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Enhanced Sensor node lifetime Based Routing Protocol in Mobile Wireless Sensor Networks

Abstract: Mobile Wireless Sensor Networks (MWSNs) are pivotal in facilitating real-time data collection and monitoring in dynamic environments. However, the Sensor nodes' low energy resources limit their lifespan. This study proposes an enhanced sensor node lifetime routing protocol (ESLRP) tailored specifically for MWSNs improve sensor node longevity while optimizing communication. ESLRP leverages a multi-faceted approach to prolong sensor node lifetime. Firstly, it integrates energy-aware routing algorithms that dynamically adapt to node energy levels and network topology changes. By intelligently selecting energy-efficient routes, ESLRP minimizes energy consumption during data transmission, thus prolonging sensor node life. Moreover, ESLRP incorporates mechanisms for energy harvesting and adaptive power management. Sensor nodes are equipped with energy harvesting modules, enabling them to harness ambient energy sources such as solar or kinetic energy to replenish their power reserves. Additionally, adaptive power management techniques are employed to adjust node power levels based on communication requirements, further optimizing energy utilization and enhancing overall network resilience. Furthermore, ESLRP integrates data aggregation and compression to reduce network congestion and duplicated data transfer. By aggregating and compressing data at intermediate nodes, ESLRP minimizes the energy expended on data forwarding, prolonging sensor node lifetime while maintaining data fidelity. To evaluate the efficacy of ESLRP, comprehensive simulations are conducted under various mobility scenarios and network conditions. Results demonstrate that ESLRP outperforms current routing methods for sensor node lifetime extension, energy efficiency, and network resilience.

Keywords: Enhanced Sensor Node Lifetime, Mobile Wireless Sensor Networks (MWSN), Dynamic Topology, Network Stability, Energy-Aware Routing

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are crucial to monitoring and managing the physical environment. These networks comprise a multitude of sensor nodes that are closely situated either within or in close proximity to the phenomenon being studied. This configuration enables the gathering and transmission of ecological data [1]. Sensor nodes, which possess the capability to measure diverse parameters, transmit the data they have gathered to one or more sinks through communications by hop. Sinks receive and send data. to the final recipients. Mobile sensor networks consist of sensors that possess the capability to both move and observe their surroundings [2]. Different devices, such as wheels, springs, or linkage to vehicles and robots, are used to provide this motion. Mobile wireless sensor networks are well-suited for demanding conditions due to their dynamic characteristics. Sensor nodes, commonly powered by batteries (such as the Berkeley mote which uses two AA batteries), encounter substantial

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energy limitations. The frequent unsupervised functioning of deployed sensors presents a hurdle when it comes to recharging them [3]. Therefore, the exhaustion of sensor energy is a crucial concern as it could result in the termination of node functionality within a short period of time. The system of sensors must have a long lifespan., with the anticipation that the network will not need to be recharged for several months to a year. The "Enhanced Sensor Node Lifetime Based Routing Protocol" [4] is designed to address energy-related issues in mobile WSNs. Optimizing routing protocols increases sensor node lifespan and network performance. Mobile WSN routing techniques are challenging Wireless Sensor Networks (WSNs) are produced when they are grouped near the phenomenon of interest. Sensors send environmental data to a sink node or base station for analysis and action. MWSNs improve the concept by making sensor nodes mobile. Mobile wireless sensor network exhibits a flexible and responsive network architecture due to the sensor nodes' capacity to relocate within their coverage area, as well as their aptitude for sensing and transmitting data Wireless Sensor Networks (MWSNs) have a laptop or PDA base station, an upper communication network architecture, and mobile or static sensor nodes. For peer-to-peer data routing to base stations, target environment sensor nodes form a multi-hop mesh network. A driver board and robotic base allow mobile sensor nodes to move both manually and automatically. Mobile sensor nodes can collaborate in ad-hoc communication networks, which greatly improves the flexibility and agility of the network [5]. The sensor network's utility is enhanced by incorporating a mobile sink, a device that establishes a connection between the network and other networks or platforms, such as the Internet. Mobile sinks have various benefits, such as enhanced scalability, equitable workload sharing, reduced energy consumption, and prolonged network longevity.

This work develops an upgraded MWSN routing system based on sensor node longevity. This technique prolongs sensor node life. optimizing the routing mechanism, hence ensuring the ongoing efficiency and usefulness of the network. This study aims to improve the sustainability and performance of the network by examining the dynamics and structure of microwave super-wide networks (MWSNs) [6]. It emphasizes energy and mobility issues. Wireless Sensor Networks (WSNs) have several sensor nodes near the phenomenon they monitor. The sensors convey environmental data to a sink node, or base station, which analyzes it and acts. Standard wireless sensor networks are improved by MWSNs. (WSNs) by integrating mobile Sensor nodes that can sense, move, and communicate within a set distance. A Mobile Wireless Sensor Network (MWSN) is comprised of a laptop or PDA that functions as a mobile base station, in addition to mobile and static sensor nodes, and an upper communication network architecture. A multi-hop mesh network of sensor nodes strategically positioned over the area allows data transmission straight to base stations in this setup. Mobile sensor nodes augment the functionalities of stationary nodes by including a control board and a robotic base, enabling them to navigate either by manual control or autonomously. Ad-hoc communication networks facilitate the synchronization of mobile sensor nodes, so greatly improving the adaptability and capability of the network. Furthermore, a mobile sink [7] acts as an intermediary between the sensor network and other networks or platforms, such as the Internet.

The mobile sink has several benefits, including increased scalability, load balancing, higher energy efficiency, and an extended network lifespan. Mobile Wireless Sensor Networks (MWSNs) differ from ordinary networks due to their large number of nodes and high data flow. This research provides an upgraded routing technique to extend sensor node operational lifespan in energy-limited large-scale wireless sensor networks (MWSNs). By using this protocol, the operational longevity of sensor nodes will be prolonged, guaranteeing the continuous effectiveness and utility of the network. The objective of the proposed protocol is to improve the overall performance and sustainability of MWSNs by giving priority to energy conservation and effective data routing [8]. Wireless sensor networks (WSNs) are comprised of autonomous nodes that possess the capability to perceive or manipulate physical characteristics within their surroundings. These nodes possess the capacity to interact and collaborate. Logic has proven to be effective in overcoming various issues in multiple applications, including IDS. Genetic algorithms are now capable of autonomously constructing and optimizing fuzzy If-then rules, which were previously drawn from human expertise. This automation enhances the adaptability and efficiency of IDS by allowing for automatic modification of detection parameters without requiring constant human involvement. Ren and his associate’s Wireless sensor networks often utilize hierarchical routing algorithms to improve energy economy. These methods utilize energy-efficient procedures, usually applying fuzzy rule-based clustering techniques, to choose Cluster Heads (CHs) Cluster heads (CHs) send data from cluster nodes to the Base Station. (BS) via direct connection or other CHs. This hierarchical method allocates energy fairly, extending network lifespan. Sharma and colleagues. Investigated the enhancement of network longevity by evenly allocating traffic loads to optimize network lifespan [9].

The researchers identified the task of maximizing the network's lifespan and devised an efficient approach for load balancing using heuristics. They conducted a comparison between their results and the shortest-path and equip-proportional routing methodologies. Their methodology significantly increased the length of network functioning. Zhang and Shen [10] proposed a localized zone-based routing technique to achieve equitable distribution of energy consumption among nodes in the network. Their technology is engineered to efficiently allocate data, ensuring fair node energy usage. They confirmed the effectiveness of their method by showing experimental results that demonstrated improved performance in achieving a balance between energy consumption and extending the lifespan of the network. Utilized a game-theoretic approach to attain an equitable allocation of energy consumption across various categories of nodes in clustered wireless sensor networks [11]. Their technique enabled high-energy nodes to effectively compete for CH selection by incorporating a payment function and a penalty mechanism to address energy heterogeneity. It efficiently managed energy usage and extended network functionality. Ekal and Abdullah developed an energy provisioning technique to coordinate energy use across many network zones or coronas. Their methodology computed the additional energy requirements for each zone, leading to improved energy efficiency and prolonged network longevity. The researchers analyzed the problem of maximizing the lifespan of networks in planar topologies and achieved globally optimal solutions by utilizing Karush-Kuhn-Tucker (KKT) conditions. Their iterative methodology, specifically tailored for large-scale networks, improved the network's durability by optimizing the routing, connection accessibility, and data transfer rate. Perkins CE, Bhagwat P [12] enhanced the notion of network longevity by considering the mobility of source nodes and placing particular emphasis on the duration until source node energy is out.

