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Maximizing Lifetime of IOT-Based Hetero WSNs for Sustainable Smart City Application

Janani S, Lavanya S, Manju shri S, Mrs.K.Yazhini
Department of Electronics and Communication Engineering, Kongunadu College of Engineering and Technology, Trichy, India

Abstract- IoT-based Heterogeneous WSN (HWSN) technologies are useful instruments for accomplishing sustainability objectives in Sustainable Smart Cities (SSCs) due to their adaptability and wide range of applications. Even though WSN heterogeneity is still being investigated by researchers, it is becoming increasingly crucial to develop affordable models that address many aspects of SSC while maintaining their stability and dependability. To identify disjoint CSs that are energy-aware, we suggest a novel technique, the Required Energy Aware technique (REA). In every iteration, the REA algorithm carefully attempts to create the set that optimizes longevity while abiding by CS criteria. The output simulation increases network longevity, reduces resource consumption, and permits effective distribution of data sensing and collection activities throughout the network.

Index Terms- WSN Heterogeneity, Disjoint Clusters (CSs), Energy-Aware, Energy Optimization.

I. INTRODUCTION

Sustainable Smart Cities (SSCs) are becoming more and more necessary as cities all over the world continue to expand. In order to maximize resource management, improve urban living, and guarantee long-term sustainability, these cities make use of cutting-edge technologies. The Internet of Things (IoT)-based Heterogeneous Wireless Sensor Networks (HWSNs) are one of the key technologies enabling these objectives. These networks, which are made up of numerous sensor nodes with different energy, processing, and communication range capacities, are essential for keeping an eye on and controlling urban surroundings. These nodes' diversity enables HWSNs to effectively handle a wide range of smart city applications, including environmental monitoring, public safety, energy efficiency, and traffic management.

Nevertheless, controlling energy usage and increasing these heterogeneous networks' lifespan continue to be difficult tasks. HWSNs must balance the resources of nodes with varying energy capacity, which is more difficult than in homogeneous wireless sensor networks (WSNs), where all nodes have comparable energy profiles. Because of this heterogeneity, it becomes more difficult to guarantee that every component of the network functions effectively without producing network instability or prematurely depleting the resources of specific nodes.

Therefore, creating energy-efficient models for diverse WSNs is crucial to meeting smart city sustainability goals. To overcome this difficulty, we provide a brand-new method known as the Required Energy Aware (REA) algorithm, which maximizes HWSN lifetime and energy consumption. To make sure that every sensor node contributes to the network's operation without taxing its energy reserves to the limit, the REA algorithm is made to find disjoint clusters (CSs) in the network that are energy-aware. In order to create clusters that can efficiently balance energy usage and still meet the needs of the clustering method, the algorithm carefully chooses sensor nodes for each iteration. This strategy prolongs the life of the entire network by ensuring that no single node takes on an excessive amount of work. To overcome this difficulty, we provide a brand-new method known as the Required Energy Aware (REA) algorithm, which maximizes HWSN lifetime and energy consumption. To make sure that every sensor node contributes to the network's operation without taxing its energy reserves to the limit, the REA algorithm is made to find disjoint clusters (CSs) in the network that are energy-aware.

In order to create clusters that can efficiently balance energy usage and still meet the needs of the clustering method, the algorithm carefully chooses sensor nodes for each iteration. This strategy prolongs the life of the entire network by ensuring that no single node takes on an excessive amount of work.The purpose of the REA approach is to maximize network lifetime while preserving overall stability. The algorithm optimizes network efficiency and reduces resource usage by controlling the energy distribution across nodes in each iteration. By taking into account each node's energy level, it is possible to give lighter workloads to nodes with lower energy reserves and more demanding jobs to those with higher energy reserves. Moreover, efficient task distribution within the network is made possible by the REA algorithm.

The technique assists in preventing early node failure due to energy exhaustion by carefully allocating sensing and data gathering tasks across various nodes. Additionally, it guarantees continuous and dependable data transmission, which is crucial for real-time applications in smart cities where precise and consistent data is necessary for urban systems. Simulations demonstrating the REA technique's efficacy reveal notable increases in network lifetime, decreased resource use, and optimized energy usage. The findings demonstrate that IoT-based HWSNs can effectively assist sustainable urban applications by increasing their lifespan with the help of the REA algorithm. This method offers a scalable and affordable method of managing urban resources while also improving network efficiency and lowering operating and maintenance expenses for sensor networks in smart cities.

The REA algorithm ultimately contributes to the larger objectives of smart infrastructure and urban sustainability by laying the groundwork for the development of durable and energy-efficient IoT-based sensor networks that can satisfy the demands of quickly changing Sustainable Smart Cities.

