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Enhancing the Energy Efficiency of Wireless Sensor Networks in IoT

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Abstract *— The core foundation of Internet of Things (IoT) systems are wireless sensor networks (WSNs). Energy limitations provide a significant problem for the wireless nodes in these networks that are in charge of sensing. The complexity results from the challenging task of recharging or replacing the batteries of these nodes, a task frequently met with great difficulty. The energy problem is made worse by the fact that many real-world IoT situations involve dynamic sensing components that are in motion. In light of these worries, the current research is carefully designed to solve the real-world difficulties posed by WSNs that include mobile sensing components. The main goal is to use concept of radio-frequency (RF) energy extraction to alleviate energy restrictions that are inherent in such settings. With a framework designed to handle mobile sensing components capable of RF energy harvesting, proposed technique presents a novel procedure for the election of cluster heads (CH) within WSNs. This method holds great potential for overcoming the persistent energy puzzles that have repeatedly hampered the smooth operation of such networks. This method's key strength is its capacity to harness RF energy, which renews the nodes' power sources and increases their operational lives. The effectiveness of the suggested strategy is exposed through thorough simulations, which puts it favorably in contrast to current methodologies. The parameters of residual energy, count of functioning nodes, and overall network longevity all highlight this approach's superior performance and highlight its potential to change the WSN landscape within the dynamic and energy-conscious IoT environment.*

Keywords ***— Wireless Sensor Networks, Energy Efficiency, Internet of Things, Cluster Head (CH).***

I. BACKGROUND

WSNs are key elements inside complex structure of IoT systems. Even though these networks are vital, controlling energy resources is a difficult task that poses a significant difficulty. In particular, the dilemma of either replacing or recharging the batteries of the wireless sensor nodes nested within WSNs has raised questions about their effectiveness due to energy limitations. The fact that dynamic, movable sensor components are frequently used in real-world IoT settings further complicates the situation. This places a greater emphasis on energy-related challenges because the mobility issue makes the energy constraints these networks must deal with even more severe. The idea of radio-frequency (RF) energy extraction emerges as a beacon of potential in response to this complex web of worries. This novel idea has the potential to reduce the energy constraints seen in realistic WSN scenarios with mobile sensor components. This strategy offers a way to get over the conventional energy bottlenecks and gives a sustainable technique to power these dynamic components within WSNs by utilizing RF energy.

The promise of RF energy extraction within the context of IoT is the primary emphasis of this research. It specifically aims to solve the energy limitations that have, up to now, limited WSNs' ability to operate without interruption, particularly those that use mobile sensors. This strategy tries to recalibrate the energy landscape of such networks by utilizing the latent energy potential of the surrounding environment, giving a fresh perspective on their durability. WSNs' importance is still paramount as IoT devices grow. Innovative solutions are required due to the complex interplay between energy constraints, mobile sensor components, and the dynamic nature of IoT applications. This research aims to reinvent the energy paradigm of WSNs through the perspective of RF energy extraction, opening opportunities to prolonged operation and improved efficiency within the dynamic IoT environment.

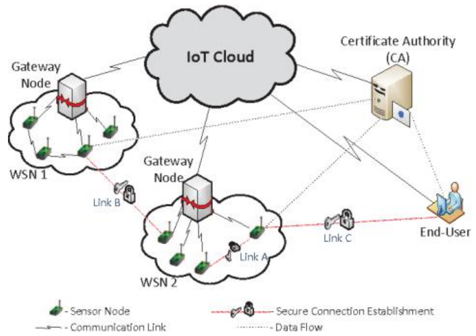


Fig.1.1: Typical WSN based IoT Network

(Source: Porambage, P., Schmitt, C., Kumar, P., Gurtov, A.V., & Ylianttila, M. 2014) [68]

IoT systems are predicted to enable device communication in a variety of environments in the near future, including homes, offices, agricultural fields, factories, transit systems, and battlefields, leading to a large rise in infrastructure needs [1]. In IoT systems, wireless sensor networks (WSNs) are crucial [2]. These networks are made up of numerous electromechanical or wireless sensing nodes that collect a variety of physical parameters and send the corresponding data to a base station/sink in the centre. It is then analyzed, processed, and transmitted over the Internet at the base station [3].

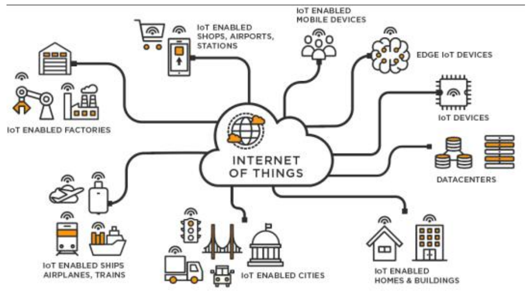


Fig.1.2: Internet of Things (IoT) connectivity with Web Applications

(Source: https://www.analyticsvidhya.com/blog/2022/09/how-to-connect-iot-sensors-wirelessly-with-a-web-application/) [69]

The need for sensing nodes has increased dramatically as a result of the Internet of Things' exponential growth. This growth is being driven by the complex interactions that IoT orchestrates between systems, devices, and data streams. Numerous problems have emerged as a result of the widespread use of wireless connections to connect these nodes, all of which call for sharp focus and creative solutions. The growing number of these interconnected nodes lies at the heart of this developing environment. While they open the door for never-before-seen data interchange and insights, this upsurge also gives rise to a number of complexities that demand careful consideration. The requirement to acquire an adequate communication frequency spectrum takes precedence over all other complications. Innovative spectrum management techniques are required to deal with the expanding number of nodes varying for a piece of this scarce resource in order to avoid overcrowding, signal interference, and general network congestion. Additionally, the increased interconnectedness calls for a significant expansion of data security measures. The sophisticated web of communication paths becomes more vulnerable to hacks, data spills, and cyberattacks as the IoT mosaic grows. Due to these nodes' dynamic nature and the volume of data they manage, data security must be approached from several angles, including encryption, authentication procedures, and anomaly detection systems.

At the same time, the expanding network of sensor nodes highlights the critical energy conundrum. Node consumption of energy resources is independent of size or complexity. This cumulative energy demand poses substantial issues as IoT deployments grow in size. As the continued operation of numerous linked devices is at stake, the race to develop energy-efficient technologies and techniques has never been more important. Transformative potential as well as complex obstacles are heralded by the symbiotic interaction between the IoT and the soaring need for sensor nodes. The solutions we develop will determine the course of the Internet of Things' continued expansion, influencing its ability to transform companies, societies, and the very fabric of connectivity itself, as we negotiate the landscape of communication frequency, data security, and energy efficiency [4, 5].

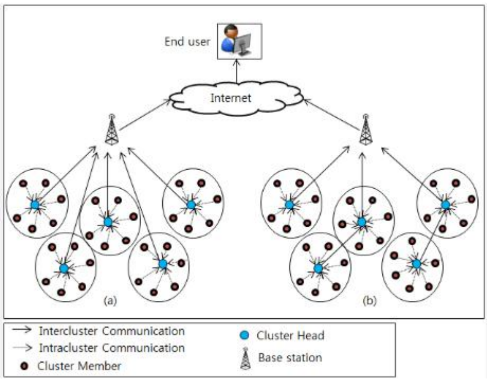


Fig.1.3: Typical wireless Sensor Network Deployment (Source: https://www.researchgate.net/figure/Cluster-based-wireless-sensor-network-WSN-with-different-data-communication-scenarios_fig1_331434432) [70]

Energy is a basic requirement for sensing nodes to operate. However, standard battery replacement or recharging procedures are impracticable in the case of WSNs because the nodes are frequently small and deployed in remote areas [6]. Energy-efficient methods have been developed to solve this problem by lowering the energy consumption of sensing nodes and extending the life of the network. Numerous research already in existence suggest clustering approaches in which the network region is separated into clusters, each of which contains several sensing nodes. Based on variables such as remaining energy and distance to the sink, cluster head (CH) chosen among nodes in each round [7]. In order to extend the lifespan of the network, the nodes in a cluster send data to the CH, which then talks with the sink for that round.

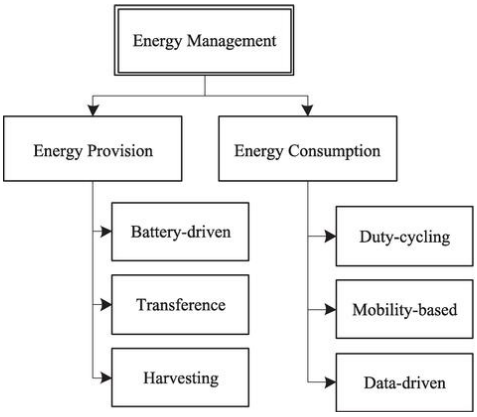


Fig.1.4: Energy Management issues in Wireless Sensor Networks

A viable method for fueling wireless sensing nodes is energy harvesting, a new technology [8]. Energy-harvesting WSNs include nodes that may draw power from ambient or specific sources [9], such as radio-frequency (RF) energy as well as non-natural sources like wind and sunshine. In particular, RF sources offer the ability for simultaneous wireless information and power transfer (SWIPT) [10]. These sources may be ambient, such as Wi-Fi or mobile towers, or they may be deployed RF sources specifically designed to energize WSN nodes [11]. Although RF sources may provide less energy than natural sources, their reliability and ongoing accessibility make them a good choice for wireless sensor nodes.

