EQT-LEACH: A Low-Energy Adaptive Clustering Hierarchy with Enhanced CH Selection and Data Aggregation

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Abstract - The significance and need of wireless sensor networks (WSNs) in many applications have been the subject of much study. The biggest problem with wireless sensor networks is energy depletion, which can be solved by lowering energy consumption and extending network lifespan. In WSN, energy-aware routing protocols are crucial, however those that just take energy parameters into account struggle to effectively reduce excessive energy use. Network node interference causes a rise in energy usage and packet loss. To increase the network's lifespan, the routing techniques should strive for load balancing and energy economy among the various nodes. One of the best methods for effectively aggregating data from the sensor nodes is clustering. One of the most often used clustering techniques for WSNs is a low-energy adaptive clustering hierarchy (LEACH). Unfortunately, there are some restrictions. In this study, we propose EQT-LEACH to enhance the energy efficiency, CH stability, and equitable distribution of CH role. The proposed upgraded protocol considers the estimated energy remaining in the nodes and the estimated energy utilized in the previous round for the purpose of choosing the CH along with generating random numbers. Its objective is to prevent this round's previously selected CH node from receiving another chance. This method correlates each node's energy consumption ratio with the threshold employed in traditional LEACH. The suggested data aggregation method evaluates the error as well as delay rates together with the connection lifespan of every viable routing option in order to aggregate the data across traffic-free channels. The experimental findings demonstrate that, in comparison to the current energy-efficient data aggregation strategies, the suggested approach extends the network lifespan.

Keywords: LEACH, Cluster head selection, EQT-LEACH, Data aggregation, Link error rate, Link lifetime

I. INTRODUCTION

WSNs are usually made up of a bunch of small, cheap sensing nodes. The main job of the nodes is to send different kinds of data to the Base Station (BS) using either a single-hop or multi-hop data transfer method. WSNs are used for a lot of different things, like tracking targets, keeping an eye on the fight, and keeping an eye on the surroundings. The batteries that power sensor nodes can't be replaced [1]. So, the main limit in WSN is how much power each sensor point uses, which determines how long the network will last. Sensing, computing, and radio connection are the main things that a sensor node can do [2]. Communication takes up more power in sensor nodes than sense and computing.

Diverse forwarding methods have been embedded into WSN to reduce the data transmission for the reason of save energy. Sensor point in a WSN transport the data to the BS located in the centre of network. When the sensor node is further from base station it requires high power consumption, because over-long distance the data packet has to move [3]. These "bottleneck zones" which are the sensors closest to the base station see a high traffic, using the node battery even more. As a result, the bottleneck zone's nodes die faster, which shortens the network's lifespan and makes it harder for it to connect to other networks.

Routing systems that only look at energy are not good at what they do. Using other factors makes forwarding procedure more efficient as well as saving energy. There are different factors that should be thought about for each application [4]. How to handle distractions is one of the most important factors. When interference happens, more packets are lost and more network energy is used. There are different reasons why interference happens in networks. One major reason is that relay network sites don't have a lot of store room.

It's called interference when a node gets too many packets, which causes many of them to be lost. Interference occurred in WSNs for much the same reasons. Interference will arise, for instance, when many nodes concurrently choose to transmit packets utilizing a common media.

One of the interesting and effective ways to raise the energy efficiency is clustering. The most underlined strategies have been the cluster development and many data transmission channels [5]. Fig 1 shows the conventional clustered network design.

