

ENERGY EFFICIENT REACTIVE NEIGHBOR ROUTING PROTOCOL FOR MOBILE WIRELESS SENSOR NETWORKS

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ABSTRACT

Wireless Sensor Networks (WSNs) experience serious problems of energy behaving, moving topology and dependable information transmission, particularly with mobile environment. In this paper, it is postulated that Energy Efficient Reactive Neighbor Routing Protocol (EERNRP) will be put forward to combine on-demand routing and neighbor-knowledge decision-making to achieve optimal communication performance. The protocol employs residual energy, distance and quality of links to choose the best routing routes, and in this manner, minimize unproductive transmissions and enhance network stability. End-to-end delay, energy consumption, packet delivery ratio (PDR), and throughput are some of the metrics used to evaluate the performance of the proposed approach. The outcomes of the simulation prove that EERNRP reduces delay following the establishment of routes, evenly allocates energy, enhances reliability, and achieves throughput consistency in dynamic conditions. The proposed protocol is effective in increasing the network lifetime and communication efficiency and so it is applicable in the mobile WSN application.

1. INTRODUCTION

WSNs have become a revolutionary technology that consists of spatially distributed self-sensing or autonomous sensor nodes that are capable of sensing, processing, and wireless communication of environmental information to a central sink or base station. The broad-based applications of these networks in areas like environmental monitoring, industrial automation, health care, and military surveillance are attributed to its scalability, ability of self-organization, and ability to be deployed in remote

or dangerous conditions [1]. This is because the decentralized WSNs can form a dynamic network that lacks infrastructures and can be applied to applications where the topology shifts frequently and nodes fail. Energy efficiency is one of the main problems of the WSNs because the nodes are usually battery-powered and have a limited energy supply. Energy efficiency is necessary to increase the life of the network and provide sustainable usage in situations where it is not feasible to maintain the battery [2], [5]. Consequently, a lot of research has been done on the development of energy-conscious routing algorithms, topology control methods, and optimization techniques to cut down on the amount of energy used but keep the network performances intact [6], [7].

Routing is a very important factor of defining the overall efficiency of WSNs. There are two basic categories of traditional routing protocol, namely, proactive, and reactive protocols. Proactive (table-based) protocols keep the routing information current on all nodes thus making sure that the latency is minimum when transmitting data. They however have a high control overhead because there are periodic updates and consequently, they consume energy especially where there is dynamic network [12], [13]. Conversely, reactive (on-demand) routing protocols create routes, when necessary, thus minimizing unnecessary overhead and wastage of energy. This renders reactive protocols more appropriate in energy limited and mobile WSN systems, although the initial delay caused in route discovery [14]. Neighbor discovery is the basic element of routing in the WSNs, whereby the nodes discover the neighbors and communicate effectively to forward data. Neighbor discovery has a great impact on routing choices,

connectivity of the network and energy consumption. Several researches investigated the effective neighbor discovery algorithms, such as asynchronous protocols, probabilistic algorithms, and wake-up schedule algorithms [3], [4], [8], [10]. Analytical energy consumption, latency and network reliability have emphasized the need to optimize neighbor discovery [11].

Several neighbor discovery protocols have been developed to make WSNs more efficient and scalable in terms of energy consumption. U-Connect, HELLO, Searchlight and BlindDate protocols use various techniques like duty cycling, wake-up scheduling, probabilistic transmission etc. to minimize energy use, and to be able to detect neighbors on time [15] -[18]. Furthermore, neighbor discovery methods that are energy efficient like the talk more listen less methods are even more optimizing of the communication overhead and the network lifetime [19]. There have also been sophisticated algorithms such as ALANO that can be used to enhance the efficiency of neighbor discovery in large scale networks [9]. Despite these developments, mobility also presents further problems in WSNs because as nodes move, there are topological changes, link failures, and a high routing cost. Conventional neighbor search and routing algorithms do not quickly adjust to dynamic networking conditions. Recent research has worked on these concerns by coming up with mobility-conscious and asynchronous neighbor discovery algorithms which enhance energy efficiency and reliability in mobile sensor networks [20]. Nevertheless, the development of a good balance amongst energy use, routing and the ability to adapt in mobile WSNs is still a research problem. Recent studies have aimed at alleviating these issues by developing scalable and power-saving routing protocols that combine the aspect of neighbor-based decision-making and adaptivity [21], [22]. These solutions are meant to increase the lifetime of network, ratio of delivery of packets, and minimize communication overhead in dynamic networks.

