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Enhanced Energy Efficient Routing Protocol (EEE-RP) to forward the Data Packets and to improve QoS in Wireless Sensor Networks by Means of Machine Learning Methods

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Abstract

Objectives: To propose an energy-efficient routing protocol for forwarding Data Packets for effective transmission of captured data using Machine Learning Methods in order to enhance WSN service efficiency. **Methods:** This study proposes a new routing mechanism Enhanced Energy Efficient Routing Protocol (EEE-RP) to extend the network life by reducing end-to-end delays by forwarding data packets to their destinations in the most efficient and optimal way possible using the best path. To forward data packets in a dynamic and noise-free manner, machine learning approaches such as reinforcement learning, random walk data collection, and Markov decision process framework methods are used. **Findings:** To demonstrate the efficiency of the proposed EEE-RP protocol, the NS2 Version 35 simulator is used. The simulation results are compared to the baseline EH-WSN and ECO-LEACH protocols in terms of data arrival rate, packet drop ratio, packet delivery ratio, energy consumption, network traffic, delay and network lifetime to show the superior performance in forwarding the data packets in an efficient manner. **Novelty:** According to the results of the comprehensive study, EEE-RP performs better at detecting network failures, selecting the most appropriate route to forward data packets, minimizing energy consumption, minimizing delay time, and enhancing the network lifetime.

Keywords: Energy Efficient Protocol; Sensor Networks; Machine Learning; Packets; Routing

1 Introduction

At present, enormous research is being conducted in this field to improve service quality where efficient communication protocols are necessary. There are many challenges to the built-in properties at sensor nodes while interacting with communication protocols, such as energy consumption. In order to increase efficiency such as delay, output and overhead control, WSN's protocols would rely mainly on reducing energy consumption. Multi-hop connectivity is discussed in nodes contributing to minimum energy consumption, which is easier than single-hop data communication. Due to the high degree of functionality, WSN expands its domain to many real-world implementations. Nodes in WSN do not have the power supply connectivity, but they depend entirely on built-in batteries. For these applications, energy use is considered to be a very important task. WSN aims at decreasing the energy usage while other network types concentrate on optimizing efficiency measurement outcomes such as output, overhead and latency. WSN deployment is seen as another consideration in the advancement of WSN protocols, which never predetermines node positioning. Here, the hierarchical protocols rely on the clustering of nodes, which forms a hierarchy. This method of routing is a viable approach to minimize energy consumption when redundant data are minimized. This routing protocol can also efficiently manage load between the sensor nodes by allocating separate tasks for each sensor node according to its capabilities. To increase the life span of network IWDARP is proposed and it is analyzed that the protocol fails in forwarding packets in large environment[1]. An improved EERP is proposed and it is found that due to the real time originate the enhancement of network lifetime becomes toughest task. In other hand SAM techniques and largest sensing are utilized to identify the energy efficient protocols. Swarm intelligence and genetic algorithms also utilized to detect link failure and to enhance lifespan but due to link relocating the dynamic failure arises[2–4]. Follow-up research has been done to explore protocol and network, revealing that sensing connectivity absorbs more resources and that forwarding packets and delivery to other nodes accounts for close to 80 percent of their overall power usage[5]. Various routing protocols are projected for active and efficient routing in the large network environment, data fusion technique also used to enhance the node survival[6]. EH-WSN and ECO-LEACH are being proposed for best energy storage and for the effective transfer of data packets, but the network is not able to accept packets sent by sink due to low latency and end-to-end latency[7]. It also suggested for sending the parent node packets to the point in which the parent is located where all packets are sent, but the variable metric architecture has become a concern in the parent node's recognition by other search space nodes. The transmission relation efficiency is also assessed by using the anticipated data transmission count, which indicates the lack of connection between the two arms for transmission[8]. Energy Efficient using machine learning techniques are proposed[9] and executed. Harmony based energy efficient routing is framed to extend the network lifetime, but due to throughput failure the protocol fails to detect the link and find the ideal route[10]. Multi-Hop graph Packet forwarding is proposed for energy efficient routing[11]. Numerous routing techniques have been identified to maximize the energy efficiency and packet forwarding process of WSNs, covering almost all layers of protocols ranging from the bottom to top in WSN[12,13]. Opportunistic energy efficient is proposed for dynamic routing and it is found that the data forwarding gets fails in large range of network[14]. Connection failure happens in OPRTM protocol due to overload[15]. In order to maximize the network lifetime, TRPSN[16] proposed for WSN to take care of immediate routing optimization problems. It operates by measuring the static routes available and picking them by testing the time available. The findings reveal that it takes more time for the protocol to send the packet to the destination, where it implicitly means that the network lifespan is shortened. For WSN, Efficient Sensor Routing[17] was proposed to preserve routing in a network that changes topology. Routing reliability was lost with the use of blind routing. Blind forwarding infrastructure has contributed to floods, network congestion, and reduced network life. The protocol was suggested to improve energy efficiency underwater routing[18] to enhance QoS by cluster-based, multi-path, effective routing in wireless captors, but due to dynamic connecting failure, it does not provide further transmission of packet in a large range. IEERP[19] is designed to find the best way to optimally transmit the packets efficiently. The node spent more time selecting the finest path which contributes to increased energy usage and fails to work properly due to the need for more routes. In order to identify the dynamic connection failure and locate the alternative path from source to destination, RVSRP[20] was suggested. To prolong WSNs utilization hierarchical routing[21] is followed based on fog computing, but due to new cluster identification the protocol fails to forward data efficiently. DRL based sleep scheduling[22] is introduced to enhance lifetime, since genetic algorithms are utilized, the sensor performance is not up to the mark for data forwarding process. Multi sensor node technique[23] is proposed for larger WSN performance and it fails to cover in unattended area for sensing original datas.