WSNs consist of mobile sensing nodes rather than fixed ones in many real-world applications [12]. Soldiers, military vehicles, or animals in their natural habitats are some examples of naturally moving objects in the sensing environment that are included in Mobile Wireless Sensor Networks (MWSNs) [13]. Additionally, vehicles with sensors that function as mobile sensing units can be a part of smart transportation systems. The difficulties with replacing batteries in MWSNs are significantly more complicated than in static WSNs, highlighting the critical function of energy management. In this situation, RF energy harvesting can be quite important.

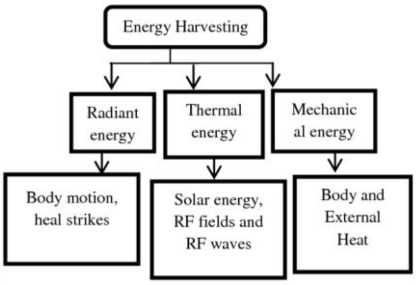


Fig.1.5: Energy Harvesting - WSNs

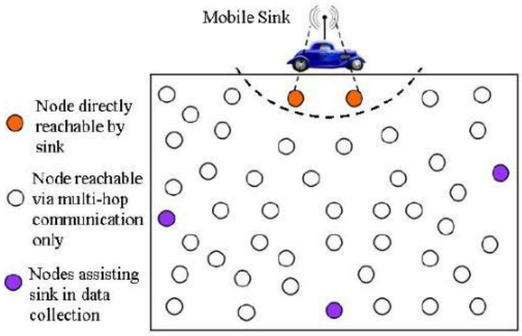


Fig.1.6: Mobile Wireless Sensor Networks (MWSNs)
(Source: https://www.researchgate.net/figure/Network-architecture-of-a-mobile-wireless-sensor-network_fig2_260120791) [71]

Surprisingly little research has been done in the area of Mobile Wireless Sensor Networks (MWSNs) that can use RF energy. This gap in knowledge and research offers an enticing chance to delve into a world full with promise. The goal is to address an important issue: how to maximize the energy efficiency of nodes inside MWSNs, particularly when these networks collide with real-world scenarios involving mobile elements. The standard paradigms of energy management fall short in these dynamic contexts, necessitating creative solutions that can meet the constantly changing energy needs of mobile nodes. Therefore, the main goal of this research is to close the current energy efficiency gap by combining tried-and-true energy-saving techniques with the cutting-edge idea of RF energy extraction. This research aims to usher in a new era of energy sustainability for MWSNs by combining tried-and-true energy-conservation methods with the promise of RF energy harvesting. The main objective is to make it possible for these networks to thrive by being mostly self-sufficient, in addition to functioning seamlessly in the face of mobility. This project has the potential to fundamentally alter how we think about and use wireless sensor networks in mobile contexts. It is not only an academic undertaking. These networks could power themselves by utilizing the ambient RF energy that is all around us, minimizing reliance on outside energy sources and opening the door for longer-lasting, more autonomous, and environmentally responsible network operations.

As the research moves on, it hopes to not only add to the body of knowledge about MWSNs but also to elicit useful implications. These effects could improve the effectiveness of smart transportation systems or make it possible to monitor wildlife in far-off locations more successfully while resolving the energy issues that have hitherto hindered such attempts. This research sets out on an aim to close the MWSN energy efficiency gap. It aims to revolutionize the mobile wireless sensor network landscape through the merging of well-established energy-efficient tactics and RF energy extraction principles, ushering in an era of sustainability, resilience, and transformational possibilities for real-world applications. Cluster Head (CH) will finally be chosen for each simulation round, assuring energy-efficient CH choice and RF energy extraction in order to increase lifetime of the network as a whole by increasing sensing nodes lifespan. In the study, variables which are used for the analysis include:

- Initial/remaining energies
- Energy - Harvested
- Location changes
- Node's Average Energy

"Initial energy" and "remaining energy" relate to the energy levels of individual sensor nodes within wireless sensor networks (WSNs).

Initial Energy: Each sensor node in a WSN is initially powered by a specified amount of energy, which is often provided by batteries or other power sources. This initial energy is a representation of the node's initial energy level as it starts to function inside the network. It's an important parameter since it controls how long the sensor node can function before running out of energy.

Remaining Energy: The remaining energy is used by each sensor node as the WSN runs to perform various tasks like sensing, processing, communication, and maybe other operations like data aggregation and routing. The quantity of energy that a sensor node has left over after carrying out its duties for a while is known as the leftover energy. Monitoring the remaining energy is essential for determining the network's health, estimating the nodes' remaining life, and enhancing energy-saving tactics.

Network administrators and researchers can make well-informed choices about node deployment, energy-efficient routing protocols, data collecting schedules, and methods for extending the overall network lifetime by being aware of the starting and residual energy levels in a WSN. Because the energy sources of the sensor nodes in WSNs are typically limited and non-rechargeable, managing energy usage is a significant concern.

Energy Harvested: "Energy harvested" in the context of wireless sensor networks (WSNs) refers to the act of gathering energy from outside sources to power the sensor nodes within the network. Energy harvesting, as opposed to exclusively depending on batteries, allows sensor nodes to recharge by obtaining energy from the environment, which can increase the operating lifetime of the network and decrease the need for frequent battery replacements. Radio Frequency (RF) technology can be used for energy harvesting. Through rectifying circuits, energy, or ambient RF signals like Wi-Fi or cellular signals, can be transformed into useful electrical energy. When it is inconvenient or expensive to replace the batteries in sensor nodes, especially in remote or difficult-to-reach areas, energy harvesting is extremely useful. WSNs can operate more sustainably and for a longer time by using environmental energy. The fluctuation in energy supply, the effectiveness of energy conversion, and the development of energy management systems that balance energy consumption and energy harvesting rates are some of the issues associated with energy harvesting.

Location Changes: "Location changes" often refer to the mobility of sensor nodes inside wireless sensor networks (WSNs). While nodes in typical wired networks are immovable, nodes in wireless sensor networks (WSNs) can be mobile within a given space or environment. In terms of network administration, data collecting, and communication, this mobility may present both benefits and constraints. Routing protocols, energy management approaches, localization procedures, and network architecture concerns are all used to control location changes in WSNs. It necessitates addressing the trade-offs between energy usage, data accuracy, network resilience, and data gathering efficiency.

Node's Average Energy: "Node's average energy" in the context of wireless sensor networks (WSNs) refers to the typical amount of energy used or left in a sensor node over a given amount of time. It is a statistic used to assess the effectiveness and energy efficiency of each node in the network. Designing energy-efficient protocols and methods requires an understanding of the node's average energy in order to evaluate the network's overall health and lifetime.

The idea of node's average energy operates as follows:

- Energy Consumption: Sensor nodes in a WSN use energy for a variety of functions, including environment sensing, data processing, data transmission and reception, and network connection maintenance. Depending on the exact applications and tasks the nodes are performing, the energy consumption pattern may change.
- Initial Energy: When a sensor node joins the network, it comes with an initial supply of energy, often delivered by batteries or energy-harvesting devices. The node's ability to function is determined by its initial energy.
- Energy Depletion: The node's energy level gradually drops as it fulfills its duties. The tasks carried out and the component efficiency of the node determine the rate of energy depletion.

- Calculating the Node's Average Energy: To get the node's average energy, divide the total energy used or still present in the node by the length of time used to collect the energy measurements. This computation reveals how quickly the node's energy is depleting and how long it can function without needing to be recharged or replaced.
- Energy management: It's essential to keep track of the node's average energy when coming up with energy management plans. Nodes with low average energy may require recharge or replacement, whereas nodes with high average energy may be better suited for tasks that require more energy.
- Network Lifetime: The total network lifetime is influenced by the average energy of all network nodes. A longer average energy across nodes may result in a longer network operating lifetime.
- Researches can create energy-efficient protocols and algorithms, such as duty cycling, data aggregation, adaptive routing, and sleep-wake scheduling, by studying the node's average energy consumption.
- Fault Detection: Extremely low average energy levels may signify faulty nodes or nodes with energy-sipping problems, which could cause network deterioration.

Given the scarce energy resources accessible to sensor nodes and the need of assuring the network's lifetime, measuring and managing the node's average energy is a crucial component of preserving the effectiveness and sustainability of wireless sensor networks.