Inspired by these issues, in this paper I present an Energy Efficient Reactive Neighbor Routing Protocol of Mobile Wireless Sensor Networks that opens the concept of on-demand routing and smart neighbor selection as a way of saving on energy use and ensuring reliable communication in mobile environment. The proposed study will overcome these

shortcomings by presenting an Energy efficient Reactive Neighbor Routing Protocol of Mobile Wireless Sensor Networks E2RNR-MWSN.

2. Literature Review

WSNs have been widely researched with the main emphasis laid on energy efficiency, network routing, and scalability. The initial studies focused on energy conscious communication protocols, with the reduction of the transmission and control overheads found to be a major consideration in increasing network life [1], [2]. Top-down and optimization-driven methods have also been suggested to optimize energy usage on a node-by-node basis and avoid early node failures and enhance network sustainability [5], [6]. Multi-objective optimization approaches have received considerable interest in the research of the WSN because of the necessity of simultaneously resolving the conflicting performance measures, which can be energy consumption, latency, reliability, and throughput. Fei et al. [2] have thoroughly surveyed the optimization techniques, such as evolutionary algorithms, metaheuristic techniques, and note their usefulness in dynamic and intricate network situations. On the same note, it has presented machine learning-based optimization models to improve the rate of convergence and the adaptability of the optimization model to facilitate efficient decision making in large-scale deployment of WSNs [6].

Neighbor discovery is a vital factor that determines the routing performance in the WSNs as it allows nodes to discover and establish communication paths with their neighbors. The neighbor discovery must be efficient to provide trustworthy routing paths and reduce the communication overhead. The article by Pozza et al. [3] gives a comprehensive overview of the neighbor discovery methods in IoT settings with a focus on the trade-offs between the discovery latency, the energy usage, and the reliability. Cohen and Kapchits [4] also examine continuous neighbor discovery mechanisms with asynchronous methods of keeping networks connected in a dynamic environment. It has created a few protocols that enhance the efficiency of neighbor discovery in energy constrained environments. Some of the early methods like the Birthday protocol [8] used

probabilistic methods of low-energy discovery with subsequent papers adding deterministic scheduling and hybridization to boost performance. Vasudevan et al. [10] analyzed neighbor discovery using probabilistic models, providing theoretical insights into discovery latency and efficiency. Zheng et al. [12] proposed optimal wake-up scheduling techniques to minimize idle listening and energy waste, which significantly improved network lifetime.

Besides theoretical models, practical neighbor discovery algorithms like U-Connect [15], HELLO [16], Searchlight [17] and BlindDate [18] have also been extensively studied. These schemes utilize different measures such as duty cycling, asynchronous wake-up scheduling, and adaptive transmission schemes to minimize the use of energy and yet guarantee timely detection of neighbors. Qiu et al. [19] also increased energy efficiency by suggesting communication strategies, which reduce the unnecessary listening operations, which decrease the total energy consumption. Recent developments have been on hybrid and adaptive neighbor discovery mechanisms. Mekala and Chatrapati suggested a combination model based on the deterministic and probabilistic model that can achieve better scalability and adaptability to dynamic environments in WSNs [7]. Their efforts indicate that there are several strategies that can be combined to achieve a substantial reduction of discovery latency and use of energy with high level of accuracy in neighbor identification. Mobility further increases the complexity in WSNs because an increasing topology and intermittent link instability is caused by the movement of nodes. Traditional routing protocols and the neighbor discovery protocols may not be able to keep up with the performance in such conditions. Chen et al. [20] coped with this issue by coming up with energy efficient methods of asynchronous discovery of neighbors with specific reference to mobile sensor networks. Their contribution sheds light on the need of mobility-conscious mechanisms to ensure reliable communication as well as minimize the routing overhead.

Simultaneously, energy-efficient routing protocols have developed to include clustering, topology

control and adaptive decision-making protocols. Chang et al. [5] presented a dynamic hierarchical scheme that optimizes the formation of clusters and routing routes with the help of combinatorial optimization methods. Their methodology proves to have a better energy balance and network lifetime as opposed to traditional protocols. Moreover, uses of scalable and hybrid routing structure have been studied recently to overcome the problem of large scale and heterogeneous WSN environments [21], [22]. Though there has been a great improvement, there are still a number of challenges that are not solved. The current protocols tend to concentrate on either of the two energy efficiency or neighbor discovery without much integration of both in one system. In addition, most of the methods had not been optimized to meet mobile WSN needs under dynamic topology where reactive and adaptive routing strategies are needed. The restrictions indicate the necessity of a holistic solution encompassing energy efficient routing as well as smart decision making based on neighbors in mobile setups.