The protocols shall comply with the following criteria for periodic operations by the node in the search space or networks.

- **Dynamic Packet Forwarding:** Forwarding datas to BS or parent node without any noise to minimize the packet drop ratio.
- **Efficient Routing:** Dynamic ideal routing is necessary to preserve energy and maximize the lifespan and efficient data forwarding to next layer.
- **Minimization of End to End Delay:** Minimizing latency is indispensable for successful packet delivery and to enhance the lifetime of the network.
- **Dynamic Route Reconstruction:** The protocols should have the capability of route renovation based on the data capture and it should have its own stability to connect and disconnect.

Different protocols are established to address the EH-WSN and ECO-LEACH problems. However, all protocol metrics are focused on node counts and throughputs, rather than concentrated on discovering the best way to reduce the routing time end to end in the dispersed WSN quest region. The goal of this work is to create a novel energy efficient data forwarding routing protocol to i) minimize the end to end latency time (ii) efficient data forwarding from source to destination (iii) minimize the energy consumption, packet drop ratio and maximize the network life. The protocol detects the dynamic link failure occurs during the data transmission and finds the ideal path to forward the data packets from one end to another end in the network search space.

2 Proposed Methodology

The effective data forwarding and transmission model is introduced via EEE-RP. In the baseline protocols it is clearly noted that there is no success rate in delivering the data packets by identifying the CHs and BS accurately. Lot of duplicates and noisy datas are found. Here, In comparison with other sensor nodes, data traffic received by the sink in WSN reduces the energies of neighboring sensor Nodes. This is called a hot point problem in the network of wireless sensors. To overcome this issue, Flooding and Gossiping technique is used in the proposed EEE-RP to communicate between the nodes and to broadcast the messages. In this technique, any sensor continuously transmits data packets to its neighbors in the process of flooding before it receives data packets or the maximum number of hops for the packet. Gossiping, on the other hand, is a slightly improved flood variant in which the node sends the packet out to a randomly chosen neighbor. This neighbor would select another random neighbor to give the data to, etc. During the signal processing between the nodes, CHs and BS compressive sensing is utilized.

Assume that n is node and ni is next node and in the same sequence the set of neighbor node in CHs are selected and the probability $P\ (nni)$ is calculated. A simple random walk at a time step t is calculated. In the time t the node communication and data transmission delay is calculated based on the distance$d$. Thus the probability is calculated and given in the below equation,

$$P\,(nni) = P_0 + \sum_{n=1}^{n} \left(d = n - \frac{P}{distance} \right), max(n \ and \ Pni) \tag{1}$$

Each sensor transmits data only when it has the ability to affect the main module's decision in this energy efficient data transmission technique. Vertical predicates define integer ranges beyond which the network's state can remain unchanged. As a result, if the current sensor reading falls beyond this range, data could not be submitted. In this case, the control module should recognize that if a sensor fails to relay data, its readings have not changed dramatically, and it is possible to use the previously determined probability value. Load balancing technique is followed here when there is huge number of data packets transmission flows from node to node and the energy level is optimized for effective delivery of data. In this case to reduce the load of SN, the load is distributed among the neighboring nodes and makes the decision about the state of SN and calculates the energy level of each node during and after transmission. To calculate the distance between the source nodes and sink nodes Dxi and Dyj are termed as source and destination distance in the search space.