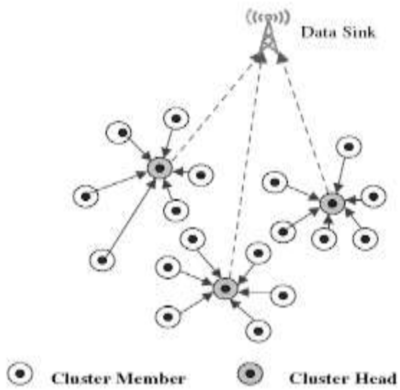

Fig 1: Network topology of a clustered WSN

Cluster-based routing techniques, as opposed to non-clustering protocols, may make better use of network sensor nodes. A CH is responsible for removing related data that may decrease the overall amount of data available. After then, the BS would receive the combined data from the CH. In order to reduce energy consumption throughout communication over long distances, sensor nodes are divided into clusters using cluster-based routing protocols. Clustering can assist in lowering overall energy consumption and distributing the load among nodes due to the significant disparity in energy loss between the cluster leaders along with other nodes [6]. Hence, clustering presents a power-efficient means to spread network lifetime then achieve energy efficiency. Moreover, most of clustering approaches furnish the optimal CH selection for delaying network death and avoid sensor node exhaustion prematurely [7]. a means to operationalize energy efficiency and preservation of life cycle.

The LEACH protocol enables an extended network lifespan. Nonetheless, there exist some shortcomings that can be remedied to enhance the efficacy of novel LEACH-oriented procedures. Here are some of these issues along with their fixes.

- LEACH relies on a random selection process to choose cluster heads which can lead to premature death of CHs.

- LEACH affects the protocol's scalability by assuming that every node can reach the sink. Multi-level clusters along with multi-hop routing capabilities can be used to address this.

- The associated overhead because variations in CH result in inefficient utilization of energy. Reducing the number of rounds in the cluster rebuilding phase is unique way to solve this issue.

- If a cluster head with low energy is selected or dies prematurely, the data from all its member nodes is lost.

In this study, we propose a unique enhanced LEACH (EQT-LEACH) to further extend the lifetime of WSNs and solve these shortcomings of existing techniques. In order to avoid the previously elected CH node from being given another opportunity in the current round, the suggested strategy links the threshold utilized in standard LEACH with each node's energy ratio. In this study, we offer an effective data aggregation strategy to improve network lifespan through energy efficiency. The suggested data aggregation strategy estimates the delay rate (DR), link error rate (LER), and link lifespan (LL) of all feasible routing options in order to aggregate the data over interference-free channels.

Contributions in this paper

- • The anticipated remaining energy of sensor nodes is employed to generate random numbers and set the threshold for balancing energy consumption alongside network longevity.
- The former CHs are not chosen as CHs in the next round due to more data aggregation work. This is because CH has consumed much more energy compared to the non-CH nodes in the previous round. It prevents the already-selected CHs node to be reselected in next rounds.
- The proposed efficient in terms of energy data aggregation platform intends to minimize costs while maintaining end-to-end connectivity and interference management.

II. LITERATURE SURVEY

Pramod Singh Rathore et al [8] provided a novel strategy for selecting CHs for use in this study. The cluster head's role is determined by the nodes' proximity and energy levels. The quickest route relay node idea is being used to choose cluster heads in order to increase sustainability of energy along with network longevity. When a limited number of subcluster nodes experience high load, this leads to accelerated energy consumption, necessitating the initiation of the designated trajectory cluster to attain standard energy depletion. The distances between the clusters significantly influence energy usage.

Anurag Shukla et al [9] proposed a hierarchical clustering approach for network deployment and an efficient Relay Node (RN) selection method considering the node density in a cluster, selecting the closest neighbour as RN and choosing its communication range to be used as criterion of next RN selection. A recommended official routing mechanism that would meet the model. The protocol has been evaluated against conventional WSN routing protocols.

Mandli Rami Reddy et al [10] presented a variation to GWO (EECHIGWO) for sustainability of energy

CH choosing problem to deal with the concern of premature convergence and diversity imbalance in exploration and exploitation of original GWO algorithm. In the context of cluster head selection, this paper investigates a new and indepth application: cluster head reinforcement using EECHIGWO aiming at enhancing the average throughput, energy efficiency, network lifetime, and stability of WSNs.

M. B. Shyjith et al [11] developed a hybrid optimization technique for CH selection. Employing this metric, choosing a CH is split into three stages: setting up, transfer, along with assessment. At the start of the simulation, a network is formed and given energy and node mobility. During setup, CH is chosen using Efficient Sleep-awake Energy-Efficient Distributed Clustering, which provides the optimal threshold, and CH is found using the suggested Rider-Cat Swarm Optimization (RCSO) technique. The created RCSO is built using the Rider Optimization Method along with Cat Swarm Optimization. In this scenario, the threshold along with CH are determined by time, energy, along with distance multi-objective constraints. Then, data transfer from the CHs to the base station begins. The nodes' residual energy are updated during the evaluation period.