3. System Model and Methodology

The paper is a proposal of an Energy Efficient Reactive Neighbor Routing Protocol (EERNRP) which is to be used in mobile wireless sensor networks (WSNs). The protocol combines both reactive routing and neighbor-aware decision-making to reduce environmental energy usage and enhance the performance of the network in dynamic environments. In the proposed work, a Mobile Wireless Sensor Network (MWSN) is assumed, which is a group of sensor nodes $N = \{n_1, n_2, \dots, n_k\}$ randomly distributed within two-dimensional sensing space. Every node is provided with a sensing, processing, and wireless communication. The sensor nodes are all regarded as homogeneous with regard to both initial energy and hardware setup. The nodes however are mobile which results in the dynamism of the network topology. Every node knows the amount of residual energy and can determine the distance of its neighboring nodes based on Received Signal Strength Indicator (RSSI) or localization. The interconnection of the nodes is deemed to be two-way and a fixed sink node is put either inside or outside the sensing field

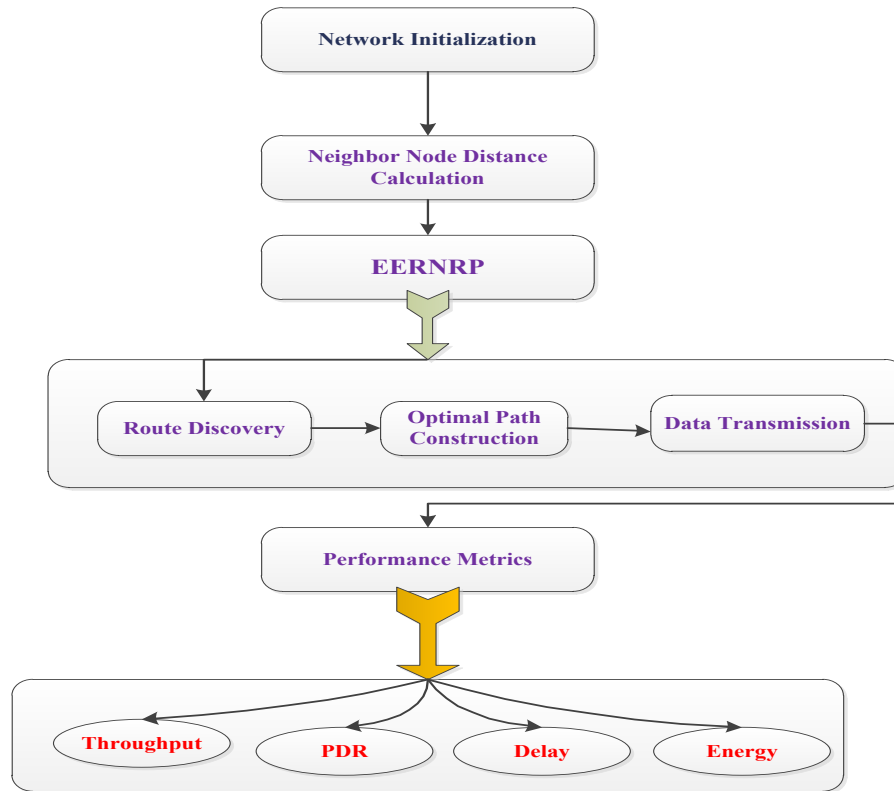


Fig.1. Flowchart of proposed methodology

3.1 Proposed Methodology

The general process includes the following steps: Network Initialization, Neighbor Discovery and Distance Estimation, Reactive Route Discovery, Optimal Path Construction, Data Transmission, Performance Evaluation. The flowchart of proposed methodology is described in the figure 1. In a bid to solve the issues of energy efficiency and mobility in WSNs, the energy Efficient Reactive Neighbor Routing Protocol (EERNRP) is proposed in this paper. The protocol proposed has incorporated reactive routing principles with the neighbor awareness-based decision-making to ensure efficient and reliable communication. The first step involves the deployment of sensor nodes randomly during the network setup phase with an initial value of energy. Periodically, each node transmits HELLO messages in order to determine other nodes in its range of communication. Depending on the signal received or positioning data, nodes approximate the distance to their neighbors and add them to a neighbor table with the necessary data including residual energy and link quality.