Problem Statement

For wireless sensing nodes in Wireless Sensor Networks (WSNs), energy-related issues provide a significant and challenging barrier. This problem is mostly caused by the complex barriers involved in changing or recharging the batteries in these nodes. This conundrum is further complicated by the inclusion of mobile sensing components in a wide range of real-world Internet of Things (IoT) applications. The current energy problems are greatly made more difficult and complex by the integration of mobility. Gaining a thorough understanding of WSN situations that embrace the idea of mobile sensing elements is crucial in order to properly address these important issues. The ultimate objective is to develop methods and solutions that can successfully reduce, ease, or even avoid the severe restrictions imposed by energy resources by diving deeply into the dynamics of such scenarios. By doing this, we open the door for WSNs to operate more sustainably and long-term in the face of tightening energy supplies.

II. PURPOSE OF THE STUDY

The need to overcome the restrictions provided by energy constraints inside wireless sensor networks (WSNs) is driving the field of research to move its focus towards the analysis of practical situations that involve mobile sensing elements. The goal of this project is to develop creative solutions to the enduring energy-related problems that arise in such situations. Radio-frequency (RF) energy extraction offers a promising option for investigation in order to tackle these imposing problems. In this method, WSNs are strategically reconfigured to include a crucial component known as the cluster head, which houses movable sensing elements capable of capturing RF energy from the surroundings. The energy dynamics within WSNs could be completely altered by this integration of energy gathering capabilities. While earlier research has focused mostly on improving energy efficiency of WSNs through analysis of variables like initial energy reserves, residual energy levels, mean energy consumption & inter-node distances, there has been a glaring lack of research into the field of energy harvesting strategies designed to improve the energy efficiency of WSNs in practical, real-world scenarios. The significance of the suggested strategy, which aims to fill this information gap by introducing a CH selection system, is highlighted by this crucial gap. This innovative technique introduces a new age of increased energy utilization efficiency by enabling individual nodes within the WSNs to actively accumulate RF energy. According to the proposed technique, WSN behavior in mobile sensing scenarios would undergo a comprehensive makeover. The suggested strategy not only has the potential to ease the energy-related challenges of mobile WSNs, but also to redefine the very fabric of energy sustainability within these networks. It does this by capitalizing on the untapped potential of RF energy extraction and integrating it with strategic CH selection mechanisms.

In short, research will address the following objectives.

- Addressing energy constraint in IoT applications in wireless sensing nodes in WSNs.
- Designing WSN nodes (mobility) by coming up with various clustering protocols for enhancing energy efficiency of WSNs and prolonging network lifetime.
- Coming up with a novel technique that will combine RF energy extraction with clustering scheme in order to extend lifespan of a MWSN.
- Validating effectiveness of proposed technique by demonstrating improvements in energy, node count, and network lifetime.

Research Questions

- Is it possible to address a significant constraint of energy requirements of WSN nodes?
- How to design real time scenario of mobility in WSN nodes using different clustering protocols for enhancing energy efficiency and prolong the network lifetime?
- How to come up with a novel technique combining RF energy with clustering scheme in order to extend the lifetime of a mobile wireless sensor network?
- How to validate the effectiveness of the proposed technique?

Significance of Research

The main goal of the study is to demonstrate the effectiveness and applicability of the suggested methodology by demonstrating how it affects many vital features of wireless sensor networks (WSNs). The suggested method seeks to greatly increase the number of operational nodes inside the network, fortify residual energy reserves of WSN nodes & extend network's total lifespan through thorough simulation-based analysis. The novel approach under discussion has ramifications that go beyond theoretical research since it is positioned to be a crucial tool in evaluating the viability and effectiveness of real-world Internet of Things (IoT) applications that are built on the basis of WSNs with mobile components. This suggests that the suggested technique has the potential to offer insightful analysis and workable solutions for situations where mobile components are crucial to data gathering and transmission. It's interesting to note that this strategy can be used in situations without naturally mobile objects. Additionally, it may be fluidly expanded to include scenarios in mobile WSN frameworks where elements might not necessarily have movement properties. This flexibility highlights the approach's adaptability because it can be modified to suit a variety of mobile WSN scenarios, regardless of whether mobility results from inborn movement or outside influences. The flexibility with which the proposed scheme can be altered to support alternative mobility models also highlights how adaptable it is. This adaptability aspect makes it possible to fine-tune the technique to suit the particular needs and dynamics of a particular application. This ensures the scheme's relevance and effectiveness in a variety of settings by allowing for smooth integration into a wide range of contexts. In addition to the theoretical justification of the technique's benefits, researchers are also interested in its real-world applications for improving mobile WSNs' energy efficiency, network robustness, and lifetime. The proposed technique emerges as a flexible and useful tool with broad implications for the area of wireless sensing and network sustainability by showcasing its potential through simulations and recognizing its applicability in both real-world IoT scenarios and diverse mobility settings.

III. LITERATURE REVIEW

In IoT systems, charging wireless sensor nodes turns out to be a significant obstacle. In Wireless Sensor

Networks (WSNs), the procedure of changing batteries is labor-intensive and ineffective, especially when nodes are placed in difficult-to-reach places. These scenarios involve detecting forest fires or attaching nodes to moving objects like soldiers or animals. It is clear that in order to get out of this jam, energy-efficient power management for sensor nodes requires a planned strategy. [15]. Researchers have created a wide range of clustering algorithms in response to the requirement to reduce excessive power consumption and improve the energy use of individual nodes. These algorithms are cutting-edge approaches created to improve the energy consumption patterns in WSNs. These algorithms try to more evenly distribute energy depletion across the network by intentionally establishing clusters of nodes and designating specific nodes as cluster chiefs. This distribution technique is especially important when certain nodes are required to consume a lot of energy because of their functions or the surrounding circumstances. Additionally, these clustering algorithms attempt to increase the operational lifespan of the entire WSN in addition to addressing issues with energy efficiency. The network as a whole becomes more resilient and sustainable by reducing the energy consumption of individual nodes, especially in extended deployments or situations where routine maintenance is impractical. Innovative solutions are required to address the problem of charging wireless sensing nodes in IoT systems in order to maintain their long-term durability and efficacy. By optimizing energy use, fostering network life, and improving the overall performance of WSNs in a range of practical scenarios, the implementation of effective clustering algorithms constitutes a significant step towards resolving these problems [15]. An early clustering algorithm, the low-energy adaptive clustering hierarchy (LEACH) algorithm [16], selects Cluster Heads (CHs) at random for each round in order to disperse energy depletion across nodes and prolong the network lifetime. To improve network performance, changes have been made to the LEACH protocol [17]. There have been several efficient clustering strategies [18] that take energy into account for CH selection [19]. In contrast to earlier systems [16, 18], a different strategy concentrates on energy of sensing nodes [20].

Researchers have explored various approaches for data aggregation in WSNs. One such approach is the cyclic grid-based approach (CBDAS), which divides the WSN into grids and utilizes a main head node to transmit data to the sink [21]. In contrast to CBDAS, an alternative grid-based network deployment (GHND) selects a zonal head based on factors such as energy levels & average distance b/w sensing nodes [22]. Another method, surpasses GHND in terms of stability & network lifetime, considers parameters such as the distance between nodes, the zone center, and the remaining energy to determine the zone head [23] [24].

In the literature, different Mobile Wireless Sensor Networks (MWSNs) are discussed, depending on whether the base station. Mobile-LEACH routing protocol analyses the communication between mobile sensing nodes and CHs [25]. Several strategies are used in the selection of cluster heads (CHs) in the context of a Mobile Wireless Sensor Network (MWSN). One such method, known as LEACH-mobile average energy (LEACH-MAE), establishes CHs based on the network's average energy levels [26]. When selecting CHs, another technique known as LEACH Distance-M considers things like remaining energy, threshold distance, and minimal mobility [27]. A modified variant of LEACH is suggested for MWSNs in a different investigation, where the clusters are constructed by taking into account the predicted placements of nodes in the future [28]. The LEACH-mobile energy-efficient and connected (LEACH-MEEC) routing protocol was developed to choose CHs by taking into account both residual energy and the connectivity status of nearby nodes in order to improve energy efficiency and connectivity [29]. The choice of CHs is also addressed when dealing with a MWSN that includes both mobile and stationary nodes in addition to a stationary base station [30].

Due of the lower energy requirements of WSN nodes, RF energy harvesting has received substantial research as a substitute energy source [31]. RF energy harvesting circuits, protocols, and their effects on RF energy harvesting networks have also been covered [32]. The impact of RF energy harvesting on wireless nodes' capacity for packet transmission has been studied [33]. It has been investigated how to design RF energy harvesting antennas, with a preference for small, wide-band antennas for IoT applications [34]. Utilizing rechargeable batteries or cognitive nodes without batteries, RF energy harvesting has also been incorporated into cognitive radio networks [35, 36, 37]. There has been relatively little study on energy harvesting strategies in real-world settings involving mobile nodes. Incorporating RF energy collecting, this work suggests a CH selection technique for WSNs installed on moving objects.

The provision of sustained electricity to wireless sensing nodes is the fundamental challenge facing IoT systems. In a Wireless Sensor Network (WSN), replacing batteries on a regular basis is not only laborious but also extremely inefficient [38], especially given the potential deployment of nodes in distant or difficult-to-reach areas like forests for fire detection or on moving objects like animals or soldiers. In these cases, it becomes necessary for sensor nodes to use energy-conscious power management mechanisms, ideally freeing them from the need for batteries. Researchers have developed a number of clustering algorithms [39] that try to minimize unintended node energy use in order to optimize energy usage.