II. LITERATURE REVIEW

The study revolves around the infusion of IoT-based Heterogeneous Wireless Sensor Networks (HWSN) for the development of Sustainable Smart Cities (SSC), which aim to improve the urban life cycle in terms of sustainable resource management, environmental monitoring, and automation. Heterogeneous Wireless Sensor Networks exhibit differences with traditional WSNs in that they are composed of sensor nodes that can vary in capability, including energy levels, computational power, and communication ranges-a feature that, on the downside, imposes another layer of difficulty in ensuring energy efficiency, reliable data transmission, and network stability on the system. Remote researchers have been studying the various techniques to optimize network performance against challenges associated with clustering mechanisms, energy- aware algorithms, and routing protocols.

Clustering has become one of the core paradigms in prolonging the network's life with less communication overhead and maximizing energy consumption. Contrary to HWSNs, traditional clustering algorithms, such as LEACH (Low-Energy Adaptive Clustering Hierarchy), PEGASIS (Power-Efficient GAthering in Sensor Information Systems), and HEED (Hybrid Energy-Efficient Distributed Clustering), have been extensively researched, but their application to heterogeneous environments is quite restricted by their assumptions of homogenous networks. There are many existing energy-aware clustering approaches that have been introduced to optimize cluster head selection and cluster formation based on heterogeneous characteristics. Current trends indicate fuzzy logic, machine learning, and bio-inspired algorithms for adaptive clustering and energy management. The fuzzy-based approaches would use multiple parameters, such as residual energy, node centrality, and communication cost, to dynamically determine optimal cluster head selection.

Likewise, machine learning-based approaches are applied to energy consumption pattern prediction using reinforcement learning and neural networks for optimizing operations at the network level. Bio-inspired techniques like PSO and genetic algorithms are also used to improve clustering decisions based on the concept of natural selection and swarm intelligence. Still, despite these advancements, it poses a challenge to strike a balance between energy efficiency and network stability. The Required Energy- aware (REA) technique, explored in this work, represents a new level of energy-aware clustering by adding an approach that focuses on disjoint cluster set (CS) formation, thereby ensuring energy efficient cluster meetings with long life for the network. Compared with traditional techniques of clustering, REA is formed in an iterative way.

It constructively adds clusters while at the same time ensuring that the chosen CS prolongs the network life while not violating the fundamental clustering constraints. A study in this field points to energy optimization through load balancing as being of crucial importance, conventional methods are mostly inflexible and proceed on the basis of dynamic network conditions, while others fail with regard to various capabilities across heterogeneous nodes.The simulation results of REA have shown that there is an improvement in network life about energy expenditure and load management for sensing and data collection activities. This supports other studies which contend that energy-aware clustering is crucial for maximizing the life of WSNs applications in smart cities.

Energy-efficient data transmission approaches such as compressive sensing, data aggregation, and multi-hop communication, are complementary to clustering approaches. Data aggregation methods decrease redundant transmissions which in turn conserve energy while multi-hop communication methods use intermediate nodes to pass data from source nodes to the sink. Further studies have looked into integrating software-defined networking (SDN) and edge computing to increase HWSN flexibility in SSCs by giving centralized control, dynamic resource allocation, and real-time decision support. However, they will also need their relatively heavier infrastructure and computation resources, making it sometimes less feasible to adopt in the large deployment of smart city-level programs. To wrap up, while the contributions towards energy- aware clustering in HWSNs are commendable, there is still a need to design solutions that are cost-effective, scalable, and adaptive. The proposed REA clusters energy efficient applications and thus contributes to the body of knowledge. Future work may include using AI-based predictive analytics, blockchain-based-security mechanisms, and hybrid communication architecture to improve the resilience and sustainability of HWSNs in the smart city environment.

III. METHODOLOGY

In order to achieve the best possible energy efficiency, stability, and lifespan, a series of interrelated processes make up the suggested approach for implementing the Required Energy Aware (REA) strategy in an IoT-based Heterogeneous Wireless Sensor Network (HWSN) for Sustainable Smart Cities (SSC). Initialization of the network, cluster selection, creation of an energy-aware disjoint cluster set (CS), data collecting, and performance assessment are all steps in the process.

Initialization of the Network

In order to monitor different environmental and infrastructure characteristics in the SSC, heterogeneous sensor nodes (SNs) are placed in the HWSN, which is modeled as a multi-tier network. Cluster heads (CHs) with improved processing and communication capabilities, high-power mobile sensors, and low-power static sensors make up the network. Specific characteristics like energy capacity, sensor range, transmission power, and computing power are initialized for every node. Depending on the deployment scenario, nodes are positioned either randomly or deliberately.

