ENERGY EFFICIENCY AND RELIABILITY EFFICIENT CLUSTERING AND ROUTING (EEREC) IN WIRELESS SENSOR NETWORKS

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Abstract: An infrastructure-less network of nodes known as Sensor Nodes (SN) is called a Wireless Sensor Network (WSN). An energy limitation is always the main factor influencing network performance of Wireless Sensor Network (WSN). To maximize the network's longevity, an energy-balanced clustering mechanism must be developed. The EEREC technique is used to construct clusters due to its ability to identify exact core clusters, which leads to improved packet delivery ratio, increased throughput, longer network lifetime, and lower power consumption. The quality metric, residual energy, distance to neighbours, and sink node distance are the four core elements around which the clustering approach is built. It chooses the most effective routes for sending the data to the sink node. The results according to the proposed approach's output, proving the most efficient energy use for data transmission.

Key words: wireless sensor networks, energy, clustering, cluster head selection.

1. INTRODUCTION

The WSNs are made up of widely dispersed Sensor Nodes (SN) with wireless information sensing, computation, and communication abilities. WSNs serve as foundational technologies in numerous real-world applications such as precision farming, environmental monitoring, defence systems, and industrial process automation. These networks comprise spatially distributed sensor nodes that operate on limited power supplies and are often situated in remote or hard-to-reach locations with little to no human oversight. Since SN are usually battery-powered and placed in locations where battery replacement is not feasible, one of the primary concerns with wireless sensor networks is the effectiveness of energy.

Countless clustering and routing strategies have been put forth to address energy consumption. Given their limited power supply and computational capacity, enhancing

the energy efficiency and reliability of WSN operations remains a critical research challenge [1, 2]. The overall efficiency of a WSN is significantly influenced by how effectively CHs are selected and how routing paths are managed [3, 4]. Similarly, hybrid swarm intelligence techniques have been shown to significantly reduce energy consumption and extend network lifetime by optimizing the CH election process [2].

Recent developments have seen the incorporation of evolutionary techniques, such as genetic algorithms and fire hawk optimization, to refine cluster formation and routing decisions, particularly in Internet of Things (IoT) applications [7, 10]. Moreover, intelligent systems employing fuzzy logic, particle swarm optimization, and deep reinforcement learning are now being applied to create adaptive routing protocols capable of responding to real-time network dynamics [8, 9].

These diverse approaches underline the importance of adaptive, efficient, and intelligent algorithms in managing energy resources within WSNs. Motivated by these developments; this research proposes a novel method called as an Energy Efficiency and Reliability Efficient Clustering and Routing (EEREC) for further improve network longevity and energy efficiency in sensor networks with limited resources. EEREC leverages both residual energy and link quality for CH election and integrates route stability metrics to ensure dependable data transmission.

The primary contributions of this work are: A dual-objective CH selection method that considers both energy and communication reliability. A dynamic routing algorithm that adapts to changing network conditions using reliability metrics. Comprehensive simulation results demonstrating improvements over existing protocols in terms of energy consumption, packet delivery ratio, and network lifetime.

The paper is organized as follows: The introduction is explained in the first section. A brief overview of relevant works on network lifetime extension strategies is provided in Section 2. In Section 3, the suggested approach is outlined in detail. In Section 4, the outcomes in comparison to the current methodology are described. Section 5 summarizes the conclusion of the research study.

2. RELATED WORK

Several investigations have concentrated on using sophisticated clustering and routing algorithms to improve the performance and energy efficiency of WSNs. To reduce energy consumption and increase data transmission efficiency, a hybrid optimization approach utilizing both stationary and mobile sink nodes has been tested out. [5]. Genetic algorithms have been explored for optimum selection of cluster heads in order to optimize distribution of loads among sensor nodes and reduce energy consumption. [7]. In the context of vehicular communication, multicast routing strategies were developed to support cooperative collision avoidance and increase routing efficiency [13]. In [14] introduced a fuzzy logic-based routing algorithm that considers multiple network parameters to determine the most energy-efficient path, resulting in better resource utilization and enhanced data delivery reliability.