Among the earliest suggestions was the Low-Energy Adaptive Clustering Hierarchy (LEACH) [40], a ground-breaking clustering technique. The energy depletion across nodes is balanced by LEACH's randomized cluster head (CH) selection technique in each round, extending the network's operational lifetime. On top of this foundation, later research has improved network performance by introducing changes to the LEACH protocol [41]. In this regard, Qing et al. 42] introduced an effective clustering strategy for CH selection. In contrast to Qing et al. [42], Mishra et al. [43] developed an energy-aware strategy, basing CH selection on residual energy per round, and achieved greater network lifespan. In contrast to earlier works [39,41], Leu et al. [44] developed a clustering process that took into account the average energy of the cluster as well as the residual energy of particular nodes. This mechanism increased the average network lifetime.

Alternative strategies have also surfaced in the interim. A data aggregation technique was devised by Chiang et al. [45] that divided the WSN into grids, each with a specific head node for cyclic data transfer. Farman et al. [46] developed a grid-based network deployment method that outperforms Chiang et al. [45] by taking energy levels and average distances into account while choosing zonal heads. When Farman et al. [47] used residual energy and the distance between nodes and zone centers to pick zone heads, the stability and lifetime of the network were increased compared to their earlier work [46]. Behera et al. [48] outperformed Farman et al. [46] in terms of network stability and longevity by introducing a thorough CH selection scheme that took initial energy, residual energy, and optimal CH values into account.

Mobile Wireless Sensor Networks (MWSNs), taking into account mobile nodes or base stations, are also covered in literature. A mobile-LEACH routing protocol was investigated by Kim and Chung [49] for communication between mobile sensing nodes and CHs. LEACH-Mobile Average Energy (LEACH-MAE) technique, which chooses CHs inside MWSNs using the average energy levels, was introduced by Ahmed [50]. Khandnor and Aseri [51] developed the LEACH Distance-M method for MWSNs, which includes CH selection taking into account things like remaining energy, threshold distance, and minimal mobility. Corn and Bruce [52] improved the LEACH technique for MWSNs to forecast upcoming node placements for cluster reconfiguration. Ahmad et al. [53] developed the LEACH-Mobile Energy-Efficient and Connected (LEACH-MEEC) protocol for CH selection to address connection and residual energy. Zhang and Yan [54] investigated the subject and chose CHs based on node mobility and distance in the context of MWSNs that include both mobile and stationary nodes in addition to base stations.

Harvesting of RF energy is included in the scope. In their review of RF energy harvesting for WSNs, Tran et al. [55] suggested it as an alternative energy source. Nintanavongsa [56] covered RF energy harvesting circuits, protocols, and their effects in great detail. The impact of RF energy harvesting on wireless node packet transmission was looked into by Wu and Yang [57]. Divakaran et al. [58] investigated design difficulties for RF energy harvesting antennas and identified antennas with broad bandwidth as appropriate for IoT. Even cognitive radio networks [59,60] have used RF energy harvesting, integrating it into battery-free cognitive nodes [61] and utilizing rechargeable batteries for power storage [62]. For network power requirements, Zhang et al. [63] suggested RF energy harvesting integration with wireless power transfer.

Importance of variables including starting, residual & average energy, and distance in improving effectiveness of Wireless Sensor Networks (WSNs) has been highlighted by earlier studies. These variables have served as the main focus of efforts to improve the energy dynamics in these networks [64, 75-77]. Despite these initiatives, there is still a glaring gap when it comes to dealing with the energy issues in real-world settings that include mobile nodes. This knowledge gap emphasizes the scant investigation into energy collecting techniques adapted to the special requirements given by mobile node scenarios.

The suggested method introduces a novel approach that includes a Cluster Head (CH) selection mechanism tailored specifically for WSNs in which nodes are attached to moving objects, like animals, with the capacity to harness Radio-Frequency (RF) energy, in order to fill this crucial knowledge gap. The usual paradigms of energy management inside mobile WSNs are redefined by this novel technique, which successfully integrates the synergies of mobility and energy harvesting [65-74].

The envisioned methodology introduces a paradigm change by incorporating RF energy harvesting capabilities into nodes placed on mobile elements. Instead of using conventional battery replacement or recharging, it tries to capture the energy potential already available in the environment to power these nodes. The energy landscape of WSNs functioning in the dynamic world of mobile elements might be revolutionized by this strategy, which not only adheres to the sustainability standards [66-72].

The suggested solution includes a two-pronged strategy: it simultaneously takes advantage of the untapped energy resources contained in the ambient RF waves and the mobility of certain WSN units. The envisioned CH selection scheme holds the potential to significantly improve the energy resilience and longevity of mobile WSNs through the integration of these aspects, thereby fostering their sustained operation in situations where conventional energy sources prove to be impractical or unfeasible [67-73]. A new range of possibilities is opened up by the strategic combination of energy harvesting with mobility, which paves the way for more flexible and robust mobile WSNs in a variety of practical applications.

IV. RESEARCH METHODOLOGY

- **Model**

The Wireless Sensor Network (WSN) system created for a monitoring scenario was the main subject of this study. In this situation, the base station stayed stable while the field-deployed sensing nodes were presumptively mobile. These wireless sensing nodes were carried by the users who were in the vicinity, who were regarded as mobile elements. Furthermore, it was anticipated that the wireless sensing nodes could collect Radio Frequency (RF) energy and had distinct interfaces for doing so and for communicating the data they had gathered.

The Multi-Hop Wireless Sensor Network (MWSN) was made up of many 'N'-style wireless sensing nodes. These nodes were strewn across the network field at random. A method known as K-means clustering was used to effectively handle these nodes. With the help of this technique, the randomly dispersed nodes were organized into 'M' clusters, each of which held a particular number of nodes. Sensing nodes were assigned to clusters using K-means clustering based on their Euclidean distance from the cluster centroid. This clustering strategy was chosen because it can cut down on energy use by shortening the distance between Cluster Heads (CHs) and nodes.

Due to the nodes' mobility, clusters were reconstructed using the K-means clustering method after each round, taking into account the nodes' most recent positions. The selection of the Cluster Head (CH) then happened. As all the sensing nodes had identical energy levels at this point, the CH was first selected at random among nodes within a specific cluster. The CH was chosen for following rounds based on a variety of factors, including average energy level, residual energy, and node placements.

The remaining energy in each round was calculated based on the energy used and gathered in the round before to ensure the system's coherence. In order to build the system model, the study operated under a number of reasonable hypotheses, including the mobility of WSNs, immobility of sink (base station), uniform initial energy distribution across nodes, the nodes' ability to move in arbitrary directions at different speeds, and the nodes' awareness of location, harvested & consumed energy for given round.

Additionally, a single CH was assigned to each cluster in each round to handle all base station communications. The possibility for energy collecting by the nodes was increased by the assumption that neighboring ambient RF energy sources existed in the network environment. Notably, the wireless sensing nodes included twin antennas, enabling them to draw power from two separate RF sources that operated in various frequency bands. The goal of this creative design was to improve the network's overall energy effectiveness.

- **Modelling for Energy**

Energy Consumption

Heinzelman and her colleagues' radio model has been widely used by low energy radio communication systems. This specific model provides accurate equations for computing the energy consumption during data exchange across sensing nodes. Equation (1) explicitly expresses the energy usage (E_{tx} [b, d]) for a node delivering a payload of b bits to a remote node positioned d′ meters away. Equation (2) is used to express the energy expenditure (E_{rx} [b]) experienced by a sensing node during the receiving of b bits of data from another node.

$$E_{tx}(b, d) = E_{tx.ele} \times b + E_{fs} \times b \times d^2, \text{ if } d \leq d' \quad (1)$$

$$E_{tx.ele} \times b + E_{amp} \times b \times d^4, \text{ if } d > d'$$

$$E_{rx}(b) - E_{rx.ele} \times b \quad (2)$$

$$d' = (E_{fs} / E_{amp})^{1/2} \quad (3)$$

$E_{tx.ele}$ and $E_{rx.ele}$ here stand for energy used by each bit in the transmitter and reception circuitry, respectively. Additionally, the transmission parameters E_{fs} and E_{amp} stand for free-space & multipath fading model's respective counterparts.

Energy Harvesting Model

Wireless sensing nodes have the potential to collect energy from nearby ambient radio frequency (RF) energy sources in addition to their many sensing capabilities. A number of variables, including transmission power, RF source frequency, distance between the node and the source, and antenna gains built into both the source and the node, affect how much energy a wireless sensing node can gather. Equation (4) explains the method by which the '*i*th' sensing node obtains energy from the '*j*th' harvesting source.

$$E_h(i, j) = \eta P_i G_i G_j t_h (\lambda_j / 4\pi R_{i,j})^2 \quad (4)$$

In this framework, G_i stands for the antenna gain of the RF receiver connected to the wireless sensing node '*i*th' while G_j refers to the antenna gain of the RF transmitter connected to the energy harvesting source '*j*th'. P_j stands for the power produced by the '*j*th' energy gathering source. '*j*th' energy harvesting source's signal is transmitted at a wavelength designated by the symbol. The spatial distance between the energy harvesting source located at the '*j*th' node and the '*i*th' node is explained by $R_{i,j}$. Additionally, "th" denotes the prescribed time period allotted for the energy harvesting procedure, while " η" represents the effectiveness of the charging process.