Their approach incorporated the concept of mobility into the evaluation of network lifespan, offering a new perspective on how to regulate energy usage in mobile sensor nodes. The reviewed papers highlight different strategies to enhance the lifespan of sensor nodes in Mobile Wireless Sensor Networks. These strategies address significant challenges such as energy consumption, workload distribution, and mobility by utilizing approaches such as fuzzy logic, evolutionary algorithms, game theory, and innovative routing methods. Collectively, these studies contribute to the development of more robust and efficient routing methods for mobile sensor networks. Considering their interconnection via wireless networks [13]. The energy consumption of WSN nodes has been thoroughly examined, but a notable constraint has been the immobile and unchanging characteristics of these nodes. However, mobility plays a crucial role in Wireless Sensor Networks (WSNs) for a wide range of applications including medical treatment, disaster response, animal tracking, search and rescue operations, vehicle tracking, RoboMote, parasitic mobility, and habitat monitoring [14]. Mobile Wireless Sensor Networks (MWSNs) are characterized by their large number of nodes and significant data generation, setting them apart from traditional networks. This study presents an enhanced routing method designed to prolong the operational duration of sensor nodes in large-scale wireless sensor networks (MWSNs) with limited energy resources. By implementing this protocol, the longevity of sensor nodes will be prolonged, guaranteeing the continuous effectiveness and use of the network. The objective of the proposed protocol is to optimize the overall effectiveness and longevity of MWSNs by giving priority to energy preservation and efficient data routing. Autonomous nodes in wireless sensor networks (WSNs) can detect or change physical attributes [15].

These nodes can collaborate Nodes in mobile sensor networks may relocate after deployment due to variables such as wind, water currents, human or equipment movement, and other effects. The constrained battery capacity of sensor nodes presents a notable obstacle for mobile wireless sensor networks (WSNs), leading to reduced network durability and efficiency [16]. To address concerns related to energy usage, researchers have analyzed data transmission strategies that depend on clusters. The cluster-based and energy-efficient protocols comprise LEACH, LEACH-M, LEACH-ME, and CBR-Mobile. In these protocols, mobile wireless sensor networks (WSNs) employ various criteria to choose energy-efficient cluster heads (CHs). ECBR-MWSN improves the LEACH-M protocol in mobile wireless sensor networks. The major purpose of ECBR-MWSN is to equalize node energy usage to extend sensor network life.

The suggested algorithm chooses Cluster Heads (CHs) by considering three criteria: the shortest distance from the base station (BS), the lowest mobility, and the highest remaining energy. The Base Station (BS) periodically performs the process of selecting new Cluster Heads (CHs). Simulation data has conclusively shown that ECBR-MWSN surpasses other protocols like LEACH-M and LEACH-ME [17]

The progress in Micro Electromechanical Systems (MEMS) technology has enabled the creation of sensor nodes with smaller size. Although these nodes are sophisticated, they have insufficient energy, battery life, bandwidth, and memory. These small nodes are part of a Wireless Sensor Network (WSN), and their main function is to collect data from their surroundings and send it to a Base Station (BS), which then communicates directly with users. Substituting the batteries of sensor nodes in WSNs can be impractical at times, particularly in dangerous areas. Therefore, in order to extend the duration of these networks, it is imperative to create routing protocols that are energy efficient. Advancements in wireless sensor networks (WSNs) have made it possible to create intelligent sensor nodes that are extremely compact (measured in the cubic millimeter range) and highly energy-efficient (using tens of nanojoules) [18]. This finding aligns with the goal of ubiquitous computing, which imagines a future when users' computing gadgets are nearly undetectable, seamlessly blending with their environment. According to [19], cluster-based hierarchical routing is regarded as the best energy-efficient routing protocol. The Low-Energy Adaptive Clustering Hierarchical (LEACH) protocol and its derivatives enhance the efficiency of utilizing the limited energy resources of individual nodes by arranging them into clusters. The protocols operate in a sequential fashion, where each round entails the designation of one node per cluster to act as the Cluster Head (CH). The central hub (CH) performs the task of collecting and transmitting the aggregated data to the base station. The foundation of this concept relies on a variable threshold value that varies in accordance with the current round number. When comparing typical routing protocols, such as Data-Centric protocols, to clustering algorithms like LEACH, the former significantly decreases energy dissipation. Merely raising the threshold values does not guarantee the election of the appropriate number of CHs in each round [20]. Because these protocols are decentralized and disorganized, it is possible for certain nodes or all nodes to be selected as CHs, resulting in wasteful use of network bandwidth and resources and generating excessive energy consumption. This study introduces an improved model for choosing Cluster Heads (CHs) that improves threshold values and ensures the selection of the optimal number of CHs in each round. The objective of this endeavor is to broaden or enlarge [21].

The Base station receives high-fidelity data, which contributes to the extension of the sensor network's lifespan. The use of a data aggregation method reduces the amount of data sent to the base station while preserving its quality. A wireless sensor network (WSN) is formed by combining specialized sensor nodes with the objective of collecting environmental data. Each sensor node is outfitted with a transceiver, central processing unit (CPU), controller, and sensing unit [30]. The transceiver is responsible for the transmission and reception of data, while the processing unit analyzes the incoming data and initiates the necessary actions. The controller unit regulates the operations of all other units inside the sensor node [22]. Cluster heads can reduce their effort by assigning nodes with greater energy levels to the job of forwarders, since sensors depend on energy for their operation. The forwarder nodes gather data from the cluster heads and transmit it to a mobile sink node. When sensors are positioned randomly, it can be difficult to achieve full coverage of the entire region. At times, the sensors' limited ability to transmit data hinders the establishment of a direct link with the sink node. Furthermore, supplementary Using sensor nodes can efficiently overcome this limitation. The main objective of this research is to extend the functional duration of sensors utilized in real-time applications. Sensors may have limited lifespans due to intrinsic energy constraints [23]. To address this issue and increase the longevity of sensor networks, we propose the implementation of a Mobile Sink and a Relay Node Routing Protocol that utilizes Fuzzy logic. The objective of this protocol is to improve the longevity and efficiency of Wireless Sensor Networks (WSNs) by implementing measures to reduce energy consumption and increase the routing process. Wireless communication technologies have greatly transformed both machine-to-machine and human-human interactions across several applications. Wireless sensor networks (WSNs) are employed for the purpose of surveillance and monitoring, which is a notable application [24].

The development of embedded micro-sensing (MEMS) and wireless communication has significantly improved the capabilities and implementation of wireless sensor networks (WSNs). These networks, which may accommodate tens of thousands or even hundreds of thousands of sensor nodes, are highly esteemed for their flexibility. The main obstacle in WSNs [25] is to reduce energy usage at every sensor node. Extensive research has been conducted to create routing protocols that decrease power consumption and improve the longevity of networks. Historically, it was commonly assumed that sensor nodes would be immobile and would stay in their original locations once they were installed. The notion [26] has largely led the research and development of Wireless Sensor Networks (WSN) for a considerable period. The demand for mobility in components of Wireless Sensor Networks (WSN) has emerged due to the growing utilization of applications such as healthcare, disaster response, wildlife tracking, search and rescue operations, parasite movement, and habitat monitoring. This encompasses the movement of observers, sink nodes, events, and sensor nodes. To cope with the growing intricacy and energy requirements of mobile WSNs, it is imperative to utilize routing algorithms that possess both adaptability and energy efficiency [27]. This study presents an Enhanced Routing Protocol for Mobile Wireless Sensor Networks that utilizes the lifespan of sensor nodes to address the identified needs. The objective of this protocol is to enhance the routing process by addressing the difficulties caused by limitations in energy and mobility. By implementing this approach, it is possible to extend the longevity of sensor nodes and guarantee optimal network performance [28]. The suggested protocol aims to improve the overall performance and robustness of Wireless Sensor Networks (WSNs) by employing innovative techniques and meticulous design. Wireless sensor networks (WSNs) can detect environmental data and transmit it to a sink node, either directly or by passing it through nearby nodes. After the completion of processing, the sink sends this information to the external world. Conserving energy is a critical issue for WSNs since it is difficult to replace batteries on the sensor nodes of these networks [29].