$$D_{ij}^{W}\,(t) = \ \alpha \ \cdot \ Dxi \ (t) + \ (1-\alpha) \cdot \ D_{ij}^{W}\,(t-1) \ and \ SN \ distance = \ Dyj \tag{2}$$

where t, w represents the computational time and average transmission speed in the search space is shown in the above equation.

$$max^{n+1} = distance^{h} / min \left(NodeCount^{fx} * c^{di} \left(o^{dist(npr)*h+\frac{1}{F}} : M\,(0,1) \right) - 1 \right) \tag{3}$$

where the minimum path is calculated in the search space for better data packets transmission using the cluster identification near to the Base Station. Here the Number of node connections is the grade of the node. It refers to the number of node children$n+1 \ and \ n+n$, which represents the node parent, in single path networks. The nodes that connect directly to the node to access the BS are known as the node's children. A simple scenario is assumed to explain the problem of premature network lifetime end in the case of far BS, and the energy level at which the network lifetime ends is calculated in rounds. It works to reconnect every topology of a single multi-hop path network to the one setup stage that occurs at the start of the network.

The distance between the source and destination is calculated with the help of the below equation,

$$Source^{ni+s} = (\pi D^{x} + 1) \frac{DJ}{DY} N^{n+1} D^{h+1} = \left(1 + D^{n+1} + D^{\pi}\right) Destiny^{h} \tag{4}$$

If a sensor node detects useful data, it processes it into a packet. And the route forwarding is saved in memory and the packet contributes the residual energy. The sensor node then transmits the packet in line with the forwarding route to the next hop.

When the sink node has received the packet, the packet is processed and the data detected from the surrounding area sent to the observer via the internet or GPRS. The sink node sends the packet that contains every node forwarding path in one hop to each sensor node at regular intervals. The sink node will not send any packet to a node if the new transmission path of anode determined by the sink node is the same as the one stored in the node.

Various steps involved in EEE-RP protocol for effective data forwarding process includes,

- Calculating the distance between CHs and Sink node
- Clustering using reinforcement learning
- Identifying the node failure and solving using minimal residual energy technique
- Collection of data using Random Walk method
- Ideal Route Selection using Markov framework method
- Data transmission between the nodes in WSN

In the data forwarding process, EEE-RP protocol used hierarchical search method to find the ideal route to transmit the data packets from node to destination. Randomly the neighbor node is also selected for efficient data forwarding with ideal route using harmony search algorithm. The decision-making is done using adaptive HAS algorithm to find the data transmitted rate from node to node and selects the best node to transmit the data.

2.1 Calculating the distance between CHs and Sink Node

At the beginning, the sink node sets the same transmission power with sensor nodes and transmits to sensor nodes a packet with a number of hops initialized at 0. When nodes are received, record the least bumps into the node and ignore the packet that includes larger hops into the node. Then they let the hops plus 1 value and stream the packet to the next nodes. All nodes can thus get their lowest hopes to sink node. Here the travel distance is calculated between the sink and CHs by using the finite distance calculus method. The main aim of the proposed algorithm is to pick CHs from the usual sensor nodes, taking energy efficiency into account, in order to extend the network's lifetime. We consider the residual energy of the sensor nodes and the various distance parameters including the average intra cluster distance between the sensor nodes and their distance from the sink in order to pick CH effectively with energy efficiency.

$$cluster\,(x) = Di_0 + \sum_{n=1}^{\infty} \left(DN = \; a_n node \frac{n\pi x}{Nodecount} + b_n sink \frac{n\pi x}{n-1} \right) \tag{5}$$

where, CH is cluster head, N is the node and b is balance count of nodes and distance calculated and DN is the final distance of nod in search space.

2.2 Clustering using Reinforcement Learning Method

Here the clusters will be acting as learning mediator and once the nearest node is found the reinforcement model for clustering is decoded to calculate the finest route. After the closest CHs are found, CHs need to be selected to transmit data to the parent node. The path selection is made by collecting detailed information from the chosen clusters about the distance value, the amount of energy available and the time, etc. The requirements for the path mug identification are also included. When the data has been collected for better route selection for the transmission of data by a CH, a sink node is used to obtain ready state packets. Consider S1, S2 and S3 as separate number data for the target node from the nearest CHs parent node, and S as routes for N to the target node. The ratio between the CHs and BS are calculated based on data transmission rate. Also the intra cluster and node distance is calculated.