Turki Ali Alghamdi et al [12] employed four criteria: energy, latency, distance, along with safety, a novel clustering methodology is generated, along with optimum CH choosing. This paper also presents a unique hybrid method called fire fly substituted placement update in dragonfly, which combines the ideas of both the Dragon fly along with Firefly strategies to identify the best CHs.

Santanoo Madhu et al [13] suggested a technique that is location agnostic. Because there is no location, the energy loss that happens when GPS modules are functioning is minimized, allowing the sensor nodes positioned beneath gateways, known as CHs, to be clustered into clearly defined load balanced clusters. The proposed approach is emulated and its outcomes are compared to those of a few different methods that already available.

Panimalar Kathiroli et al [14] developed a hybrid Sparrow Search method that combines Differential Evolution and Sparrow Search to choose the cluster head, therefore resolving the problem of reducing energy consumption in WSNs. The suggested technique makes use of Differential Evolution's dynamic potential and the great search efficiency of the Sparrow Search strategy to extend node lifetimes. The effectiveness of the hybrid model appears to be increasing the total number of nodes (living and dead), throughput, along with residual energy.

III. PROPOSED MODEL

Proposed EQT-LEACH method

This section details the proposed CH selection procedure as well as how it mitigates the randomness issue. A random number is multiplied with the estimated energy consumption of nodes based on dropping packet at previous round and expected residual energy (to force suggested method depending on the node's charged).

The nodes in the non-secure scheme present in LEACH generate a random number for the initiation of CH selection. Then, it contrasts that found number with a threshold. If we obtain some or another random value, smaller thant the threshold- the node turns into a CH for this round. However, the LEACH method was not able to provide this although its benefits since the current residual energy of it cannot be assured for ever employed CH. In traditional LEACH-based protocol, only the probability that a node is selected as CH will be considered and when calculating the threshold TH(n), the energy of nodes is ignored. In such a way, CHs are randomly chosen however when in case some node is selected to be the CH with lesser energy, it will terminate at once.

The proposed way of selecting CH, which considers the energy used in the last round along with predicted remaining energy, leads to enhancement in system performance and network life.

CH selection

This simple shift in the way random number are generated enables efficient selection of CHs with energy consumption. It multiplies the random number to amount of energy estimated spend in last round and desired energy left with sensor nodes. This dependency on the energy of the nodes is dramatically magnified when these components are compounded into the process of producing random numbers. The following provides an explanation of the estimated energy spent in the previous round and the projected remaining energy in the proposed round:

Predicted residual energy: The estimated residual energy, the difference between the node's starting energy (e_i) and total energy spent (e_{ec}) thus far is known as PR_e. Because the prediction of energy skips the weaker nodes in CH candidate participation, PR_e is assessed here rather than residual energy.
The anticipated energy that node "n" will have left is provided by

$$PR_e^T(n) = e_i^T(n) - e_{ec}^T(n)$$

Where, E_{ec} of n is

$$e_{ec}(n) = e_{i,n} + e_{n2S} + e_{el} + e_{ae}$$

Here, $e_{i,n}$ & e_{n2S} are the transmitting energy for "l" bits from node "i" to "n" and "n" to base station S or sink, respectively, and e_{ae} is aggregating energy of a data, e_{el} is energy consumed by the receiver circuit per bit.

$e_{i,n}$: Energy for "l" bits is sent from node i to node n.

e_{n2S}: Energy transfer from node n to sink or base station S.

e_{ae}: Energy required for aggregating the data.

e_{el}: The energy utilized by each bit in the receiver circuit.