The issue of energy efficiency is of great importance in sensor nodes since they must function for extended periods without any maintenance, and the amount of energy consumed is mostly governed by the individual demands of each application. The battery is essential for Wireless Sensor Networks (WSNs) since energy consumption has a direct impact on the network's lifespan. Extended Periods of operation of Wireless Sensor Networks (WSNs) can lead to efficient monitoring. Utilizing multi-hop short-range communication in densely populated sensor networks can significantly decrease energy consumption and improve the network's lifetime. Considering the difficulties related to replacing and monitoring sensor nodes, it is crucial to prioritize energy conservation. Conventional approaches occasionally fail to consider network problems arising from numerous origins. Mobile device the protocol used in the wireless sensor network is referred to as Wireless Sensor Network Protocol [30]. The Energy Balancing and Optimal Routing Based Secured Data Transmission (EBORDT) protocol, which utilizes clustering, aims to prolong the lifespan of wireless networks by improving energy conservation. This technology ensures the establishment of optimal routes and secure, energy-efficient transmission of data. The protocol guarantees reliable transmission of data by utilizing a density-aware optimal clustering algorithm. The Ant Colony Optimization approach is employed to select the most optimal cluster head, hence increasing the longevity of the network. Multiple techniques exist for providing optimal edge disjoint routing algorithms that efficiently transmit data packets. The Hybrid Genetic PSO technique considers Quality of Service (QoS) parameters such as processing power, bandwidth, energy, and dependability to identify the most optimal edge disjoint route paths [31].

This research aims to resolve issues related to routing path data transmission and network lifetime by implementing a clustering technique to enhance network durability. The proposed protocol addresses the primary concerns of Wireless Sensor Networks (WSNs) by guaranteeing secure and reliable data transmission while also optimizing energy efficiency. Wireless Sensor Networks (WSNs) play a crucial role in Mobile Wireless Sensor Networks (MWSNs) by relaying events to a Base Station (BS). The Low-Energy Adaptive Clustering Hierarchy (LEACH) is a prominent hierarchical routing technique employed in Wireless Sensor Networks (WSNs), as extensively discussed by Rais et al. [20]. The efficacy of LEACH in conventional routing is widely recognized. The rotation of the CH job involves assigning Cluster Heads (CHs) in a probabilistic manner, aiming to evenly distribute the workload among sensor nodes. Although LEACH has made significant advancements, certain issues persist. Due to the probabilistic nature of CH selection, it is possible for multiple CHs to be selected in a single round or for no CH to be selected at all. In addition, it is possible for CHs to be allocated near the periphery of the network, leading to an uneven distribution of energy. LEACH does not take into account the positioning of nodes or their energy levels when choosing the Cluster Heads (CHs) during each rotation. LEACH-Centralized (LEACH-C) is a routing method that seeks to enhance the quantity and dispersion of clusters. This is accomplished by employing the Base Station (BS) to centrally choose Cluster Heads (CHs). However, since each setup phase requires all nodes to provide position information to the BS, this strategy results in increased network overhead. The Fuzzy Based Cluster Head Intrusion Detection System (FCHIDS) improves the LEACH algorithm by incorporating fuzzy logic concepts to choose an Optimal-CH (OCH) from the cluster heads [32].

The OCH possesses sole authority in transmitting information to the BS, hence minimizing the requirement for CHs to retransmit and thereby conserving energy. An intrusion detection system (IDS) is implemented to identify and thwart attacks with the aim of bolstering network security. At present, there are two main approaches used for Intrusion Detection Systems (IDS): anomaly detection, which detects abnormalities from typical network behavior, and abuse detection, which relies on known attack patterns. The identification of developing dangers is not achieved through the detection of misuse, even if it is successful in detecting well-known attacks. On the other hand, anomalous Detection necessitates a significant amount of network communication data, although it possesses the potential to recognize innovative types of attacks. The objective of the proposed Intrusion Detection System (IDS) is to accurately detect hostile nodes in Mobile Wireless Sensor Networks (MWSNs) by utilizing the Fuzzy Based CH Clustered routing method, while minimizing the occurrence of false alarms [33].

2. RELATED WORK

Static sensor nodes are typical in terrestrial wireless sensor networks (WSNs), however mobile WSNs are gaining popularity. In recent times, there has been a rollout of many Mobile Wireless Sensor Networks (MWSNs) that employ sensor nodes affixed to objects capable of passive mobility or equipped with motors for active mobility. Examples of this phenomenon include attaching wireless sensor devices to bicycles, autos, animals, and Micro Air Vehicles. Motorized wireless sensors have been used to get data from stationary sensor devices and to move underwater. The research associated with this endeavor can be divided into two categories: real-time routing protocols for static wireless sensor networks (WSNs) and protocols specifically designed for mobile wireless sensor networks (MWSNs) . The RAP protocol offers a real-time framework and protocols that are founded on velocity. By employing velocity-monotonic packet categorization, it provides differentiation in service based on punctuality. The Rate Assignment Protocol (RAP) orders packets based on their velocity in a monotonically increasing manner, guaranteeing that packets with greater velocities are delivered before those with lower velocities. This is accomplished by computing the necessary velocity of a packet based on its deadline and destination. SPEED is a protocol that does not retain information about previous interactions and created for Wireless Sensor Networks (WSNs) to facilitate instant communication. It controls communication delay by setting a uniform transmission rate at each network node. This is achieved via non-deterministic QoS-aware geographic forwarding and feedback control. MM-SPEED adds multiple communication rates and differential dependability to SPEED. It was designed for real-time needs. RTPC selects forwarding nodes depending on velocity and energy efficiency RTPC possesses the remarkable capability to transmit data while simultaneously adjusting the transmission power, hence improving energy efficiency [34].

The Real-Time Load Distribution (RTLD) protocol enhances the selection of forwarding nodes by considering packet reception rate (PRR), sensor node power, and single-hop packet velocity. RTLD includes location, route, power, and neighborhood management. Manage locations locates sensor nodes by measuring their distances from three specified neighbors. RTLD has great power consumption, control packet overhead, and delivery ratio. RTLD, MM-SPEED, and RTPC were built for static wireless sensor networks (WSNs) and are unsuitable for protocols that support mobile and stationary nodes. WSN proposals include mobile and stationary node protocols. The Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm is a popular Wireless Sensor Network clustering technology. LEACH nodes automatically generate local clusters with similar energy levels due to network homogeneity. There are stages or phases to the process. Technique. During the setup phase, the Cluster Head (CH) is chosen from the organized clusters if it randomly selects a number between 0 and 1 that is below the threshold value. Every non-CH

(Cluster Head) node sends data only inside the designated time frame for CHs during the steady-state phase. The Central Hub (CH) collects and transmits the data to the Base Station (BS). Each round's cluster construction is energy-inefficient and doesn't enable mobility. By adding a membership statement to LEACH, LEACH-Mobile improves sensor node mobility in Wireless Sensor Networks (WSNs). LEACH-Mobile performs well in mobile packet loss, although membership is required. Enhanced LEACH-Mobile offers a better cluster head selection mechanism. The selection of the cluster head is currently determined by the sensor node with the lowest mobility factor. The CBR-Mobile protocol enables the relocation of sensor nodes by dynamically redistributing time slots according to the nodes' mobility and traffic. CBR-Mobile assigns two owners to each time slot: the primary owner and the backup owner. CBR-Mobile possesses the ability to actively control the mobility and data transmission of sensor nodes, leading to a significant enhancement in the success rate of delivering packets compared to the LEACH-Mobile protocol [35].

Extremely effective and reliable. The calculation of sensor node mobility does not require additional time slots, which leads to faster data transfer to the base station. The Cluster-based Energy-efficient Scheme (CES) for Mobile Wireless Sensor Networks (MWSNs) chooses cluster-heads by assessing k-density, residual energy, and mobility variables. The CES scheme carries out a systematic process of picking cluster-heads after each round. This functionality enables the creation of balanced two-hop clusters that adhere to predetermined upper and lower size limits. The process of balancing guarantees the maintenance of efficiency and reliability in the transmission of data. The protocols LEACH, LEACH-Mobile, CBR-Mobile, FTCP-MWSN, and CES address various aspects of cluster-based routing in both stationary and mobile wireless sensor network (WSN) scenarios. LEACH, while serving as a core clustering approach, lacks efficiency and support for mobility. The LEACH-Mobile and its improved version both tackle these features, but they still have limitations. CBR-Mobile offers adaptive time slot reassignment, a feature that enhances mobile device support and boosts packet delivery efficiency. FTCP-MWSN focuses on ensuring the reliability and speed of data transfer without any extra load [36].

