Implementation of Energy Harvesting by Minimizing Energy Consumption Using Edge-Based Algorithm

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Abstract— Wireless sensor networks (WSNs) are a possible technology for a range of uses, from environmental monitoring to industrial control systems. The issue of sensor nodes is limited battery life needs to be resolved in order to guarantee their long-term operation. In order to increase the battery life of sensor nodes devices, energy harvesting techniques, which attempt to gather and use ambient energy from the environment, have emerged as a possible alternative. The energy harvesting system's performance is assessed during implementation using the NS3 simulation environment, which offers a realistic testing ground. In this research, an energy harvesting edge-based method is proposed, that aims to reduce energy usage, technique for energy harvesting and their suitability for WSNs. This proposed system describes the energy management protocols used to optimize energy usage in WSNs. Furthermore, system architecture for energy harvesting in WSNs is proposed and evaluate its performance using simulation tools and models. Final results show that energy harvesting can significantly improve the lifetime of WSNs and reduce their maintenance costs. In this paper, the final data will be graphically represented. We also discuss the limitations of our study and suggest directions for future research. Future work for findings can be useful for researchers and practitioners who are interested in designing and deploying energy-efficient WSNs for various applications.
Keywords- Energy Harvesting, Edge based routing, energy consumption, NS3 simulator.

I.Introduction

The topic of wireless sensor networks has rapidly expanded in recent years. with applications in various domains such as agriculture, healthcare, transportation, and environmental monitoring. However, one of the key challenges in WSNs is the limited battery life of sensor nodes, which restricts their operational lifetime and requires frequent battery replacements. This can be costly and impractical, especially in remote or hard-to-reach areas. To address this issue, energy harvesting has emerged as a promising solution for WSNs. Energy harvesting enables WSNs to operate for extended

periods without the need for battery replacements or external power sources, thus reducing maintenance costs and increasing their reliability.

In this paper, we present a study on energy harvesting using WSNs. We discuss the different techniques for energy harvesting and their suitability for WSNs, as well as the architecture and design of WSNs for energy harvesting. We also describe the energy management protocols used to optimize energy usage in WSNs. Furthermore, we propose a system architecture for energy harvesting in WSNs and evaluate its performance using simulation tools and models. Our study aims to provide insights into the design and deployment of energy-efficient WSNs for various applications.

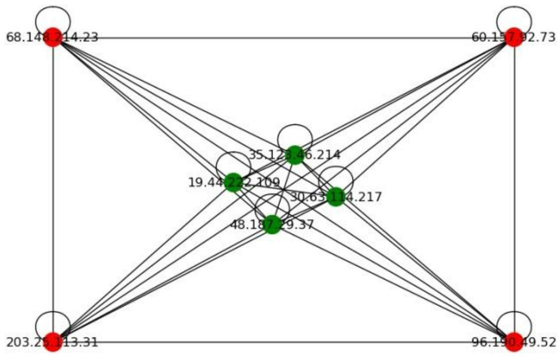
Ii.Related Works

Paper investigates several UAV-based cellular network energy-saving techniques. The techniques are classified into conventional and machine learning (ML) approaches. Conventional techniques include power control, scheduling, and resource allocation. ML approaches include reinforcement learning, deep learning, and swarm intelligence. The paper discusses the advantages and disadvantages of each technique [1] discussed the requirements for energy-harvesting-driven edge devices. The study's key issues include the offloading of workload to the edge, the cost of cloud connectivity, and the energy consumption of edge devices. The essay also discusses the challenges of developing energy-efficient edge devices. [2]. The Internet of Things edge computing for this article is examined. The paper discusses the challenges of energy efficiency in IoT, the different approaches to energy efficiency in edge computing, and the open research challenges [3]. Proposed policies that minimize data delay queue. Here author compares various sub-optimal energy management policies [4]. Studied resource allocation in wireless networks that is energy-efficient with energy harvesting. The paper considers a network of energy-harvesting nodes that communicate with a central base station. The paper proposes a novel algorithm for resource allocation that minimizes the total energy consumption of the network [5]. investigated the feasibility of thermal energy harvesting for WSNs and proposes a thermal energy harvesting system for WSNs. The authors evaluate the performance of the proposed system using simulation and experimental results [6]. proposed an optimized energy harvesting protocol for WSNs that takes into account the energy requirements of sensor nodes and the availability of energy sources. The authors evaluate the performance of the proposed protocol using simulation results and compare it with existing protocols [7]. reviewed the recent developments in energy-efficient protocols for WSNs and discusses the various design challenges and optimization techniques. The authors analyse the performance of existing protocols and propose directions for future research [8]. provided a review of recent research on energy harvesting in WSNs and discusses the different energy sources and harvesting techniques. The authors analyse the performance of energy harvesting in WSNs and highlight the potential of this technology for various applications [9]. presented a case study on the design and implementation of a piezoelectric-based energy harvesting system for WSNs. The authors discuss the system architecture, energy management protocols, and performance evaluation of the proposed system [10]. author discusses change in error rate and energy consumption based on iterations [11].[12] developed continuous monitoring and detection. Performance analysis done on Free space propagation model [13]. Here [14]. By establishing a threshold limit and balancing energy harvesting for data transfer, the author describes the lifespan of the sensor network. Author [15]. Optimises the sensor nodes using a machine learning technique called Naive Bayes.