Energy Spent in the Previous Round: The percentage of energy used up in the sensor rounds during the preceding rounds is the definition of the parameter Energy Spent in the Previous Round. In order to avoid the same node from being chosen as CHs in the next rounds, it is crucial to examine this value. The following is the mathematical expression for this parameter:

$$ESR = \frac{e_i^T - e_r^T}{(r-1)_T}$$

Where, $e_i^T$is initial energy ande_i^T, is residual energy of every node and r is present round at time T. In the next round, CH will be selected based on ESR from the previous round. Because of its extraordinarily high ESR compared to non-CH nodes, a CH from the previous round will not be selected as a CH in the next round.

The standard LEACH representation for a normal random integer is $rand\ (n)$. The following equation may be used to illustrate the enhanced random number process in the suggested approach.

$$rand(n)' = rand(n) * (ESR_n + PR_n)$$

The sensor nodes' threshold values are now compared with an enhanced random number. A key element in the CH selection process is the threshold function. This function uses the probability values of nodes to determine the CH. Efficient energy utilization by the nodes in the threshold function can significantly impact the network's performance.

To balance energy consumption, each network node takes turns being the CH. Every node has an equal chance of selection based on the CH probability, which is influenced by the node's energy. The proposed method's threshold function considers the energy levels of all nodes across the network.

The threshold function compares the modified random number to the threshold value.

$$rand(n)' \leq TH(n)$$

Where $TH(n)$ can be denoted as:

$$TH(n) = \begin{cases} \dfrac{P_n}{1 - P_n\left[\left(r \bmod \dfrac{1}{P_n}\right)\right]} * (ESR + PR) + \dfrac{r}{P_n}, & if\ n \in G \\ 0, & otherwise \end{cases}$$

P_n = probability of n to become CH,

r = round number.

If the random value is smaller than the threshold, the node is selected as the CH; if not, the algorithm advances to the next node. The chosen CHs will inform the other nodes of their decision for the present round when the CH picking procedure is over. Every other node receives a message from each CH that contains an advertisement. A member node's choice to join a particular cluster is determined on the intensity of the signal it receives from the broadcast of the CH.

Proposed data aggregation scheme

In this research, we present an energy efficient data aggregation strategy based on connection lifespan parameters, delay rate, and error rate to achieve more dependable data transmission in WSN. For each communication cycle, the aforementioned parameters of all accessible connections are calculated in order to create potential routing pathways from source nodes to CHs.

Delay Rate: When a node obtains extra packets than it can forward, interference happens, leading to delays as well as packet loss. The time among two consecutive packet arrivals at a node is called the packet arrival time (t_p), which is inversely related to the packet arrival rate (r_p). Similarly, the packet service time (s_t) and packet service rate (s_p) also have an inverse relationship. The packet service time refers to the interval between when a packet arrives and when it is forwarded. The total waiting time (t_w) includes the time spent in the queue waiting for other packets to be processed, as well as any time waiting for retransmission.

$$r_p = {}^{1}/_{t_p}$$

A node is subjected to less delay if the interference is less. The interference aids in identifying communication delays. It is measured as the packet arrival rate divided by the packet service rate. The cost of the route is calculated using the following formula, which takes into account CH interference:

$$d_r = \sum_{i=1}^{n} n_{inf}$$

$$n_{inf} = r_p / ({}^{1}/_{s_t})$$

The d_r is more if r_p is greater than s_r and indicates node has experienced interference. Larger the d_r value, result in more interference and delay at the given node.

Link Error rate: Wireless channel error rate is a traditional issue affecting sensor network operation. High error rate links increase routing costs and prevent data aggregation. Therefore, considering link error rate is crucial for improving energy efficiency during data aggregation. The metric e_r between nodes i, j can be described as follows:

$$e_r = d_i, j / b_s^j$$

Where, $d_i, j \text{ and } b_s^j$ are the distance between node i, j and buffer size of the node j respectively.

Link life time: The link lifetime (l_t) is a crucial parameter in predicting the maximum duration of data transfer between sensor nodes in each cluster. A higher l_t value indicates a larger network lifetime, as it considers multiple parameters and the link between sensor nodes. l_t is formulated as follows

$$l_t = \frac{2 \times e_x + e_n}{\beta + s_p + r_p + t_r + \|d_x - d_n\|}$$

where, s_p is packet sending rate, r_p is packet receiving rate, t_r is the transmission range and β represents the constant value, $e_x \text{ and } e_n$ are the energy of normal node along with CH and $\|d_x - d_n\|$ is the distance between the nodes.

