODOLOGY

This section includes the extended analysis of the IoT network that is considered in this research work in order to simulate the IoT network using LoRaWAN protocol within an IoT domain and a detailed explanation of the parameters adopted, along with the model of how the Optimized Low-Power Wide Area Network is going to be implemented using suitable tools.

3.1 Framework of the Research

The research framework was formulated based on the proposed objectives of the research work. The proposed methodology describes how spreading factor allocation to various end nodes was implemented using the network simulator MATLAB to simulate the IoT network based on the LoRaWAN protocol and to allocate spreading factors to end devices across the IoT network. The parameters were adopted from the journal of [18] and [17]. The figure below shows the research framework.

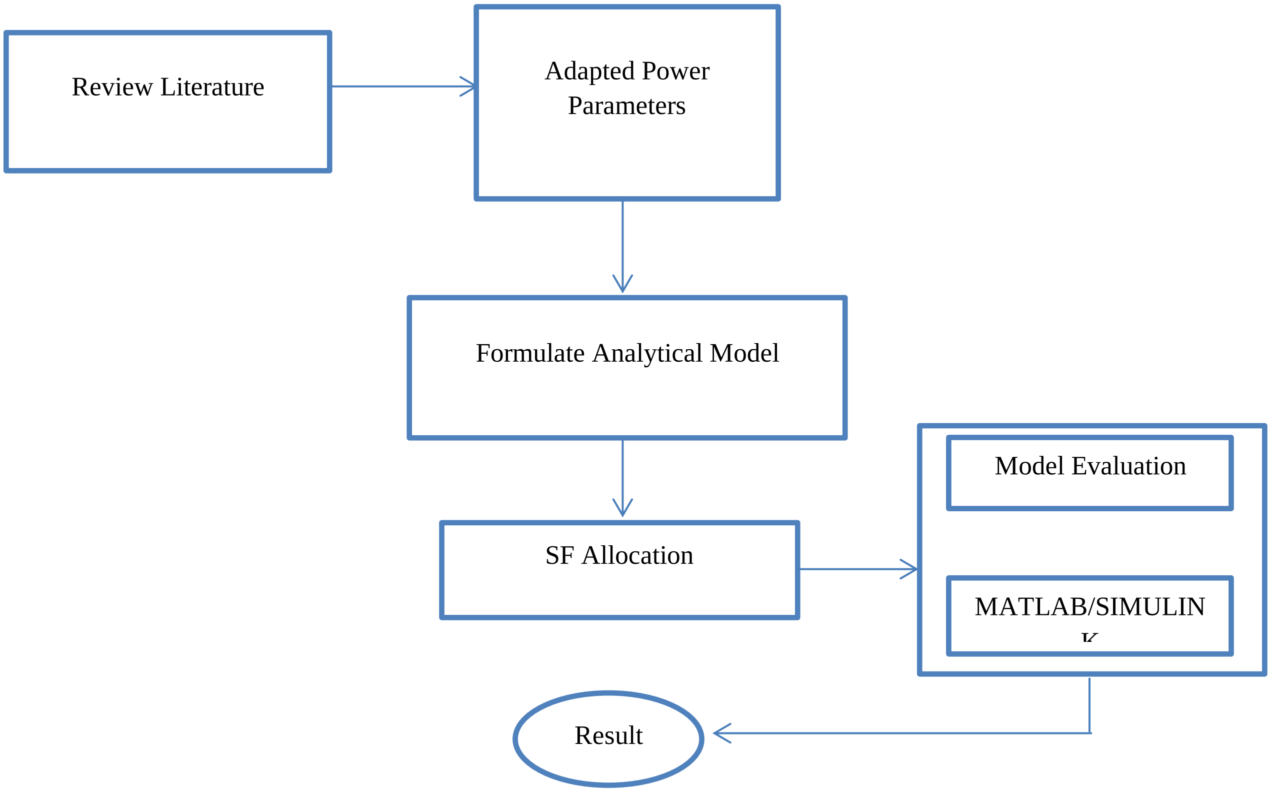

Figure 3.1. Framework for the Proposed Model

3.2 IoT Architecture

Many scholars have varied opinions about the number of levels in IoT technology design. The five layers of the IoT architecture are described by [34] as follows: perception, network, middleware, application, and business. The authors also state that architectural design must be programmed according to the requirements of IoT technologies to receive accurate data from IoT applications. Therefore, selecting appropriate hardware and software is necessary when using the IoT application type. [6] have mentioned that IoT architecture has four layers as follows: application, information processing, network infrastructure, and sensing.