Residual Energy

According to Aslam and colleagues' study, a threshold energy level (E_{thr}) can be determined by classifying the sensing nodes into Mode 1 and Mode 2 for each subsequent round. Nodes with energy levels above the specified E_{thr} value are categorized as Mode 1 nodes in this classification. Both sensing and energy-harvesting operations are being actively carried out by these nodes. At the conclusion of each round, equation (5) was used to calibrate residual energy levels of nodes belonging to Mode 1.

$E_{r,i}$ (rn + 1) = $E_{r,i}$ (rn) = $E_{consume}$ (rn) + $E_{h,i}$ (rn) (5)

$E_{r,i}$(rn + 1) in this context denotes energy level of '*i*th' node in the round, while $E_{r,i}$(rn) denotes energy level of identical node in round before it, labeled as (rn). The variable $E_{consume}$(rn) represents energy used by '*i*th' node during the round with the round number (rn), while variable $E_{h,i}$(rn) represents energy that '*i*th' node obtained during (rn)th round.

Nodes having energy levels below E_{thr} are classified as operating in Mode 2, which forbids them from doing any sensing operations. Instead, these nodes focus solely on energy harvesting, working to replenish their energy levels until they reach the required level. The residual energy levels for these specific nodes were calculated using equation (6).

$E_{r,i}$ (rn +1) = E_{ri} + $E_{h,i}$ (rn) (6)

Cluster Head (CH) Selection

The mobile sensing nodes in this investigation were presumptively mobile in a manner consistent with the random waypoint mobility model. In this model, nodes make decisions at random, such as choosing a direction and traveling in that direction at a speed randomly chosen from a range of speed thresholds. This motion continues until a stop of arbitrary duration happens, at which point the procedure is repeated with nodes selecting new motion directions. The cluster layout was recalculated after each iteration based on new locations of sensing nodes. Cluster Head, chosen from pool of individuals associated with respective cluster, was assigned to each of these redesigned clusters. However, only nodes classified as Mode 1 were eligible to be chosen as CHs during a particular round, while nodes classified as Mode 2 were not taken into account for CH selection during that round.

The selection of CH was determined from among the Mode 1 nodes taking into consideration both its own residual & cluster's average energy levels of sensing nodes. This decision-making process was based on a determined ratio known as "R," which stood for ratio of average energy ($E_{avg,i}$) & residual energy ($E_{r,i}$) for each individual node. Equation (7) was used in the development of this ratio.

To elaborate further, this movement strategy simulates the randomness and variability encountered in real-world scenarios, allowing the system to adapt to the dynamic changes in node positions and energy levels. The subsequent cluster formation and CH selection process takes into account both energy metrics to optimize network efficiency and prolong the network's overall operational lifespan.

$R_i = E_{r,i} / E_{avg,i}$ (7)

The CH for the given round was chosen as the node with the greatest R value. The numerous processes for the CH selection process are shown in the figure below.

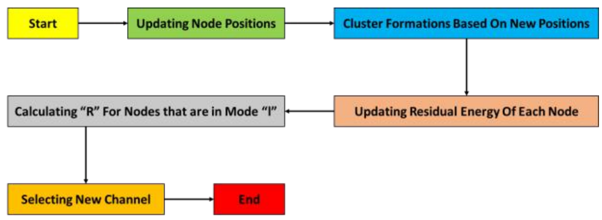


Fig.3.1: Cluster Head (CH) Selection Process

- **Algorithm Development**

It is possible to effectively separate the operational process of the proposed Multi-Hop Wireless Sensor Network (MWSN) into phases: first phase, which includes Cluster Head selection, & second sensing phase that includes sensing, data communication & energy harvesting activities. This all-encompassing strategy guarantees the network's effective operation and enhances the dynamics of its energy consumption. The proper positioning of the deployed sensing nodes is the initial phase's main concern. These positions act as the cornerstone for the development of 'M' clusters, a task carried out by K-means clustering framework. Computation of nodes' residual energy values is a crucial step after these clusters are successfully created. The amount of energy that nodes harvested and used during the previous cycle of operations is a factor in this calculation.

The sensing nodes have two modes, 1 & 2, according to their residual energy levels, further defining the process. Mode 1 is aligned with nodes with high energy reserves, while Mode 2 is aligned with nodes with low energy reserves. The crucial process of CH selection takes place in Mode 1. The CH's function is crucial since it includes all subsequent communications with the central sink.

The CH designated from Mode 1 assumes a variety of duties as the sensing phase begins. The execution of sensing activities, energy harvesting projects, data aggregation from nodes inside its specified cluster, and ensuing transfer of this aggregated data to the central sink are some examples. In contrast, nodes designated for Mode 2 focus entirely on energy harvesting and momentarily halt their sensing functions.

These processes develop repeatedly over subsequent rounds as the network develops, sustaining a loop of energy-efficient data collecting, transmission, and energy replenishment. The network's agility, resource optimization, and continued functionality are highlighted by this all-encompassing operational strategy as it takes on real-world obstacles brought on by varying energy levels and dynamic node movements.

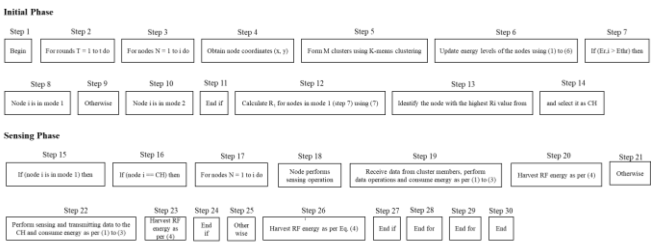


Fig.3.2: Algorithm

Simulation & Discussion

- NS2

The technique proposed will be analyzed using NS2 simulations. NS2 provides a variety of tools and functions for numerical computation, plotting and visualization, programming, and application development. It is widely recognized for its easy-to-use syntax and powerful data analysis capabilities.

NS2 has several characteristics that make it a popular choice for scientific and engineering applications. Here are some of its key characteristics:

- High-level language: NS2 is a high-level language, which means that it is designed to be easy to read and write. It uses a syntax that is similar to traditional mathematical notation, making it easier for users to express mathematical concepts in code.
- Interactive environment: NS2 provides an interactive environment that allows users to experiment with code and test ideas in real-time. This is particularly useful for exploring data and developing algorithms.
- Extensive library of functions: NS2 comes with a large library of pre-built functions that can be used for a wide range of applications, from signal processing to machine learning.
- Graphics and visualization: NS2 provides powerful tools for creating graphs, visualizations, and other types of data representations.
- Interoperability: NS2 can be used with other programming languages and tools, making it a flexible choice for many applications.
- Platform independence: NS2 runs on a variety of platforms, including Windows, Linux, and mac OS.
- Application development: NS2 can be used to develop standalone applications that can be distributed and run on other computers, making it a powerful tool for creating custom solutions for specific problems.

The researcher has used NS2 for the analysis.

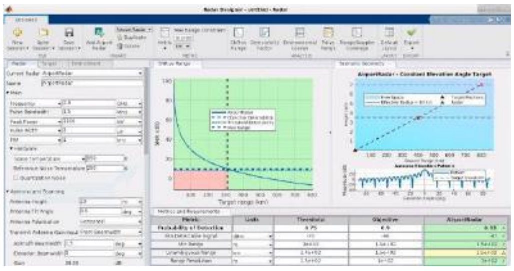


Fig.4.1: Generic NS2 Analysis Snapshot

- Deployed Conceptualized Network

In the course of our research, we investigated a Multi-Hop Wireless Sensor Network (MWSN) configuration with a total of 100 nodes that were purposefully and randomly placed throughout a sensing field with measurements of 100 meters by 100 meters. This network was launched against a stationary base station that was carefully placed at the coordinates (50, 50). Table 4.1 provides a detailed summary of the simulated parameters.

Table 4.1: Parameters for Simulation

Energy of the Initial Node	I, J
Energy used by each bit in the transmitter & reception circuitry ($E_{tx.ele}/E_{rx.ele}$)	50 nJ/bit
Transmission parameters for the free space model (E_{fs})	10 pJ/bit/m^2
Transmission parameters for the multipath fading model (E_{amp})	0.00129 pJ/bit/m^4
Threshold energy level (E_{thr})	0.10 J
Size of the Packet	3000 bits
Ambient Radio Frequency (RF) sources frequency bands	900, 1800 MHz
Antenna Gain (G_i/G_j). Antenna gains of the RF receiver of the *i*th (G_i) wireless sensing node and the RF transmitter of the *j*th (G_j) energy harvesting source.	1
Charging Efficiency	0.3
Harvesting duration/round	1 s
Power Transmitted by the *j*th harvesting source (P_j)	100 mW
Mobility Model	Random Waypoint Model
Node speed limits	0 - 5 m/s
Node directions	-180 & +180

In the context of wireless sensor networks (WSNs), the **Random Waypoint Model** is a popular mobility model for assessing the functionality and behavior of networking protocols, algorithms, and tactics. It is applied to model the temporal behavior of nodes (sensors or devices) in a network. The underlying premise of this model is that nodes behave independently and arbitrarily inside a predetermined simulation region.