Data transmission phase

The route selection standards are applied by the CH to assess all links that are accessible. After determining the best routes, the CH creates a routing table for every cluster node. For the best-selected route, a unique record is added to the routing database.

The routing tables are subsequently dispersed to each cluster node by the CH. Every node gets its routing table by the time this operation is complete. This step's main goal is to ascertain each incoming packet's next hop at each node, guaranteeing effective data transfer throughout the network. Following the reception of a data packet, the receiving node carries out the following tasks: The data should be sent straight to CH if that is the next hop node. If not, look for neighbors that are available. If neighbors are located, compare each neighbor's d_r value, designate the node with the lowest $d_r, e_r \text{ and } l_t$ value as the forwarder node, then forward the data to that node. Choose the node with $e_r \text{ and } l_t$ and send the data if all of the neighboring nodes have comparable d_r values.

Energy analysis

In the whole sensor region, let N be the total number of sensor nodes. Since there are k sensors in the created cluster, the separated region contains N/k clusters. The sensor nodes uniformly send M bits of data. The energy necessary to send and receive " l " bits of data at a distance of D_n is given by the Radio Energy Dissipation framework of the sensor node as $E_{trans}(l, d)$ and $E_{recv}(l, d)$, respectively. This means that

Let N represent the total quantity of sensor nodes in the whole sensor area. The quantity of sensors in the generated cluster is k, meaning that there are N/k clusters in the separated region. M bits of data are transmitted evenly by the sensor nodes. According to the Radio Energy Dissipation framework of the sensor node, the need of energy to send and receive "l" bits of data across a distance of D_n is $E_{trans}(l, d)$ and $E_{recv}(l, d)$ respectively, such that

$$E_{trans}(l, d) = \begin{cases} lE_{ec} + l\varepsilon_{fs} d^2, & d \le d_0 \\ lE_{ec} + l\varepsilon_{mp} d^4, & d \ge d_0 \end{cases}$$

$$E_{recv}(l, d) = lE_{ec}$$

Path loss exponent (n) determines the amount of energy needed for transmission; n = 2 for open space and 4 for multipath interference. The energy used by the transmitter and receiver electronics for a single bit is measured as E_{ec}. The distance "d" is the separation between the transmitter and receiver. Based on the route loss exponent, the transmitter amplifier's energy consumption is determined by ε_{fs}, ε_{mp}. The "m" bits of data are consolidated into less "h" bits since the sensor nodes carry out aggregation. E_{CD} provides the energy usage of the CH model, which usages centralized data aggregation. E_{SD} provides the energy consumption of the proposed Data Aggregation procedure employed in the sensor node. The energy gain E_{gain} that the suggested approach produces for a cluster is,

$$E_{SD} = m\left(E_{ec} + \varepsilon_{fs} d^2\right) + mE_{ec}$$

$$E_{CD} = h\left(E_{ec} + \varepsilon_{fs} d^2\right) + hE_{ec}$$

$$E_{gain} = E_{SD} - E_{CD}$$

$$E_{gain} = (2m - h)E_{ec} + (m - h)\varepsilon_{fs} d^2$$

Since there are N/k clusters in the sensor region. The Total energy gain of the proposed method is given by