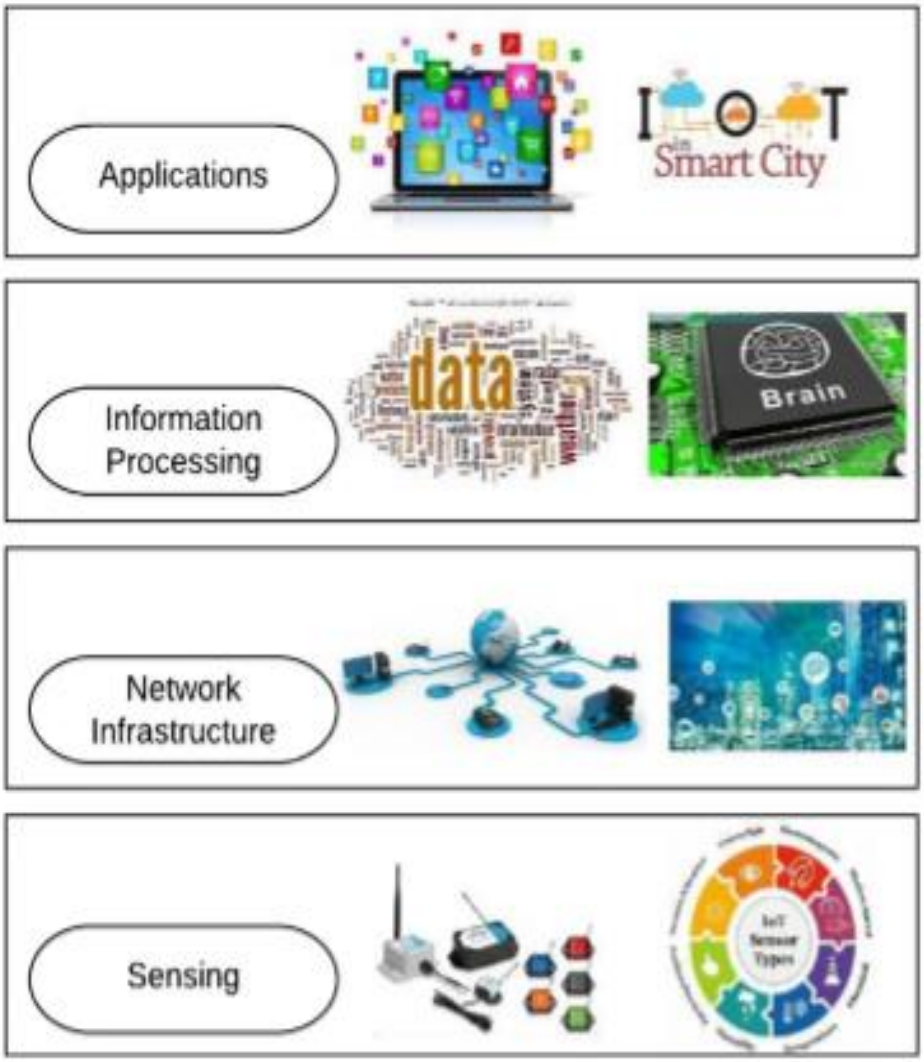

Figure 3.2. IoT Four-Layer Model

3.2.1 Sensing Layer

IoT is anticipated to be a physically interconnected global network in which devices are seamlessly integrated and capable of being remotely controlled. Smart systems on tags or sensors can automatically perceive the surroundings and communicate data among devices in the sensing layer. The IoT has significantly expanded in recent years, thanks to advances in sensing and communication technologies that have made objects with RFID or sensors more adaptable and accessible. This is because objects can now be uniquely identified, and the environment around them can be monitored for a variety of uses. Every IoT object has a digital identification that makes it simple to trace it online. A universal unique identifier (UUID) is the process of giving a thing a distinct identification (UUID) [21].

3.2.2 Network Infrastructure Layer

According to [34], the network layer is in charge of defining networking support and information operation via wired and wireless networks. To make it easier to transfer data from the perception layer to the processing layer, a network layer might be installed. Current IT infrastructures (such as corporate systems, transportation systems, electricity grids, healthcare systems, ICT systems, etc.) can provide data to the networking layer. It is not to be confused with the network layer of the International Organization for Standardization/Open Systems Interconnection (ISO/OSI) architecture, which only routes data within the network following the best path. It incorporates all the technologies and protocols that enable this connection. At this layer, wireless protocols play a significant role. Instead of requiring cables, wireless sensors can be placed in hard-to-reach locations and erected with less material and labor. Additionally, nodes in a wireless sensor network can be added, removed, or placed differently without having to restructure the entire network. Which protocol is utilized depends on the size of the network, how much power each node uses, and the required transmission speed for a particular application.

3.2.3 Information Processing Layer

The information or service processing layer is referred to as the layer above the network infrastructure layer. It is in charge of managing the services in accordance with the requirements of the customers. Information analytics, security management, process modeling, and device management are among the main [6].

3.2.4 Application Layer

The application layer integrates apps and offers ways for users and applications to communicate with one another. Support sublayers are frequently built for unique requirements like edge/fog computing and cloud computing. On the LPWAN gateway and server side, comparable layers can be added and utilized [7].

3.3 Parameters for the Implementation of the Proposed Model

The parameter for the implementation of the proposed model comprises both generic and specific parameters. It was adopted to address the pressing challenge of connecting and networking different computer systems due to the rapid development of information technology [21]. However, IoT has its network architecture which corresponds to each layer of the OSI reference model.

3.3.1 Generic Parameters

Based on the perception of [21], there is a conventional standard for heterogeneous devices to participate on a network in general called the Open System Interconnection (OSI) reference model in general. According to [6], IoT uses IP to connect different types of sensors and objects worldwide. In the last few years, different layered architectures have been proposed by different researchers, as stated by [34] and [6]. However, there is no consensus on a single globally agreed architecture for IoT. But for the purpose of this research, a four-layer model for IoT architecture is adopted from the journal of [6], as shown in Fig. 3.2 above. The proposed research will use 50 numbers of nodes for the implementation of spreading factor assignment using the particle swarm optimization algorithm. An area of 30m × 20m will be used for the simulation experiment. A duty cycle of 1% will be used across the three categories of end devices: A, B, and C.

3.3.2 Specific Parameters

These are parameters adopted from the journal of [17] and [18] for the implementation of appropriate spreading factor allocation to the end device, thus reducing network traffic for efficient energy conservation. According to [39], the carrier frequency, transmit power, spreading factor (SF), bandwidth (BW), and code rate are the five critical LoRa physical parameters (CR). As was already mentioned, LoRa operates at three main carrier frequencies: 433 MHz, 868 MHz, and 915 MHz.

3.3.3 Spreading Factor (SF)

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 decreases the data rate and vice versa. Each symbol is spread by a spreading code of length 2SF chips. At the transmitter, the spreading code is subdivided into codes of length 2SF/SF. Then each bit of a symbol is spread using the sub-code, so it takes 2SF chips for spreading one symbol (SF bits × 2SF = 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 [28].

3.4 Proposed Energy Model

The first approach consists of an active mode, which is the duration during which the sensor nodes are active, and the duration in which the element is in sleep mode. All the gadgets are powered by 3.3V except for the sensor unit that requires a power supply of 2V (2V) to operate. The quantity of power the sensor uses could change as a result of the energy used in this mode. Thus, there is a need to take into account the sleep mode consumption. The total used energy by the end node is given by equation (3.1):

$$E_{Total} = E_{Sleep} + E_{Active} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

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 (3.2):

$$E_{Sleep} = P_{Sleep} * T_{Sleep} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

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):

$$E_{Active} = E_{SU} + E_m + E_{proc} + E_{WUT} + E_{Tr} + E_R \ldots\ldots\ldots\ldots \quad (3.3)$$

E_{SU} is the used energy for the sensor startup, E_m represents data measurement, E_{proc} is 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 in the reception mode of the packets in the network. The model above depicts the total energy consumption of a wireless sensor network [3].

Table 3.2. Spreading Factors and Corresponding Chip Length in LoRa

Spreading Factor	Chip Length 2^{SF}
7	128
8	256
9	512
10	1024
11	2048
12	4096

3.5 Bandwidth (BW)

LoRa provides three scalable BW settings of 125kHz, 250kHz, and 500kHz. The transmitter sends the spread data at a chip rate equal to the system bandwidth in chips per second per Hertz. So a LoRa bandwidth of 125kHz corresponds to a chip rate of 125kcps [28].

3.6 Carrier Frequency

According to the LoRa Alliance, the selection of LoRa frequency bands used is the very first step before designing a LoRa-based IoT network because each country has its own frequency regulation. As mentioned by [15], the Industrial, Scientific and Medical (ISM) band ranging from 137MHz to 1024MHz is a range of bands in which various countries use for their transmission frequency across the LoRaWAN network. [28]

3.7 Code Rate

Code rate (CR) Forward error correction (FEC) techniques are used in LoRa to further increase the receiver sensitivity. The code rate defines the amount of FEC. LoRa offers CR values between 0 to 4, where CR = 0 means no FEC. LoRa uses code rates of 4/5, 2/3, 4/7, and 1/2, also shown in Table 3.3. This means that if the code rate is denoted as k=n, where k represents useful information and the encoder generates n number of output bits, then n − k will be the redundant bits. The redundancy allows the receiver to detect and often correct errors in the message, but it also decreases the effective data rate. Data rates corresponding to each CR value in LoRa are shown in Table 3.3, over three bandwidths. As the CR value increases, the effective data rate decreases in each bandwidth spectrum [35].

