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EE-MRP: Energy Efficient Multi-Level Routing Protocol for Wireless Sensor Network

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Abstract -WSN is a collection of tiny nodes deployed in a particular area connected wirelessly to form a network and sense the data from the environment. The nodes have resource constraint property which collects the data from the environment and transmits it to the base station. Clustering is one of the efficient ways to enhance network performance. In the clustering process, one node is selected as a cluster node and all other nodes are called as cluster members. The cluster member sends data to their respective Cluster Head and then forwarded it to the sink. The proposed Energy Efficient Multilevel Routing Protocol (EE-MRP) is proposed. The network is portioned into regions and sub-regions based on the longitudinal distance from the base station. The advanced and Normal nodes are used in the network. The election of Cluster Head depends on trust criterion and neighbor nodes as parameters. The trust in the proposed protocol is calculated using the maximum node remaining energy and minimum base station distance as a ratio. The CH-to-CH communication is performed within the network and enhances network performance.

Keywords: *cluster, environment, node, Energy Efficient Multilevel Routing Protocol (EE-MRP), constraint*

1. Introduction

A Wireless Sensor Network (WSN) is a system that continuously monitors the environment, finding applications in various domains such as weather conditions forecasting, defense surveillance, and more [1]. These networks consist of nodes, which can be either wired or wireless, and are powered by batteries, making energy conservation a challenging task. In recent years, encroachments in technology have enabled the development of small-sized, cost-effective, and efficient IoT applications [2]. Currently, there are over 5 billion interconnected devices, and it is projected that by 2022, this number will reach approximately 30 billion, offering extensive opportunities for IoT research in diverse fields [3]. To facilitate IoT device integration, certain sensor networks have been specifically designed to be IoT-friendly [3]. These networks employ wireless connectivity among the nodes to form a network that performs data processing tasks and transmits the information to a base station (BS). Additionally, the nodes collaborate with each other using sleep and wakeup techniques [4]. The WSN is influenced by several crucial factors, including design goals, cost, hardware limitations, battery constraints, and the intended applications [5]. The key objective of a sensor network is to achieve maximum network coverage with the minimum number of nodes to avoid coverage holes—areas that lack sensor node coverage and remain unmonitored. Furthermore, WSNs aim to continuously monitor the network and track objects within it [6]. When deploying nodes in a WSN, they can be placed in a deterministic or random manner. However, because of the limited battery power of sensor nodes, optimizing energy consumption becomes a critical task as it determines the system's lifespan and stability [7]. Sensor networks consist of both homogenous and heterogeneous nodes. Homogenous nodes possess similar properties, while heterogeneous nodes differ in capacities such as power, sensing capabilities, and communication [8]. To achieve Quality of Service (QoS), sensor nodes are distributed across a large network area. Random deployment of nodes can lead to issues such as overlapping and coverage holes, which necessitate the use of various techniques for resolution. An important aspect to consider is resource utilization in WSN specially for IoT-enabled applications [8].

In WSN the SN has battery constraints i.e. limited battery power and also they are not rechargeable. SNs consume energy in every mode i.e. sleep, awake, idle, communication, data transmission etc. due to which they are dying early in the network which affects the stability period, throughput and network lifetime. Clustering is a way to improve network lifetime in which SN reduces the energy consumption. The clustering is mechanism in which SNs are grouped called as Cluster Member (CM) and form different clusters [9].