$$Total_{gain} = \left(\frac{N}{K}\right) E_{gain}$$

Algorithm

For all the nodes 'n' where $n \in N$

Divide the nodes as 'k' clusters

End for

CH selection

For all node 'n' where $n \in k$

Calculate $RAND, ESR, PR$

$rand(n)' = RAND(n) * (ESR_n + PR_n)$

$TH(n) = \{ th * (ESR_n + PR_n)\}$

If $rand(n)' \leq TH(n)$

$CH \rightarrow n;$

End if

End for

Data transmission

For all the available paths

Calculate d_r, e_r, l_t

If $(d_r(n), e_r(n)$ & $l_t(n) == low)$

$n \rightarrow forwarder$

Else

$n = n + 1$

End if

End for

IV. SIMULATION RESULTS AND ANALYSIS

Simulation setup

The proposed EQT-LEACH is simulated with NS2, and its performance is calculated and compared with existing techniques. The sensor nodes are randomly distributed around the network area. The network area measures 1000 by 500 meters. The initial energy of each sensor node is 100 j. The network consists of between 50 and 200 nodes. The constant bit rate (CBR) traffic agent creates consistent traffic throughout data transfer. UDP is the protocol used to transport data. The experimental parameter values are displayed below table 1.

Table 1: Network Simulation table

Parameter	**Value**
Total Network area	1000 m x 500 m
Total Sensor Nodes	50 to 200
Size of Cluster	4
Energy of Node	100j
Size of Packet	1024 bytes
Routing protocol	AODV

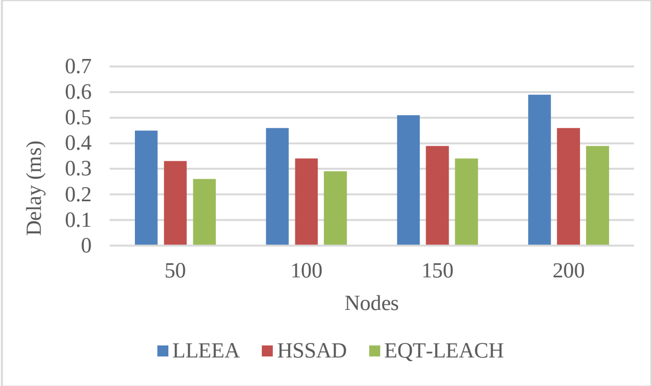

Fig 2: Network delay performance

The duration of a packet's network travel from its source to its destination is referred to as the "end-to-end delay". The calculation of the suggested approach's end-to-end delay time is shown by the fig 2. Using a random number together with energy expenditure and consistent CH selection reduces CH rotation. Additionally, low overhead relays are selected using the relay selection process of the QoS reputation model, which also minimizes end-to-end latency by utilizing connection quality and longevity. Unlike the suggested approach, the prior approaches encountered significant delays of up to 0.59 ms, with the lowest average delay in the network being 0.26 ms.

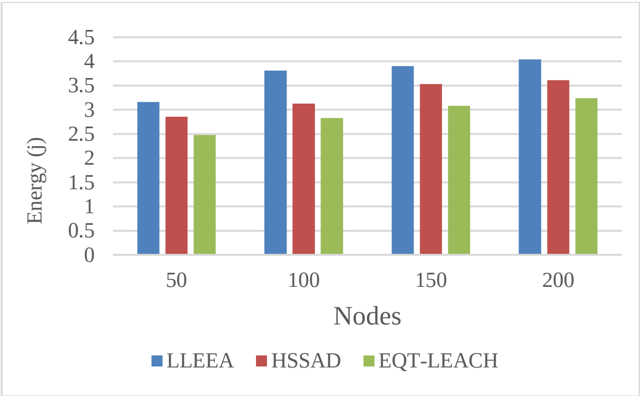

Fig 3: Performance of Energy consumption

The sensor nodes have an initial energy of 100j to carry out network operations. With each network action, energy is used. Every network should optimize its energy use for extended periods of network operation. By using energy-correlated random numbers in the CH selection process and choosing relay nodes with reduced interference values, the proposed network's low energy consumption is achieved by doing away with the necessity for retransmission and other energy-intensive network activities. The suggested strategy yielded an average energy consumption rate of 2.8j. Fig 3 shows the overall energy consumption.