The mobility of sink nodes has been addressed using genetic algorithm-based strategies to improve energy-efficient data routing [15]. For optimum performance in both choice of cluster heads and inter-cluster routing at the same time, a two-level

genetic approach was introduced [16]. Enhancements in hierarchical clustering protocols for heterogeneous networks was introduced to increase network stability [18]. However, many existing approaches still struggle to strike a balance between energy efficiency, scalability, and reliability, especially in complex or heterogeneous sensor networks. This gap forms the motivation for the proposed EEREC (Energy Efficiency and Reliability Efficient Clustering and Routing) protocol, which aims to integrate multi-criteria decision-making with adaptive routing to better support long-term WSN operations.

By utilizing a dual-metric CH selection strategy and responsive routing mechanism that mutually account residual energy, link stability, and data traffic load into consideration, the suggested EEREC (Energy Efficiency and Reliability Efficient Clustering and Routing) protocol intends to address these problems. This makes EEREC a relevant and useful contribution to the continuous creation of solid WSN communication frameworks.

3. PROPOSED SYSTEM

Energy Efficiency and Reliability Efficient Clustering and Routing (EEREC) is a proposed method that uses a two-stage clustering strategy. The initial step of the clustering process involves electing and rotating the cluster leader. To find the optimum Cluster Heads (CH) for reducing and balancing energy usage while enhancing network resilience, the new cost function was created. Every time interval t, the node that acts as the sink transmits an advertisement message to rotate the CH. The candidate neighbour set NEB_x nodes that are not in the range of CHs is included in the final candidate member set for every node x [3]. This is formally expressed in the equation (1).

$$NM_x = \{(y|y) \in NEB_x, T_y = 1\} \tag{1}$$

where, NM_x - is the neighbour set of sensor node x is not impacted by a CH.

$$T_y = \begin{cases} 1, & if\ node\ y\ is\ not\ covered\ by\ any\ cluster\ head \\ 0, & otherwise \end{cases} \tag{2}$$

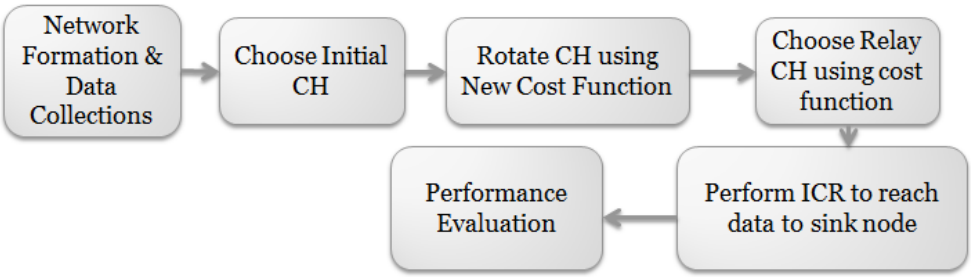

Figure 1. System architecture of proposed method

Equation (3) presents the proposed new link quality metric of candidate cluster head x at time t in this research.

$$QM_x = \sum_{l \in NM_x} (1 - MRR_{xl}(t)) \tag{3}$$

The message receipt ratio for the link is expressed by MRR_xl (t). Cluster head nodes are picked according to the average intra-cluster distance (ICD) in order to reduce delivery latency [3]. The ICD for sensor node x can be obtained by equation (4):

$$ICD_x = \frac{\sum_{y \in NM_x} ED_{xy}}{|NM_x|} \quad (4)$$

The distance measured from Euclid among nodes x and y is denoted by EDxy [16]. The cluster load indicator for node x at a period t is specified by expression (5) as follows:

$$CL_x(t) = \sum_{n=1}^{t-1} \eta_x^n \quad (5)$$

where $\eta_x^n = \begin{cases} 1, & if\ node\ x\ is\ chosen\ as\ a\ CH\ during\ time\ interval, n \\ 0, & otherwise \end{cases}$