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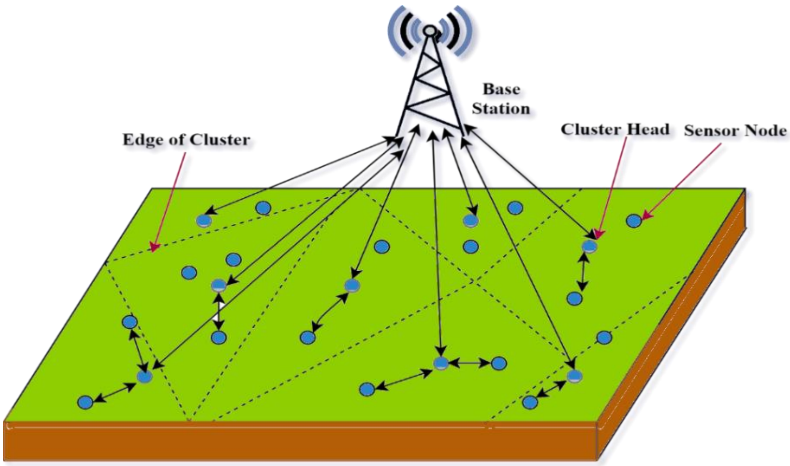

Fig 2.1. Wireless Sensor Network Architecture

The EE-MRP proposes a technique that partitions the network region into different regions and sub-regions. The main focus of this protocol is to enhance the selection process of Cluster Heads (CH) by considering factors such as maximum trust and maximum neighboring sensor nodes (SN). The CHs play a crucial role in aggregating data and transmitting it to the Base Station (BS), as illustrated in Figure 1.1.

1.1 Routing Protocol in WSN

WSN routing protocols are distinct from typical because of their unique properties. The goal of a routing protocol is to design system which reduce energy utilization and data transmission, based on several applications several routing approaches are used [21]. In WSNs, routing protocols can be either static or dynamic. They are characterized on the basis of several aspects such as based on network architecture and protocol operation based routing protocol [22].

Based on network architecture sensor network it can be classified as hierarchical, flat and location based routing [23]. Depending upon the protocol operation, it is classified into five categories as multi path, QoS, query, negotiation and coherent based. In the flat based routing all the sensor nodes are perform similarly based on the functionality and role in the network [24]. In hierarchical based routing clusters are formed by grouping the sensor node. The one node is elected as the cluster head and the rest act as cluster members. The CH gathers the data and forward to the sink node.

All the CM forward the sensed data to the CH then it transmits the data to the BS. In routing, based on location the node's location is used to for transmission and communication.

2. Literature Review

A study by **A. Yousaf et al.** [10] compared different variants of the LEACH protocol with the original LEACH protocol to assess energy efficiency and network lifetime improvements.

Another research paper [11] introduced the ARZ-LEACH protocol, which focuses on static based clustering and enhances CH selection in the network, with the Base Station near the center. Advanced nodes collect data from CMs and other CHs, transmitting it to the BS. The ARZ-LEACH protocol selects CHs based on maximum RE in the rectangular cluster, improving system performance through efficient task allocation.

In [12], **Y. Yazid et al.** presented deep analysis of cluster based routing protocols for Heterogeneous network, that in the Stable Election Protocol (SEP), the Normal nodes (NN), and the Advanced Nodes (AN) are deployed. AN has more chances to become CH in comparison to the NN, which causes various issues.

In [13**], M. Islam et al.** presented Extended Stable Election. It is an enhanced version of the SEP protocol. In E-SEP protocol three-tier nodes are used namely normal node, moderate nodes and advanced node. Moderate nodes and advanced nodes have more chances to become CH.

In [14], **N. Mittal et al.** presented an Energy Efficient-Stable Clustering on Fuzzy Type-2 Bat Flower Pollinator (BFP) for WSN. In this paper, the MR-SEP protocol was introduced, an extended variant of SEP. In this protocol cluster is formed, each with its own CH. Minimum distance is used as a parameter for the cluster member to join the head node. The cluster member transmit data to head node. The CHs in the top layer serve as SCHs for the CHs in the bottom layer. Using various stacking methodologies, the head node are deployed uniformly in the network. The protocol employs a multi-hop technique.

In [15], Han et al. introduced the concept of relay nodes for transmission of data in the network, improving system performance and enhancing network lifetime.

In [16], Tang et al. proposed the HEED protocol, which selects head nodes based on node RE and proximity principles, reducing network overhead and increasing the network's lifespan.