The Random Waypoint Model operates as follows:

- Initialization: Within a predetermined simulation area, nodes are dispersed at random. A starting location is assigned to every node.
- Each node chooses a random waypoint (target point) inside the simulation area, as well as a random pace at which it will travel there.
- Phase of movement: The node advances at the given speed in the direction of the chosen waypoint. The movement can be simple and consist only of the node moving in a straight line in the direction of the destination, or it can be complex and involve changes in direction or speed.
- When a node reaches its chosen waypoint, it pauses for a predetermined amount of time before choosing a new destination point and speed and resuming the process.

The Random Waypoint Model's main attributes are:

- Independence: Each node autonomously decides how to move, making it appropriate for situations where nodes don't adhere to predetermined patterns or coordinate.
- unpredictability: By introducing diversity into the simulation through unpredictability in waypoint selection and movement speed, researchers can evaluate different network protocols.
- Realistic: Despite the model's simplification and potential shortcomings, it offers a solid foundation for understanding how networks behave in dynamic environments.
- The model's parameters include the nodes' top speeds, waypoint pause intervals, and length of the simulation. These settings can be changed to examine various mobility patterns.
- Challenges: Some node movements, such as those driven by environmental variables like topography, impediments, or social interactions, may not be adequately modeled by the model.

The Random Waypoint Model can be used to assess several wireless sensor network characteristics, such as routing protocols, power usage, data aggregation, and localization methods. Researchers can learn more about how various networking solutions function in dynamic situations and spot possible problems and optimizations by simulating the mobility of nodes.

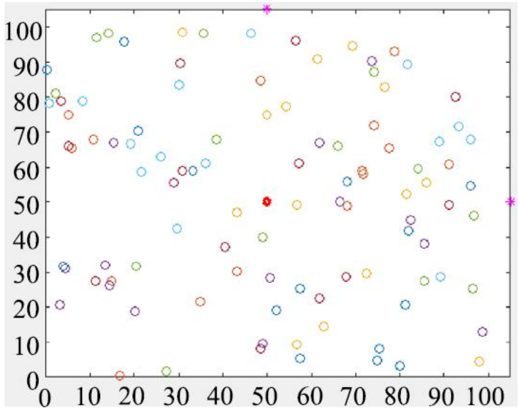
It's crucial to emphasize that while every node in this network was given mobility, the base station stayed still. The environment surrounding the network field was assumed in our research to have ambient Radio Frequency (RF) energy sources. The two cellular mobile RF sources that made up these ambient RF energy sources were identified as operating in separate frequency bands and placed at the coordinates (50, 105) and (105, 50), respectively. The fact that cellular mobile radio systems typically output constant power levels across time, with small power changes related to service scheduling judged unimportant, is an important observation.

To emphasize the idea of randomization in their placement, I placed the RF energy sources in this study somewhat close to network field. Wireless nodes, on the other hand, had the cutting-edge ability to wear dual-band antennas, giving them capacity to harvest energy from not just one but two different RF sources, each operating within a different frequency band. This strategy improved the network's sensing nodes' abilities to acquire energy.

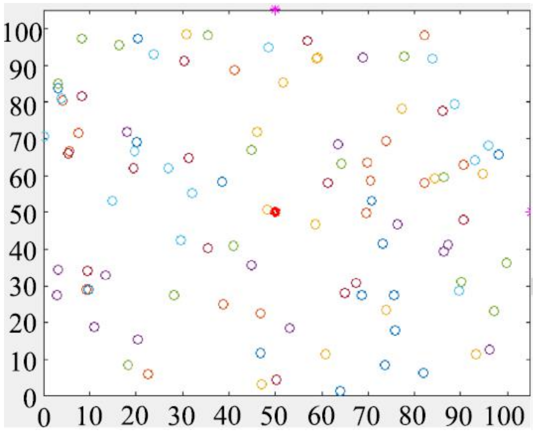
The definition of a threshold energy level (E_{thr}) was a key component of our suggested methodology. One-tenth of the nodes' initial energy reserves were chosen as this threshold. This particular energy level was determined to be adequate to support the necessary operations within Mode 1 for a prolonged period of at least 10 additional rounds. It's crucial to remember that wireless sensing nodes were constantly collecting RF energy from the defined RF sources. This was made possible by the nodes' innate design, which included distinct channels for data transmission and energy collecting.

The temporal scope of each round was standardized at 1 second for the purposes of our simulations. This choice made it easier to develop a coherent and understandable framework for analyzing network dynamics. As a result, the duration of energy harvesting for each round was evenly fixed at 1 second due to the round's continuous energy gathering.

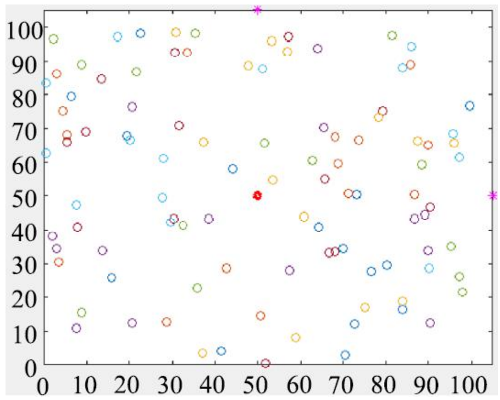
Figure 4.1 (a to d), which shows the gradual transition in the distribution and placements of mobile sensing nodes at different times, specifically t, t + 25, t + 50, and t + 100, was shown to graphically represent the evolving network scenario. This representation gave concrete understanding of the network's dynamic development throughout time.



(a) Initial phase beginning at time instant t = 0



(b) Time instant t = t + 25



(c) Time instant t = t + 50

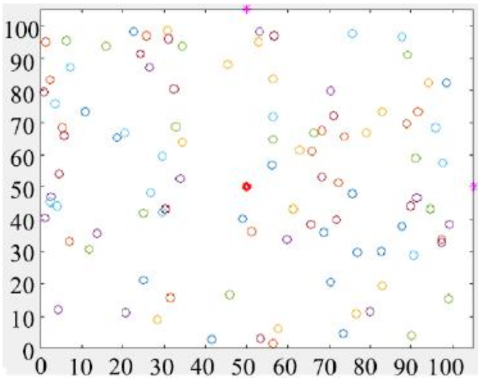


Fig.4.1: Positions of Mobile Sensor Nodes: Network Deployment

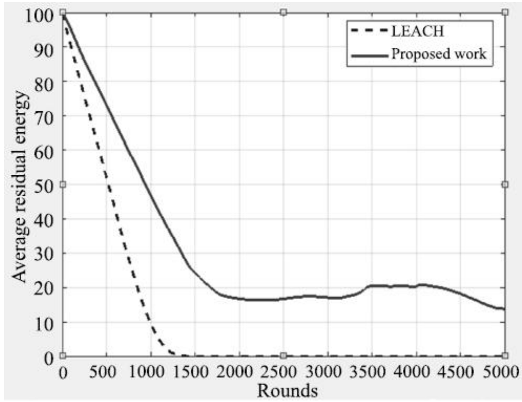


Fig.4.2: Average Residual Energy

- **Performance Analysis**

The average residual energy, no of functional nodes, & network lifetime were all evaluated as part of the proposed technique's evaluation. Understanding the idea of "half-network-dead point," or point where half of network's sensing nodes stop functioning, is crucial within this paradigm. In addition, network lifetime captures period of time from death of first node to end of final node's functionality.

I conducted a thorough comparison, testing the suggested method against a variety of static & mobile WSNs, in order to contextualize this evaluation. We examined LEACH, CBDAS, GHND, IGHND, and R-LEACH among static WSNs, and mobile-LEACH, LEACH-MAE, LEACH-Distance-M, and LEACH-MEEC among mobile WSNs. This in-depth analysis intended to highlight the relative advantages and disadvantages of the suggested method in a wider range of situations.

The average residual energy between LEACH and the suggested approach throughout the first 5000 rounds were compared in Figure 4.2 in a useful way. Notably, the LEACH network's residual energy levels collapsed to zero before 1500 rounds had been completed. The proposed method, however, maintained its operational integrity well after 5000 rounds. The proposed technique's seamless integration of RF energy collecting and consumption for different operational tasks, which promoted continuous energy balance, logically supported this distinction.