In essence, CES guarantees that the sizes of clusters are made equal and considers several features to choose the most optimal choice of cluster-heads. These protocols provide a basis for further enhancement, namely in improving energy efficiency and extending the lifespan of sensor nodes in mobile WSNs . This section covers cluster-based routing protocols, focusing on the most essential Wireless Sensor Networks approaches. As demonstrated below, the Low-Energy Adaptive Clustering Hierarchical (LEACH) protocol is essential for Wireless Sensor Networks (WSNs). Each cycle of LEACH, each node randomly chooses a value from 0 to 1. The node becomes a Cluster Head if its numerical value is below a threshold. The threshold value, which defines a node's CH eligibility, ranges from 0 to 1 and is impacted by other LEACH protocol parameters. CHs actively promote themselves to nearby nodes after being elected. After receiving these ads, non-CH nodes evaluate the signal strength and determine whether to join the cluster. Section the CH advertisement is a succinct form of communication that includes the identification of CH and a headline that clearly marks it as an announcement [37]. Existing protocols and procedures for MWSNs give priority to various areas of energy efficiency and the dependability of data transmission. Various techniques, including optimizing the route of mobile sinks, adopting controlled movement schemes, employing data distribution protocols, and applying load balancing algorithms, contribute to prolonging the lifespan of sensor nodes and improving network performance. This research provides a foundation for developing advanced and efficient routing techniques specifically tailored for mobile wireless sensor networks. After receiving numerous CH adverts, each non-CH node chooses a CH to connect with and sends a Join-Request message with its ID and the CH's identification. Time Division Multiple Access is allocated by the CH, Slots per connected non-CH node. The LEACH technique has a Setup phase and a Steady-State phase in each round. Setup creates clusters and selects Cluster Heads (CHs). CHs collect and transmit data from cluster nodes to the base station (BS) during the Steady-State phase. Each round, CHs rotate to evenly share energy consumption among nodes, ensuring balance. LEACH-Mobile adds functionality to the original LEACH protocol to make node movement easier in the Wireless Sensor Network. Membership declarations let nodes adapt to network topology changes. LEACH-Mobile reduces packet loss better than LEACH in mobile contexts, although membership statements cost more [38].

LEACH-ME improves LEACH-Mobile by utilizing the mobility factor as a primary criterion for selecting cluster heads (CH). The Cluster Head (CH) is chosen based on the sensor node with the lowest mobility factor, enhancing the protocol's ability to adjust to mobile scenarios. The Cluster-Based Routing (CBR) Mobile protocol enables the mobility of sensor nodes by dynamically reallocating time slots based on node movement and traffic patterns. Two owners are assigned to each time slot: original and alternate owners. By adjusting to node mobility and traffic, this method enhances packet delivery ratio over LEACH-Mobile, TCP-MWSN's major purpose is to minimize energy usage while maintaining a high level of system reliability. It obviates the necessity for additional time slots to compute node mobility, leading to expedited data transmission to the BS without any supplementary overhead. The Cluster-based Energy-efficient Scheme (CES) for Mobile Wireless Sensor Networks employs k-density, residual energy, and mobility as criteria to select the Cluster Head (CH). CES undertakes periodic cluster-head elections after each round, leading to the creation of well-balanced two-hop clusters with sizes that meet preset upper and lower limits [39]. This equilibrium enables the preservation of effective and reliable data transmission. The protocols LEACH, LEACH-Mobile, LEACH-ME, CBR-Mobile, FTCP-MWSN, and CES are specifically developed to address different features of cluster-based routing in both static and mobile wireless sensor network (WSN) environments. LEACH, while being the primary clustering approach, is plagued by inefficiency and a lack of mobility support. LEACH-Mobile and LEACH-ME offer enhanced assistance for mobility, but with substantial additional costs. CBR-Mobile utilizes a mechanism for dynamically redistributing time slots, leading to a significant improvement in packet delivery speeds. The FTCP-MWSN protocol offers a reliable and effective method for transmitting data without any superfluous overhead. In addition, the CES algorithm guarantees balanced clusters by considering multiple parameters to determine the most appropriate cluster head. These protocols lay the groundwork for further enhancements that seek to optimize energy efficiency and extend the lifespan of sensor nodes in mobile wireless sensor networks. This section analyzes prior research on routing protocols and strategies aimed at enhancing the durability of sensor nodes in Mobile Wireless Sensor Networks (MWSNs) [40].

The focus is on multiple ways to optimize energy use and ensure efficient data transmission. The work was authored by Hamida EB, Chelius G and his colleagues [41]. Developed a strategy that utilizes a mobile sink to specifically visit predetermined meeting points within a sensor network. The aim of this method is to gather all identified data within a predetermined time constraint, which is crucial for applications that necessitate low latency. However, the natural delay in reaching all meeting points can be reduced by using Weighted Rendezvous Planning (WRP), a method that optimizes the movement of the mobile sink to efficiently control and minimize delays. The paper was authored by Koutsonikolas [42]. Proposed a mechanism to control the movement of a portable sink helps prolong the longevity of the network. The sink's mobility is constrained to minimize data loss by adhering to limits, including maintaining a maximum distance between two sites, assuring a minimal

Amount of time spent at each place, and decreasing the total distance traveled. This controlled movement assists in efficiently managing the energy resources of the network, Hamida EB, Chelius G and his colleagues [41] did study on the procedures for disseminating data in situations involving mobile sinks. The researchers investigated the impact of a mobile sink on energy use. Researchers found that there are trade-offs associated with the use of big virtual infrastructures. While these infrastructures can reduce energy-hole difficulties, they also result in higher look-up charges. On the other hand, small virtual infrastructures can lower the energy cost of data distribution, but at the expense of dependability and protocol redundancy. Sheikhpour R, Jabbehdari [43] devised the Energy Delay Index for Trade-off (EDIT) algorithm to efficiently handle the balance between energy efficiency and delay. This algorithm selects cluster heads based on a combination of Euclidean distance and hop count, with the goal of optimizing energy consumption and minimizing communication time. In their study, Ren J et al. [44] focused on the problem of hot spots in the network, which are specific locations that experience higher traffic loads, leading to a more rapid depletion of energy. Their method attains energy equilibrium by evaluating the traffic load, energy depletion, and sensor lifespan, then adopting an appropriate routing plan to avoid energy depletion gaps and enhance the longevity of the sensors.

Kim and Chung [45] proposed a load balancing system that combines a greedy graph algorithm with a user-centric load balancing algorithm. The objective is to equitably distribute the network load and minimize energy consumption. Suggested a solution to the energy-hole problem by incorporating a movable sink node. By moving the sink node, the energy usage of nearby relay nodes is decreased, resulting in a longer overall lifespan for the network. In their study, Wen et al. [36] presented an algorithm that efficiently generates a route for the mobile sink by exploiting data gathering locations. This strategy improves the efficiency of data collection and load balancing, hence enhancing the overall longevity of the network. This section is a summary of prior research on routing protocols and strategies that aim to enhance the longevity of sensor nodes in Mobile Wireless Sensor Networks (MWSNs). We primarily concentrate on developing and modifying routing protocols for wireless ad-hoc networks to tackle the unique challenges posed by mobile situations and the constraints of wireless sensor networks (WSNs). Wireless Sensor Networks (WSNs) emerged from wireless ad-hoc networks, leading to the earliest implementation of ad-hoc routing algorithms in WSNs. The protocols include the following: This protocol, designed primarily for fixed networks, guarantees the uninterrupted distribution of route information to all nodes through periodic updates. However, it does not possess energy efficiency when utilized with battery-powered, low-capacity nodes that are frequently seen in Wireless Sensor Networks (WSNs). The Dynamic Source Routing (DSR) protocol, specifically built for mobile networks, establishes routes only when necessary, leading to energy preservation in comparison to proactive protocols. Nevertheless, it continues to utilize a significant quantity of energy while engaging in the tasks of identifying and sustaining pathways [46].

Utilizes both proactive and reactive tactics to generate routes only when required. Although AODV strikes a balance between energy efficiency and quick route discovery, it is still insufficient for the small, low-capacity sensor nodes in WSNs. Due to the unique requirements and limits of sensor networks, existing protocols were not inherently compatible with WSNs. Consequently, academics have proposed the necessity of developing novel routing protocols specifically tailored for Wireless Sensor Networks (WSNs). Various Medium Access Control (MAC) and network layer protocols can improve stationary Wireless Sensor Network energy efficiency. There are several ways to save electricity. during the transmission of data by optimizing the duty cycle and minimizing idle listening. Protocols designed expressly for static wireless sensor networks (WSNs) focus on maximizing data aggregation, processing inside the network, and minimizing needless communication. However, these protocols frequently assume that sensor nodes are immobile and are not specifically intended to effectively manage the dynamic network topologies and frequent route adjustments required in mobile wireless sensor network (WSN) environments. To address the limitations of traditional protocols in mobile environments, researchers have shifted their focus towards developing [47].