In [17], Meddah et al. presented the EEDCA algorithm, focusing on energy-efficient routing and density control. The selection of CH takes into account node RE and position. Hierarchical transmission in sensor networks is utilized, with clustering for data transmission from cluster members to head nodes, and then to the BS.

In [18], Kalla et al. introduced the Social Group Optimization (SGO) technique, an optimization approach that reduces transmission duration and the number of CHs. CHs are dynamically selected using this technique.

In [19], Parwekar et al. discussed a range-free localization algorithm using fuzzy logic. It employed RSSI and LQI information from anchor nodes to predict the location of SNs, reducing energy consumption in the network.

3. Proposed Work

The EE-MRP introduces a network architecture that partitions the network into diferent regions and further sub-regions. Notably, the Base Station (BS) is positioned out of the network area. The protocol adopts a two-tier or two-level approach for data transmission within the network.A key feature of the EE-MRP is the communication between Cluster Heads (CHs) at different levels. This enables efficient data exchange and routing within the network. The specific details and visualization of the EE-MRP protocol can be observed in Figure 4.1.

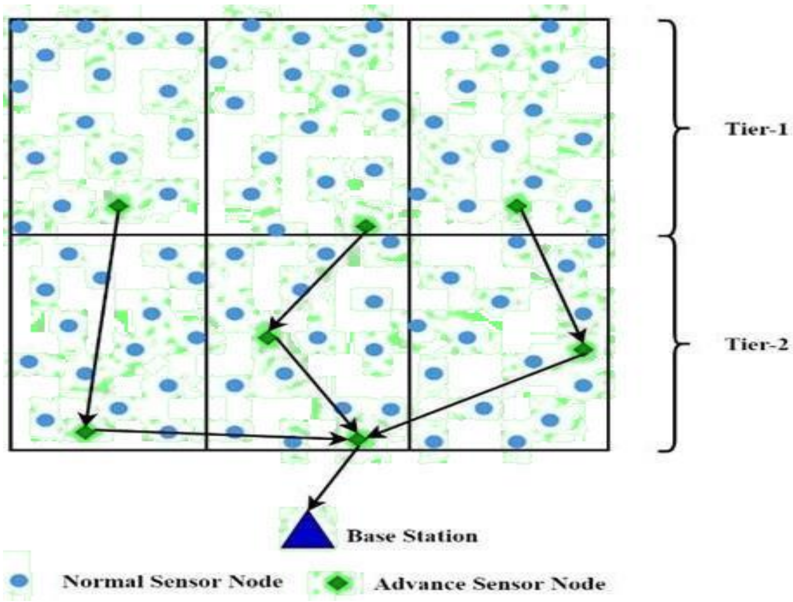

Fig 4.1: Energy-Efficient Multi-Level Routing Protocol

The proposed protocol mainly focuses on an efficient trust-based CH selection process. The CH is elected using maximum rank and the maximum number of neighboring nodes as described in algorithm 2. The trust of the SN is calculated by taking the ratio of the Residual Energy of node and the base station distance.

3.1 Proposed model for Cluster Head Selection

3.1.1. Setup phase

It is the first and the initial stage. Here the network is partitioned into region and sub-region based on longitudinal measure from the sink node. The network is divided into 2-tiers. The responsibility of the base station is to divide the network area into 2-tiers. The exact position of Tier-1 is at a great distance from the sink node, and Tier-2 is lpositioned close to the sink node.

3.1.2. Cluster formation

In the direct transmission method, each SN sends the data to the BS directly so data transmission number increases and sensor network lifetime decreases[24] [25]. In multi-hop transmission the data is transmitted by multiple hops due to which energy consumption is high and the network lifespan reduces. In clustering, small clusters are formed in which one is head and rest are the members [26]. The CM forward the data to the head node which is further forwarded to the BS. Hence the data transmission number reduces ,while network lifetime improved. In the proposed EE-MLR protocol nodes are deployed randomly and cluster is formed and an identification number based on its location is assigned to each SN. All the SN can join only its neighbour.