Turning to Figure 4.3, the figure showed how the functional node count changed over time relative to rounds for both LEACH and the suggested method. This story held my attention because, in the instance of LEACH, all nodes shut down after roughly 1500 rounds. But using the suggested method, 40% of the nodes were still functional even after 5000 rounds. The creative energy management method was the main supporting element in this case. Specifically, nodes replenished themselves by RF energy harvesting, changed from a functional (Mode-1) to a rechargeable (Mode-2) state upon reaching specified energy threshold & then returning to operational status.

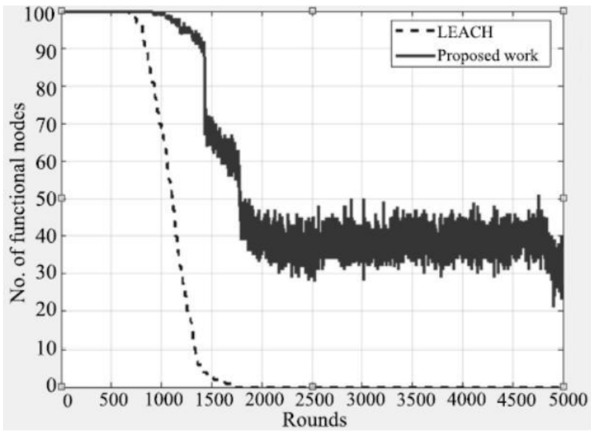


Fig.4.3: Average Residual Energy

Comparison of half network dead points & network lives (Figures 4.4 and 4.5) was a crucial point in the evaluation. The suggested method was evaluated in comparison to a wide range of other WSNs, including LEACH (low-energy adaptive clustering hierarchy algorithm), CBDAS (Cycle-Based Data Aggregation

Scheme), GHND (grid-based network deployment), IGHND (improved grid-based network deployment) and R-LEACH (Residual low-energy adaptive clustering hierarchy algorithm).

A popular clustering-based technique is **Low-Energy Adaptive Clustering Hierarchy (LEACH)** was created for energy-efficient communication in WSNs. LEACH's main objective is to extend network lifespan by minimizing energy consumption, which is crucial in WSNs since sensor nodes are frequently powered by batteries with limited capacity. LEACH opened the door for a number of expansions and enhancements to clustering-based WSN protocols. To overcome its drawbacks and adapt it to various situations, such as unequal node distribution and mobility, researchers have suggested tweaks and improvements.

A specific approach or methodology for carrying out data aggregation in the context of Wireless Sensor Networks (WSNs) is referred to as the **"Cycle-Based Data Aggregation Scheme" (CBDAS)**. In this method, data aggregation takes place in rounds or cycles, with sensor nodes in the network gathering and processing data over a set time or cycle. In this context, the term "cycle" designates a period of time during which data is gathered, processed, and aggregated prior to being sent to a central node or sink. The cycle-based method has a number of benefits, including increased scalability, decreased communication overhead, and energy efficiency. Reduced energy usage owing to localized processing and decreased data transfer, which might result in an increased network lifetime, are the main advantages of a Cycle-Based Data Aggregation Scheme in WSNs. This method works especially well in applications where network durability and energy efficiency are important considerations.

In wireless sensor networks with variable grid sizes, the **grid-based hybrid network deployment (GHND)** framework enables energy efficiency and load balancing. In all circumstances of node density and beginning energy, GHND has more rounds than other techniques, extending the network lifetime.

Improved Grid-Based Hybrid Network Deployment (IGHND), a multi-criteria-based CH selection model in IoT-based WSN, uses a number of characteristics, including level, energy, and distance, which affect network lifetime and node energy.

R-LEACH (Residual low-energy adaptive clustering hierarchy algorithm outperforms LEACH, CBDAS, GHND, and IGHND for all energy values because it selects stable nodes as CH).

Using the above algorithms, all comparisons were made using a uniform packet size of 2000 bits for the sake of parity, testing various beginning energy levels (0.25 J, 0.5 J, and 1 J) throughout simulation spans of 4000, 5000, and 6000 rounds. The results were startling: even after 6000 rounds, the proposed technique continually surpassed the competition in terms of half-network-dead points. At same time, proposed method significantly increased network lifetime and was able to preserve operational integrity throughout the whole simulation period. This significant improvement was primarily caused by the wireless sensor nodes' superior capacity to efficiently capture RF energy compared to other approaches.

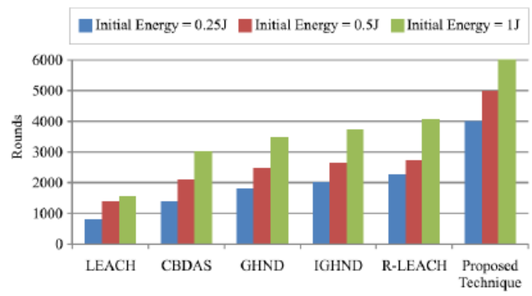


Fig.4.4: Half Network Dead Times (initial energies of 0.25, 0.5 & 1 J)

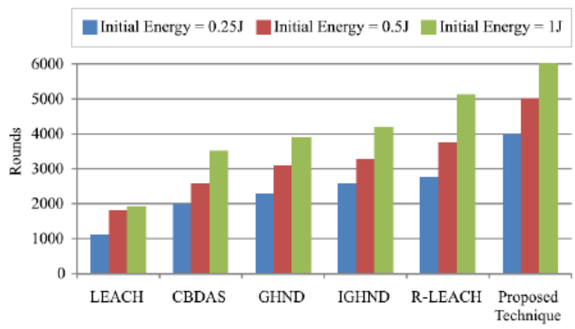


Fig.4.5: Network lifetimes (initial energies of 0.25, 0.5 & 1 J)

In Figures 4.6 and 4.7, a significant divergence was seen when the suggested method was compared to several Mobile Wireless Sensor Networks (MWSNs), such as mobile-LEACH, LEACH-MAE, LEACH-Distance-M, and LEACH-MEEC. Using a common packet size of 40 bits, these evaluations took into account the residual energy & no of functioning nodes across rounds. It is clear that the suggested method excelled on both counts, as evidenced by the fact that it kept the residual network energy level far higher during the observation period and had significantly more operational nodes even after a thousand rounds. This significant gain was made possible by the suggested technique's careful integration of the symbiotic link between energy use and harvesting, a detail frequently missed by competing approaches.

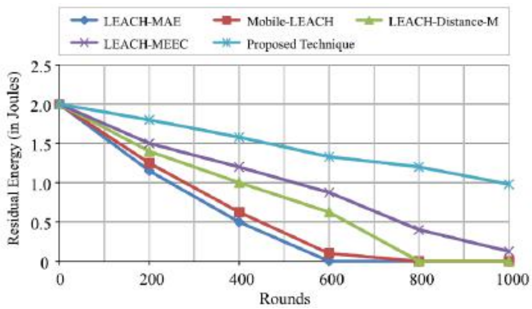


Fig.4.6: Comparison (residual energies of various MWSNs)

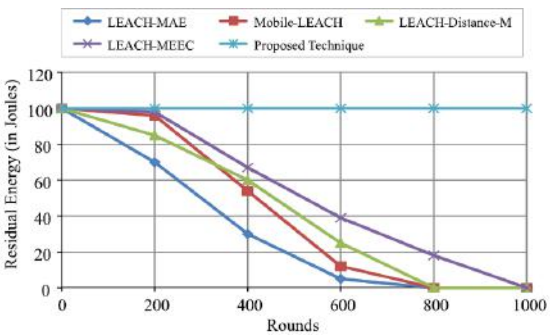


Fig.4.7: Comparison (no of functional nodes of various MWSNs)

The proposed technique's strong effectiveness was highlighted by this thorough examination, notably because of its dynamic energy management framework, which includes energy harvesting and consumption and contributes to improved network longevity and overall performance. It is noteworthy that this method deviated from typical approaches by taking into account both the limitations of mobile nodes & potential of RF energy harvesting, leading a significant increase in network lifetime and increased energy efficiency.

V. CONCLUSIONS AND FUTURE WORK

- **Conclusions**

The research thesis explores an urgent issue centered on energy requirements of WSNs, a crucial component of Wireless Sensor Networks (WSNs) designed for Internet of Things (IoT) applications. This paper does a good job of tackling the problem head-on, especially when it comes to mobile WSN nodes, which are a crucial component of real-world IoT scenarios.

Researchers have worked to develop various clustering algorithms over time in an effort to address the problem with WSN energy usage. The main objective of these initiatives has been to prolong the useful life of these networks. The unusual efficacy of the proposed method in the complex domain it functions in, however, is what distinguishes it. The clever incorporation of the idea of capturing ambient Radio Frequency (RF) energy is key to this novel approach. The proposed strategy emerges as a beacon of hope inside this complex environment by cleverly combining this energy source with a sophisticated clustering design. It highlights a tactical combination that is carefully designed to absorb and channel RF energy, hence boosting the sensor nodes' energy reserves.