Table 3.3. Code rate in LoRa

CR Value	1	2	3	4
No. of redundant bits	1	2	3	4
Coding rate	4/5	2/3	4/7	1/2

3.8 Duty Cycle

The duty cycle is determined by dividing the total transmissions by the observation period, which by default is one hour. The duty cycle, which represents the amount of transmission time in the used frequency band, ranges from 0.1% to 1%. It aids in preventing network congestion. The number of transmissions and the duty cycle for each region affect the battery life. There are no distinctions made about the evenness of message spacing; just the maximum duty cycle must be observed. The number of transmissions is determined by the needs of the application. [35]

3.9 Optimization Techniques

The researcher used Particle Swarm Optimization (PSO) algorithms as a tool for spreading factor allocation to various end devices over the LoRa network. Kennedy and Eberhart created the Particle Swarm Optimization (PSO) in 1995, and it is based on the social behavior of swarm-living creatures like flocks of birds. PSO starts with a population of N randomly generated particles that are dispersed throughout an S in D dimensions. Each particle, which represents a potential solution to a problem, is described by three crucial parameters: its current position, its current velocity, and the best place it has ever found during the search process. The particles move throughout the search space in quest of the optimal solution. A particle's journey is affected by both its immediate surroundings and its own experiences. The velocity of the i-th particle is updated at each iteration using

$$\upsilon_i(t) = \omega * \upsilon_i(t-1) + c_1 r_1(p_i^b - x_i(t)) + c_2 r_2(g^b - x(t) \ldots\ldots (3.4)$$

Where i = 1,2, …,N; c_1 and c_2 are constants denoting cognitive and social parameters, respectively. The values of c_1 and c_2 are chosen in the range [0.5, 2.5]. They are applied to cater for the influence of the particle's historical best position $P_i^b$and the swarm's best position g^b, respectively. Parameters r_1 and r_2 are random numbers uniformly distributed within [0,1], while ω denotes the inertia weight; it helps to dampen the velocities of the particles to assist in the convergence to the optimum point at the end of the optimization iteration. In order to keep the particle's velocity bounded, a further arbitrary parameter $V_m = (\upsilon_{m2}, \upsilon_{m1}) \in S$ was defined. Whenever a vector element exceeds the corresponding element of V_m, the element is reset to its upper limit. Once the velocity has been updated by using Eq. (3.4), iteratively, each particle's position is updated using

$$x_i(t+1) = x_i(t) + \upsilon_i(t+1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$ [29]

3.10 Area of Simulation

An area of 30m × 20m will be used for the simulation experiment. A duty cycle of 1% will be used across the three categories of the end devices: A, B, and C.

3.11 LoRaWAN End Device Class

To meet the requirements of various applications, LoRaWAN provides three classes of devices [26], which are outlined below:

3.11.1 Class A

The most commonly used class of end devices is Class A, which allows the sensor to initiate uplink transmissions as needed and only requires two brief downlink messages. In comparison to other classes of equipment, this is the basic class and is the most energy-efficient. However, it employs a pure Aloha strategy, which results in a significant loss of efficiency. This type of device sleeps for the majority of the time to conserve energy [35].

3.11.2 Class B

The gateway sends periodic ping slots as downlink messages to this group of devices. By doing this, time windows are allocated for the end device to send uplink messages. However, the high data throughput and frequent beacons from the gateway lead to additional power consumption. The end device periodically receives one of the network's beacons to synchronize its internal clock with the network. This timing reference, which is based on beacons, can be used by the end device as a reception window [35].

3.11.3 Class C

This category of end devices uses nearly constant open receive windows, consuming the most power. Due to the flexibility of downlink transmission, they provide the lowest latency. Typically, over-the-air firmware upgrades are the best option for this type of device. While they function similarly to Class A devices, Class C devices do not close their receive window until the next transmission [35].

3.12 Programming Language

MATLAB was used to simulate and analyze the wireless sensor IoT network, as mentioned in [29], to confirm its effectiveness. For technical computing, MATLAB is a high-performance language. It combines programming, visualization, and computation in an environment that is easy to use and in which problems and solutions are presented using a well-established mathematical language. The name MATLAB stands for matrix laboratory. Simulink is an environment for multi-domain simulation and model-based design for dynamic and embedded systems. MATLAB Simulink is a platform for model-based design and multi-domain simulation for embedded and dynamic systems. It offers a customized set of block libraries and an interactive graphical interface to expedite the design, simulation, implementation, and testing processes for various systems, including those for communication, control, signal processing, video processing, and image processing [2]. MATLAB was used as the programming language for the proposed research based on the justifications provided by [30] and [2].

4 RESULTS

This section of the research provides details of the experiment that was conducted using MATLAB software. Spreading factors were appropriately assigned to various nodes across the simulated wireless sensor IoT network using the particle swarm optimization algorithm in the MATLAB environment.

4.1 Simulation of IoT Network

The first part of the experiment involved simulating the wireless sensor network using the MATLAB environment. The network consisted of wireless sensors, microcontrollers, and the gateway. The sensors were randomly positioned using a random function in the MATLAB working environment. Additionally, the experimenter maintained consistent levels of packet loss, delay, and throughput throughout the experiment. Below is a graph depicting the simulated LoRa network, showing wireless sensors randomly distributed in a farm-like setting.