In order to reduce communication overhead, the base station (BS) is thought to be positioned strategically.The network topology is also dynamically adjusted to account for variations brought on by node failures, mobility, and energy consumption. By taking into account urban layouts, the deployment method minimizes redundant sensing while guaranteeing excellent coverage and connection. Coverage efficiency is further increased by sophisticated localization methods including machine learning-based node placement optimization and GPS-assisted positioning.

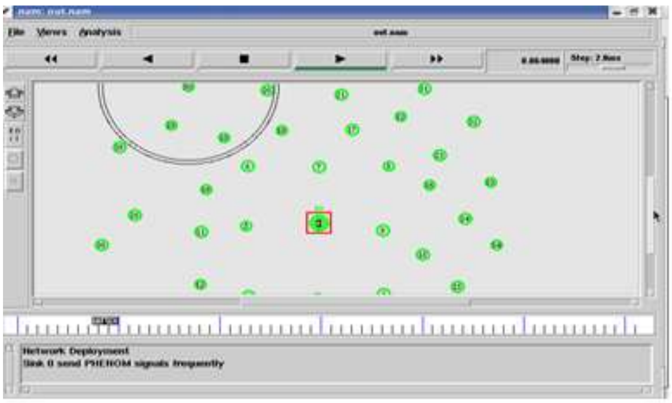

Fig1.Network Initialization

Cluster Formation and Cluster Head Selection

A clustering strategy is used to efficiently regulate energy consumption. Based on the nodes' energy and spatial properties, clusters are created. A hybrid selection method that takes communication cost, node centrality, and residual energy into account is used to choose a CH for every cluster. An even distribution of CH roles among nodes throughout various rounds is ensured by the probabilistic model of the CH election process. Data from their individual clusters must be aggregated by the CHs before being sent to the BS. Adaptive re-clustering mechanisms, which dynamically modify clusters in response to network and environmental changes, are also incorporated into the cluster creation process. This avoids hotspot problems, in which a heavy workload causes some nodes to use up their energy more quickly. Heterogeneous cluster hierarchies and other multi-tier clustering techniques improve network energy balancing even further.

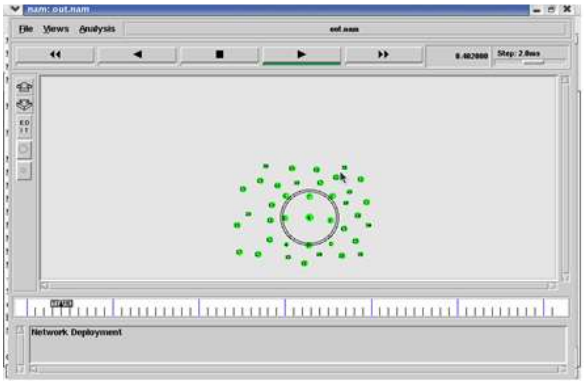

Fig2. Data Transmission

Essential Energy Aware (Rea) Algorithm For Cluster Sets That Are Disjoints

By creating energy-aware disjoint CSs, the REA algorithm aims to increase network lifetime. This method maintains the energy levels of individual nodes while guaranteeing that data collection is effectively spread across several rounds. The following phases comprise the iterative operation of the REA algorithm.

Cluster Analysis

Each cluster's energy levels and communication costs are evaluated at each iteration. For data transmission activities, nodes with more leftover energy are prioritized. The energy model takes into account things like power management strategies, energy harvesting potential, and sleep schedules. Furthermore, procedures for real-time energy monitoring guarantee that CH selection dynamically adjusts to changing power levels.

Formation of CS

Based on an optimization criterion that increases network lifetime while preserving connection and stability, disjoint

CSs are created. In order to guarantee that nodes with lower energy consumption take precedence in the set creation.The selection procedure takes energy limits into account. Techniques for reducing node redundancy are also Balance of Loads.

Balance of Loads

The technique prevents energy depletion in particular network locations by distributing sensing and data transmission tasks among several CSs in an equitable manner. To increase efficiency, load balancing techniques including role rotation, mobility-aware clustering, and duty cycling are combined.

CS Scheduling

In order to save energy, a scheduling system makes sure that only the most energy-efficient CSs are active throughout each cycle, with the others remaining in an idle or low-power state. To predict energy requirements and dynamically modify the active sensor sets, the scheduling model uses predictive analytics based on machine learning. Over time, resource allocation is optimized by reinforcement learning approaches.