Equation (6) calculates the cost function of designating node x as the CH.

$$CHCost_x(t) = \frac{EM_x(t)}{ICD_x * ED_{(x,sink)} * (CL_x(t)+1) * (1+QM_x(t))} \quad (6)$$

As a relay node, the CH with the highest energy and the lowest load should be selected. Equation (7) provides the developed relay energy meter for CH y at period t.

$$REM_y(t) = \exp\left(\frac{RE_y(t) - (NDR_y(t) * SE_{xy})}{IE_y}\right) \quad (7)$$

where SE_xy- is the single-hop transmission energy from node x to node y and RE_y (t)- is the network load of the CH. For CH x to choose CH y as a relay node, the $RCost_{xy}(t)$ must be as follows:

$$RCost_{xy}(t) = \left(REM_y(t) + \frac{1}{ED_{(y,sink)}}\right) * PRR_{xy}(t) \quad (8)$$

Equation (8) implies that a relay node will be the CH with the greatest cost value.

Algorithm 1: Algorithm for selecting EEREC Cluster heads

```
Proc_1- Identify Uncovered Neighbors
Proc_1: IdentifyUncoveredNeighbors(x)
  For each neighbor z in NEB_x
    Notify z that x is a "member"
    If z is not afftected by any CH
      Add z to NM_x[]
    End If
  End For
End Proc-1
Proc_2 - Select Cluster Head
Proc_2: SelectClusterHead(x)
  Broadcast CHCostx(t) to neighbors
  For every candidate CH node i from 0 to CH - 1
    H[i] = CHCost of node i
  End For
  H_max = maximum value in R[]
```

```
  ch = index of H_max
  next_ch[x] = ch
End Proc_2
```

Algorithm 2: Algorithm for EEREC next hop selection

```
Proc: Next_Hop_Selection(x)
  For each z in NEB_x do
    Receive RE_z(t), MRR_xz(t), and NDR_z(t) from z
    If ED(z, sink) ≥ ED(x, sink) OR z is already in next_hop[]
      Skip z
    Else
      Compute RCost_xz(t)
      Store RCost_xz(t) in P[z]
    End If
  End For
  P_max = 0
  best_z = null
  For each z in P
    If P[z] > P_max
      P_max = P[z]
      best_z = z
    End If
  End For
  If best_z is not null
    Add best_z to next_hop[]
  End If
End Proc
```

4. PERFORMANCE EVALUATIONS

The proposed EEREC is contrasted with the current GOC, LEEC, EEDC, and EAIC in terms of efficiency, packet delivery ratio, end-to-end latency, throughput, and network longevity.

4. 1. Simulation environment

The settings for simulation are listed in Table 1. These settings were chosen to simulate real-world constraints and to benchmark the proposed EEREC protocol against standard performance metrics such as energy consumption, network lifetime, and packet delivery ratio. The proposed EEREC protocol was evaluated through simulations carried out using the NS-2 network simulator.

To assess performance under varying network densities, the number of sensor nodes was incrementally increased from 100 to 500. This approach allowed for a comprehensive evaluation of the protocol's behaviour in both sparse and dense deployments.

Table 1. Simulation Criteria

S.NO.	***Parameter***	***Value***
1	*The total amount of nodes*	*100-500*
2	*The starting energy of every node*	*0.5 joules*
3	*Range of the Transmission*	*150 meters*
4	*Data packet size*	*30 bytes*
5	*The length of the queue*	*10-25 packets*
6	*A type of node queue*	*Priority Queue*
7	*The rate of transmission*	*512 kbps*

4.2. Network Lifetime

The figure 2 compares the maximum route lifetime of the proposed EEREC protocol with existing approaches across different node counts, showing that EEREC consistently achieves the longest network lifetime. This demonstrates EEREC's efficiency in extending overall network lifetime.