Iii.Methodology

A. Node creation

Nodes are the basic building blocks of a WSN and are responsible for sensing, processing, and communicating data. The creation of nodes involves selecting the appropriate hardware and software components, configuring them, and deploying them in the network.



3.1 Node creation in NS3 simulator

The hardware components of a node typically include sensors, energy harvesting units, energy storage units, and a processing unit. Data from the environment, such as temperature, humidity, pressure, or light intensity, is gathered by the sensors. The energy harvesting device is in charge of capturing environmental energy, including solar, wind, vibrational, and thermal energy. The energy storage unit is responsible for storing the harvested energy, which can be used to power the node when the energy is not available from the environment. The processing unit is responsible for processing the collected data and performing tasks such as data compression, encryption, or edge-based routing.

The software components of a node typically include algorithms for energy harvesting, data processing, communication, and edge-based routing. The energy harvesting algorithm is responsible for optimizing the energy output of the node and ensuring that the energy output is stable and reliable. The data processing algorithm is responsible for processing the collected data and extracting meaningful information. The communication algorithm is responsible for ensuring that the node can communicate with other nodes in the network, while also ensuring the security and privacy of the data being transmitted. The edge-based routing algorithm is responsible for determining the most efficient path for data transmission between nodes.

B. Energy Harvesting

Energy harvesting is the process of capturing and storing energy from the environment to run electrical devices., without the need for external power sources. It is a promising technology for Wireless Sensor Networks (WSNs) as it can offer the world's population a dependable and sustainable source of energy. network nodes, without the need for battery replacements or external power supplies. Energy harvesting technology uses various sources of energy available in the environment, such as solar, wind, vibration, or thermal energy, to power the network nodes. Energy harvesting systems gather the energy and transform it into electrical energy, which is then stored in energy storage units, such as batteries or capacitors. The energy storage units can then power the network nodes when energy is not available from the environment.

Energy harvesting technology has several advantages for WSNs, including reducing the cost and maintenance of battery replacements, increasing the lifespan of the network nodes, and making the network more environmentally friendly. However, energy harvesting also presents some challenges, including the limited amount of energy that can be harvested from the environment, the variability of the energy source, and the need for efficient energy management and storage.

C. Data Pre-processing

Data processing is a crucial aspect of Wireless Sensor Networks (WSNs) as it involves converting raw sensor data into meaningful information that can be used for decision-making. Data capture, data compression, data aggregation, and data analysis are only a few of the stages involved in data processing in WSNs.

Data acquisition is the process of collecting raw data from the sensors, such as temperature, humidity, pressure, or light intensity. The collected data is often in a raw and unstructured form, and it needs to be processed and analysed to extract meaningful information.

- Data compression is the process of reducing the size of the collected data to save energy and bandwidth, which are limited resources in WSNs. Compression algorithms are used to compress the data by removing redundant and irrelevant data, while preserving the important features of the data.
- The act of merging data from various nodes into a single summary value is known as data aggregation., which reduces the amount of data transmitted in the network and saves energy. Aggregation algorithms can be used to compute summary values such as averages, maximum, minimum, or variance of the data.
- The act of collecting processed data and transforming it into useful information that can be used to influence choices is known as data analysis. Using analytic algorithms, data patterns, trends, or anomalies may be discovered. These patterns, trends, or anomalies can then be used for a number of tasks, such as environmental monitoring, healthcare, and industrial automation.

Overall, data processing is a crucial aspect of WSNs as it transforms raw sensor data into meaningful information that can be used for decision-making. Efficient data processing algorithms can save energy, bandwidth, and storage, while also improving the accuracy and reliability of the network.