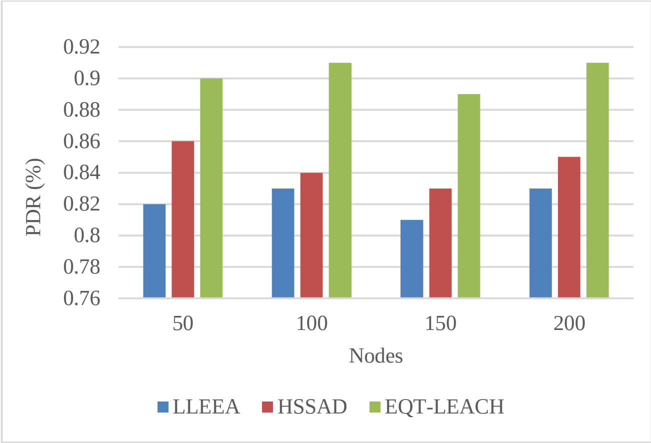

Fig 4: Packet delivery ratio

The packet delivery ratio (PDR) is the ratio of data packets received at the receiving end to those transmitted by the sender. Effective relay selection facilitated data aggregation, which increased transmission rates. The selection of dependable and balanced CHs, as well as the best relay selection utilizing the QoS parameter, greatly help in the effective flow of data between sensor nodes. While the current tactics sustained an average PDR rate of 0.80, which is a relatively low PDR rate, the new strategy reached a maximum PDR of 0.91%. Fig 4 represent the delivery ratio of network.

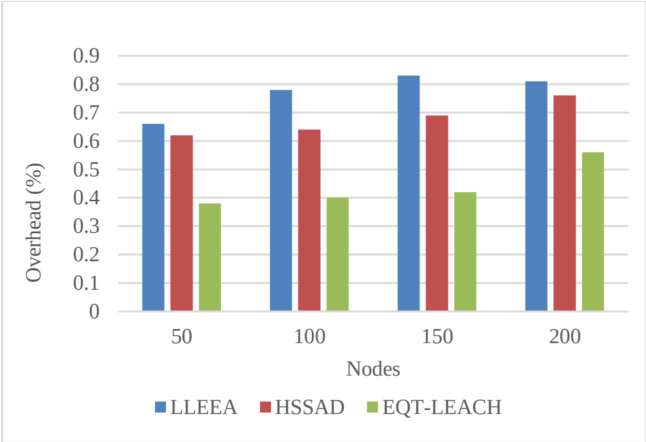

Fig 5: Network overhead

The overhead is based on how many control packets are delivered across the network while transferring data. While the overhead in the known approaches ranged from 0.66 to 0.81, the average overhead in the suggested method was reported at 0.36. The chosen pathways are guaranteed to be free of inference by using QoS selection factors to optimize relay selection. Therefore, the suggested technique maintains a minimal overhead. The network overhead performance evaluation shows in fig 5.

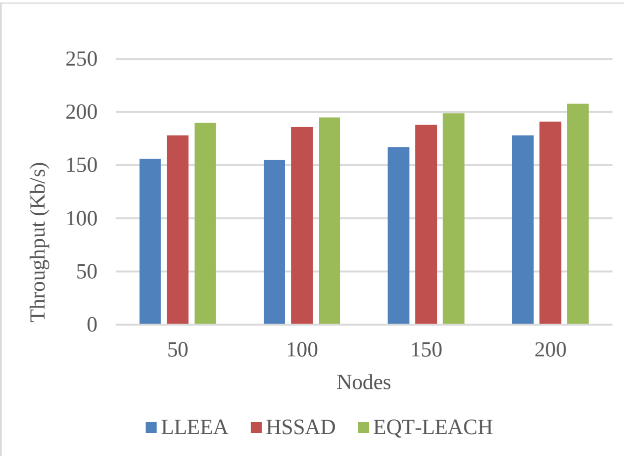

Fig 6: Network performance

The quantity of data units that a node can handle in a specific length of time is known as throughput. To get the best possible data aggregation, the energy-constrained CH selection with the optimum relay selection along with the energy wasted value is applied. The accompanying table illustrates how the proposed strategy yields a high throughput rate in comparison to existing methods. While the existing ways maintained a lower throughput rate than the recommended approach, the suggested approach maintained the maximum throughput rate of up to 208 kbps throughout the testing.

