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Enhancing Security and Energy Efficiency in Cluster Head Selection and Data Transmission for Wireless Sensor Networks

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Abstract:
Many different fields, including the military and civilian sectors, environmental monitoring, and target tracking, use wireless sensor networks (WSNs) extensively. Therefore, for energy constrained WSNs with large-scale deployments, improving network architecture becomes crucial. Optimization simplifies routing, balances load efficiently, and prolongs network lifespan. The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol caters to WSNs' unique requirements. However, conventional LEACH suffers from increased energy consumption due to inadequate consideration of the cluster heads (CHs) distribution on a rotating basis. Moreover, complex security mechanisms face limitations imposed by sensor nodes' restricted bandwidth and other constraints. Hence, this study addresses the critical objectives of enhancing energy efficiency, CH stability, and secure data transmission in WSNs. The modified procedure, known as EC-LEACH, was inspired by these difficulties and will improve CH stability and energy efficiency. For CH selection and random number generation, EC-LEACH makes use of the Energy Cost Ratio (EC) of the nodes. Additionally, it stops a former CH node from being re-elected in the current round. This approach establishes a correlation between the threshold employed in traditional LEACH and each node's energy consumption ratio. Additionally, added an Integrated Reputation-Driven Data Transmission (IRDT) scheme to facilitate secure data transmission. According to simulation results when compared to cutting-edge methods, our suggested EC-LEACH protocol demonstrates higher performance in terms of secure communication, network lifespan, and energy usage.

Index Terms: LEACH Protocol, Secure Communication, Cluster Head, Energy Cost ratio, Integrated Reputation-Driven Data Transmission, Energy Dissipation.

1. INTRODUCTION:

1.1 Motivation:

Due to the vast range of applications for WSNs, they are frequently employed in networking. These networks are made up of tiny battery-operated sensor nodes that are used to gather and send data to SINK nodes over wireless links. WSNs, however, present difficulties because of the scarcity of energy resources. Clustering, self-organization, and routing protocols are essential to WSN performance because they maximize energy usage, network longevity, and operational efficiency. Despite their benefits, WSNs are constrained by their lack of processing power and buffering capacities. Energy consumption in the sensor nodes is mainly attributed to communication, data processing, and sensing activities. Communication energy, comprising data processing and transmission energies, plays a significant role in overall energy consumption. Optimizing energy usage is crucial for prolonging sensor nodes' lifetime, ensuring network availability, and connectivity in WSNs, given their limited energy sources. Network design and operation must take energy efficiency into account, especially when sensor nodes must communicate. Cluster formation and various communication modes have gained popularity in recent years [1]. The traditional architecture of clustered network is depicted in Figure 1. Clustering-based routing protocols offer more efficient utilization of sensor nodes' energy compared to non-clustering protocols. In this method, a cluster leader, also known as a Cluster Head (CH), is crucial in removing associated data and lowering the total amount of data. The Base Station (BS) receives aggregated data from the CH. By grouping sensor nodes into various clusters and taking into account the energy consumption variances across nodes and CHs, clustering saves energy consumption and balances the workload. Effective clustering methods greatly increase energy effectiveness and increase network longevity. In clustering algorithms, choosing the best CHs can assure a longer network lifetime and stop sensor nodes from dying too soon. [2].

In WSNs, security is the major concern, encompassing data security, integrity, and protection against internal and external attacks, in addition to energy efficiency challenges. Traditional energy management protocols do not adequately address security issues. While numerous conventional secure techniques exist to protect node data from external attacks, their applicability in WSNs is limited due to bandwidth constraints and the small size of nodes[3].

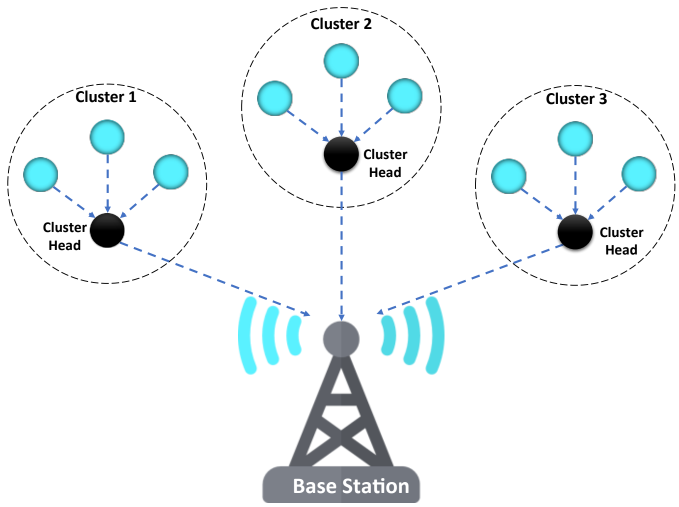

Fig.1: Network Topology of a Clustered WSN.