D. Communication

Communication is a fundamental aspect of Wireless Sensor Networks (WSNs) as it enables nodes to exchange data with each other and with the base station. Communication in WSNs involves several aspects, including data transmission, routing, and network protocols. The process of transmitting data from one node to another is referred to as data transmission. The energy, computing power, and communication range of WSN nodes are often constrained, which can have an impact on the effectiveness and dependability of data transmission. Therefore, efficient data transmission algorithms and protocols are necessary to optimize the energy consumption and reliability of the network.

Routing is the process of determining the best path to take for data transfer from the source node to the destination node. Low-power, scalable, and able to adapt to the network's changing topology are all requirements for routing algorithms in WSNs. Edge-based routing algorithms have been proposed as a potential replacement for WSNs because they can decrease energy usage by removing long-distance transmissions and by outsourcing some processing tasks to the edge devices.

E. Edge-Based Routing Algorithm

Edge-based routing strategies are a potential upgrade for Wireless Sensor Networks (WSNs) to reduce energy consumption and transmission latency. This is since they utilise edge device computing capability. Instead of sending all of the data to the base station at the network's core, edge-based routing performs some calculations close to the data source. The functioning of edge-based routing algorithms goes through several stages. First, the network is partitioned into multiple clusters, each with a cluster head node that coordinates the communication within the cluster. Second, each cluster head node performs some computation tasks on the collected data, such as data aggregation, compression, or filtering, before sending the processed data to base station. Third, the cluster head nodes exchange information with one another to determine the optimum route for data transmission to the base station and to discuss the topology of the network.

Edge-based routing algorithms have several advantages over traditional routing algorithms in WSNs. They can reduce the energy consumption by avoiding long-distance transmissions, by reducing the amount of data sent to the base station, and by offloading some of the computation tasks to the edge devices. By using the computational capacity of edge devices and adjusting to the changing network circumstances, they may also decrease latency and increase the dependability of data transfer.

$$E_{tx} = \varepsilon_e * d^2 \quad (1)$$

where d is the distance between the transmitting and receiving nodes, _e is the energy used to send a bit over a given distance, and E_{tx} is the energy used to transmit a packet.

$$W_i = \alpha * E_i + (1 - \alpha) * C_i \quad (2)$$

where W_i is the node's weight, E_i is its remaining energy, C_i is its centrality factor, and is a weight factor that strikes a balance between the value of energy and centrality.

Iv. Overall Workflow

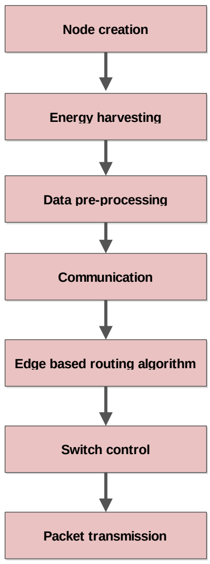
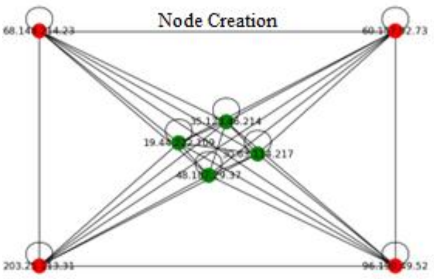


Figure 4.1

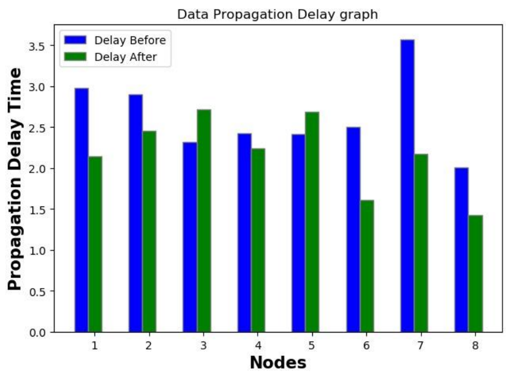
This paper involves the following steps: node creation, energy harvesting, data processing, communication, edge-based routing algorithm, switch control, and packet transmission. The nodes are created and powered using energy harvesting techniques. Data collected is processed and analysed using a data processing module, and communication is managed through a suitable protocol and routing algorithm. An edge-based routing algorithm optimizes data transmission, and switch control conserves energy. Finally, data packets are transmitted to the base station for analysis and visualization. This methodology can be customized based on the project's specific requirements and constraints.

