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Topology Optimization for Low-Power-Wide-Area Networks (LPWANs) within Internet of Things (IOT)

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Abstract: Low-Power Wide-Area Networks (LPWANs) have emerged as a critical enabler for large-scale Internet of Things (IoT) deployments due to their long-range communication capabilities and low energy consumption. However, achieving optimal performance in LPWAN-based IoT systems requires careful network topology design to balance energy efficiency, coverage, scalability, and reliability. This paper investigates topology optimization strategies tailored for LPWANs, focusing on technologies such as LoRaWAN, NB-IoT, and Sigfox. We propose a multi-objective optimization framework that considers node placement, gateway density, data traffic patterns, and energy constraints. By applying both simulation and analytical modeling, we showcase notable enhancements in network longevity, delay performance, and packet delivery efficiency. Our results provide practical guidelines for deploying scalable and sustainable LPWAN topologies in diverse IoT applications, ranging from smart cities to remote environmental monitoring.

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

I. Introduction

The rapid expansion of the Internet of Things (IoT) has driven the need for efficient and scalable communication technologies capable of connecting billions of devices across vast geographical areas. Devices that interact using technologies such as RFID tags, sensors, actuators, and mobile phones collaborate to complete specific tasks. The Internet of Things (IoT) comprises three key aspects: "Things oriented," focusing on the physical objects involved; "Internet oriented," which supports connectivity among different components; and "Semantic oriented," which manages and interprets the data being exchanged. traffic of communicating devices within IoT networks Low-Power Wide-Area Networks (LPWANs) have emerged as a leading solution to meet these demands due to their ability to support long-range communication with minimal energy consumption. Technologies such as LoRaWAN, NB-IoT, and Sigfox have become increasingly popular for enabling large-scale IoT deployments in various domains, including smart cities, agriculture, industrial monitoring, and environmental sensing.

Despite their advantages, designing effective LPWAN topologies presents significant challenges. Network performance is heavily influenced by factors such as node placement, gateway density, traffic patterns, and energy constraints. Improper topology design can lead to reduced network lifetime, increased latency, and poor data reliability, which hinder the scalability and sustainability of IoT applications.

Recent developments in IoT communication have paved the way for Low-Power Wide-Area Networks (LPWANs), which are wireless protocol standards designed specifically for IoT platforms. Low cost, low power consumption, and wide coverage that connect multiple heterogeneous devices within a continuous network [14]. Studies have shown that LPWAN technologies exhibit different levels of performance in terms of energy consumption, communication range, coverage area, and latency. LPWAN is a technology triggered within the IoT that is characterized by low-power operating devices, less expensive network devices, and wider coverage.

This paper focuses on topology optimization strategies tailored specifically for LPWANs, aiming to balance the trade-offs between energy efficiency, coverage, scalability, and reliability. By leveraging multi-objective optimization techniques and combining simulation with analytical modeling, we seek to provide actionable insights and design guidelines that facilitate the deployment of robust and efficient LPWAN infrastructures.

II. Motivation of The Study

Power-efficient conservation and a wide range triggered the evolution of LPWAN technology within IoT.

The rapid rise in the number of end devices has increased network density, leading to higher energy consumption and a decline in the energy efficiency of LPWAN technologies. Proper allocation of Spreading Factor (SF) values plays a vital role in optimizing energy usage in LoRaWAN systems, highlighting the need for further research into more effective assignment methods. The rapid growth of the Internet of Things (IoT) has led to the deployment of billions of connected devices, many of which operate in environments with limited energy, bandwidth, and computational resources. Low-Power Wide-Area Networks (LPWANs) have emerged as a critical enabler for long-range, energy-efficient communication in such scenarios. Technologies such as LoRaWAN, Sigfox, and NB-IoT are widely adopted due to their ability to support massive IoT deployments with minimal power consumption.

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Optimizing the topology of LPWANs offers a promising solution to enhance network efficiency, coverage, scalability, and energy conservation. By intelligently organizing the layout and connectivity of nodes, topology optimization can significantly improve data delivery, extend network lifetime, and ensure reliable communication. Despite its importance, there remains a gap in practical, adaptive, and scalable topology optimization strategies tailored specifically for LPWAN constraints and IoT application requirements.

This study is motivated by the need to bridge that gap—by developing and evaluating topology optimization methods that align with the unique characteristics and limitations of LPWAN-based IoT systems. Such advancements are vital to support the sustainable growth of IoT infrastructures across diverse sectors such as smart cities, agriculture, logistics, and environmental monitoring.

1.2 Aim and Objectives of the Study

The aim of this study is to develop and evaluate topology optimization strategies for Low-Power Wide-Area Networks (LPWANs) within Internet of Things (IoT) environments to enhance network performance, improve energy efficiency, and support scalable and reliable device connectivity.

The objectives are to:

I.To analyzes existing LPWAN topologies used in IoT systems and identify their limitations in terms of energy efficiency, coverage, and scalability.

II.To investigates the impact of network density and device distribution on LPWAN performance, particularly in terms of power consumption and data transmission reliability.