3.1.3. Cluster Head selection

CH is selection on maximum trust and maximum neighbour nodes. After the selection of CH, a message is broadcast in the network to all the SN to grouped and turned to CM. The SN gets the joining message from the CH to join immediately [27]. For routing of the data packet efficient CH selection is performed. In this protocol, the tier 1 CH sends the data which is far away from the BS to the tier 2 CH which is near to the BS. Data is aggregated at tier 2 CH and transmit it to BS [28].

3.2 Trust of the Sensor Node

The proposed EE-MLRP protocol is a trust based CH selection process in which trust can be defined as:

$$Trust = \alpha \times RE/IE \times D/(avg\ D) \qquad (1)$$

Here,

α= initial number of CHs percentage probability in the network

IE: It represents the initial energy level of the sensor nodes before data transmission.

RE: It indicates the remaining energy of the node after each round of data transmission.

D: It represents the distance between the Base Station (BS) and all the SNs in the network.

avg_D: It refers to the average distance from the BS.

Assumptions:

- Heterogeneous nodes: The proposed protocol assumes the use of heterogeneous nodes, meaning that the SNs have different characteristics and capabilities.
- Noise and collision: The system ignores the impact of noise and collision in the network.
- Cluster head aggregation: The responsibility of aggregating all the data and transmitting it to the BS lies with the Cluster Head(s).
- Random and deterministic distribution: The SNs are assumed to be distributed in the network in a random and deterministic manner.
- Non-rechargeable battery: The protocol assumes that the SNs have non-rechargeable batteries and that the BS continuously supplies power to the network.

ALGORITHM: CH Election using Maximum Trust and Maximum Number of Neighbouring Nodes.

Initialization:

Input:

- Residual energy (R_i) for each sensor node i

- Initial energy (INE_i) for each sensor node i

- Distance to base station (DBS_i) for each sensor node i

- Average distance of node (DAVG_i) for each sensor node i

- Probability of initial percentage of CHs (α)

- Number of neighboring nodes (NB_i) for each sensor node i

Output:

- Cluster head (CH_i) for each sensor node i

1. **for each** sensor node i in the network:

   a. Calculate SNR_i = R_i / INE_i

   b. Calculate SNTRUST_i = α * (SNR_i / INE_i) * (DBS_i / DAVG_i)

   c. Calculate SNNB_i = NB_i

2. Determine the node with the maximum SNTRUST_i and SNNB_i:

   a. **If** there is a unique node i with the maximum SNTRUST_i and SNNB_i, set CH_i = 1 (node i is the CH).

   b. Otherwise, if there are multiple nodes with the maximum SNTRUST_i and SNNB_i, choose one arbitrarily to be the CH.

c. **If** (no node satisfies both conditions)

Choose the node with the maximum SNTRUST_i as the CH.

3. **for each** CH_i in the network:

a. The CH_i aggregates data from its member nodes.

b. **If** the CH_i is within transmission range of the base station, it sends the aggregated data directly to the base station.

c**. else,** the CH_i forwards the data to another CH_i closer to the base station.

4. **for each** non-CH_i in the network:

a. The non-CH_i sends its data to the CH_i to which it belongs.

5. **End.**

5. Simulation and Result

In the simulation of the proposed EE-MRP protocol, MATLAB is used as the simulation environment. The simulation scenario involves the deployment of 100 heterogeneous nodes within a 100m x 100m area. The Base Station (BS) is positioned outside the boundary of the network area. Within the network, 10% of the sensor nodes (SN) are designated as Advanced Nodes (AN), while the remaining SNs are considered as Normal Nodes (NN). This heterogeneity allows for variations in capabilities and characteristics among the nodes. The proposed EE-MRP protocol is compared with two other protocols, LEACH and SEP. These comparisons aim to evaluate the performance and effectiveness of the EE-MRP protocol against the existing protocols. The simulation in MATLAB provides a platform to assess and analyze the behavior and outcomes of the proposed protocol in comparison to the other protocols, based on predefined metrics and performance indicators.