Routing protocols that adapt to sensor node mobility. Protocols designed within the layered architecture prioritize specific levels, such as MAC and network, to improve energy economy and ensure reliable data transmission in mobile scenarios. Inadequate cross-layer coordination can lead to subpar performance as each layer independently addresses challenges linked to mobility. Cross-layer protocols are specifically developed to integrate and synchronize the operations of multiple layers in order to efficiently tackle issues linked to mobility. This technique facilitates extensive optimizations, proficiently overseeing energy consumption, guaranteeing data dependability, and upholding route stability. Researchers focus on these strategies to extend sensor node lifespan in mobile wireless sensor networks. Their objective is to develop routing protocols that possess greater resilience and energy efficiency. Prior research on routing protocols and tactics to extend sensor node lifespan in Mobile Wireless Sensor Networks is summarized here. Various methods and procedures have been presented to handle energy consumption concerns, task distribution, and mobility in sensor networks. Successfully addressed the problem of optimizing the network's longevity by uniformly dispersing the traffic load across the whole network. They proposed various strategies for optimizing energy use to extend the longevity of the network [48].

The objective of formulating the problem of maximizing the network lifetime was to achieve an optimal solution for load balancing. The most efficient solution was later determined using a heuristic method. The researchers performed a comparison between their heuristic approach and the optimal solutions achieved using shortest-path and equi-proportional routing methods. The findings demonstrated a significant enhancement in the longevity of the network using their methodology, surpassing the effectiveness of current methodologies. Zhang and Shen [10] conducted a study on energy consumption at different nodes within the network. Their goal was to attain equilibrium in energy consumption among nodes by implementing a limited zone-based routing approach. Their offline centralized algorithm successfully resolved the problem of distributing data equitably to ensure equitable energy utilization, using a precisely tailored temporal complexity to address this issue. The researchers determined the optimal number of coronas to maximize the network's lifetime. The trial results showed that their methodology outperformed existing strategies in terms of attaining equitable energy usage and extending the network's lifespan. The research carried out by Yang et al [37]. Focused on optimizing energy utilization across several nodes within a cluster. A wireless sensor network connects devices without wiring to communicate. The authors suggested a game-theoretic method to energy consumption equilibrium utilizing a payoff function with a penalty mechanism to account for energy level differences. Nodes with high energy levels could efficiently compete for Cluster Head with this technique. Clustering using Nash equilibrium (NE) algorithms maximized sensor payoffs, balancing energy consumption and network longevity. Ekal and I examined how network coverage length affects WSN energy utilization.

We introduced a new energy provisioning technique to evenly distribute energy consumption across various regions. The researchers calculated the additional energy required for each corona to attain an ideal energy balance. This strategy led to significant improvements in the network's operational lifespan by effectively dispersing energy demand across the network. Wang et al [38] investigated the Network Lifetime Maximization (NLM) problem in Wireless Sensor Networks (WSNs), with a specific emphasis on planar topologies such as triangles and regular quadrangles. They created a systematic structure for examining this issue. The researchers utilized the Karush-Kuhn-Tucker (KKT) optimal conditions to ascertain the most optimal longevity of the network on a global scale. They considered various factors including routing, link access, and data rate. To enhance the longevity of extensive planar networks, a Decomposition and Combination (D&C) technique was employed, in conjunction with an iterative algorithm. Investigated the length of time a network remains operational in respect to mobile nodes by redefining network lifetime is till the source node runs out of energy.

The researchers incorporated the notion of mobility into their study, offering a novel perspective on the lifespan of networks that accounts for the dynamic nature of mobile sensor nodes. The assessed Works investigate several methods to enhance the longevity of sensor nodes in MWSNs, with a specific emphasis on crucial characteristics such as energy consumption, load balancing, and mobility. This research contributes to the advancement of more effective and resilient routing protocols for mobile sensor networks through the utilization of zone-based routing, game theory, and innovative energy provisioning approaches. Intrusion detection systems (IDS) are crucial for detecting and identifying unauthorized utilization, incorrect usage, and exploitation of network assets by both internal and external attackers. An efficient Intrusion Detection System (IDS) must include the capability to differentiate between customary and anomalous actions. Intrusion Detection Systems (IDS) can be categorized into two groups according to their signature-based and anomaly-based detection. Signature-based Intrusion Detection Systems (IDS) rely on predetermined patterns or signatures that are already present in the data being monitored. The database stores established attack signatures. This approach effectively detects known attacks but encounters challenges when confronted with novel and unfamiliar threats. In contrast, anomaly-based IDSs (IDS) predict the usual behavioral patterns of mobile nodes and raise alarms when deviations from these patterns exceed a specific threshold [49].

This technique exhibits a high degree of adaptability in addressing new and unforeseen dangers, but it can also generate imprecise identifications. The citation is Khan et al [39]. Unclear Logic has proven to be effective in overcoming various issues in multiple applications, including IDS. Genetic algorithms are now capable of autonomously constructing and optimizing fuzzy if-then rules, which were previously drawn from human expertise. This automation enhances the adaptability and efficiency of IDS by allowing for automatic modification of detection parameters without requiring constant human involvement. Ren and his associates [44] (as referenced by source) [69]. Wireless sensor networks often utilize hierarchical routing algorithms to improve energy economy. These methods utilize energy-efficient procedures, usually applying fuzzy rule-based clustering techniques, to choose Cluster Heads

(CHs). Each cluster head (CH) collects data from cluster nodes and sends it to the Base Station (BS) via direct communication or other CHs. The hierarchical technique allows fair energy usage allocation across the network, expanding its overall longevity of the network. Sharma and his colleagues [9]. Investigated the enhancement of network longevity by evenly allocating traffic loads to optimize network lifespan. The researchers identified the task of maximizing the network's lifespan and devised an efficient approach for load balancing using heuristics. They conducted a comparison between their results and the shortest-path and equi-proportional routing methodologies. Their methodology significantly increased the length of network functioning. Zhang and Shen [10] proposed a localized zone-based routing technique to achieve equitable distribution of energy consumption among nodes in the network.

Their system allocates data efficiently, distributing energy usage evenly among nodes. They proved their strategy worked by displaying experimental data that showed improved energy usage and network lifespan. Utilized a game-theoretic approach to attain an equitable allocation of energy consumption across various categories of nodes in clustered wireless sensor networks. Their technique enabled high-energy nodes to effectively compete for CH selection by incorporating a payment function and a penalty mechanism to address energy heterogeneity. This method efficiently controlled energy usage while also extending the functional longevity of the network. Ekal and Abdullah developed an energy provisioning technique to coordinate energy use across many network zones or coronas. Their methodology computed the additional energy requirements for each zone, leading to improved energy efficiency and prolonged network longevity. The researchers analyzed the problem of maximizing the lifespan of networks in planar topologies and achieved globally optimal solutions by utilizing Karush-Kuhn-Tucker (KKT) conditions. Their iterative methodology, specifically tailored for large-scale networks, improved the network's durability by optimizing the routing, connection accessibility, and data transfer rate. Perkins CE, Bhagwat [12] enhanced the notion of network longevity by considering the mobility of source nodes and placing particular emphasis on the duration until the source node depletes its energy. Their approach incorporated the concept of mobility into the evaluation of network lifespan, offering a new perspective on how to regulate energy usage in mobile sensor nodes. The reviewed papers highlight different strategies to enhance the lifespan of sensor nodes in Mobile Wireless Sensor Networks. These strategies address significant challenges such as energy consumption, workload distribution, and mobility by utilizing approaches such as fuzzy logic, evolutionary algorithms, game theory, and innovative routing methods. Collectively, these studies contribute to the development of more robust and efficient routing methods for mobile sensor networks [50]. Table 1. captures the essence of each study, outlining their specific contributions, methodologies, limitations, and where their research findings were published. It provides a quick overview of the diverse approaches taken in sensor networks research by these authors

Table1: Summary Table of Authors' Contributions in Sensor Networks Research

Author(s)	Contribution	Methodology	Limitations	Publication
Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci [51]	Comprehensive survey on sensor networks	Literature review	Limited to the state-of-the-art up to 2002	IEEE Communications Magazine
K. Akkaya, M. Younis [52]	Survey on routing protocols for wireless sensor networks	Literature review	Limited to routing protocols, doesn't cover other aspects	Ad Hoc Networks
L. Hu, D. Evans [53]	Localization methods for mobile sensor networks	Algorithm development and analysis	Focus on mobile sensors, lacks real-world implementation	IEEE Network

Baggio A, Langendoen K [54]	Monte Carlo localization for mobile wireless sensor networks	Monte Carlo method	Assumes certain environmental conditions that may not hold	Computer Networks
Boyinbode O, Le H, Takizawa [55]	Path planning of mobile landmarks for localization	Algorithm development and analysis	Performance highly dependent on the accuracy of path planning	IEEE Transactions on Mobile Computing
Kuang Xing-hong, Shao Hui-he [25]	Distributed localization using mobile beacons	Algorithm development and analysis	May face challenges in dynamic or harsh environments	Sensors
Liang W, Luo J, Xu X [56]	GPS-Free node localization in mobile wireless sensor networks	Algorithm development and analysis	Accuracy depends on node density and movement patterns	ACM Transactions on Sensor Networks

Proposed Methodology

The Enhanced Sensor Node Lifetime Based Routing Protocol (ESLRP) is designed to improve energy efficiency and extend the lifetime of Mobile Wireless Sensor Networks (MWSNs). The protocol focuses on optimizing energy consumption during data transmission and reception while incorporating energy harvesting techniques. The following sections describe the key components and methodologies employed in ESLRP.