1.2 Contributions in this Paper:

- This paper establishes a correlation between random number generation, Node density and threshold values with the Energy Cost ratio (EC) of sensor nodes. This correlation effectively balances energy consumption and extends the network lifetime.
- A novel approach is introduced where Cluster Heads (CHs) selected in the previous round are excluded from being chosen as CHs in the subsequent round. This exclusion is based on the significantly higher EC of these nodes compared to non-CH nodes.
- By implementing this approach, the paper ensures that previously elected CH nodes do not receive another opportunity to become CHs in the present round, promoting fairness in CH selection.
- The Integrated Reputation-Driven Data Transmission (IRDT) approach to improve the security of data transmission between sensor nodes. It achieves this by selecting relay nodes using a hybrid node reputation model.
- The paper introduces a technique for determining the Quality of Service (QoS) reputation rate that takes node energy and link quality into account. Only nodes with enough energy and a strong link are allowed to participate in data forwarding in this calculation, which maximizes the packet delivery ratio. Overall network performance is enhanced as a result of this.

The paper is organized as follows: A comprehensive analysis of the available literature is provided in Section 2. With a focus on the Leach protocol, Section 3 offers a thorough examination of the foundations. Section 4 of the proposal covers the specifics of the job. The presentation of the results and the discussion that follows are both contained in Section 5. The conclusion of this study, which summarizes all of the work done in Section 6, is finally found there.

2. Literature Survey:

Energy consumption is a critical concern when designing Wireless Sensor Networks (WSNs) as it directly impacts the network's lifespan. Clustering is a widely adopted strategy to prolong the network lifetime by minimizing energy consumption. Several methods have been proposed to ensure secure data transmission in WSNs.

In the study [17], the authors introduced the Dynamic Fuzzy C-Means Clustering for Unequal Cluster Sizes to address hotspot issues and minimize the size of clusters closer to the Base Station (BS). Another study by Santhosh

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V. Purkar et al. [18] proposed an energy-efficient clustering method for Heterogeneous WSNs (HWSNs). The method considers various parameters such as residual energy, initial energy, and hot count for Cluster Head (CH) selection. The proposed approach demonstrated improvements in energy efficiency, network lifetime, stability, and throughput compared to other methods like SEP, DEEC, and LEACH.

These advancements in clustering techniques and CH selection contribute to enhancing the overall performance of WSNs, ensuring efficient energy utilization and prolonging the network's lifetime.

A hybrid unequal energy-efficient clustering and layered multi-hop routing approach for WSNs was proposed by Seyed Mostafa Bozorgi et al. [19]. The protocol determines the strategy based on neighbour node information, enabling layering. By reducing excess control messages, the method achieves lower energy consumption and network overhead. Simulation results demonstrate the improved stability of the proposed HEEC method compared to FHRP, LEACH-ERE, EADUC-II, and HUCL.

Salil Bharany et al. [20] presented an energy-efficient clustering methodology for data collection and transmission, optimizing the LEACH protocol. Their approach reduces energy utilization for data transmission, resulting in better packet delivery ratio and energy efficiency compared to existing LEACH protocols.

A clustering-based routing method for energy resource optimization and load balancing was proposed by Sadia Firdous et al. [21]. Their approach manages energy utilization through cluster-head rotation and distance calculation. Simulation results show a 60% improvement in average energy consumption and network lifetime compared to the LEACH algorithm.

A layered arrangement and load balancing method between Cluster Heads (CHs) for data packet management. The network is partitioned into unequal sizes to route data packets among sensor nodes, leading to improved energy consumption, network lifetime, and reliability [22].

Anshu Kumar Dwivedi et al. [23] addressed hotspot issues in WSNs by proposing balanced energy dissipation. Their method involves cluster formation and CH selection based on fuzzy inference systems. Experimental results demonstrate the superior performance of the EE-LEACH method compared to DFCR and SCHFTL protocols.

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Paper	Objectives	Advantage	Limitation	Future work
MOFCA_ CLONALG-M [25]	Improve The energy efficiency	The primary emphasis is on optimizing routing strategies to mitigate the energy hole issue. The simulation encompasses a range of network scales to verify the scalability of the proposed approach.	It does not focus on CH selection methods.	Improved comparative techniques can be employed to assess the proposed approach more effectively. To maintain its lightweight nature, online function approximation can be implemented.
DRE-LEACH [26]	Reduce the energy consumption. Improve network lifetime.	Utilizing a variable range helps narrow down the necessary calculations, resulting in reduced computational workload.	The inclusion of numerous calculations in determining node scores could potentially lead to increased energy consumption.	It is important to take into account multihop routing between cluster head environments and to regularly update routes as they dynamically change.
FA-ROA [27]	Maximize the normalized energy. Minimize the distance, delay, load, and temperature.	The primary focus is on optimizing multiple objectives. The proposed model aims to achieve a high coverage ratio while minimizing redundancy.	The algorithm could potentially encounter challenges in striking a balance between exploration and exploitation.	The proposed method can be employed for testing network traffic rate, network density, as well as the quality of service (QoS) within the network.
Yao [28]	Increase the energy efficiency.	The selection of Cluster Heads (CHs) plays a pivotal role in improving the performance of clustering algorithms	During the CH selection process, it is crucial to prioritize factors such as residual energy and the total number of clusters within the network.	It is complex than traditional cluster head selection algorithms. This may increase the computational overhead of the network.
R.K. Yadav[29]	Energy-conscious CH selection framework for WSNs using hierarchical routing and a hybrid algorithm	SLnO (Sea Lion Optimization) and the Particle Swarm Optimization (PSO) algorithms are combined in a novel hybrid approach called PDU-SLnO (Particle Distance Updated Sea Lion Optimization).	There is no comparison of the accepted method's with network delay.	The accepted method lacks a comparison with previous models in terms of network delay, energy consumption, and throughput.