2.3 Identifying the node failure and solving using MRET

To identify the next hop node in the search space, the Minimum Residual Energy Technique is used. This method's cost parameter is inversely proportional to the change in the selection of the node and the selection of CH. Although the target is proportional to the congestion rate of the neighbors, the routing path and energy required for a packet is linearly proportional. The achievement of the destination also affects the difference between the current nodes of sending packets more than the other metrics.

The MRET approach is used using the following equation, which is the following:

$$Max^i = 1 - (1 - (s_l))\, N^{xdi\ stances}(nj)/MS^{no\ de} x \frac{R^{\text{closest} \ast h-1}}{\text{Total Distance}} W\, X^{ij} \tag{6}$$

where the term R denotes the range of the node and the closest distance is calculated to forward the packets to the CHs parent node is shown in equation 4.

2.4 Collection of data using RWMT

Identify and remove non-functional nodes from routing systems with algorithms that allow data to be compressed locally at cluster heads using techniques of dimensional reductions to extract the similarity and dissimilarity in different sensor readings. Selecting the suitable cluster head to maximize energy efficiency and increase the lifespan of WSNs using the proper function ranking and selection of the machine learning approach. Random Walk Method is used to detect the link failure in search space in wireless sensor networks. During the data collection, to prevent anomalous and suspicious data transmission by detecting outliers, saves energy from WSN nodes, and extends WSN lifetimes considerably ML algorithms are utilized. Elimination of incorrect and malicious readings and avoid the discovery, to enhance WSN reliability, of unintended information affecting critical actions. Malicious threats and bugs protection, automatic online learning and malicious attack and vulnerability prevention.

$$(CH)^i = \sum_{i=0}^{p-i\,(closestnode)} (BS)\, n^k l^{n-1} + BS\; NodeDistance \tag{7}$$

The route is chosen and the protocol delivers the message ready to ensure that the packets are prepared from the source. The message is then sent. However, the MPR would not consider remaining resources for the transmission phase to meet the energy usage of the whole network.

2.5 Ideal Route selection using Markov framework

The probability of transmission from one node to other node (or) CHs to BS is found using Markov process model. The transition matrix is calculated. As nodes are well aware of their search space and role, every node has the capacity to use diverse frequencies to forward packets and receive packets, and it is imagined that the node has a transceiver on a bi-channel. Each node can transfer data packets over a longer path. In this case, the new approach was to forward the packets to the destination where the nodes have various parameters such as size, energy level and time from the CH node. To make detailed and quick predictions of identifying the shortest path, this model is utilized.

Finding the hidden states, Markov states, computation of probability is done using the matrix calculation. This matrix is called stochastic matrix and it is defined the transition probability between the source and destination. P denotes the probability function is calculated with the help of below equation,

$$P = XT\frac{N^{ie} - N^{th}}{N^{trans}} N^{max(i\ and\ j)} \sum_{i=0}^{distancemax} (P)\, node^{closestCHs} \tag{8}$$

2.6 Data transmission between the nodes in WSN

Once the process is completed and the ideal route is identified, the noisy datas are removed as discussed in the Markov framework, all the original data is passed through the shortest path nodes to the destination and here the EEE-RP forwarding process is successfully implemented. The data packets will reach the destiny without any error the duplicates are removed automatically by DMSF technique. The performance metrics of EEE-RP is shown below towards the process evaluation of the proposed method.

3 Performance Metrics

The following metrics are used in this analysis to compare the performance of the proposed protocol EEE-RP to the baseline protocols EH-WSN and ECO-LEACH, which were chosen as the baseline protocols in the previous chapter.

- **Packet Drop Ratio** — The drop ratio of data packets during data transmission is measured.
- **Packet Delivery Ratio** — Calculates the efficient transmission of packets from the source to destination.
- **Energy Consumption** — Conservation of energy by node.
- **Network Traffic** — Measures the Traffic during the data packet forwarding in WSN.
- **Delay —** Latency time consumption by the protocol to deliver the packets from source to destination.
- **Data Arrival Rate** — Measures the accurate time of data arrival from source to destination during the process of forwarding.
- **Network lifetime** — Calculates the lifetime of the network performance for transmission.