A reactive route discovery process is initiated when a source node wants to send information and this is using a Route Request (RREQ) message that is broadcasted. In contrast to the conventional flooding algorithms, the suggested protocol is energy-conscious since it is limited to forward the RREQ to the intermediate nodes having adequate residual energy. This forwarding selectivity is used to minimize redundant transmissions and to save energy. After the RREQ has been received by the destination node, a Route Reply (RREP) is created and sent back to the source node over the path that has been discovered. To enhance the working of the reactive routing protocol, efforts are directed in optimization of the path choice between the source and the destination node with reference to various parameters like the shortest path, remnant energy of the nodes and the stability of the nodes. These various aspects assist in choosing the paths that not only reduce the delay but equally spread the energy usage throughout the system and extend the routes length, thus decreasing the common route re-discoveries. Using energy availability, the protocol intends to prevent excessive utilization of those nodes

that have low battery levels, and node stability metrics will be used to select those paths that are less likely to be broken because of mobility.

The route exploration stage of the existing reactive protocols such as AODV or DSR is adjusted to take these new measures. The protocol does not only concentrate on the minimum number of hops in the route, but adds information on energy and stability to the route request (RREQ) and a route reply (RREP) message. This allows nodes to create several attributes of routes before creating a route hence enhancing the overall routing performance and consistency. The route discovery process is tailored in the NS2 TCL scripts to have it if any node starts transmitting data; the node activates the enhanced

discovery process which values the newly added metrics as the most important ones. Also, the routing agents in NS2, especially in agents applying a protocol such as AODV are modified to accommodate the new selection criteria of the path. This will include the extension of the agent code to accommodate more parameters with regard to node energy and stability in route selection and maintenance. The routing agents can be customized so that the data packets can use the best and the most reliable paths thus limiting the amount of packet loss, delay and excessive use of energy. The protocol improvements make up a stronger and energy efficient communication system applicable in dynamic and resource limited wireless sensor networks.

Algorithm of proposed EERNRP

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Input: Sensor nodes N
Output: Energy-efficient route
1. Initialize network and assign energy to all nodes
2. Each node broadcasts HELLO to discover neighbors
3. Construct neighbor table (Distance, Energy, Link Quality)
4. If source S has data:
   Broadcast RREQ
5. Intermediate node i:
   If residual energy > threshold:
     Forward RREQ
   Else:
     Drop
6. Destination D:
   Send RREP to source
7. Source S:
   Compute route cost:
   Cost =  $\alpha \cdot \text{Distance} + \beta \cdot (1/\text{Energy}) + \gamma \cdot \text{LinkQuality}$ 
8. Select minimum cost path
9. Transmit data
10. If link failure:
    Re-initiate route discovery
End
    
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When the source receives several replies on the routes, it chooses the paths based on a multi-criteria cost function that considers distance and residual energy and link quality. The cost function can be given as:

$$\text{Cost} = \alpha \cdot d + \beta \cdot \frac{1}{E} + \gamma \cdot$$

LQ $\alpha, \beta, \gamma \in [0,1]$

where dis the path distance or the path length, E is the energy remaining of the nodes in the path, and LQ refers to the quality of links. The factors of weighting α , β , and γ are applied to balance the impact of these parameters. The least cost route is chosen as the best route of transmitting the data. At

the stage of data transmission, packets are transmitted with the help of the chosen route, and their energy reserves and connection status are constantly observed by the nodes. When a node moves, or the energy in a node is depleted, thereby causing a link failure, the protocol triggers a local route repair process or a new route discovery process to ensure a continuous flow of communication. This dynamic network adaptation behavior provides robustness in dynamic network environments. The proposed EERNRP protocol can adequately optimize network lifetime, increase reliability, and minimize communication overhead in mobile wireless sensor networks by combining energy awareness and

reactive neighbor-based routing. The table 1 illustrates the comparison of existing and proposed Table 1. Comparison of existing and proposed model

model in different aspects.