5.1. Simulation Parameter

Simulation parameter used in the protocol are listed in the table below.

Table 5.1: Used Simulation Parameters

Parameter	**Value**
S.N	100
Network Region	$(100x100)m^2$
Multipath Model(*Eamp*)	$0.0013pJ/bit/m^4$
Free Space Model (*Efs*)	$10pJ/bit/m^2$
Initial Level of Battery(E_o)	0.5 J
Initial Energy in ANs	$E_0\,(1+\boldsymbol{E_\alpha})$.
Electronic Circuit (ERX)	50nJ/bit
Data Aggregation(EDA)	10nJ/bit/

The proposed EE-MRP protocol was compared with the LEACH and SEP protocols in a heterogeneous setting over a duration of 3500 rounds. The simulation results were analyzed for various performance metrics, including the network lifetime, first node failure, half node failure, last node failure, number of alive nodes, energy consumption of the network, and packets sent to the Base Station (BS). The results were visualized in corresponding figures, highlighting the trends and outcomes for each metric.

	LEACH	SEP	EE-MRP
First node dead	700	950	1200
Half node dead	1180	1350	2230
Last node dead	2850	3140	3420
Average	1578	1813	2283

In the comparison of the LEACH protocol and the SEP routing protocol, the First Node Dead (FND) index achieved a value of 700 for LEACH and was extended to 950 with the use of the SEP protocol. However, the proposed EE-MRP protocol utilizes a clustering approach to further enhance the FND index. The EE-MRP protocol optimizes the clustering process of Wireless Sensor Network (WSN) nodes by employing a Multi-Level Hierarchy-based clustering algorithm. This algorithm aims to decrease energy dissipation within the clusters and balance energy consumption throughout the WSN. In implementing the proposed EE-MRP protocol, the FND index is extended to 1200 rounds, as demonstrated in Figure 5.1. This improvement signifies the protocol's effectiveness in prolonging the network lifetime and delaying the occurrence of the first node dead.

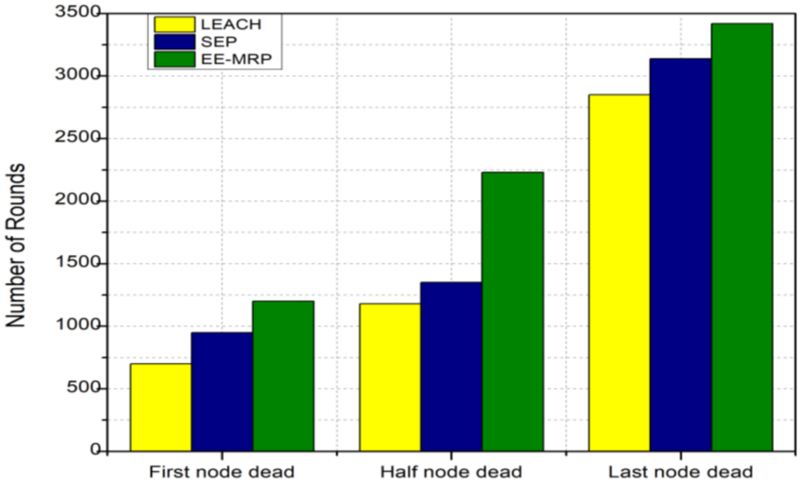

Fig 5.1. Energy dissipation at various points

In the comparison of average residual energy among different protocols, the LEACH protocol demonstrated the lowest average residual energy with a value of 0.37J. On the other hand, the proposed EE-MRP protocol achieved the highest average residual energy, reaching 0.47J over a period of 500 rounds. Furthermore, the proposed EE-MRP protocol exhibited sustained performance over a longer duration, lasting for 3000 rounds with an average residual energy of 0.15J. In comparison, the SEP protocol lagged behind, maintaining a similar average residual energy but for a shorter duration of 2500 rounds. These results indicate that the proposed EE-MRP protocol effectively manages and preserves energy resources, allowing for a higher average residual energy and extended network lifetime compared to the LEACH and SEP protocols.