3.1 Simulation and Experimental Settings

The efficiency of the EEE-RP was evaluated using the NS2 network simulator in this section. There is currently no suitable and trusted simulator for evaluating protocols in a large environment. EEE-RP is compared against the baseline protocols EH-WSN and ECO-LEACH. The TCL language is preferred for use in the NS2 simulator in this research study. Table 1 shows the simulation setting used for evaluating the proposed EEE-RP protocol.

Table 1. Simulation & Experimental Settings in NS2 Simulator

Parameters	Values
Number of Nodes	500 - 2750
Time period	125 ms
Rate of Data packets	0.5 packets
Initial Transmission Range of Deployed Nodes	80m
Type of Traffic	Wireless
Initial Energy of Each Node	25 J
Sensing Range	12 m
Threshold Distance	80 m
Mobility Model	Random Way Point
Simulation Time	5500 s
Data Payload	2250 bit

4 Results and Discussions

4.1 Packet Drop Ratio

Figure 1 reflects the ratio of the packet drop to the node count. During the data packet forwarding process, it is clearly noted that if the number of nodes increases, the drop ratio of the packet increases slightly. The packet drop ratio is reduced to 10% and an average of 17% during the implementation of EEE-RP protocol, which is lower than the EH-WSN and ECO-LEACH baseline protocols. With the support of the proposed protocol, packets are sent to the WSNs with a nominal drop ratio. It is noted that the proposed protocol is performing better than the existing protocol and has achieved excellent results.

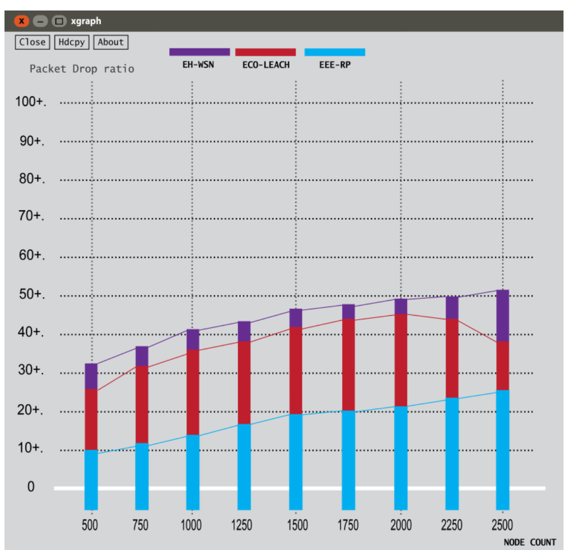

Fig 1. Packet Drop vs Nodes

4.2 Packet Delivery Ratio

The ratio of packet delivery against the node count is shown in Figure 2. It is observed that the delivery ratio of the packets is substantially reduced as the node count increases. This is because of the huge data transmission and overload, forwarding of data packets to the destination is slightly degraded. In the EEE-RP protocol, the packet delivery ratio is up to 96% and an average of 89% based on node count and is comparatively higher than the existing EH-WSN and ECO-LEACH protocols. It is credible that the new protocol is performing better in terms of delivering the data packets from source to destination in a better way.

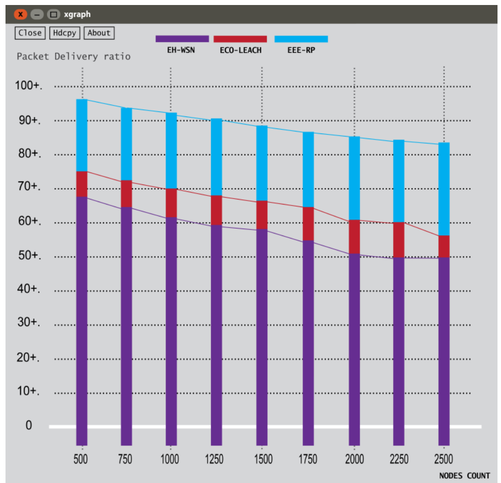

Fig 2. Packet Delivery vs Nodes

4.3 Delay

Delay analysis of the proposed EEE-RP protocol is shown in Figure 3. It is noted that the latency time during the data transmission is slightly increasing due to increase of node count and range. But, during the testing, it is found that EEE-RP performs well compared to the existing baseline protocols EH-WSN and ECO-LEACH. Only due to increase in node count and wide coverage range the latency time differs. When compared to EH-WSN and ECO-LEACH, EEE-RP took minimum of 15% delay to forward the data packets from source to destination comparatively very low than existing routing methods.