These studies highlight various approaches to enhance energy efficiency, stability, load balancing, and network lifetime in WSNs, contributing to the advancements in WSN design and operation.

3. PRELIMINARIES

3.1 Leach Protocol:

As a clustering-based routing protocol, the LEACH protocol has been widely embraced to overcome the difficulties in extending network lifetime and generating scalable solutions. By grouping the nodes into clusters, which each have a Cluster Head (CH) in charge of data gathering, aggregation, and routing to the SINK node, the system tries to share the energy load across the nodes in an equal manner. A probability threshold, denoted by TH(n) (Eq. 1), which takes the probability P into account, controls the choice of CHs. To keep the battery from running out on a single node, the CH duty is alternated among nodes.

$$TH(n) = \begin{cases} \frac{P}{1-P\left[\left(r \bmod \frac{1}{P}\right)\right]}, & if\ n \in G \\ 0, & otherwise \end{cases} \quad (1)$$

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Nodes are clustered during the setup phase, and data transmission from the source to the SINK nodes takes place during the steady-state phase. To reduce overhead, the steady-state phase is lengthened. Based on the receipt of the advertisement message, non-cluster nodes join a particular CH. In the cluster, member nodes use the CH to transfer and combine received data before sending it to the SINK. Global network knowledge or control data from the SINK are not necessary for LEACH [4-6].
To improve upon the LEACH protocol, new LEACH-based protocols have addressed certain weaknesses. These include:

- Scalability: The assumption of all sensor nodes reaching the SINK can be addressed by implementing multi-hop routing and multi-level clusters.
- Energy inefficiency: Overhead and CH changes may result in inefficient usage of energy. Reducing the number of rounds during the cluster rebuilding process will help to solve this problem.
- CHs chosen depending on energy remaining: In classic LEACH, the probability of choosing CHs does not take node energy remaining into account. As a result, cluster separation and energy depletion may occur more quickly. This problem is solved by taking each node's energy consumption ratio into account.
- Unbalanced cluster partitions: Variations in the number of CHs can produce unbalanced cluster partitions, which raise energy usage.

This paper proposes an improved energy-efficient protocol called EC-LEACH to overcome these limitations and increase the network lifetime. The proposed method correlates the traditional LEACH threshold with each node's energy consumption ratio and node density, ensuring that previously elected CH nodes have another chance in the present round. If its, threshold value is less.

Table 1: List of the abbreviation.

Abbreviation	Term
WSN	Wireless Sensor Network
SN	Senor Node
CH	Cluster Head
BS	Base Station
LEACH	Low Energy Adaptive Clustering Hierarchy
EC-LEACH	Energy Cost ratio - Low Energy Adaptive Clustering Hierarchy
MAC	Medium Access Control
IRDT	Integrated Reputation driven Data Transmission

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4. PROPOSED WORK:

4.1 Energy Efficient Cluster Head Selection

The Cluster Head (CH) selection procedure in the traditional LEACH protocol begins with the creation of random integers by the various nodes. These generated random values are then put up against a predefined threshold. If a node's generated random value falls considerably below the cutoff in this situation, it becomes a CH for that round [25]. Despite the LEACH protocol's many benefits, it cannot ensure that the CH's present residual energy will be preserved. Traditional LEACH-based protocols have historically used a threshold selection mechanism, abbreviated as TH(n), which largely concentrates on the selection of nodes as CHs, regardless of their respective energy levels. When nodes with lower energy levels are labeled as CHs, this method may result in the premature depletion of energy in CHs. In response to these limitations, a novel Cluster Head (CH) selection procedure has been proposed, encompassing a comprehensive selection process based on the sensor nodes' Energy Cost ratio (EC) and Node Density. This advancement contributes to an overall enhancement in system performance, thereby extending the network's lifespan.

Node Density Calculation:
Begin by calculating the node density, which quantifies how many nodes are there in the network per unit of space or inside a given area.Typically, this calculation takes the form:
NodeDensity=Total Number of Nodes / Area of the Network

Node Density Threshold:
Next, establish a threshold value for node density, referred to as Node_Density_Threshold. This threshold serves as a benchmark for the desired or acceptable node density level within the network. It can either have a fixed value or be dynamically altered in accordance with the unique needs of the network. You might choose to set Node_Density_Threshold to 10 nodes per square meter, for example.