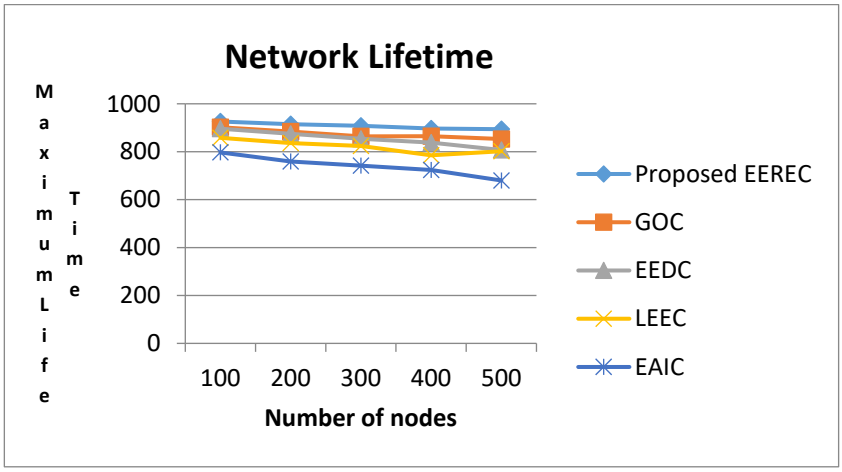

Figure 2. Maximum network life recorded for EEREC approach

4.3. Throughput

The figure 3 demonstrates that the proposed EEREC protocol consistently delivers superior throughput compared to existing models across varying node densities. Its stable performance shows better handling of increased network load. This proves EEREC's effectiveness in maintaining high throughput across scenarios.

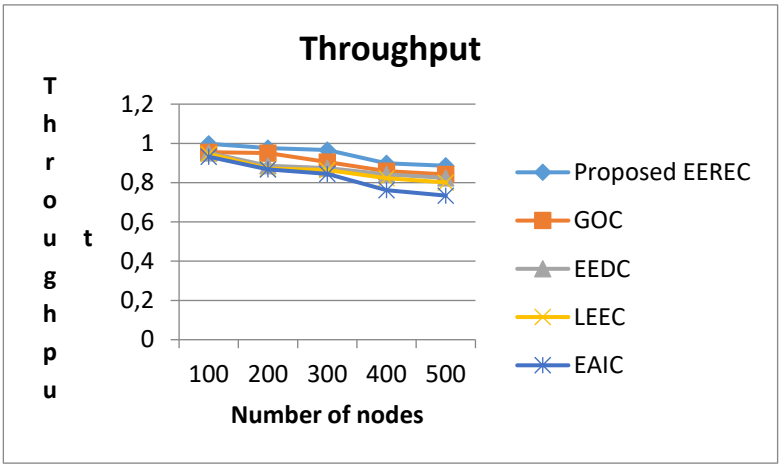

Figure 3. Estimated throughput for EEREC in comparison to current models

4.4. End to End Latency

The figure 4 indicates that EEREC achieves the lowest end-to-end latency among all models, ensuring faster data delivery as network size increases. It highlights EEREC's efficiency in reducing delays in data delivery and ensures that this approach is suitable for real time applications.