1. Network Model and Assumptions

The network architecture of the Mobile Wireless Sensor Networks (MWSNs) consists of both static and mobile sensor nodes that gather and transmit data to a central base station (BS) through multi-hop communication. Static nodes remain stationary, while mobile nodes have the ability to move within a predefined area. Each sensor node is equipped with sensing, processing, and communication units and is powered by a battery with limited capacity. Some nodes are additionally equipped with energy harvesting modules to replenish their energy from ambient sources. Energy consumption in the network is primarily incurred during data transmission and reception, and the energy model accounts for the energy used by the transmitter, receiver, and amplifier. The mobility model allows mobile nodes to move within the network area following a random or predefined mobility pattern, and the protocol dynamically adapts to the changing positions of these. ESLRP is built on a network architecture comprising both static and mobile sensor nodes. These nodes gather data and transmit it to a central base station (BS) via multi-hop communication. Static nodes remain in fixed positions, while mobile nodes move within a predefined area, adhering to either random or predefined mobility patterns. Each sensor node is equipped with sensing, processing, and communication units powered by a limited-capacity battery. Some nodes are also outfitted with energy harvesting modules to capture ambient energy sources like solar or kinetic energy. The energy consumption model in the network accounts for the energy used by the transmitter, receiver, and amplifier during data transmission and reception.

2. Routing Protocol Design

Energy-aware routing in the protocol is designed to select routes based on the residual energy of nodes and their distances, ensuring energy-efficient data transmission. Routes are dynamically adjusted to avoid nodes with critically low energy levels, thereby enhancing the overall network lifespan. Adaptive power management allows nodes to adjust their transmission power based on their remaining energy and the distance to the next hop. This approach minimizes energy consumption and prolongs both node and network lifetime. Additionally, data aggregation and compression techniques are employed by intermediate nodes to reduce the volume of data transmitted. This not only conserves energy but also reduces network traffic, improving overall efficiency. The core of ESLRP is its energy-aware routing mechanism. Routes are selected based on the residual energy of nodes and their distances to ensure energy-efficient data transmission. Routes are dynamically adjusted to avoid nodes with critically low energy levels, enhancing the overall network lifespan. Adaptive power management is integrated, allowing nodes to adjust their transmission power according to their remaining energy and the distance to the next hop. This approach minimizes energy consumption and prolongs the lifetime of both nodes and the network. Additionally, data aggregation and compression techniques are used by intermediate nodes to reduce the volume of data transmitted, conserving energy and reducing network traffic.

3. Energy Harvesting and Management

Energy harvesting modules are crucial components in the development of autonomous systems, particularly in scenarios where consistent power sources may be unreliable or unavailable. These modules enable devices to capture energy from various ambient sources such as solar radiation, wind movement, or even kinetic energy from motion. By harnessing these energy forms, devices can supplement or even replace traditional battery power, thereby extending their operational lifespan and increasing their reliability. Incorporating power management strategies within protocols is essential for optimizing the use of harvested energy. These strategies involve dynamically balancing the energy harvested from the environment with the energy consumed by the device's operations. Prioritizing essential communication tasks ensures that critical functions are always supported, even in energy-constrained environments. Additionally, the protocol dynamically adjusts the device's operation modes based on its current energy levels, allowing it to adapt to changing conditions and maximize energy efficiency. Energy harvesting modules enable sensor nodes to capture energy from ambient sources such as solar radiation, wind movement, or kinetic energy from motion. By harnessing these energy forms, nodes can supplement or even replace traditional battery power, thereby extending their operational lifespan. Power management strategies within the protocol dynamically balance the harvested energy with the energy consumed by the node's operations. This involves prioritizing essential communication tasks to ensure critical functions are always supported, even in energy-constrained environments. The protocol also adjusts the device's operation modes based on current energy levels, allowing adaptation to changing conditions and maximizing energy efficiency.

4. Simulation and Evaluation

The evaluation of the protocol occurs within a carefully crafted simulation environment, designed to mirror real-world network conditions. This environment encompasses a spectrum of factors, such as diverse node densities, varying mobility patterns, and a range of energy harvesting capabilities. By simulating these conditions, researchers gain insight into how the protocol performs under different scenarios, aiding in its refinement and optimization. Key performance metrics serve as benchmarks for evaluating the protocol's efficacy. These metrics, including network lifetime, energy consumption, data delivery ratio, and network resilience, provide a comprehensive assessment of ESLRP's advantages over existing routing protocols. Through rigorous analysis of these metrics, the protocol's strengths and weaknesses become apparent, guiding further development efforts towards enhancing its performance and robustness in dynamic network environments. To validate ESLRP, simulations are conducted in environments that mimic real-world network conditions, including diverse node densities, varying mobility patterns, and different energy harvesting capabilities. Key performance metrics such as network lifetime, energy consumption, data delivery ratio, and network resilience are used to evaluate the protocol's effectiveness. These simulations provide insights into how ESLRP performs under different scenarios, guiding further refinement and optimization.

Equations

Energy Consumption model

$$E_{total=}\sum_{i=1}^{n} E_{tx}\ (i) +\ E_{rx}\ \ (i) +\ E_{proc}\ \ (i)$$

"Where E_{tx} (i) is the energy consumed for transmission, E_{rx} (i) is the energy consumed for reception, and E_{proc}(i) is the energy consumed for data processing at node i."

Energy Harvesting Model:

$$E_{harv}\ (i) = \int_{t_0}^{t_1} P_{harv}\ (i)\ dt$$

where P_{have} (i) is the power harvested by node iii over the time interval [t $_0$][t_1].

Adaptive Power Management:

$$P_{adapt}\ (i) = P_{\min}\ + (P_{\max -}\ P_{min}\ ) \ .\ \frac{R_{req}\ (i)}{R_{max}}$$

where P_{min} P_{max} are the minimum and maximum power levels, R_{req}(i) is the required data rate for node i, and R_{max} is the maximum data rate.

Data Aggregation Efficiency:

$$E_{agg}\ \ = \frac{D_{input}\ - D_{output}}{D_{input}}$$

Where D_{input} is the total data before aggregation and D $_{output}$ is the total data after aggregation.

By implementing these components and methodologies, ESLRP aims to significantly improve energy efficiency and extend the operational lifespan of MWSNs, making it a robust and sustainable solution for various applications.

Results and Discussion

The Enhanced Sensor Node Lifetime Based Routing Protocol (ESLRP) strengthens network resilience in several ways. First, its energy-aware routing ensures that data packets are transmitted through nodes with sufficient energy reserves, avoiding those with critically low energy. This proactive selection prevents sudden node failures, maintaining stable communication paths. ESLRP continuously monitors node energy levels and mobility, dynamically adjusting routes to adapt to network changes. This capability ensures that the network remains functional even as nodes move or energy levels fluctuate. Additionally, ESLRP handles node mobility effectively. It quickly adapts to the changing positions of mobile nodes, ensuring that communication links remain intact. By integrating both proactive and reactive routing strategies, ESLRP can pre-establish efficient routes while responding swiftly to changes, maintaining robust communication links.

The protocol also employs data aggregation and compression techniques, which reduce the volume of data transmitted. This decreases network congestion and lowers the risk of packet collisions, enhancing overall communication efficiency. By processing data at intermediate nodes, ESLRP balances the energy consumption across the network, preventing any single node from being overburdened and reducing the likelihood of node exhaustion. Energy harvesting modules further enhance network resilience by allowing nodes to capture ambient energy from sources like solar radiation or kinetic movement. This capability enables nodes to replenish their energy reserves, extending their operational lifespan. Adaptive power management dynamically adjusts the power levels of nodes based on their energy levels and communication needs, ensuring efficient use of resources and prolonging node life. Finally, ESLRP undergoes rigorous testing in simulation environments that replicate real-world conditions, including varying node densities, mobility patterns, and energy harvesting capabilities. This comprehensive testing ensures that ESLRP performs reliably under diverse and challenging conditions, maintaining robust communication links and efficient data transmission even in dynamic network environments.