Probability Adjustment Based on Node Density:
The probability (Pn) of a node becoming a Cluster Head (CH) must be adjusted based on the current node density in order to maximize energy efficiency and network performance in a variety of node density situations. By balancing CH selection and node density, this modification aims to maximize the efficient use of energy resources.
A straightforward approach involves increasing Pn as node density decreases, encouraging more CHs in low-density areas. Conversely, Pn can be decreased as node density increases, thereby limiting the number of CHs in high-density areas.

Modified Threshold Function:
To accommodate the influence of both the Energy Cost ratio (EC) and the adjusted Pn based on node density, it's essential to modify the threshold function. (Equation 2). This modification ensures that CH selection is contingent on both energy consumption and node density.
The modified threshold function is expressed as follows:

$$TH(n) = \{ Adjusted\_Pn / (1 - Adjusted\_Pn) * [(r \bmod (1 / Adjusted\_Pn)) * EC + (r / Adjusted\_Pn)], \text{ if } n \text{ is in } G; 0, \text{ otherwise.}\} \quad (2)$$

In this equation:

- Adjusted_Pn represents the probability adjusted based on node density.
- r denotes the current round number.
- G stands for the group of nodes that can be chosen for CH based on the revised threshold.

By incorporating node density considerations into the protocol and dynamically adjusting CH selection probabilities, the EC-LEACH protocol can better adapt to varying network conditions and achieve improved energy efficiency and performance.

Traditionally, the LEACH protocol-initiated CH selection with the generation of random numbers by individual nodes. The CH assignment for a particular round was then determined by comparing these random numbers to a predefined threshold. Unfortunately, this method did not guarantee the retention of a CH's remaining energy, creating certain difficulties. In contrast, the proposed EC-LEACH protocol introduces a significant modification by incorporating EC into the random number generation process.
The mathematical formulation of EC is expressed through Equation (3):

$$EC = Einitial-Eresidual\ /r-1 \qquad (3)$$

Here,

- Einitial represents the node's initial energy,
- Eresidual represents the remaining energy, and r signifies the present round number.

In the subsequent round, CH selection relies on the EC values from the previous round. The node possessing the lowest EC value in the preceding round is designated as CH for the forthcoming round. Importantly, a node that served as a Cluster Head in the prior round is not automatically retained as a Cluster Head in the next round if its EC surpasses that of non-CH nodes.

In the suggested protocol, random number generation is adjusted as follows and is essential to the CH selection process. (Equation 4):

$$Randomnew=Randomold\times EC \qquad (4)$$

Where Randomnew is the adjusted random number, and EC is the Energy Cost ratio.

The protocol also includes a threshold function that accounts for the probability (Pn) of a sensor node turning into a CH, the round number (r), and the EC. The threshold function facilitates the efficient utilization of nodes' energy levels, ensuring optimal network performance.

Additionally, to maintain uniform energy consumption, the CH role is rotated among sensor nodes throughout the network. According to its selection probability, which is based on the node's energy, every node has an equal chance of becoming a CH. Based on the EC value from the previous round, CHs are chosen for the following round by prioritizing nodes with lower ECs. If a node's EC exceeds a predetermined limit, it is disqualified from CH candidacy in the following round. Only nodes with sufficiently low EC values are identified as CHs thanks to this threshold function.

Consideration is given to the additional energy requirement of CH nodes compared to others in the cluster. Low energy nodes are not chosen to be CHs in the initial round to prevent rapid energy depletion, ultimately preserving the network's longevity and system performance. CH selection probabilities are integral to determining the threshold function for all nodes, effectively utilizing their energy levels throughout the network's operation. This approach is instrumental in prolonging the sensor network's operational lifespan while enhancing its overall performance.

After the Cluster Heads (CHs) have been elected based on the Energy Cost ratio (EC), they will proceed to notify the remaining nodes about their selection for this particular round. Each CH node will communicate this information to all other nodes via a broadcast message that takes the form of an advertising. The strength of the broadcast message sent from each CH node to the Base Station (BS) will determine whether or not each node should participate in the cluster formation.

4.2 Secured Data Transmission:

By implementing a successful security strategy, the network has been protected from both known and unknown threats. In order to accomplish this, the network is divided into clusters, and each cluster elects a Cluster Head (CH) to manage its operations. The CH receives the collected data from member nodes, aggregates it, and then relays it to the Base Station (BS). This communication pattern can be described as one-to-many, with the potential for malicious nodes to mount attacks within the network. Each node bears the responsibility of not only monitoring its surroundings but also establishing mutual trust with neighboring nodes. Furthermore, this paper introduces a novel framework called the Integrated Reputation-Driven Data Transmission (IRDT) for enhancing the security of data transfer.

Within the IRDT framework, sensor node reputations are assessed based on two distinct criteria:

i. Network Reputation Rate: This rate is provided by neighboring nodes.

ii. Quality of Service (QoS) Reputation Rate: Calculated based on the node's QoS performance.