The method's potential impact is increased by strategically combining it with a deftly planned clustering architecture. The coordination of this synergy is done on purpose to meet the specific requirements of Multi-Hop Wireless Sensor Networks (MWSNs). The overarching goal is to significantly increase the network's ability to operate for a longer period of time. The suggested strategy optimizes energy use and distribution, enabling effective communication between nodes and therefore extending the lifespan of the network as a whole.

This research is a testament to creative problem-solving in the intricate and constantly changing field of the Internet of Things, where the interaction of energy, communication, and longevity is crucial. The thesis comprehensively addresses the energy dilemma encountered by mobile WSN nodes by skillfully merging ambient RF energy capture and a carefully built clustering architecture. By doing this, it adds to the theoretical foundations of WSNs and IoT and broadens the implications of those foundations to real-world applications where network sustainability and efficiency are crucial.

A paradigm-shifting discovery that sheds new light on the field of energy augmentation was made within the context of this thesis: ambient Radio Frequency (RF) energy can be used as a backup energy source. This discovery revealed the possibility of utilizing the ubiquitous RF signals that permeate our environment and transforming them into a source of useful energy to power the sensor nodes inside the network. The idea was revolutionary in and of itself because it called for a paradigm shift away from traditional energy sources and toward the untapped possibilities of the nearby electromagnetic spectrum. This shift needed the creative construction of energy harvesting devices that could capture minute amounts of energy from the ubiquitous RF signals in modern society. This energy, which would have otherwise been lost to the environment, was captured and transformed into a transforming force for the sensor nodes.

A strategic clustering plan developed as a crucial ally for this energy revolution as the thesis set out on the path of actual implementation. This plan wasn't just any old construction; rather, it was carefully planned to work with the larger goal of improving energy efficiency. The thesis unlocked a dual-pronged method that would form the cornerstone of its proposed technique by combining this deftly designed clustering architecture with the energy-harvesting mechanism. This method, a complex fusion of energy dynamics and communication strategy, served as a witness to creativity. Multi-Hop Wireless Sensor Networks (MWSNs) underwent a paradigm shift as a result of the intricate interweaving of the threads of ambient RF energy utilization and the advanced clustering technique. This impact was characterized by a significant increase in network lifetime, a development that has the potential to completely alter the way that networks are operated.

The effectiveness of the dual-pronged plan was obvious. The technology successfully addressed both the energy shortage and effective network communication issues by deftly combining the capacity to capture ambient RF energy with an intelligently controlled clustering architecture. The nodes were given access to an additional energy source and were led by an ideal communication strategy, ushering in a new era of MWSNs defined by enhanced network functionality and resilience. In addition to shedding light on the unexplored world of ambient RF energy, the research also staged a revolutionary dance between energy harvesting and clustering tactics. The environment of multi-hop wireless sensor networks witnessed a dramatic change as a result of the convergence of these two forces, promising long-lasting and significant network operations. This thesis is at the forefront of innovation in the fields of network engineering and Internet of Things applications thanks to the disclosure of the potential of ambient RF energy and its harmonious integration into a well-designed clustering scheme.

As a crucial component of this research project, the validation procedure of the suggested technique developed, providing a solid base for its legitimacy and practical applicability. Adopting rigorous simulation tools was crucial to this validation since they provided a way to empirically validate the advantages and efficacy of the suggested approach.

The simulation environment served as a regulated setting where the effectiveness of the suggested strategy could be painstakingly assessed and tested against predetermined key performance metrics. Metrics that highlighted the network's usability, durability, and energy conservation were of utmost importance. The research studied the method's effects on critical aspects such as node operability, the extension of the network's lifespan, and the conservation of residual energy resources with great attention to detail.

This thorough assessment offered verifiable proof underscoring the method's capability to strengthen and improve these essential network characteristics. The empirical information gathered from these simulations shed light on the beneficial impacts of the suggested technique on the various facets of network performance. It strengthened the justification for the strategy, supporting the claim that it had the potential to improve not only energy consumption but also the sustainability of the entire network. These practical results served as a bridge between the theoretical and the practical, supporting the applicability of the proposed strategy in real-world situations. This was especially noticeable in fields with mobile workforces and flexible operational environments. This made areas like environment monitoring and combat surveillance suitable testbeds to determine the method's usefulness in the real world.

The suggested method was well received in situations where nodes are naturally movable and operational conditions are continually changing. The solution directly addressed the problems created by these unstable situations by harnessing ambient RF energy and regulating clustering tactics. The method showed off its adaptability to situations where continual mobility and shifting conditions are the norm by prolonging network lifespan and optimizing energy usage. The suggested strategy successfully closed the gap between theoretical claim and practical impact by establishing its empirical worth through simulation-based validation. This verification emphasized the method's adaptability and viability and highlighted its potential to change a variety of applications, particularly those hampered by mobility and changing environments. As a result, this research thesis made a significant contribution to the field of network engineering while simultaneously laying the groundwork for the method's easy incorporation into practical settings, where its effectiveness really shines.

The recommended method's adaptability and adaptability stand out as defining characteristics, demonstrating its capacity to transcend a wide range of mobile Wireless Sensor Network (WSN) scenarios. The ability of this flexibility to adapt its application to the complex requirements of numerous dynamic situations is particularly noteworthy. The technique is an appealing option for solving the complex problems posed by mobile WSNs because of its inherent capacity to be selectively simplified. The method's adaptability to various mobility effects is an amazing trait. The strategy can be deliberately optimized in situations where mobility is a prevailing component but not always linked to the natural movement of the nodes. The primary focus of this selective reduction is on energy losses brought on by node movement. This subtle adaptation effectively disallows internal node dynamics considerations, such as biological or physiological movement, which can be unimportant in particular application domains.

By adopting this narrow emphasis, the strategy keeps its essential efficiency while removing components that might be superfluous in some situations. The method's range of applications is broadened by this streamlining process, enabling it to smoothly connect with a variety of application fields. Due to its dynamic adaptability, the approach can be applied to any setting where mobility has a substantial impact, regardless of the underlying causes of that movement. The method's applicability is broadened by this customized approach. Think of applications like asset tracking, industrial automation, or vehicle monitoring. Mobility is crucial in these situations, and the method's ability to reduce energy loss caused by movement could be a game-changer. The technique fits the requirements of these sectors, where constant movement is the norm, by focusing on this particular energy consumption component.

The suggested approach develops into a flexible toolkit that may work with a range of situations without sacrificing its effectiveness or relevance. Its adaptability is not simply a theoretical idea; it is a real-world claim that has the power to change how mobile WSNs are used. The method demonstrates its devotion to custom-made solutions, capable of improving energy efficiency and extending network functionality in a variety of application settings, by dynamically shifting its focus to meet particular mobility patterns. This adaptability demonstrates the method's inventiveness and highlights its potential to serve as a fulcrum of innovation in a variety of mobile WSN sectors.

The proposed method's inherent adaptability goes beyond its existing limitations and encompasses a wide range of options, underscoring its status as a framework that is extremely flexible. This method stands out because to its innate ability to accommodate and support a wide range of mobility models, each of which is specifically designed to satisfy the requirements of various application scenarios. Due to its inherent versatility, the technique can be used to handle a variety of problems throughout the spectrum of mobile Wireless Sensor Networks (WSNs) rather than just as a one-size-fits-all solution. The technique's reliability and adaptability are demonstrated by the ease with which it may be integrated with other mobility models. It becomes a priceless tool for network engineers and IoT practitioners because it can adapt to various conditions with ease. The method can be tailored to fit the particular dynamics of each circumstance, whether the application involves nodes traveling in predictable trajectories, following random patterns, or reacting to outside inputs. This adaptability is not limited to a particular model; rather, it covers the full spectrum of possible movement patterns, guaranteeing that the technique continues to be a useful and practical solution in a constantly changing environment.

A gripping narrative of the complex interactions between energy harvesting, mobility, and strategic clustering is left behind as the investigation comes to a close. This dynamic connection draws attention to the proposed technique's transformative potential. The method emerges as a catalyst for revolutionizing energy-efficient network architecture by utilizing ambient RF energy, optimizing network communication through clustering, and dynamically accommodating multiple mobility models. This conceptual convergence creates a potent trinity with the potential to transform network engineering in the context of the growing Internet of Things (IoT) paradigm.

In summary, this research highlights the complex interaction between energy dynamics, mobility factors, and clustering techniques. The suggested method is more than just an idea; it is a real innovation that successfully combines theory and application. Its extraordinary adaptability, as evidenced by its compatibility with many mobility models, establishes its position as a framework that can go beyond the limitations of single solutions. By doing this, it sets out on a quest to reimagine energy-efficient network architecture within the constantly changing IoT environment. This research opens the way for a future in which the intricate confluence of these ideas will surely affect how we perceive and construct wireless networks inside the IoT ecosystem. It is rich in theoretical underpinnings and practical ramifications.

- **Future Research**

The development of energy efficient methods for mobile wireless sensor networks based IoT has the potential to satisfy the urgent demand for energy conservation while facilitating the smooth operation of linked devices in the future. The fusion of several technology fields, including as energy harvesting, data processing, communication protocols, and AI, is expected to enhance this area and support the long-term expansion of IoT applications.

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