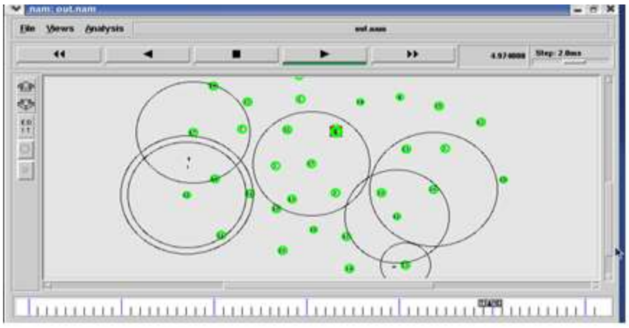

Fig3. Data Transmission Scenario 2

Transmission and Aggregation of Data

In order to minimize total power consumption, CHs gather and combine sensed data before sending it to the BS via an efficient multi-hop communication technique. Data transmission efficiency is improved via secure data fusion processes, compression algorithms, and redundancy removal procedures. Data integrity and authenticity are guaranteed by blockchain-based security methods.

Fig4. Energy vs. No. Of Nodes

Sensing and Gathering Data

IoT-enabled sensor nodes continuously sense and gather information about the SSC's sociological, infrastructure, and environmental components. To minimize power consumption, the gathered data is combined at CHs and sent over a multi-hop routing protocol.

To further improve energy efficiency, advanced data compression and encoding techniques are used to decrease the quantity of data delivered.By processing data closer to the source, the system uses edge computing capabilities to lower latency and bandwidth usage. Algorithms for anomaly detection are also used to remove inaccurate measurements and guarantee data reliability. Adaptive reactions to environmental changes are made possible by artificial intelligence-driven decision-making processes and real-time data analytics.

Analysis and Assessment of Performance

In a network simulator environment, comprehensive simulations are used to assess the REA-based HWSN's performance. Among the important performance indicators are Network longevity, which measures overall energy efficiency, is the amount of time before the first and last node dies.Energy Consumption are The network's overall energy usage as measured by several simulation cycles.

The data packet delivery ratio, which ensures data transmission dependability, is the proportion of successfully sent data packets. Throughput and Latency are the amount of data that is successfully transported over time and the delay in data transmission.

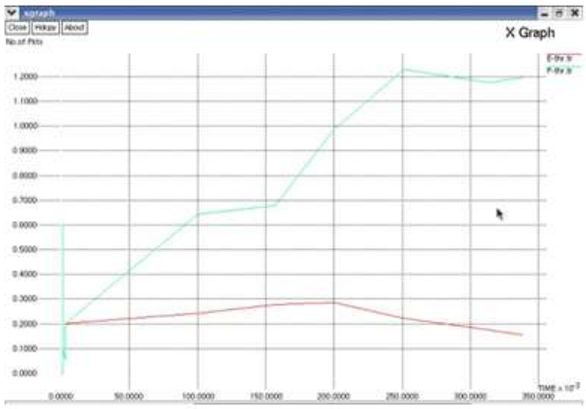

Fig5. Throughput vs. No. Of Nodes

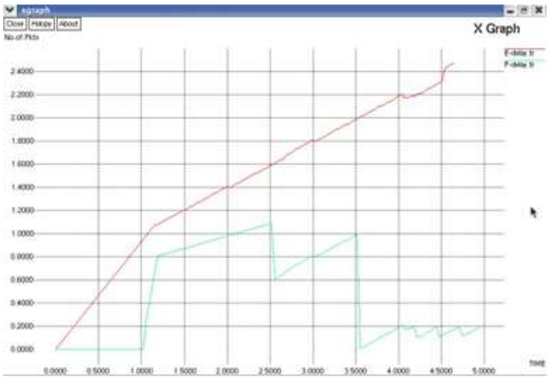

Fig6. Delay vs. Nodes

The network's capacity to manage fluctuatuing traffic conditions and growing node density is known as scalability and adaptability. Security and credibility are assessment of inntrusuion detection system and blockchain-based authentication. In terms of extending network life-time, lowering energy consumption and guaranteeing data transfer the REA-based method performs better.Furthermore, experimental validation using real-world testbed installation is taken into account to evaluate the suggested framework's practically.

IV. CONCLUSION

To sustainable and energy-efficient operations in SSC, the suggested methodology successfully combines an energy-aware clustering mechanism with IoT-based HWSN. The REA algorithm is a workable option for actual SSC deployments since it dynamically optimizes CS selection, balances energy consumption, and improves network stability. In order to further improve adaptive energy management tactics in HWSNs, future research can concentrate on using machine learning approaches. Additionally, by solving security and privacy issues, implementing blockchain-based secure communication techniques can enhance data integrity and network trust.Furthermore, by incorporating edge intelligence, real-time feedback loops, and 6G-enabled smart communication techniques, network operations can be further improved. The system can become completely self-sustaining by including energy-harvesting methods like solar and RF-based wireless power transfer, which can further increase network lifetime.

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