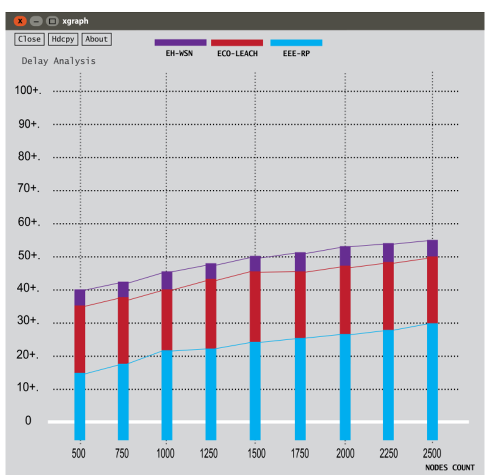

Fig 3. Delay vs Nodes

4.4 Energy Consumption Ratio

The ratio of energy consumption of sensor nodes is shown in Figure 4. It shows how much energy is spent in WSN during data transmission from one end to the other. It is undisputed that the energy consumption of EEE-RP is considerably lower than that of EH-WSN and ECO-LEACH. Even the number of nodes increases, the consumption of energy is low due to ideal route formation of delivering packets from source to destination. EEE-RP only consumed the necessary energy of 10% and average of 16%, whereas EH-WSN and ECO-LEACH used more energy power nearing to 40% for data forwarding and it leads to node failure due to data overload.

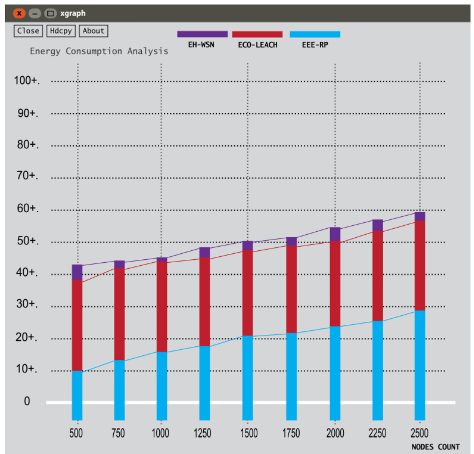

Fig 4. Energy Consumption vs Nodes

4.5 Data Arrival Rate

The data arrival ratio is presented in Figure 5. It is noted how much time it takes to deliver information from source to destination in wireless sensor networks without duplication and also shows how much noise data is collected and removed during broadcasting. In this analysis, it is clearly understood that, compared to the EH-WSN and ECO-LEACH protocols, the data delivery rate in the EEE-RP protocol is high since the EEE-RP protocol chooses the correct and ideal route rediscovery process during energy depletion. The arrival rate is approximately 96% and an average of 88% is achieved whereas usage of the existing protocols the data arrival rate is only up to 70%.

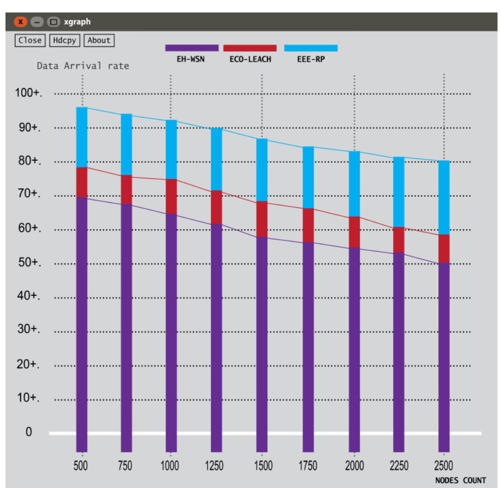

Fig 5. Data Arrival vs Nodes

4.6 Network Traffic

Figure 6 demonstrates the performance analysis of the network traffic. This indicates the efficient route traffic during the transmission of data or the amount of data transmitted at a given time point. The proposed EEE-RP protocol shows a high rate in the packet forwarding in the WSN search space even the load is high compared to the existing EH-WSN and ECO-LEACH baseline protocols. The data transmission rate is high up to 95% compared to existing protocols since EEE-RP collects cluster heads points at the initial stage.

Fig 6. Network Traffic vs Nodes

4.7 Network Lifetime

The network lifetime is showcased in Figure 7. It indicates how long the network operates during the data transmission process and how far data packets are successfully transmitted from one node to another. Using EEE-RP, network life is maximized to 97% with an average of 88% whereas the EH-WSN and ECO-LEACH protocols do not show any efficiency in optimizing network life. The proposed EEE-RP protocol has done a well of improving the lifetime of the network. It shows that the stability of the protocol is high compared to the existing one.