These reputations are combined to generate a composite reputation score for each sensor node. This score serves as a metric for assessing the reliability and trustworthiness of the sensor nodes. The IRDT scheme, proposed in this paper, employs these reputation scores to select forwarder nodes for each round of communication. Specifically, the node with the highest IRDT score is designated as the forwarder node for the current communication round.
The paper evaluates two types of reputation rates within the context of the proposed composite reputation-based routing protocol: QoS reputation and network reputation. QoS reputation is used to assess the energy and link quality of nodes, while network reputation is determined through both direct and indirect means.

NETWORK REPUTATION:

Network reputation that includes direct reputation (DR) and indirect reputation (IDR). Here's a formula for network reputation that follows a similar structure:

Network Reputation Score (NRS) = $w1 \cdot DRn(t) + w2 \cdot IDRnk(t)$ (5)

- NRS (Network Reputation Score): This is the calculated network reputation score for an individual node or entity within the network.

- DR_n(t): Direct Reputation of node at a specific time. It represents the reputation of the node based on its own actions and observed behavior within the network.

-IDR_nk(t): Indirect Reputation of node with respect to neighboring node (k) at time (t). Indirect reputation may consider how node is perceived by others in the network through interactions with node.

- w_1 and w_2: Weight vectors that assign weights to the direct and indirect reputation components, respectively. These weights reflect the relative importance of each component in determining the overall network reputation.

-k: The number of neighbors or nodes in the network with which node interacts. This parameter is relevant when calculating indirect reputation based on interactions with neighbors.
This formula allows for the aggregation of both direct and indirect reputation metrics, each with its associated weight. This provides a way to assess an individual node's reputation within the network, taking into account both its own actions and how it is perceived by others through interactions.

QOS REPUTATION:

The QoS reputation rate is a critical metric used to assess the quality of service in a network. It plays a vital role in identifying potentially malicious nodes that may exhibit anomalous energy consumption patterns compared to legitimate nodes due to malicious activities or unnecessary data storage. For instance, malicious sensor nodes often exhibit significantly lower residual energy (Er) compared to their legitimate counterparts. Calculating the QoS reputation of each sensor node is essential to ensure the integrity of the routing path by identifying and isolating nodes engaged in malicious activities.
In the proposed Integrated Reputation-Driven Data Transmission (IRDT) algorithm, the QoS reputation is determined by considering both energy and link quality parameters:

QoS Energy: The sensor node's residual energy, which is calculated as the difference between its original energy (Einitial) and the energy used (Econ) up to the present time (t), is used to determine the QoS energy parameter.

Following is the definition of the equation (Eq. 6) for determining the residual energy (Er(n)) of node "n" at time "t":

$$Er(n) = Einitial(n) - Econ(n) \quad (6)$$

The initial energy of node "n" is represented by Einitial in the given equation, whereas the consumed energy is denoted by Econ. Due to its irregular actions, it is generally assumed that a malicious node will have less remaining energy than the threshold value. Therefore, under the QoS reputation model, the reputation can be determined as illustrated in the following equation (Eq. 7) when the node's residual energy Eres drops below the designated threshold value:

$$QoSenergy(t) = \{ 0, \text{if } Eres < Eth$$

$$1 - Econ, \text{otherwise} \quad (7)$$

In this representation, the reputation score $QoSenergy(t)$ is determined based on whether the node's remaining energy $Eres$ is less than the specified threshold Eth. If $Eres$ is below Eth, the reputation score is set to 0. Otherwise, it is calculated as 1 minus the consumed energy $Econ$.
This calculation allows IRDT to assess the energy consumption patterns of sensor nodes and identify those exhibiting suspiciously low residual energy, which may indicate malicious behavior. By considering both energy and link quality parameters, IRDT enhances the network's ability to detect and respond to potential threats while maintaining the quality of service.

QoS Link Assessment: The quality of service (QoS) for network links is evaluated by taking into account factors such as received signal strength, link capacity, and link quality. Signals tend to degrade or attenuate as they propagate over longer distances. This phenomenon, often referred to as propagation loss, can occur due to environmental conditions and other parameters like multipath propagation. Link quality can be estimated using the following equation (Eq. 8) based on the link quality between nodes and their current coordinates:

$$QoSLQ = 1(1 - RnTxn + 1) \quad (8)$$

In this equation, LQn represents the link quality of node 'n,' Txn denotes the maximum transmission range of the node, and Rn signifies the node's radius.

Combined Node Reputation: The overall reputation of a node is determined by combining its community reputation and QoS reputation evaluations. Equation (9) illustrates the calculation of the hybrid reputation score 'TR' for node 'n':

$$TR = \text{N}RS + QoSR \quad (9)$$

Where 'CR' is the community reputation rate and '$QoSR$' represents the QoS reputation.

Node-Specific Hybrid Reputation: The node-specific hybrid reputation score 'TRn' is computed using Equation (10):

$$TRn = \alpha * \text{NRSn} + \beta * (QoSenergy + QoSLQ) \quad (10)$$

In this equation, 'TRn' corresponds to the total reputation of the node,'NRSn' is the Network reputation rate of node 'n,' and '$QoSenergy$' and '$QoSLQ$' denote the QoS reputation rates with respect to energy and link quality of node 'n,' respectively. 't' represents the current time, while 'α' and 'β'are constants satisfying the condition $\alpha + \beta = 1$, where $0 \leq \alpha, \beta \leq 1$.