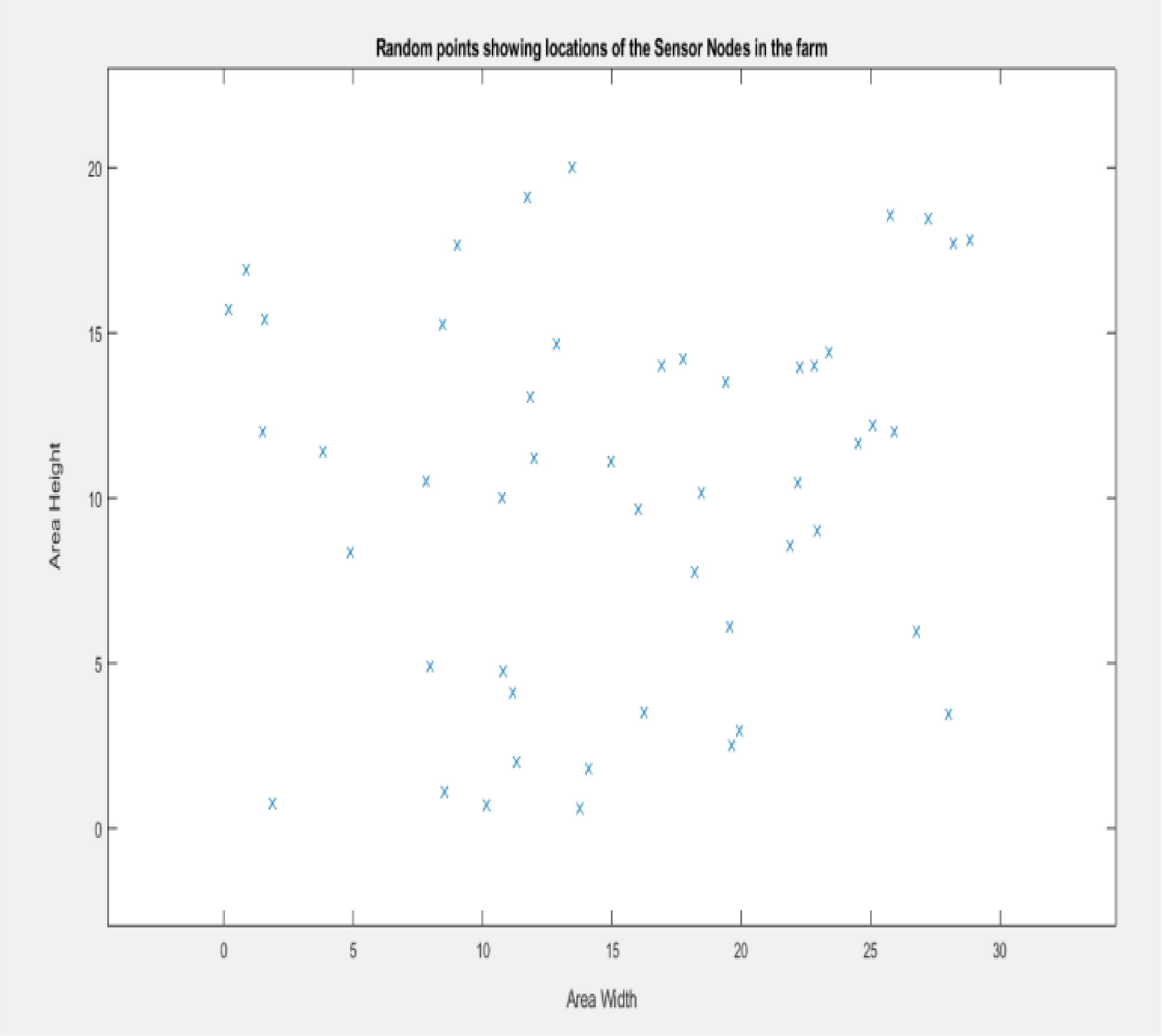

Figure 4.1: wireless sensor network

4.1.1 Experiment Scenario 1

In Experiment Scenario 1, spreading factor was implemented without optimization across the wireless sensor network shown in Figure 4.1. The scenario 1 yielded 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

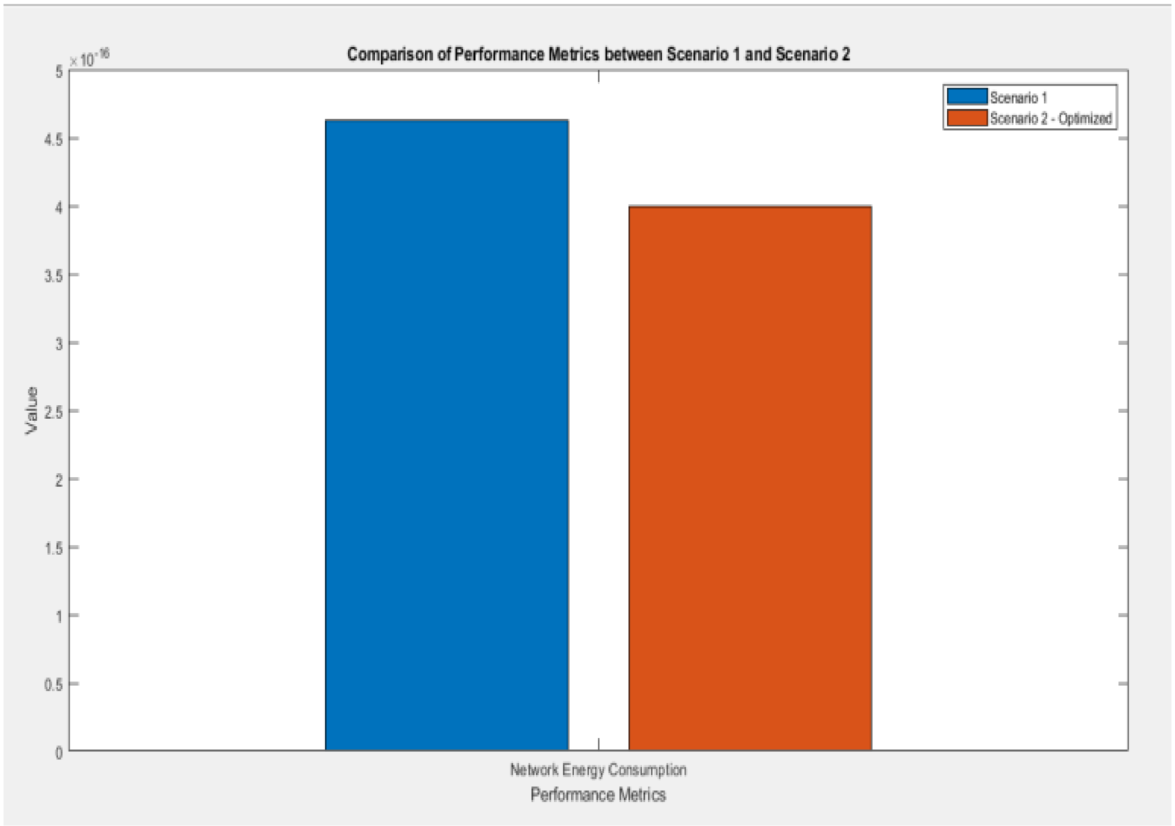

Figure 4.2. Experiment without optimization

4.1.2 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. The following results were obtained:
Network Energy Consumption optimized = 2.5230e-17 joules
Delay optimized (ms) = 1.2574
Throughput optimized (kbps) = 0.4004
Packet Loss – Optimized = 0.5499