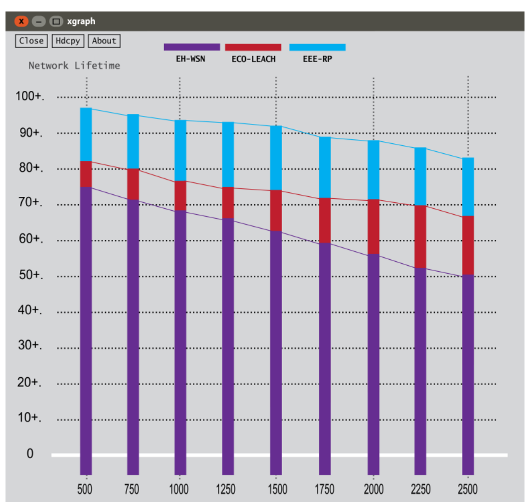

Fig 7. Network Lifetime vs Nodes

5 Conclusion

The research study proposed a new network data transmission energy-efficient protocol, namely the Enhanced Energy Efficient Routing Protocol (EEE-RP), to improve the efficiency of wireless sensor networks. Minimizing the end to the end of the delay would still increase the packet forwarding distribution ratio. Machine learning approaches such as the reinforcement learning method, the random walking data collection method and the Markov decision process framework are used in this protocol to identify the dynamic link failure and discover the best ideal route for an effective data forwarding process to make data packets to reach the destination. The key concept is to collect data from cluster heads according to their demand or request, in particular, to save the energy usage of the sink and to improve the life of the network. This protocol works on collecting the data from CHs when there is a request comes from the source node and act accordingly. So, energy saving and end to end delay is minimizing here and data forwarding progress is maximizing due to stable energy in passing nodes. The limitations of the proposed protocol are EEE-RP works with the range of 80m to 120m with the node count up to 3500. In future, data forwarding process can be enhanced during the deployment of more sensor nodes in unattended area with advanced forwarding techniques. Simulations have demonstrated to enhance the network performance in terms of data arrival rate, packet drop ratio, packet delivery ratio, energy consumption, network traffic, delay and network lifetime and compared with the baseline protocols namely EH-WSN and ECO-LEACH.