Forwarder Node Selection: Based on the predicted IRDT score, the proposed IRDT system chooses forwarder nodes for the current communication round. The forwarder node for the current communication round is determined by the node with the highest IRDT score.

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Algorithm:

For all nodes `n` where `n` ∈ `N`:

Divide the nodes into `k` clusters.

End for.

For all nodes `n` where `n` ∈ `K`:

Calculate the Node density `nd`.

Generate the candidate list ‘CL’.

For all nodes in the candidate list

Calculate the threshold `TH(n)`.

Estimate the randomness `r(n)`.

Calculate the Energy Cost ratio ‘EC’

Calculate the new randomness `r(n-new) = r(n) * EC_n`.

If `r(n-new) ≤ TH(n)`:

Select `n` as the cluster head.

End if.

End for.

For all nodes `n` where `n` ∈ `K`:

Calculate the direct reputation ‘dr_n’.

Calculate the indirect reputation ‘idr_n.

Calculate the network reputation ‘nrs.

Calculate the QoS-energy reputation ‘qos_energy_reputation’.

Calculate the hybrid reputation ‘hybrid_reputation’.

hybrid_reputation = alpha * nrs + beta * qos_energy_reputation

Select the next-hop node with the highest hybrid reputation.

End For

5. PERFORMANCE AND RESULT ANALYSIS:

5.1 Evaluation Metrics:

The proposed LEACH - EC undergoes simulation, with performance assessment conducted using NS2. A comparative analysis is performed against the SRN-LEACH [24], DEE approach [22], and EE-LEACH [23] mechanisms. The sensor nodes are dispersed at random over a network field that is 1000m by 1000m in size. The network size spans from 100 to 500 sensor nodes, and each sensor node starts out with an energy level of 100 j. During data transmission, a CBR traffic agent is used to assure consistent data traffic creation. UDP is a data transmission protocol. For information on the experimental parameter values, see Table 2 below.

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Table 2. The variables for the experiment

Parameter	Value
Network area	1000x1000
Number of nodes	100 to 500
Cluster size	8
Initial energy	100j
Packet size	1024
Routing Protocol	AODV

The key parameters serving as evaluation metrics are detailed as follows:
Network Lifetime: This metric counts how many network rounds a node can participate in. A node's longer survival time indicates a longer network lifespan.

Energy Consumption: These metrics give an estimate of the energy used by each network node during a single round. When all nodes provide data to the base station, the round is deemed finished.

Average Energy: After the simulation, the average energy metric assesses the remaining energy across all nodes.

Throughput: The total number of data packets transferred to the base station during each round of operation is referred to as throughput.

5.2 Result Analysis:
To facilitate network operations, the sensor nodes are initially endowed with 100j of energy. Throughout each network operation, energy is expended, necessitating optimization to extend network longevity. The Energy Cost ratio (EC) is employed to designate Cluster Heads (CHs) and relay nodes boasting higher rates of successful transactions. This selection eliminates the need for retransmissions and other energy-intensive activities, consequently reducing overall energy consumption within the proposed network. The recorded average energy consumption rate in the proposed approach was 4.2j. The simulation results are presented in the table above (Table 3), and the graphical representation of energy consumption is depicted in Figure 2.

Table 3: Energy Consumption:

Node	Proposed	SRN-LEACH[24]	EE-LEACH[23]	DEE[22]
100	3.80	3.95	4.01	4.54
200	4.05	4.13	4.28	4.9
300	4.23	4.41	4.61	5.34
400	4.48	4.59	4.99	5.88
500	4.85	5.01	5.40	6.4