1.3 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 efficient allocation of spreading factors can help minimize network traffic and reduce energy consumption in IoT environments.

1.4 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-enabled devices are known for their affordability, efficient energy usage, and extensive communication range. LoRa is a physical layer based on chirp spread spectrum modulation techniques that use wireless communication technology.

Related Work

To address the energy efficiency of IoT devices, 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-sized networks. The Media Access Control protocol is another technique that describes the rules of sending frames across the IoT network.

I.developed a universal framework to model wireless network device energy usage at the system level ii. 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.

iii. Conducted an experiment on the spatial and temporal correlation of the generated traffic in wireless sensor networks (WSNs).

The growing deployment of Low-Power Wide-Area Networks (LPWANs) in Internet of Things (IoT) applications has prompted extensive research aimed at improving network performance, particularly through topology optimization. LPWAN technologies such as LoRaWAN, NB-IoT, and Sigfox are designed for long-range, low-power communication; however, their effectiveness can be significantly influenced by the underlying network topology.

Topology Control and Optimization: Several studies have focused on optimizing LPWAN topologies to enhance energy efficiency, reduce latency, and improve overall network reliability. For example, clustering methods have been widely used to organize nodes into energy-efficient groups. These approaches help to reduce the distance between communicating nodes and the gateway, minimizing power usage and extending network lifespan. Some researchers have also explored gateway placement optimization, where the strategic positioning of gateways leads to better coverage and reduced transmission loss.

Spreading Factor Allocation in LoRaWAN: In LoRa-based networks, the spreading factor (SF) plays a key role in determining communication range, data rate, and time on air.

Energy-Aware Protocols: Energy consumption is a primary concern in LPWAN-enabled IoT systems. Researchers have proposed various energy-aware protocols and algorithms, such as Adaptive Data Rate (ADR), to adjust transmission parameters dynamically.

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Scalability and Interference Management: The scalability of LPWANs has also been studied, particularly in dense IoT deployments. Interference and packet collision become more prominent as the number of devices increases.

Machine Learning and Intelligent Topologies: More recently, machine learning and artificial intelligence have been applied to predict optimal topologies and resource allocation in real-time.

III. Methodology Research 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. The methodology integrates simulation, mathematical modeling, and algorithmic optimization to achieve efficient, scalable, and energy-conscious network designs.

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. It provides a structured approach to investigate and optimize network topology in LPWANs for IoT applications. It integrates theoretical models, simulation tools, and algorithmic optimization within a clear problem-solution-outcome pathway.

1. Research Inputs

i. Theoretical Foundation

Principles of LPWAN communication (e.g., LoRaWAN, Sigfox, NB-IoT)

IoT system architecture and data flow

ii. Technical Requirements

Device capabilities (battery life, transmission power)

Network coverage area

iii. Environmental Parameters

Node distribution (uniform/random/clustered)

Propagation models (urban, suburban, rural)

2. Research Processes

Step 1: Problem Identification and Modeling

Identify core challenges in LPWAN topology (e.g., energy inefficiency, poor scalability)

Step 2: Algorithm Selection and Development

Choose appropriate optimization techniques: o Heuristic/met heuristic (GA, PSO, ACO)

MILP / constraint-based models

Develop or adapt algorithms to:

Optimize gateway placement

Cluster IoT devices effectively

Determine optimal routing paths

Step 3: Simulation and Implementation

Step 4: Performance Evaluation

Measure performance using key metrics:

Energy consumption

Network lifetime

3. Research Outputs

i. Optimized Topology Designs

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Network layout with enhanced energy efficiency and coverage

Adaptive algorithms for node clustering and routing

ii. Evaluation Results

Comparative analysis of optimized vs. non-optimized topologies

Performance across varying node densities and network scales

iii. Design Guidelines

Recommendations for LPWAN deployments in different environments

Trade-offs between energy, coverage, and cost

iv. Outcome and Contributions

Scientific Contribution: New or improved optimization algorithms tailored for LPWAN topologies in IoT.

Practical Application: Deployable guidelines for real-world LPWAN planning (e.g., smart agriculture, environmental monitoring).

Scalability: Framework adaptable to varying network sizes and topologies.

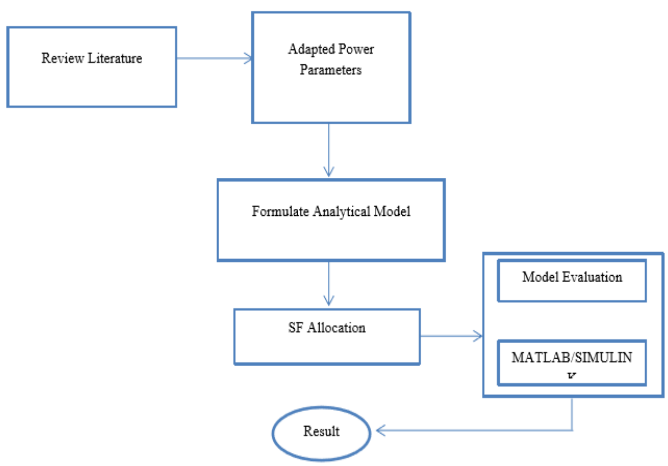

Figure 3.1. Framework for the Proposed Model

Internet of Things (IoT) Architecture

Many scholars have varied opinions about the number of levels in IoT technology design. It also states 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. have mentioned that IoT architecture has four layers as follows: application, information processing, network infrastructure, and sensing. The IoT architecture describes the layered structure that enables the collection, processing, transmission, and utilization of data from connected devices.