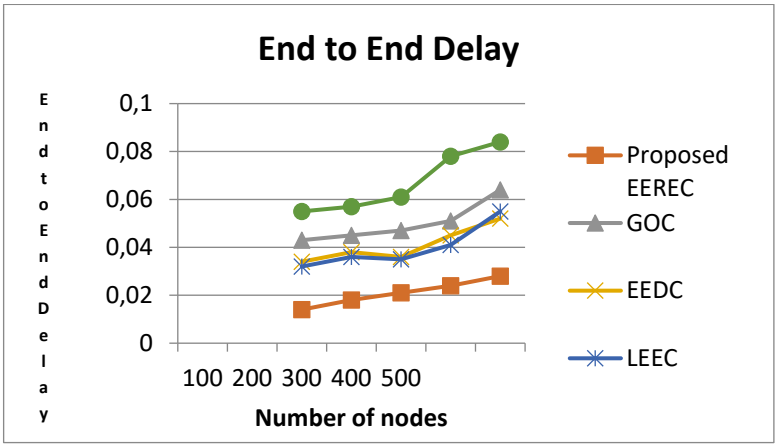

Figure 4. End to End Latency Comparisons of EEREC

4.5. Packet Delivery Ratio

Figure 5 illustrates the results of the experiment, which indicate that the created technology transported packets more efficiently than the conventional way. Compared to the traditional method, fewer losses and delays are observed. This highlights the effectiveness of the new approach in data transmission.

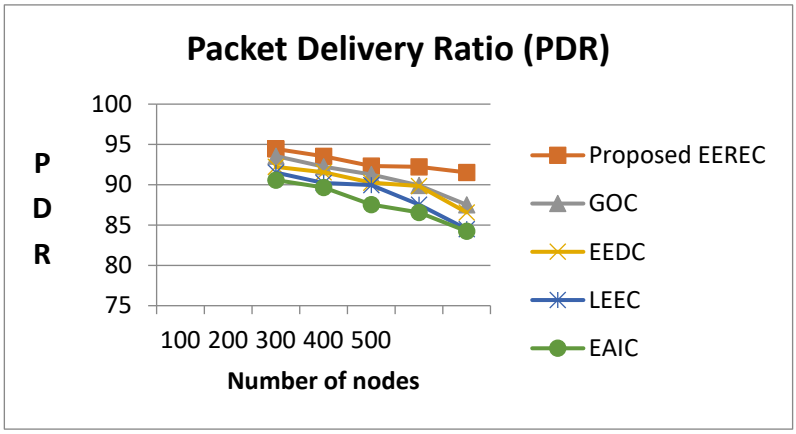

Figure 5. The packet delivery ratios for routes generated through node count are compared

4.6. Efficiency

The figure 6 indicates that EEREC achieves the highest efficiency among all compared methods, demonstrating its superior performance. This shows that EEREC performs better in conserving energy and utilizing network resources efficiently. Its high efficiency is a result of enhanced clustering and routing techniques.

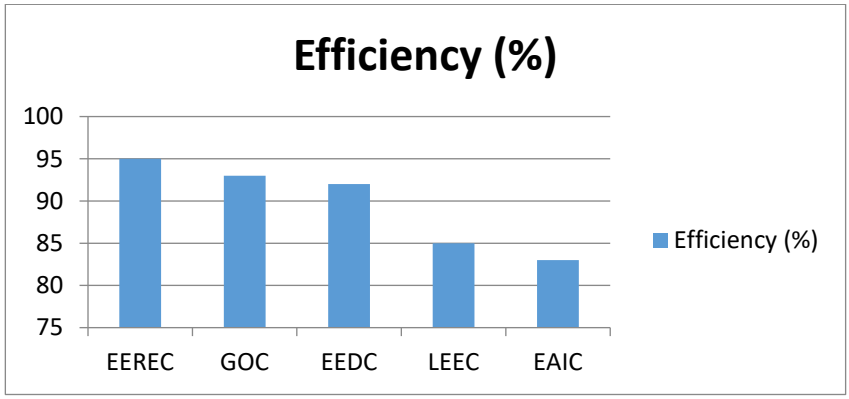

Figure 6. An efficiency comparison graph for the suggested approach

5. CONCLUSION

The experimental results show that the suggested system maintains a packet delivery ratio above 95%, which is different from popular and recent existing systems. In terms of optimization, the recommended strategy outperforms the prevailing ones. In a similar manner the recommended system's throughput significantly surpasses present techniques. The results and implementation make it evident that the proposed system has a shorter latency, which simultaneously increases the throughput and PDR. The proposed work thus outperforms well-known current methods such as GOC, EEDC, LEEC, and EAIC.

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