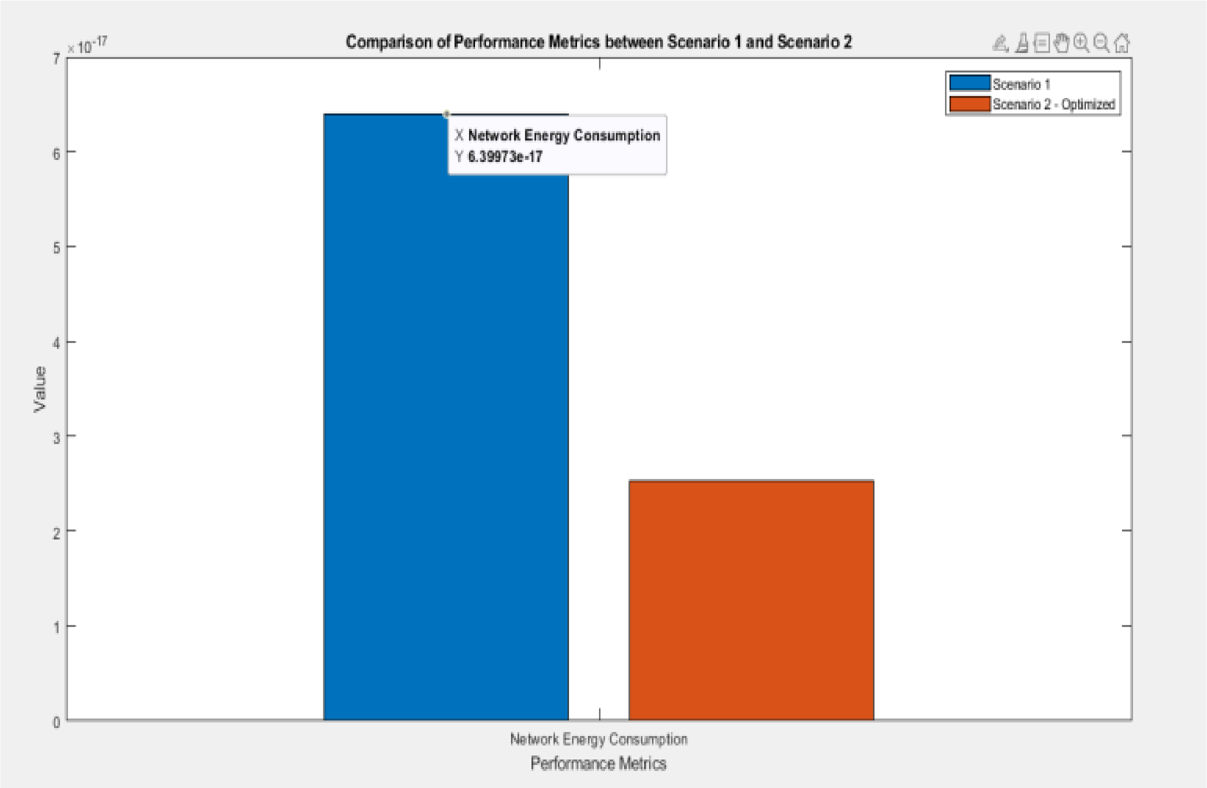

Figure 4.3. Scenario 2 optimized

Table 4.1. Total result

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 4.1 presents the experimental results obtained from the phase 1 simulation experiment. “Experiment 1 network power consumption” indicates the simulation running 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 throughout the first experiment. After the simulation without optimization, we obtained power consumption of 6.399e-17 joules.

Experiment 2 network power consumption in Table 4.1 was obtained after running the simulation again without optimization, maintaining the same throughput, packet loss, and delay as in the first experiment. The result of power consumption obtained after the simulation is 2.5230e-17 joules. Finally, the percentage improvement was calculated by subtracting the power consumption of experiment 2 from experiment 1, dividing the difference by experiment 1, and then multiplying by 100%. We arrived at a reduction in power consumption by 60% compared to the work of [4] in the 280 LoRaWAN probe setting, which uses only 44% more energy than the optimal setting.

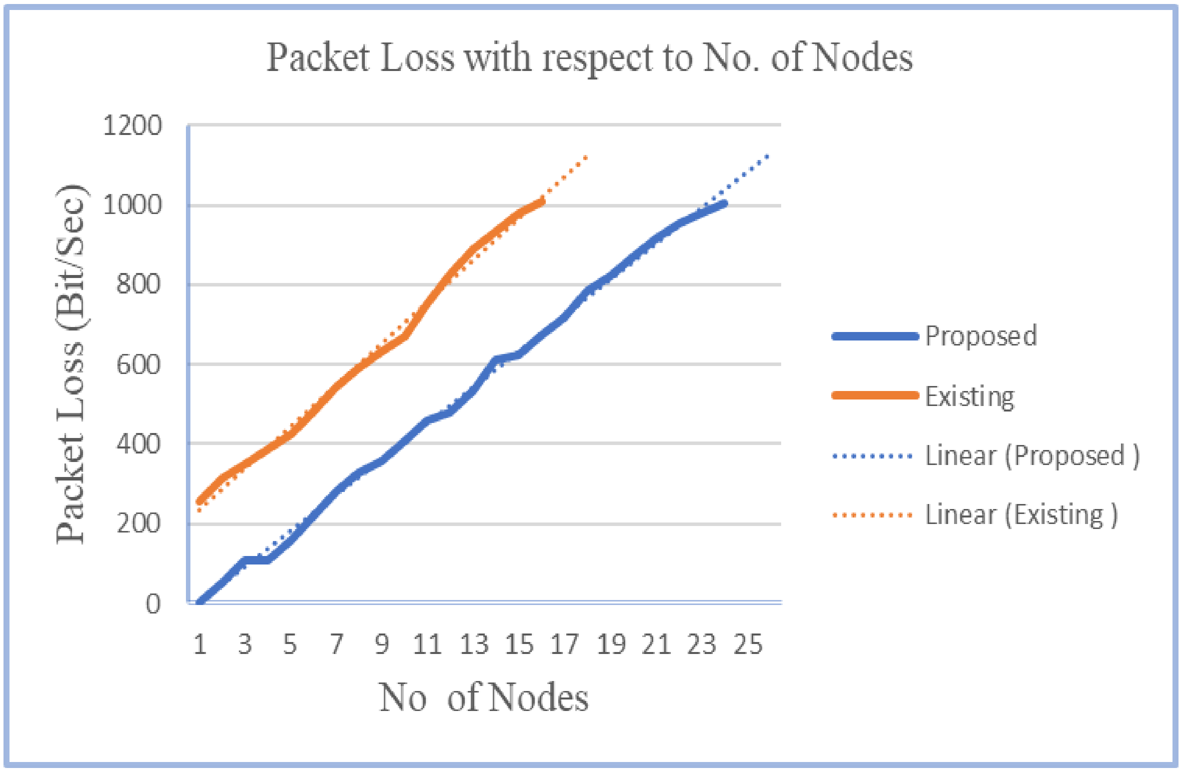

Figure 4.4. Packet Loss with Respect to Number of Nodes

The graph chart in Figure 4.4 depicts the testing of the proposed model and the existing model with respect to the number of nodes and packet loss. The experiment showed that with an increase in the number of nodes, there is also an increase in packet loss. As shown above, the proposed model in the simulation experiences less packet loss compared to the existing model due to LoRaWAN optimization. Thus, it has significantly reduced the network density as well as the energy consumption of the battery, increasing the battery life expectancy compared to the existing model [8] that used ADR for spreading factor allocation with respect to throughput and data extraction rate. The proposed model outperforms the existing model.