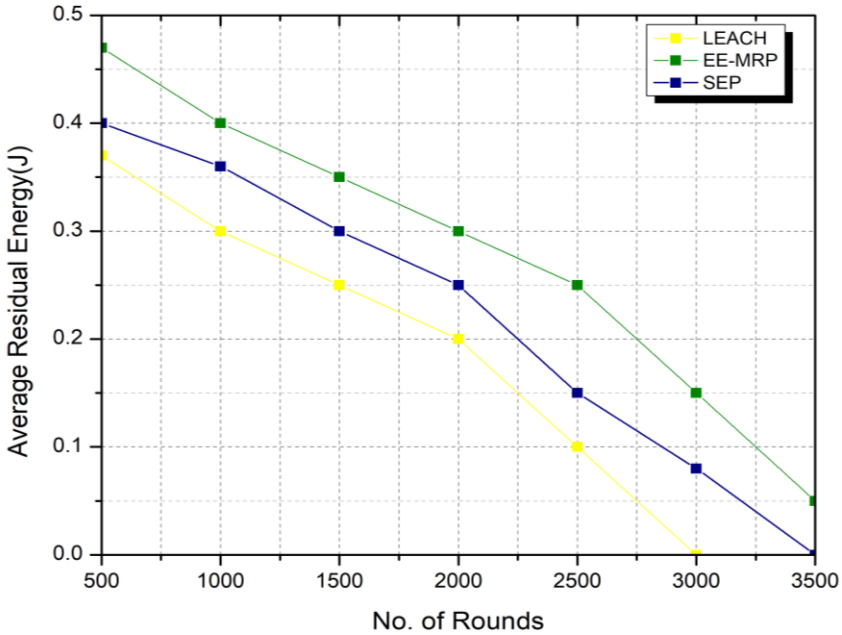

Fig 5.2. Average residual energy in network

In the given sensing environment of 100 x 100 m², a total of 100 sensor nodes were deployed. The graph depicts the relationship between the number of alive nodes, and the total number of rounds in a 100 m x 100 m region, considering that the Base Station (BS) is positioned outside the network.