References

1) Nithyanandh S, Jaiganesh V. Quality of service enabled intelligent water drop algorithm based routing protocol for dynamic link failure detection in wireless sensor network. *Indian Journal of Science and Technology*. 2020;13(16):1641–1647. Available from: https://dx.doi.org/10.17485/ijst/v13i16.19.
2) Liu Y, Wu Q, Zhao T, Tie Y, Bai F, M J. An Improved Energy-Efficient Routing Protocol for Wireless Sensor Networks. *Sensors*. 2019;19(20):4579. Available from: https://doi.org/10.3390/s19204579.
3) Zungeru AM, Ang LM, Seng KP. Classical and swarm intelligence based routing protocols for wireless sensor networks: A survey and comparison. *Journal of Network and Computer Applications*. 2012;35(5):1508–1536. Available from: https://dx.doi.org/10.1016/j.jnca.2012.03.004.
4) Ghaffari A. An Energy Efficient Routing Protocol for Wireless Sensor Networks using A-star Algorithm. *Journal of Applied Research and Technology*. 2014;12(4):815–822. Available from: https://dx.doi.org/10.1016/s1665-6423(14)70097-5.
5) Forster A. Machine Learning Techniques Applied to Wireless Ad-Hoc Networks. *IEEE Explore*. 2014;20:1–12. Available from: https://doi.org/10.1109/ISSNIP.2007.4496871.
6) Pinto AR, Montez C, Araujo G, Portugal P. An approach to implement data fusion techniques in wireless sensor networks using genetic machine learning algorithms. *Information Fusions*. 2013;p. 1–12. Available from: https://dx.doi.org/10.1016/j.inffus.2013.05.003.
7) Bahbahani MS, Alsusa E. A Cooperative Clustering Protocol With Duty Cycling for Energy Harvesting Enabled Wireless Sensor Networks. *IEEE Transactions on Wireless Communications*. 2018;17(1):101–111. Available from: https://dx.doi.org/10.1109/twc.2017.2762674.
8) Mahboub A, Arioua M, En-Naimi EM. Energy-Efficient Hybrid K-Means Algorithm for Clustered Wireless Sensor Networks. *International Journal of Electrical and Computer Engineering*. 2017;7(4):2054–2060. Available from: https://dx.doi.org/10.11591/ijece.v7i4.pp2054-2060.
9) Bharaneetharan E. Role of Machine Learning Algorithms Intrusion Detection in WSNs: A Survey. *Journal of Information Technology and Digital World*. 2020;2(3):161–173. Available from: https://10.36548/jitdw.2020.3.004.
10) Zeng B, Dong Y. An improved harmony search based energy-efficient routing algorithm for wireless sensor networks. *Applied Soft Computing*. 2016;41:135–147. Available from: https://dx.doi.org/10.1016/j.asoc.2015.12.028.
11) Rhim H, Tamine K, Abassi R, Sauveron D, Guemara S. A multi-hop graph-based approach for an energy-efficient routing protocol in wireless sensor networks. *Human-centric Computing and Information Sciences*. 2018;8(1):7–21. Available from: https://dx.doi.org/10.1186/s13673-018-0153-6.
12) Arumugam GS, Ponnuchamy T. EE-LEACH: development of energy-efficient LEACH Protocol for data gathering in WSN. *EURASIP Journal on Wireless Communications and Networking*. 2015;2015(76). Available from: https://dx.doi.org/10.1186/s13638-015-0306-5.
13) Tan N. An Improved LEACH Routing Protocol for Energy-Efficiency of Wireless Sensor Networks. *The Smart Computing Review*. 2012;2. Available from: https://dx.doi.org/10.6029/smartcr.2012.05.006.
14) Biswas S, Morris R. Opportunistic routing in multi-hop wireless networks. *ACM SIGCOMM Computer Communication Review*. 2004;34(1):69–74. Available from: https://dx.doi.org/10.1145/972374.972387.
15) Mao X, Tang S, Xu X, Li XY, Ma H. Energy-efficient opportunistic routing in wireless sensor networks. *IEEE Trans Parallel Distributed Systems*. 1934;22(11):1934–1942. Available from: https://doi.org/10.1109/TPDS.2011.70.
16) An W, Ci S, Wu D, Han Y, Qi Y, Lin T. Transmission cost minimization with vulnerability constraint in wireless sensor networks. *IEEE Wireless Communications and Networking Conference (WCNC)*. 2013;p. 1297–1302. Available from: https://doi.org/10.1109/WCNC.2013.6554751.
17) Abbasi UF, Awang A, Hamid N. A Cross-Layer Opportunistic MAC Routing Protocol to Improve Reliability in WSN. *Proceedings of Asia-Pacific Conference on Communications*. 2014;p. 36–41. Available from: https://doi.org/10.1109/APCC.2014.7091601.
18) Ahmed M, Soomro MA, Parveen S, Akhtar J, Naeem N. CMSE2R: Clustered-based Multipath Shortest distance Energy Efficient Routing Protocol for Underwater Wireless Sensor Network. *Indian Journal of Science and Technology*. 2019;12(8):1–7. Available from: https://10.17485/ijst/2019/v12i8/141788.
19) Helen D, Arivazhagan D. An Intelligent Energy Efficient Routing Protocol for Mobile Ad-Hoc Network. *Indian Journal of Science and Technology*. 2016;9(45):1–5. Available from: https://dx.doi.org/10.17485/ijst/2016/v9i45/104140.
20) Nithyanandh S, Jaiganesh V. Dynamic Link Failure Detection Using Robust Virus Swarm Routing Protocol in Wireless Sensor Network. *International Journal of Recent Technology and Engineering*. 2019;8(2):1574–1578. Available from: https://doi.org/10.35940/ijrte.b2271.078219.
21) Abidoye AP, Kabaso B. Energy-efficient hierarchical routing in wireless sensor networks based on fog computing. *EURASIP Journal on Wireless Communications and Networking*. 2021;8:391–403. Available from: https://doi.org/10.35940/ijrte.b2271.078219.
22) Sinde R, Begum F, Njau K, Kaijage S. Refining Network Lifetime of Wireless Sensor Network Using Energy-Efficient Clustering and DRL-Based Sleep Scheduling. *Sensors*. 2020;20(5). Available from: https://dx.doi.org/10.3390/s20051540.

23) Aroba OJ, Naicker N, Adeliyi T. A Hyper-Heuristic Heterogeneous Multisensor Node Scheme for Energy Efficiency in Larger Wireless Sensor Networks Using DEEC-Gaussian Algorithm. *Mobile Information Systems*. 2021;2021:1–13. Available from: https://dx.doi.org/10.1155/2021/6658840.