Aspect	Existing Model (Fedab)	Proposed Model (E2RNR-MWSN)
Communication Approach	Uses proactive neighbor discovery with continuous beacon broadcasting, even when not needed	Uses reactive neighbor routing; communication occurs only when required, reducing unnecessary transmissions
Energy Efficiency	Higher energy consumption due to continuous beacon transmissions and no interference awareness	More energy-efficient by minimizing redundant transmissions and dynamically optimizing routing paths
Interference Handling	Does not consider beacon collisions or interference, leading to possible packet loss and degraded performance	Accounts for interference and network conditions, improving reliability and reducing data loss
Network Performance Metrics	Focuses mainly on neighbor discovery latency and theoretical analysis; limited QoS evaluation	Provides better QoS with higher throughput, improved Packet Delivery Ratio (PDR), and reduced end-to-end delay
Adaptability to Mobility	Supports mobility but incurs high overhead due to frequent topology changes and repeated neighbor discovery	Better adaptability with dynamic routing decisions, reducing overhead caused by node movement

4. Performance Evaluation

4.1 Network Topology

The simulation within the NS2 processes the performance of the proposed Energy Efficient Reactive Neighbor Routing Protocol (E2RNR-MWSN), which is the wireless sensor network environment. This is in terms of the definition of important parameters like the total number of sensor nodes deployed, mobility pattern, the range of transmission, and the dimensions of the entire simulation area. An example is that sensors are placed randomly in the given simulation area that is rectangular to replicate a realistic deployment

scenario of predetermined number of sensor nodes. Transmission range is wisely chosen considering the hardware capabilities of standard sensor nodes so that to guarantee reliable communication considering the energy availability. In addition, there is the introduction of node mobility patterns which emulate real world dynamics in which the movement of nodes can vary at random or can follow a particular direction hence capturing the behaviour of mobile wireless sensor networks (MWSNs). These settings determine the underlying network conditions that can be used to test the routing protocol in different conditions of node density, mobility, and the scale of the network.

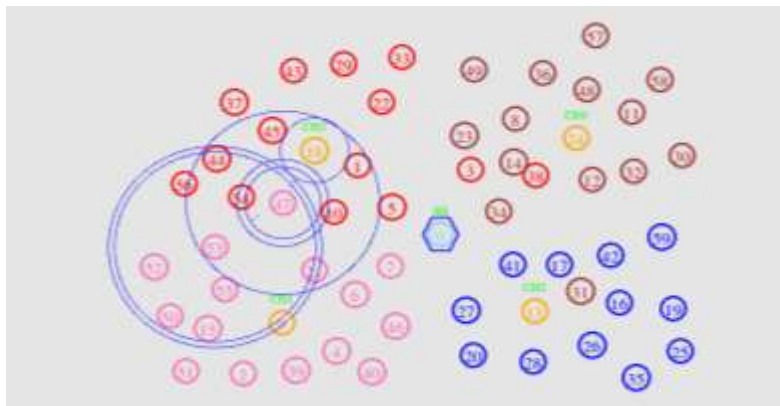


Fig.2. Node deployment in the simulator

4.2 Network Performance

The key network metrics used to fully assess the performance of the proposed Energy Efficient Reactive Neighbor Routing Protocol (E2RNR-MWSN) include throughput, Packet Delivery Ratio (PDR), end-to-end delay, and energy efficiency, which is continuously monitored when carrying out the NS2 simulations. The rate at which data is delivered successfully across the network can be measured by throughput, whereas the ratio of the number of packets successfully received to the number of packets sent can show the reliability of

communication, and this is called PDR. End to end delay evaluates the amount of time it takes to transmit data packets between the source and the destination giving information on latency. Energy efficiency monitors the efficiency that the network uses during its operation. By tracking these metrics, one can obtain a clear picture of the performance of the protocol in different network conditions and in different mobility of the nodes. The nodes deployment in the simulator area is depicted in figure. 2