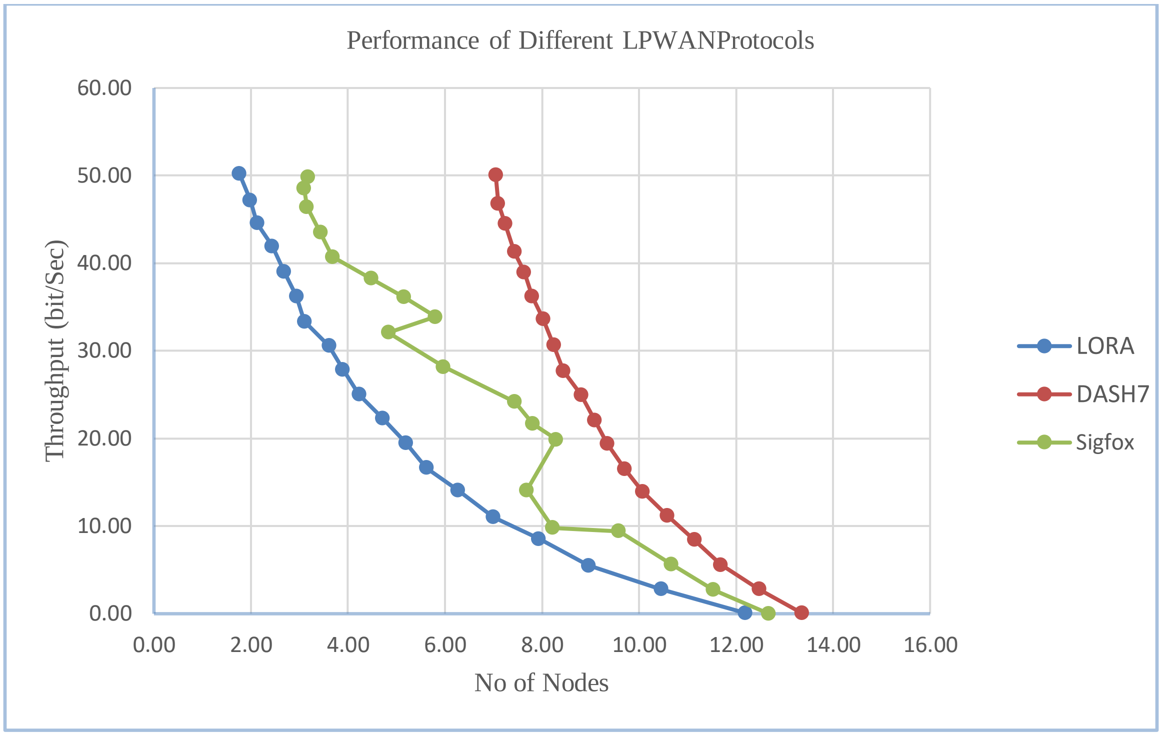

Figure 4.5. Performance of different LPWAN protocols

The graph above presents the performance comparison among LPWAN protocols, including the proposed protocol used in the model and other LPWAN protocols, in relation to the number of nodes and throughput. Figure 4.5 shows that as the number of nodes decreases, there is an increase in throughput for the proposed protocol, leading to improved performance. By implementing the spreading factor (SF) allocation policy, the network delay has been reduced, resulting in reduced traffic at the LoRa gateway and consequently lower energy consumption across the network compared to other LPWAN protocols. An evaluation of energy consumption of LPWAN technologies by [32] demonstrated that DASH7 and LoRaWAN protocols are more power efficient than Sigfox. However, with the implementation of the SF allocation policy used in our model, it is evident that the LoRaWAN protocol is the most energy-efficient among DASH7, Sigfox, and LoRaWAN protocols.

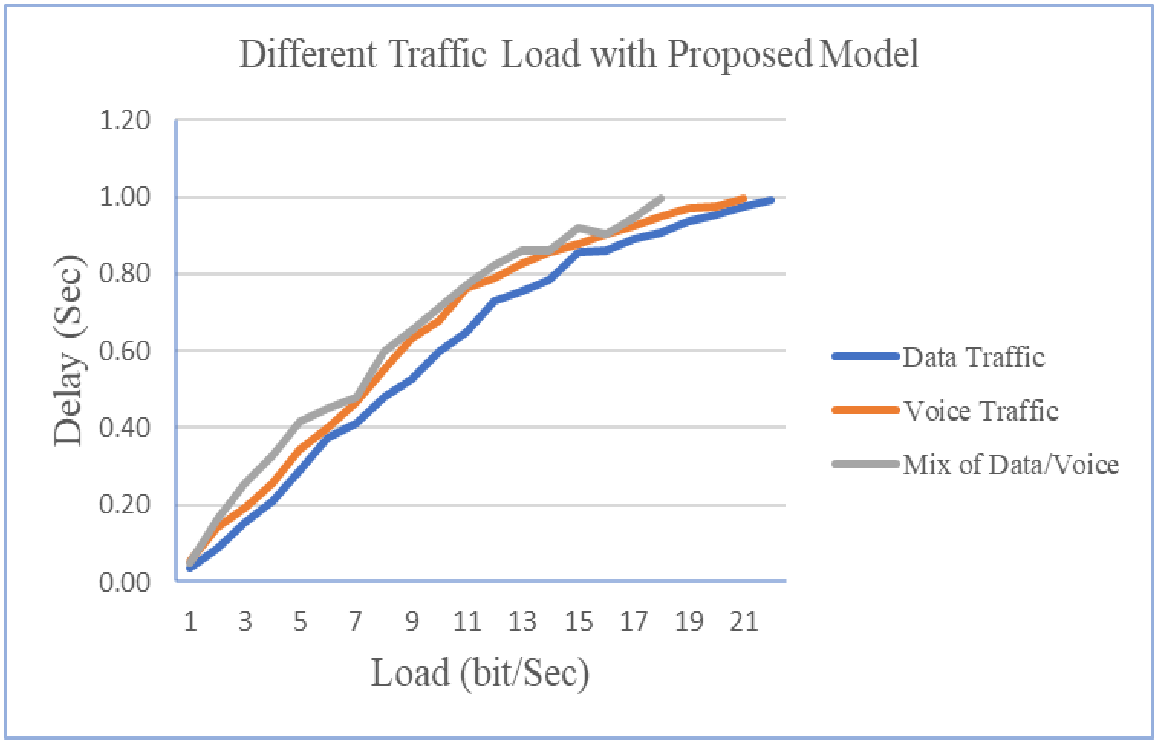

Figure 4.6. Different Traffic Loads with Proposed Model

The proposed model is tested with various communication metrics such as data traffic, voice traffic, and a mix of data and voice traffic with respect to load and delay. Figure 4.6 illustrates that an increase in load leads to an increase in delay. When comparing the three parameters presented on the graph, it is evident that data traffic has the least effect on delay with respect to load, followed by voice traffic, and finally the mix of data and voice traffic in the model.