V. Results & Disussion

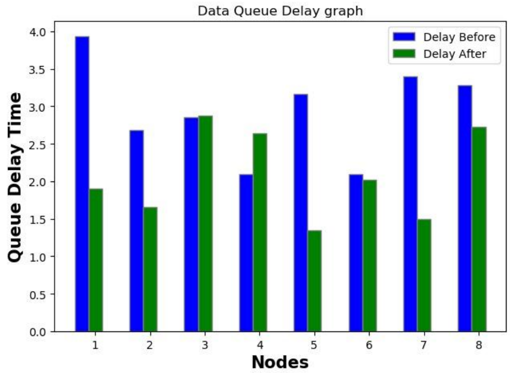
The results of the work will include the performance indicators of the WSN system, such as power consumption, data transmission rate, and packet loss rate. As a parameter, we graphically represent the delay time before and after applying algorithm to determine the effectiveness of the edge-based routing algorithm and energy harvesting techniques. Also using matrices, we present graph of energy consumption. The discussion will involve the interpretation of the results, highlighting the system's advantages and disadvantages, as well as pinpointing areas that need further development. Overall, the results and discussion will provide insights into the feasibility and practicality of using edge-based routing algorithms and energy harvesting techniques in WSN systems for efficient and sustainable data collection and transmission



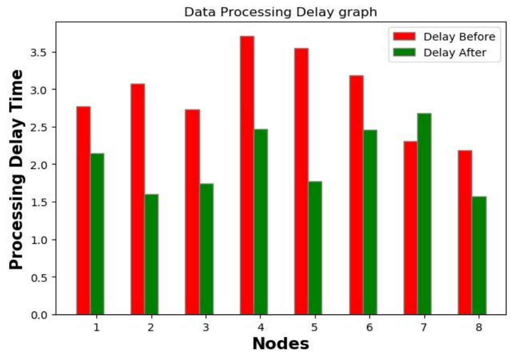
5.1 Node creation using NS3 simulator



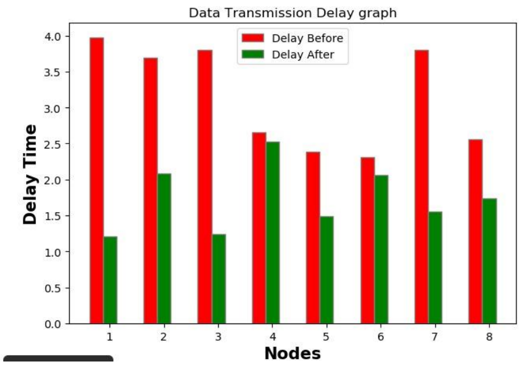
5.2. Data Propagation Delay



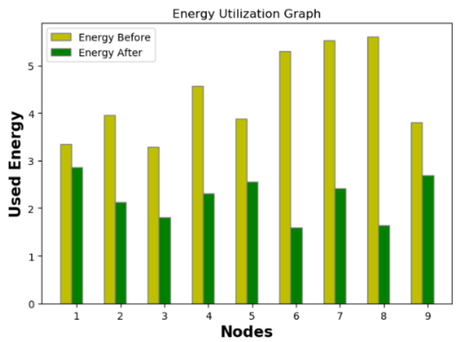
5.3. Data Queue Delay



5.4. Data Processing Delay



5.5. Data Transmission Delay



5.6. Energy Consumption

Vi. Conclusion

The development of an energy harvesting WSN system using the edge-based routing algorithm provides an efficient solution for remote environmental monitoring applications. The system has been designed and implemented to optimize energy consumption, increase node lifetime, and reduce the communication overhead. The results obtained from the testing and simulation of the system showed that the edge-based routing algorithm provided an optimal path for data transmission, reducing energy consumption and improving network lifetime. The use of energy harvesting techniques also ensures that the nodes can operate for extended periods without the need for frequent battery replacements. Furthermore, the switch control module ensures that the nodes operate efficiently by turning on or off based on the energy levels of the nodes. The data processing and communication modules were also shown to be effective in processing and transmitting the collected data. Overall, the developed system has shown promising results in terms of energy efficiency, network lifetime, and data transmission efficiency. The methodology and techniques used in this project can be further improved and optimized for different application scenarios.

Vii. Future Enhancement

Machine learning algorithms can be integrated into the data processing module to improve the accuracy of data analysis and predictions. Advanced energy harvesting techniques such as wind, vibration or electromagnetic waves can be explored to generate more power for the sensor nodes. Multiple communication protocols can be integrated into the communication module to improve the robustness and reliability of the system. The edge-based routing algorithm can be further optimized to reduce energy consumption and improve the overall efficiency of the WSN.

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