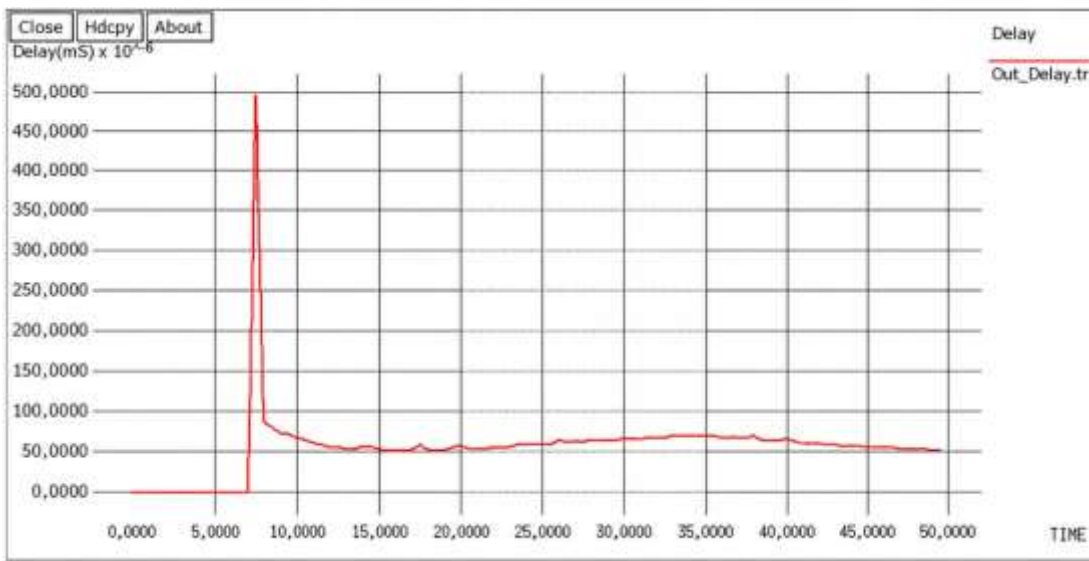


Fig.3. End-to-End Delay Analysis

Fig. 3 shows the dependence of end-to-end delay on the simulation time. At the beginning of the simulation, there is a sharp rise in delay which is mainly caused by the route discovery process and overhead in network set up. After the routes are selected, the delay is substantially lowered and balanced after a long period. Delay is fairly small and constant after 10 seconds which means that the proposed EERNRP protocol can be used to keep the communication routes stable. Small oscillations that can be observed at the later stages can be explained by mobility of nodes and infrequent rediscovery of paths. All in all, the protocol has lower latency when there is an initial convergence and it thus can be used in dynamic WSN environments.

Fig. 4 displays the energy consumption trend of the network with time. Energy will reduce slowly with progression of communication, and it is natural because there is a constant transmission and reception of data. The energy depletion is however smooth and regulated and there are no sudden decreases which implies that there is a balanced use of energy throughout the nodes. The fact that there is a small fluctuation around the mid-simulation period indicates that there is a momentary adjustment of the routes because of mobility. The energy level is not low enough to stop the process and it shows that the given protocol is effective in saving the energy and extending the network life.