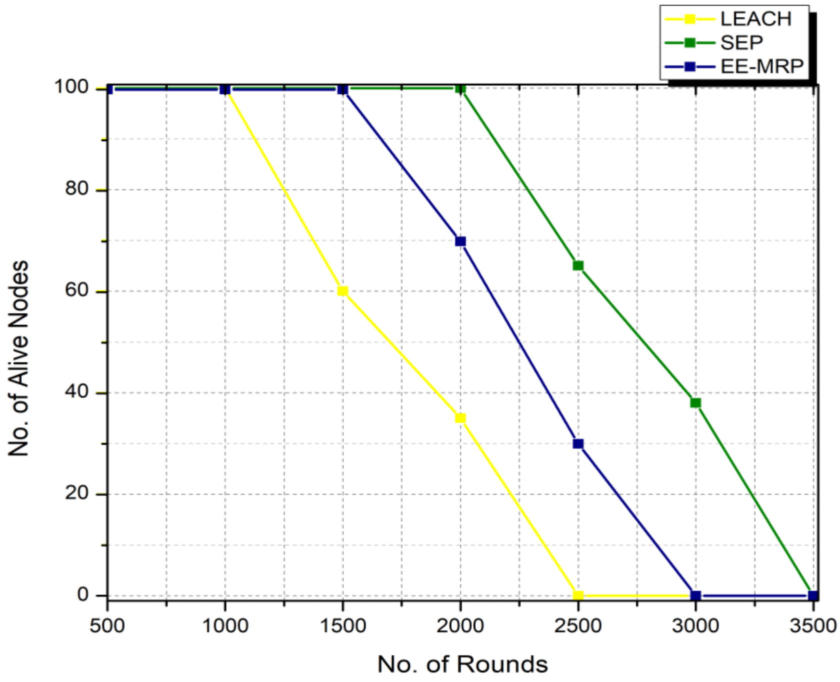

Fig 5.2. No. of alive nodes per round

Figure 5.3 illustrates the no. of alive nodes per round for the proposed EE-MRP protocol compared to the LEACH and SEP protocols. The graph showcases the varying number of active nodes at different stages of the simulation. The proposed EE-MRP protocol demonstrates superior performance, consistently maintaining the maximum number of alive nodes throughout the simulation in comparison to LEACH and SEP protocols. In Figure 5.4, the energy consumption of the existing protocols is depicted and compared with the proposed EE-MRP protocol. The graph highlights the reduction in energy consumption achieved by implementing the proposed EE-MRP protocol. This signifies the protocol's efficiency in optimizing energy utilization and minimizing energy dissipation in comparison to the other protocols.

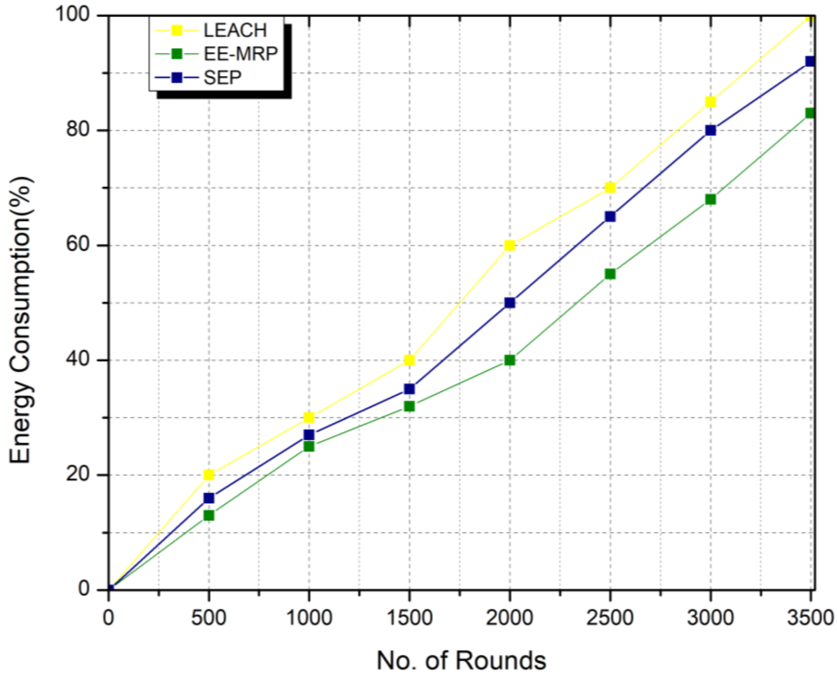

Fig 5.4. Energy dissipation at various points

Based on the simulation results, it is observed that the energy consumption in the SEP protocol accounts for approximately 92% of the total energy consumed over the course of 3500 rounds. In contrast, the proposed EE-MRP protocol demonstrates a lower energy consumption rate, with energy usage amounting to approximately 83% of the total energy for the same duration of 3500 rounds. This comparison highlights the energy-saving benefits of the proposed EE-MRP protocol over the SEP protocol. By optimizing the clustering process and balancing energy dissipation within the network, the EE-MRP protocol effectively reduces energy consumption and improves the overall energy efficiency of the system.

6. Conclusion

The EE-MRP Protocol utilizes a two-factor selection process to determine the head node: the maximum trust of the node and the maximum number of neighbour nodes. Node trust is calculated by dividing the remaining energy of the node by the minimum distance between the node and the base station. By comparing the proposed protocol to the LEACH and SEP protocol, it was found that the former protocol results in improved network lifetime, average residual energy and reduced energy consumption. Simulation results show that the proposed EE-MRP protocol outperforms the LEACH and SEP protocol in terms of lifespan and stability period.

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