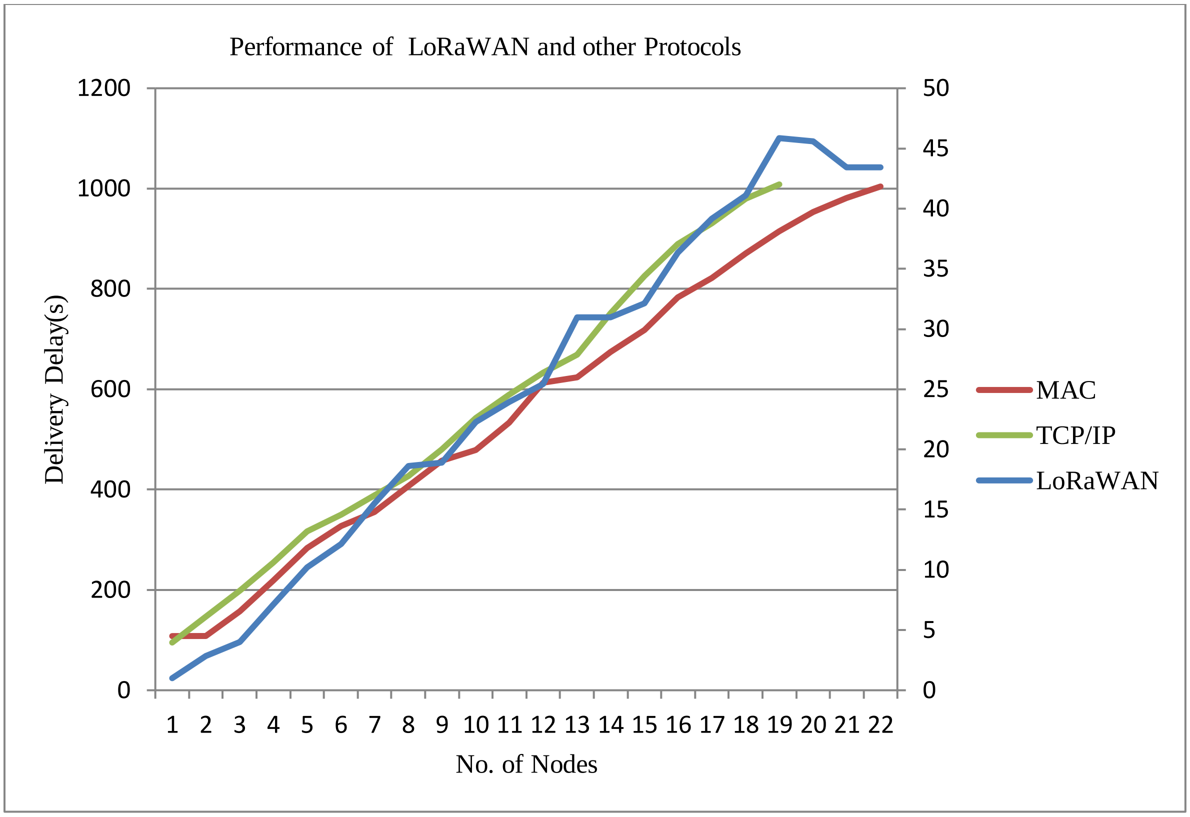

Figure 4.7. Delay Delivery with Respect to Number of Nodes

The graph above illustrates the performance of the LoRaWAN protocol concerning delivery delay and the number of nodes. The results indicate that with an increase in network density, there is an associated increase in delivery delay, aligning with the delivery delay behavior of other routing protocols as discussed in the journal of [16]. The authors revealed that as the number of nodes increases, so does the delivery delay.

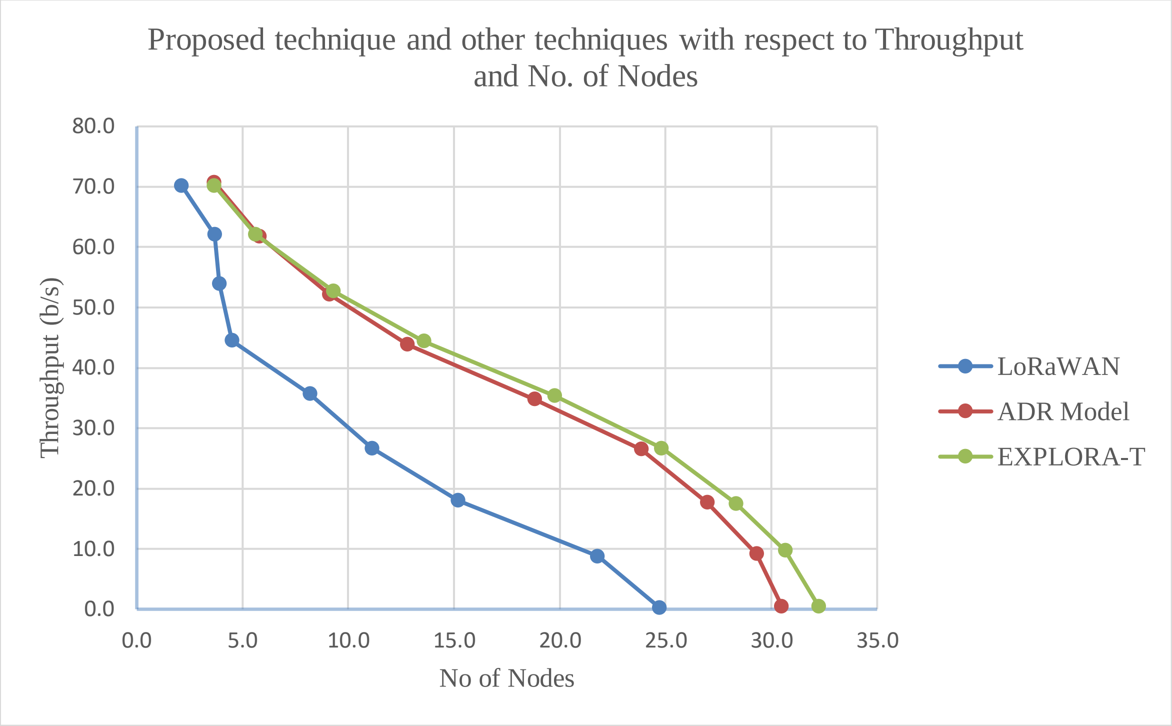

Figure 4.8. Proposed Techniques and Other Techniques

Figure 4.8 depicts a comparison between the proposed technique and other techniques with respect to the number of nodes and throughput. It is evident that as the number of nodes (density) decreases, the throughput increases. The proposed system maximizes throughput to minimize network density, thereby reducing packet loss in the proposed model. As noted in the journal [8], systems with a low packet rate perform better, and in the case of high packet rate, EXPLoRa-T performs better. This indicates that with a low number of nodes, the throughput increases.