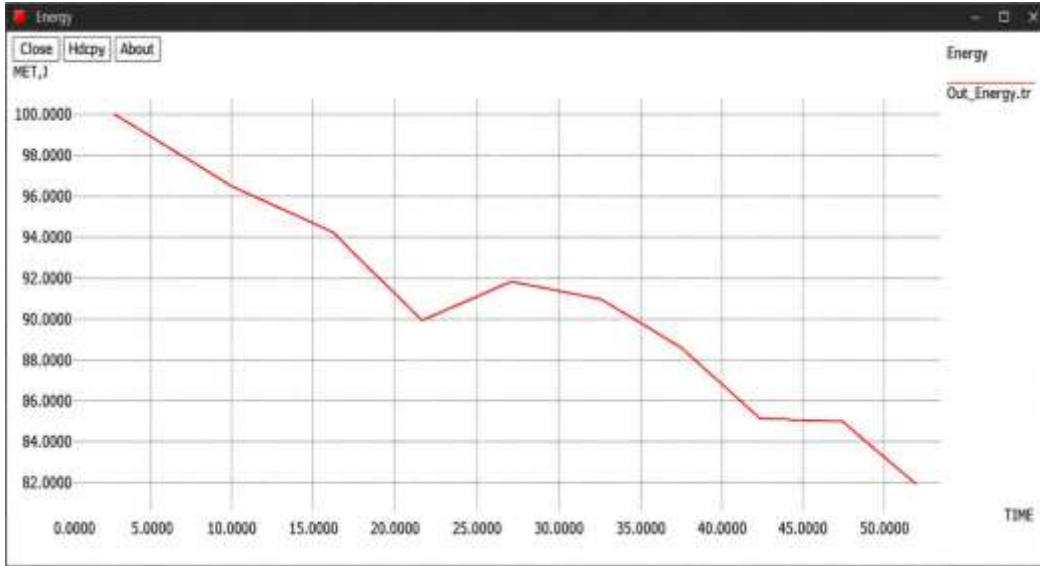


Fig.4. Energy Consumption Analysis

Fig. 5 shows the performance of the Packet Delivery Ratio (PDR). To start with, the PDR is low because there is delay in routes establishment and packet loss in the network establishment stage. The PDR continuously increases as the simulation runs reaching a high level at the conclusion of the simulation. This slow increase shows that the EERNRP protocol effectively provides stable communication paths and can adjust to topology changes. The growth in trend of PDR indicates better reliability and strong performance even where there are node mobility conditions and dynamic conditions of links.

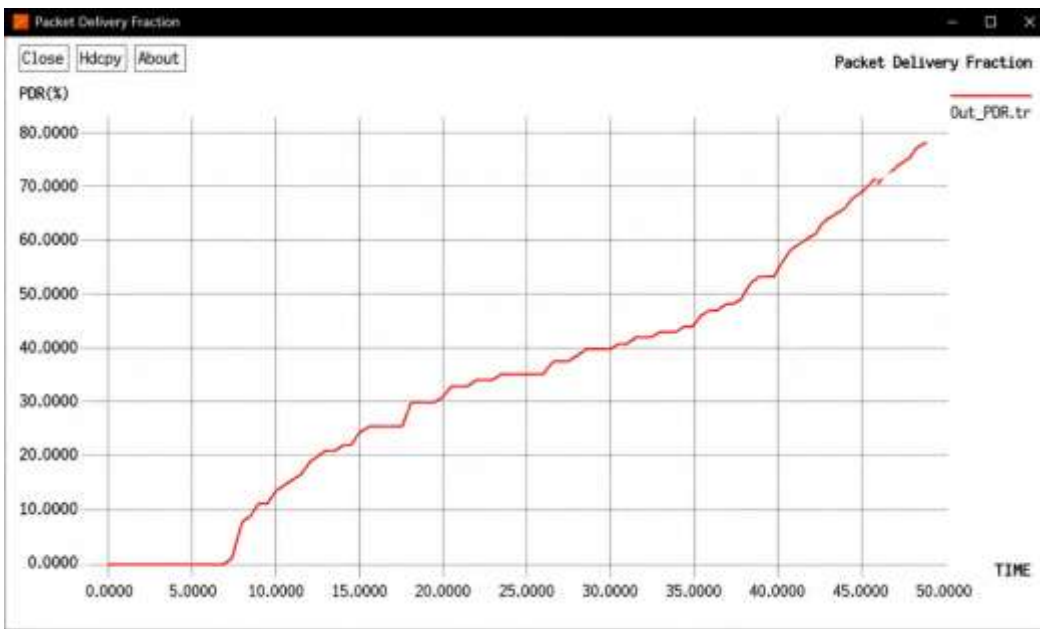


Fig. 5. Packet Delivery Ratio (PDR) Analysis

Fig. 6 provides the throughput performance of the network. During the initial stage of the simulation, there is a low throughput as there are no routes in place. After route discovery, throughput takes an upward trend with clear peaks that are associated with the transmission of successful packets. The stability of the overall throughput is achieved in the later stages though there are variations caused by mobility and variation in the network conditions. The protocol ensures a steady data transmission speed, which means an efficient use of bandwidth and a high level of data delivery.