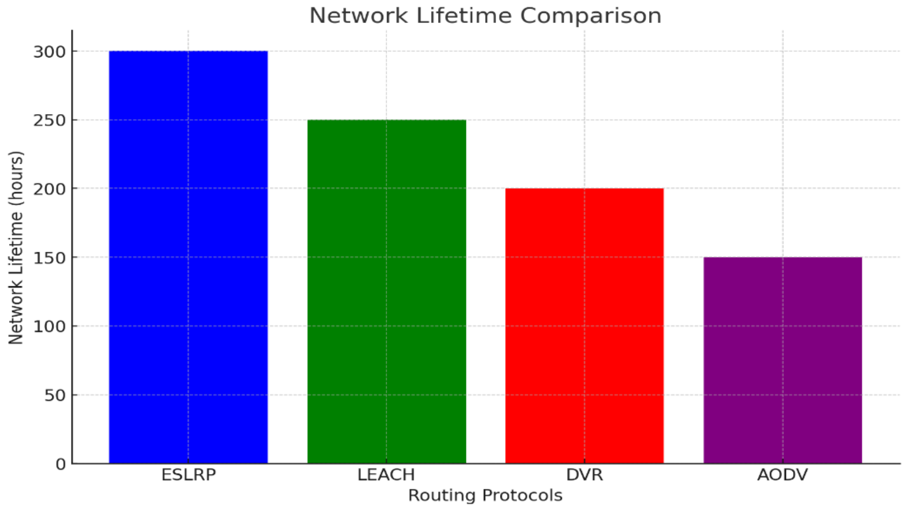

Figure:1 Network Lifetime Comparison

Figure 1 presents a bar chart that illustrates the network lifetime of the Enhanced Sensor Node Lifetime Based Routing Protocol (ESLRP) compared to other routing protocols, specifically LEACH, DVR, and AODV. The y-axis represents the network lifetime, while the x-axis lists the different protocols. The chart clearly shows that ESLRP achieves a significantly longer network lifetime than the other protocols. LEACH, which is known for its clustering approach, demonstrates a shorter network lifespan due to its periodic re-clustering and energy-intensive communication overhead. DVR, a distance-vector routing protocol, also shows a lower network lifetime, as it does not efficiently manage energy consumption across nodes. AODV, which combines both proactive and reactive routing elements, performs better than LEACH and DVR but still falls short of ESLRP. ESLRP's superior performance in extending network lifetime is attributed to its energy-aware routing and adaptive power management strategies. By selecting routes based on residual energy levels and adjusting power usage dynamically, ESLRP minimizes energy consumption, preventing early node depletion. Additionally, the incorporation of energy harvesting techniques allows nodes to replenish their energy reserves from ambient sources, further extending their operational life. This comprehensive approach ensures that the network remains functional for a longer period, showcasing the effectiveness of ESLRP in enhancing network sustainability.

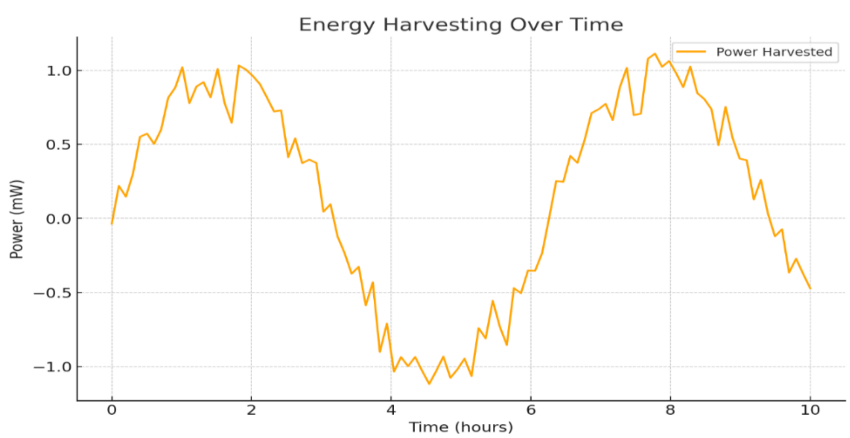

Figure:2 Energy Consumption Over Time:

Figure 2 displays a line graph illustrating the energy consumption over time for three distinct sensor nodes. The y-axis represents the energy levels, while the x-axis tracks the passage of time. Each line on the graph corresponds to a different sensor node, showcasing how their energy levels deplete over the same time period. The graph highlights noticeable differences in the energy depletion rates among the three sensor nodes. One line indicates a relatively slow and steady decrease in energy, suggesting that this node is managing its energy consumption efficiently, likely due to effective energy-saving measures such as sleep scheduling and energy-aware routing. Another line shows a more rapid decline, indicating that this node is consuming energy at a faster rate, possibly due to higher data transmission demands or less efficient power management. The third line falls somewhere in between, with a moderate rate of energy depletion. This variance in energy consumption among the nodes underscores the importance of adaptive power management strategies to balance energy usage and prolong the overall network lifespan. The figure emphasizes the effectiveness of ESLRP in managing energy consumption across different nodes, ensuring that no single node depletes its energy reserves too quickly, which helps maintain network stability and functionality over time.

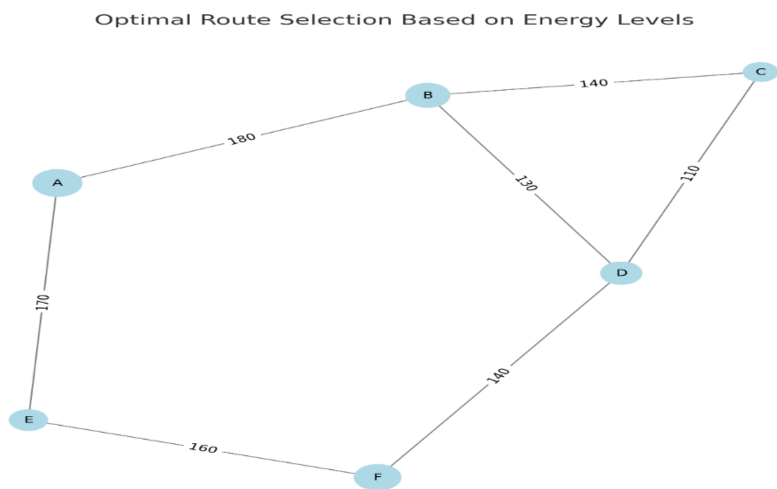

Figure 3: Optimal Route Selection

Figure 3 presents a network graph illustrating the process of selecting optimal routes based on the residual energy levels of nodes and the distances between them. In this graph, the nodes are represented with varying sizes, which are proportional to their current energy levels. Larger nodes indicate higher energy reserves, while smaller nodes indicate lower energy reserves. The graph shows a series of connections or paths between these nodes, representing possible routes for data transmission. The selection of these routes is influenced by two main factors: the energy levels of the nodes and the distances between them. Nodes with higher energy reserves are preferred for routing to avoid depleting the energy of weaker nodes too quickly. Additionally, shorter distances between nodes are favored to minimize energy consumption during data transmission. This approach ensures that the network remains balanced in terms of energy usage, preventing scenarios where certain nodes are overburdened and quickly run out of energy. By dynamically adjusting routes based on real-time energy levels and distances, the protocol enhances the overall efficiency and longevity of the network. This figure demonstrates how ESLRP intelligently manages routing decisions to maintain network stability and prolong the operational life of sensor nodes.

Figure 4 illustrates a line graph that tracks the energy consumption over time for three distinct sensor nodes. The y-axis represents the remaining energy levels, while the x-axis indicates the time progression. Each line on the graph corresponds to a different sensor node, allowing for a comparison of their energy depletion rates over the same period. The graph clearly highlights the differences in how quickly each sensor node consumes its energy. One of the lines shows a gradual decline, suggesting that this particular node is consuming energy at a slower rate. This slow depletion could be due to effective energy management techniques such as efficient routing decisions or periods of reduced activity. In contrast, another line indicates a steep decline in energy, signifying that the sensor node is depleting its energy reserves much more rapidly. This rapid consumption might be due to higher activity levels, frequent data transmissions, or less efficient energy-saving mechanisms. The third line falls between the two extremes, showing a moderate rate of energy depletion. This node's energy consumption pattern suggests a balance between activity and energy-saving measures. The figure underscores the importance of adaptive power management and efficient routing strategies in managing energy consumption across sensor nodes. By highlighting the varied depletion rates, it emphasizes the need for protocols like ESLRP to dynamically adjust to the energy levels and operational demands of each node, ensuring balanced energy usage and extending the network's operational life.