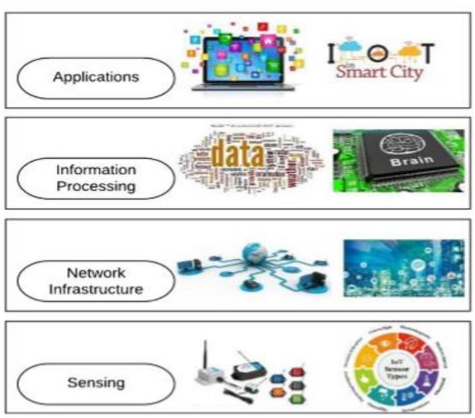

Figure 3.2. IoT Four-Layer Model

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Perception Layer (Sensing Layer)

Function: Responsible for collecting physical data from the environment.

Components: Sensors (e.g., temperature, humidity, motion)

Actuators

RFID tags

Cameras

Role:

Identifies objects and gathers data

Converts analog signals to digital

Network Layer (Transmission Layer)

Function: Transfers the collected data from perception layer to data centers or cloud platforms.

Technologies Used:

LPWAN (LoRaWAN, Sigfox, NB-IoT)

Wi-Fi / Bluetooth

4G/5G cellular networks

Ethernet

Role:

Handles data routing and transmission

Provides secure communication protocols

Information Processing Layer

The service processing layer, located above the network infrastructure layer, is responsible for managing and coordinating services to meet the specific needs and preferences of users. Information analytics, security management, process modeling, and device management are among the main.

Application Layer

The application layer integrates apps and offers ways for users and applications to communicate with one another. Support sub layers are frequently built for unique requirements like edge/fog computing and cloud computing.

Parameters for the Implementation of the Proposed Model

i. Network Deployment Parameters

ii. Device and Energy Parameters

iii. Communication Parameters

iv. Optimization Model Parameters

IV. Summary

IoT technology is increasingly embedded in daily life, influencing how people interact with devices and their environment. 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 research focused on three key approaches: developing an energy consumption model for LoRaWAN, simulating an IoT wireless sensor network, and implementing spreading factor allocation across the network Particle Swarm Optimization (PSO) is utilized to enhance the battery efficiency of IoT devices operating within LPWANs.

V. Conclusion

In LPWAN systems, managing battery power consumption is crucial, making it essential to implement effective spreading factor strategies that ensure optimal allocation to end devices from the gateway, thereby minimizing network traffic.

This study used particle swarm optimization algorithms for effective allocation and yielded better results. This study highlights the importance of topology optimization in addressing these challenges. By strategically organizing the network structure and

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efficiently allocating spreading factors to end devices, it is possible to significantly reduce power consumption, improve data transmission reliability, and enhance overall network performance. Techniques such as adaptive clustering, gateway placement and dynamic spreading factor assignment are essential to achieving these goals.

Furthermore, incorporating intelligent algorithms and context-aware strategies into LPWAN topology design can lead to more responsive and sustainable IoT deployments. As the demand for large-scale IoT systems continues to grow, optimizing LPWAN topology will play a vital role in ensuring the longevity and effectiveness of these networks.

References

1. W. Ayoub, A. E. Samhat, F. Nouvel, M. Mroue, and J.-C. Prévotet, "Internet of mobile things: Overview of lorawan, dash7, and nb-iot in lpwans standards and supported mobility," IEEE Communications Surveys Tutorials, vol. 21, no. 2, pp. 1561–1581, 2019.
2. Noreen, U., Bounceur, A., and Clavier, L. (2017). A Study of Low Power and Wide Area Network Technology. 3rd International Conference on Advanced Technologies for Signal and Image Processing (2017), (pp. 1-6). IE
3. Pham, C., Bounceur, A., Clavier, L., Noreen, U., & Ehsan, M. (2020). Radio Access Challenges in LoRa Low Power Wide Area Network (chap. 4). Retrieved October 31, 2021, from: https://www.sciencedirect.com.
4. **Augustin, A., Yi, J., Clausen, T., & Townsley, W. (2016).** A study of LoRa: Long range & low power networks for the Internet of Things. *Sensors*, 16(9), 1466. https://doi.org/10.3390/s16091466
5. **Raza, U., Kulkarni, P., & Sooriyabandara, M. (2017).** Low Power Wide Area Networks: An Overview. *IEEE Communications Surveys & Tutorials*, 19(2), 855-873. https://doi.org/10.1109/COMST.2017.2652320