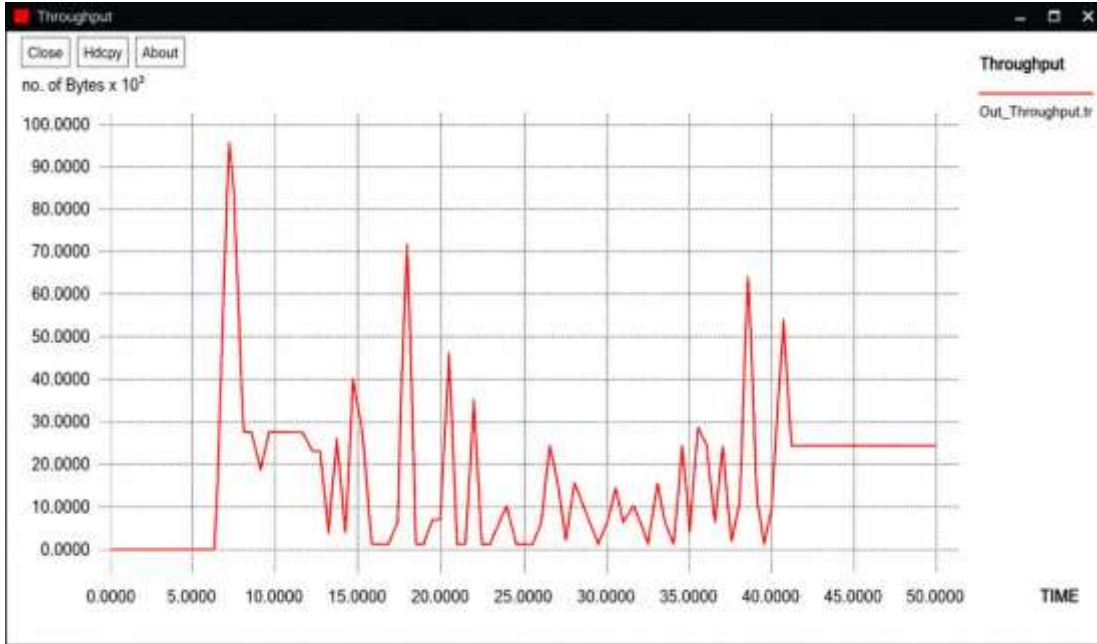


Fig 6. Throughput Analysis

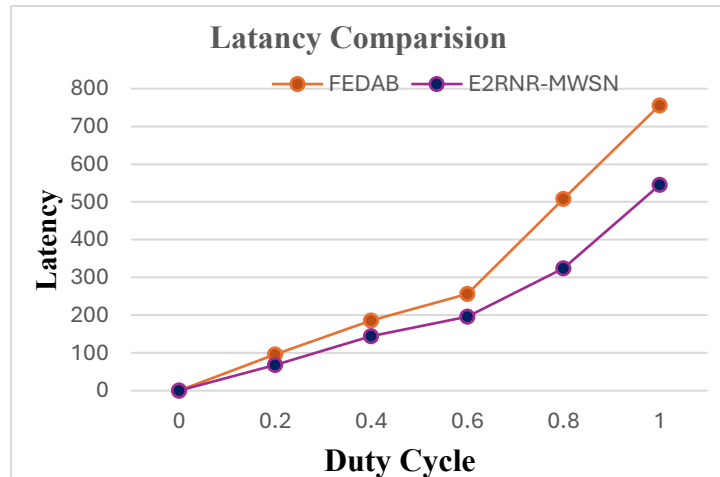


Fig. 7 Latency Comparison

The figure 7 shows a comparison graph titled “Latency Comparison,” illustrating how latency varies with duty cycles for two protocols: FEDAB and E2RNR-MWSN. The x-axis represents duty cycles ranging from 0 to 1, while the y-axis indicates latency values. From the plotted data and accompanying table, both methods exhibit increasing latency as duty cycles rise; however, FEDAB consistently produces higher latency than E2RNR-MWSN across all points. For example, at a duty cycle of 1, FEDAB reaches approximately 756 units of latency, whereas E2RNR-MWSN is lower at around 545. The gap between the two curves widens as duty cycles increase, highlighting that E2RNR-MWSN

performs more efficiently in terms of latency, especially at higher duty cycles.

Based on the above analysis it can be concluded that the proposed EERNRP protocol provides an excellent trade-off between the energy efficiency, reliability, and latency. Reactive routing that is combined with neighbor-aware decision-making makes possible:

- Reduced control overhead
- The effective use of energy.
- Better performance in terms of the packet delivery.
- Constant throughput in dynamic conditions.

The findings validate that EERNRP is an effective technique in mobile wireless sensor networks, which guarantee long network life and dependable communication.

5. CONCLUSION

To handle the problem of energy limitations and changing topology in mobile wireless sensor networks, this paper suggested an Energy Efficient Reactive Neighbor Routing Protocol (EERNRP). The protocol gives efficient and reliable communication by combining reactive routing with distance-based neighbor-aware path selection and link quality. The outcomes of the simulation show that EERNRP minimizes delay following route establishment, has constant energy consumption, higher packet delivery ratio, and constant throughput in a mobility environment. The above results identified that proposed methodology will improve network life and performance. Future work will focus on incorporating intelligent routing mechanisms and security features to further improve adaptability and robustness in real-world deployments.

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