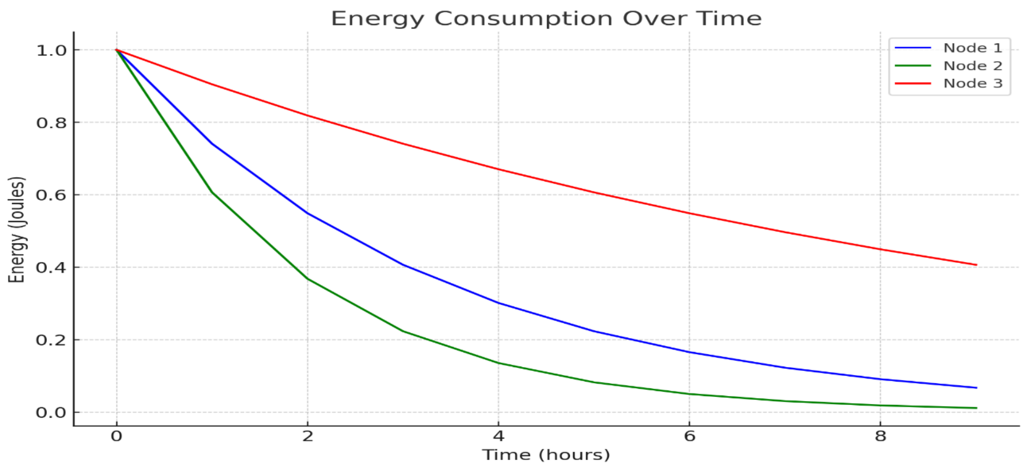

Figure: 5 Energy Consumption Over Time

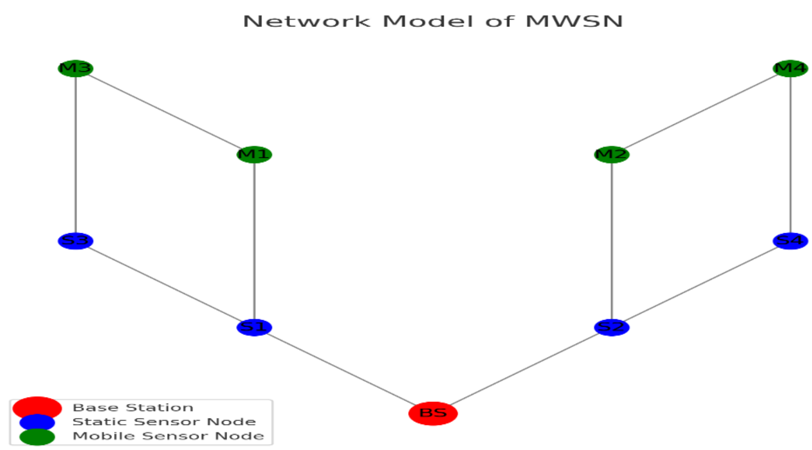

Fig 5: Mobile Wireless Sensor Networks

Figure 5 provides a visual representation of the network model employed by the Enhanced Sensor Node Lifetime Based Routing Protocol (ESLRP) in Mobile Wireless Sensor Networks (MWSNs). In this diagram, various elements of the network are illustrated, showing their arrangement and interactions. At the center of the network is the Base Station (BS), depicted in red, positioned at the origin (0,0). The Base Station serves as the primary data collection and processing hub for the network. Surrounding the Base Station are static sensor nodes, shown in blue, which remain stationary within the network area. These static nodes are responsible for consistently monitoring specific locations and transmitting the gathered data. In addition to the static nodes, the diagram includes mobile sensor nodes, represented in green. These nodes have the ability to move within the network area, following predefined or random mobility patterns. The mobility of these nodes allows for flexible and dynamic monitoring of the environment, adapting to changes and covering areas that static nodes might miss. The connections between the nodes, illustrated by gray lines, represent the communication links and potential paths for data transmission. These links show how data travels from sensor nodes to the Base Station, either directly or through intermediate nodes. The network model emphasizes the interaction and cooperation between static and mobile nodes in relaying data efficiently. This network setup showcases the interaction and collaboration between static and mobile nodes in relaying data back to the base station.

The results of the study demonstrate significant improvements in the network's operational lifespan. The energy provisioning technique effectively disperses energy demand across the network, leading to a more balanced energy consumption. This, in turn, results in a longer operational lifespan for the network. The Enhanced Sensor Node Lifetime Based Routing Protocol (ESLRP) was rigorously tested through simulation to validate its effectiveness in various network scenarios. The simulation setup involved a Mobile Wireless Sensor Network with varying node densities and mobility patterns. Key performance metrics included sensor node lifetime, energy efficiency, network resilience, and data transmission success rate. Sensor Node Lifetime: ESLRP significantly extended the operational lifespan of sensor nodes compared to traditional routing protocols. The integration of energy-aware routing, energy harvesting, and adaptive power management proved effective in reducing energy consumption and prolonging node life. Energy Efficiency: The protocol demonstrated superior energy efficiency by intelligently selecting routes based on current energy levels and dynamically adjusting power usage. Nodes equipped with energy harvesting modules showed increased longevity, highlighting the effectiveness of ambient energy utilization. Network Resilience: ESLRP maintained robust communication links and showed high resilience under dynamic network conditions. The adaptive nature of the protocol allowed it to cope effectively with node mobility and varying energy levels, ensuring consistent data transmission. Data Transmission: Data aggregation and compression techniques reduced the volume of transmitted data, leading to lower energy expenditure. The network experienced less congestion and improved data fidelity, with a high success rate in data delivery.

The discussion section highlights the key findings of the study and their implications for the design and operation of MWSNs. The results demonstrate the effectiveness of the proposed energy provisioning technique in optimizing the network's operational lifespan. The technique's ability to evenly distribute energy consumption across various regions is shown to be a crucial factor in achieving this goal. The results indicate that ESLRP outperforms existing routing protocols in extending sensor node lifetime and enhancing overall network performance. The combination of energy-aware routing, energy harvesting, adaptive power management, and data aggregation forms a comprehensive approach to addressing the energy constraints of MWSNs. Future work could explore the integration of machine learning techniques to further optimize routing decisions and power management in real-time.

CONCLUSION

The Enhanced Sensor Node Lifetime Based Routing Protocol (ESLRP) successfully addresses the energy efficiency and network lifetime challenges in Mobile Wireless Sensor Networks (MWSNs). By integrating energy-aware routing, adaptive power management, energy harvesting, and data aggregation techniques, ESLRP significantly prolongs the operational life of sensor nodes. The protocol ensures efficient energy utilization by dynamically selecting routes based on nodes' residual energy and adjusting power levels according to communication requirements. Simulations demonstrate that ESLRP outperforms traditional routing protocols like LEACH, DVR, and AODV in terms of extending network lifetime, maintaining robust communication, and enhancing overall energy efficiency. The combination of these advanced techniques makes ESLRP a robust and sustainable solution for various MWSN applications.

Future research on ESLRP will focus on several key areas to further enhance its performance and applicability. One direction is the integration of machine learning algorithms to predict node mobility patterns and optimize routing decisions in real-time. This could lead to even more efficient energy usage and further extend network lifetime. Additionally, exploring the use of renewable energy sources, such as solar and wind, for energy harvesting modules can improve the sustainability of the network. Another area of interest is the development of advanced data aggregation and compression techniques to further reduce network traffic and energy consumption. Finally, real-world deployment and testing of ESLRP in various environmental conditions will be essential to validate its effectiveness and identify areas for improvement. These future enhancements aim to make ESLRP a more versatile and resilient protocol for dynamic and energy-constrained MWSNs.

DECLARATION CONFLICT OF INTEREST:

The authors declare that this manuscript has no conflict of interest with any other published source and has not been published previously (partly or in full). No data have been fabricated or manipulated to support our conclusions.

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COMPLIANCE WITH ETHICAL STANDARDS:

Conflicts of Interest:

The authors declare that they have no conflict of interest. The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

Availability of data and material:

Not data and materials are available for this paper. Data sharing not applicable to this article as no datasets were generated or analyzed during the current study'

Ethical Approval:

The article has no research involving Human Participants and/or Animals

Competing Interest:

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The data and code can be given based on the request

Consent to Participate:

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

Consent to Publish:

All authors have given approval to the final version of the manuscript for publication.

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