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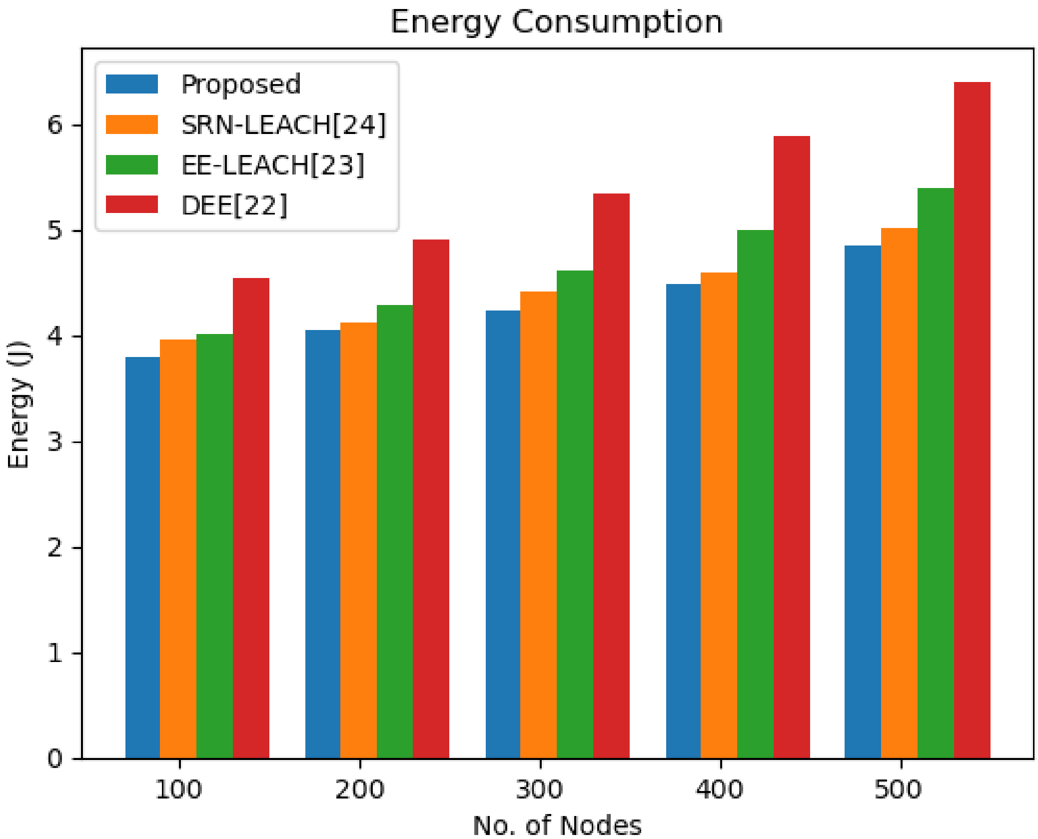

Fig. 2: Comparison graph of energy consumption

The length of time that specific network operations are carried out is known as the network lifespan. In our study, the residual energy of each sensor node over a given period of time is connected with the network longevity. Longer network lifetimes are correlated with higher quantities of leftover energy. The data in Table 4 shows that, in comparison to current methods, the suggested solution greatly extends network lifetime. Figure 3 shows the experimental data for reference.

Table 4: Network Lifetime

Node	Proposed	SRN-LEACH[24]	EE-LEACH[23]	DEE[22]
100	96.1	96.06	95.99	95.46
200	95.95	95.87	95.72	95.1
300	95.7	95.59	95.39	94.6
400	95.5	95.41	95.31	94.12
500	95.1	94.99	94.6	93.66