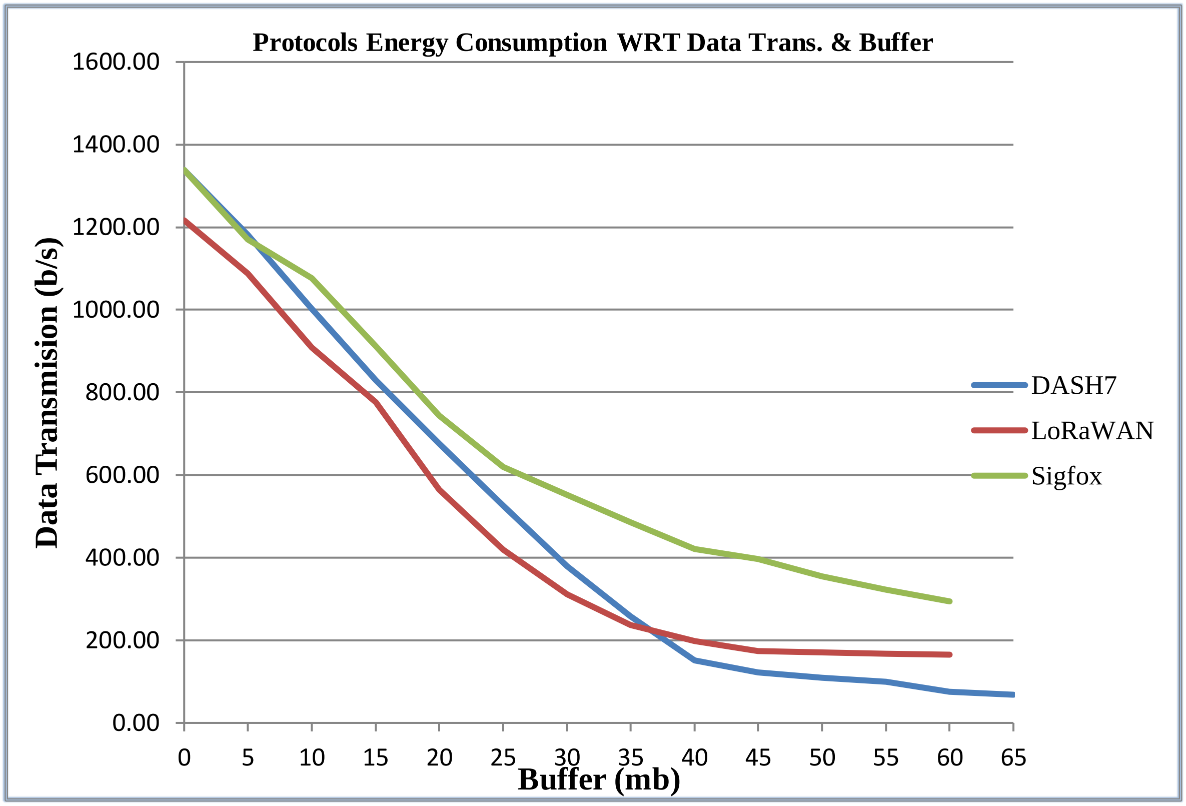

Figure 4.9. Protocols' Energy Consumption with Respect to Data Transmission & Buffer Size

Figure 4.9 illustrates the power consumption of LPWAN protocols in relation to data transmission and buffer size. The relationship shown above indicates that an increase in data transmission leads to a decrease in buffer size, and vice versa. Based on the results from Figure 4.9, it is evident that LoRaWAN is the most energy-efficient protocol compared to others. This is attributed to its technology and recent optimizations that have been carried out. As mentioned in [35], both LoRaWAN and DASH7 are more energy-efficient than Sigfox. The recent improvements made to the LoRaWAN protocol have further enhanced its efficiency, giving it an advantage over the DASH7 protocol.

4.2 Results Discussion

The experiment on battery power consumption was conducted in various stages, as outlined below: The experiment was implemented within the MATLAB environment, where a wireless sensor network was randomly simulated using MATLAB's random function across a measured area of 20x30 meters. Following the simulation of the IoT wireless sensor network, the optimization technique known as particle swarm optimization (PSO) was employed. PSO algorithms were called from the MATLAB library to assign spreading factors to the end devices at the LoRa gateway. Specific key parameters such as data rate, spreading factors, throughput, network density, delay, packet loss, and the distance between the end device and the gateway were considered for effective spreading factor allocation.

The results of the experiment are as follows: In Experiment Scenario 1, spreading factors were implemented without optimization across the wireless sensor network, as shown in Figure 4.1. The obtained results include Network Energy Consumption without optimization = 6.3997e-17 Joules, while maintaining consistent values for delay, packet loss, and throughput throughout the experiment. In Experiment 2, the network power consumption with optimization was obtained by implementing PSO for spreading factor allocation across the wireless sensor network. The result showed a power consumption of 2.5230e-17 joules with optimization. The percentage reduction in network power consumption was calculated by subtracting the power consumption of Experiment 2 from Experiment 1, dividing the difference by Experiment 1, and then multiplying by 100%. The total power conservation achieved across the LoRa network was found to be 60%, in comparison to the existing work titled "Energy-Constrained Optimization for Spreading Factor Allocation in LoRaWAN" by [28]. In their work, they optimized the Packet Reception Probability

(PRP) of the LoRaWAN protocol using a Genetic algorithm. The proposed model outperformed the existing model, with the power consumption per end device being 3.1 mA in the existing model, as opposed to the proposed model’s power consumption of 2.5230e-17 joules.

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 finding an optimal spreading factor configuration that minimizes energy consumption. Based on the result of the proposed system, using the PSO in allocating spreading factor in LoRaWAN, the network can achieve a more efficient allocation of resources, resulting in reduced energy consumption. This is crucial for IoT networks, where energy efficiency plays a significant role in prolonging the lifespan of battery-powered devices and reducing operational costs.

Different graphical models were tested with respect to various LoRa parameters such as network density, throughput, and buffer size, data transmission, packet loss, and network delay. The test goes as follows: Packet loss concerning the number of nodes. Based on the result of the experiment, the proposed model performs better compared to the existing model. Another scenario was tested based on the performance of different routing protocols, where the proposed protocol outperformed the other routing protocols. Furthermore, different traffic loads were considered with respect to the proposed model. Following the experiment, all three testing parameters scaled throughout the network, but data traffic is lower compared to voice and a mix of voice and data traffic. Additionally, the network was tested for delay delivery. The results showed that both the proposed technique and other techniques had their throughput altered with respect to network density. Figure 4.8 presents another scenario where the existing techniques were tested on the network concerning throughput and the number of nodes. Data transmission against buffer size was also presented on the graph. It tested three parameters: the proposed model and the existing models.

5

5.1 Summary

The Internet of Things (IoT) is rapidly becoming an integral part of everyday life. To support the billions of Internet-connected devices and the data they produce, Low-Powered Wide Area Networks (LPWANs) have been introduced. LPWANs are capable of providing reliable connectivity even in low-density areas and with devices consuming low amounts of energy. The study worked on three different strategies: the design of an energy power consumption model of LoRaWAN, simulation of an IoT wireless sensor network, and implementation of spreading factor allocation across the network using particle swarm optimization (PSO) for the effective battery power consumption of an IoT device within LPWANs.

MATLAB software was used for the experiment, which was carried out in two different scenarios: firstly, the allocation of SF across the simulated network without optimization, and secondly, the assigned spreading factor with optimization using PSO over the network. The discovered results were 6.3997e-17 joules and 2.5230e-17 joules respectively. Several LoRa parameters like throughput, network density, packet loss, delay, data transmission, and buffer size were tested in the network for model evaluation and power consumption efficiency. Experiments proved that the proposed model outperforms other models in terms of power efficiency.

5.2 Conclusion

Battery power consumption is a key parameter in the LPWANs domain; hence, there is a need to use an appropriate spreading factor technique for the proper allocation of spreading factors to the end device at the gateway to reduce network traffic. This study used particle swarm optimization algorithms for effective allocation and yielded better results.

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