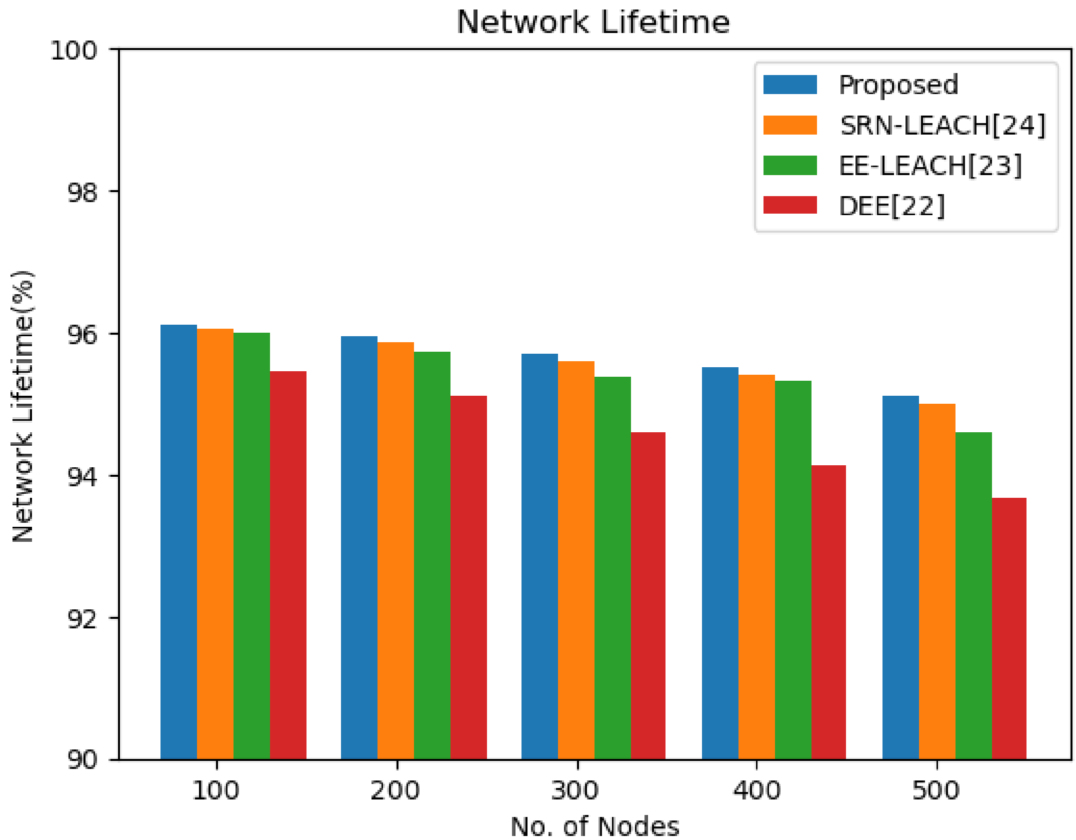

Fig. 3: Comparison graph of Network Lifetime

Throughput, another crucial parameter, is determined by the processing of the total data units within a node over a specified time frame. Optimal data aggregation is realized through the implementation of energy-constrained Cluster Head (CH) selection using Consumed Energy Ratio (CER) and optimal relay selection based on link quality and energy, as indicated by the Quality of Service (QoS) reputation. The proposed technique achieves a higher throughput rate compared to previous methods. As demonstrated in Table 5, the proposed method maintains an average throughput rate of up to 389 kbps, surpassing the throughput rates of existing methods. Network performance is visually represented in Figure 4.

Table 5: Throughput

Node	Proposed	SRN-LEACH[24]	EE-LEACH[23]	DEE[22]
100	387	358	340	309
200	388	362	341	308
300	390	358	339	308
400	389	371	342	309
500	389	377	344	311

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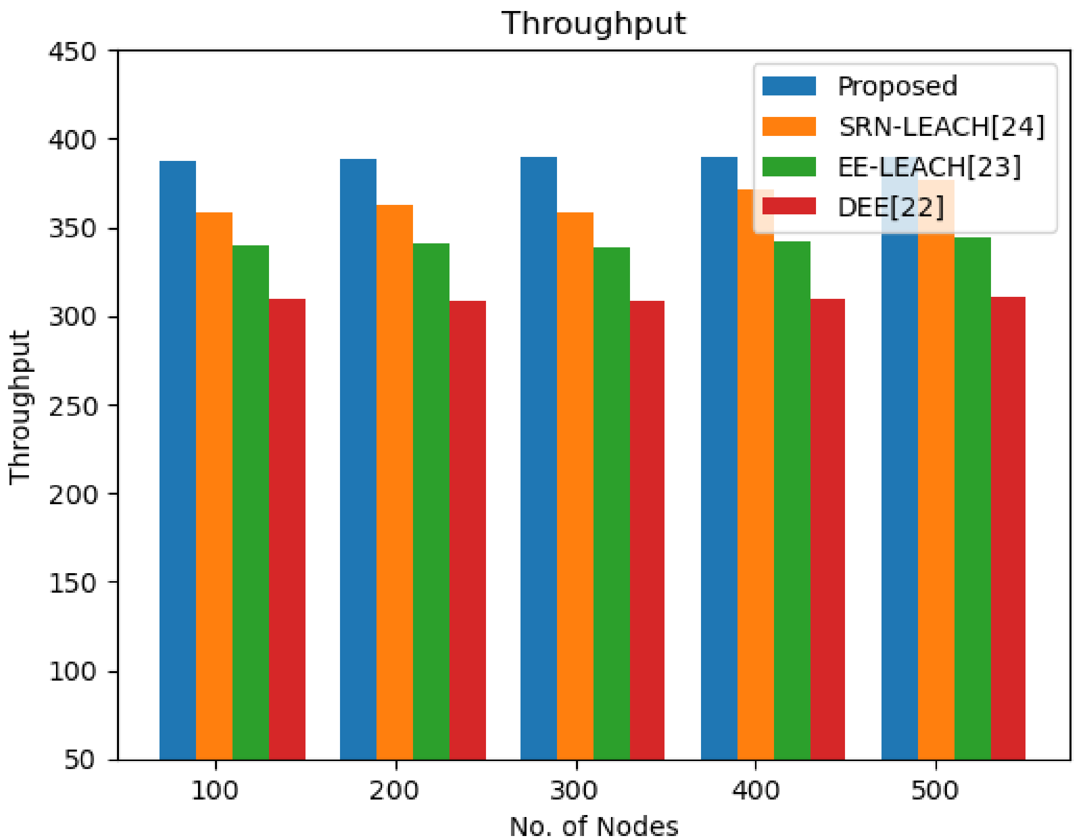

Fig. 4: Comparison graph of Throughput

6. CONCLUSION

This paper presents EC-LEACH, an enhanced LEACH-based clustering algorithm, to optimize network performance, including network longevity, energy efficiency, and dependability. Additionally, this approach is introduced to enhance energy efficiency, cluster head (CH) stability, and secure data transmission. Furthermore, an Integrated Reputation-Based Data Transmission (IRDT) scheme is introduced to ensure secure data transmission, where the reputation rate serves as a measure of sensor node reliability and trustworthiness.

The research and simulation findings show that EC-LEACH performs better than existing methods in wireless sensor networks (WSNs) in terms of energy consumption, network longevity, and secure communication. A 3.4% boost in throughput and a 0.13% extension in network lifetime are just two examples of the major improvements in quality indicators that can be seen in the results. The suggested approach also results in a 23.95% reduction in energy use.

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