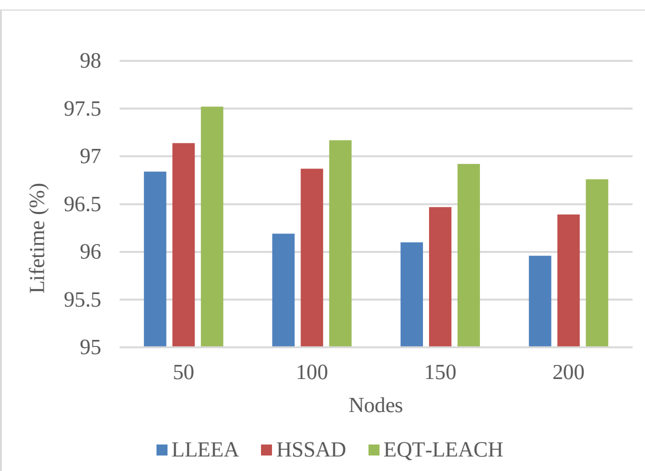

Fig 7: Performance of network lifetime

It describes the duration of the network's functioning or the time it takes for a sensor node, or set of sensor nodes, to run out of energy. In our experiment, the amount of energy that the network has left over after completing its tasks is correlated with the network longevity. A longer lifespan for the network translates into more energy left. The results in the preceding table demonstrate that, in comparison to the current approaches, the suggested solution greatly extends the network lifespan. Fig 6 shows the network lifetime.

V. CONCLUSION

In this research, we suggested a novel and improved LEACH-based clustering method to increase the longevity, energy efficiency, and efficient data aggregation of WSNs. The paper proposes EQT-LEACH, an improved clustering algorithm that addresses these issues. For the purpose of choosing a CH, EQT-LEACH takes into account variables such as estimated remaining energy and energy used in prior rounds. It attempts to stop previously elected CHs from being selected again right away and dynamically modifies the selection threshold for CHs according to the energy consumption ratio of each node. Traffic-free pathways are used by the data aggregation strategy while taking connection lifespan, error rate, and delay rate into account. The experimental results demonstrate that EQT-LEACH improves network lifetime compared to existing schemes.

VI. REFERENCES

[1] Hemanth Kumar, G., G. P. Ramesh, and C. Ravindra Murthy. "Energy efficient multi-hop routing techniques for cluster head selection in wireless sensor networks." *Further Advances in Internet of Things in Biomedical and Cyber Physical Systems* (2021): 3-9.

[2] Dattatraya, Kale Navnath, and K. Raghava Rao. "Hybrid based cluster head selection for maximizing network lifetime and energy efficiency in WSN." *Journal of King Saud University-Computer and Information Sciences* 34, no. 3 (2022): 716-726.

[3] Kumar, Anil, Julian L. Webber, Mohd Anul Haq, Kamal Kumar Gola, Pritpal Singh, Sathishkumar Karupusamy, and Malik Bader Alazzam. "Optimal cluster head selection for energy efficient wireless sensor network using hybrid competitive swarm optimization and harmony search algorithm." *Sustainable Energy Technologies and Assessments* 52 (2022): 102243.

[4] Umbreen, Sehar, Danish Shehzad, Numan Shafi, Bilal Khan, and Usman Habib. "An energy-efficient mobility-based cluster head selection for lifetime enhancement of

wireless sensor networks." *Ieee Access* 8 (2020): 207779-207793.

[5] Rawat, Piyush, and Siddhartha Chauhan. "Particle swarm optimization-based energy efficient clustering protocol in wireless sensor network." *Neural Computing and applications* 33 (2021): 14147-14165.

[6] Maheshwari, Prachi, Ajay K. Sharma, and Karan Verma. "Energy efficient cluster based routing protocol for WSN using butterfly optimization algorithm and ant colony optimization." *Ad Hoc Networks* 110 (2021): 102317.

[7] Adumbabu, I., and K. Selvakumar. "Energy efficient routing and dynamic cluster head selection using enhanced optimization algorithms for wireless sensor networks." *Energies* 15, no. 21 (2022): 8016.

[8] Rathore, Pramod Singh, Jyotir Moy Chatterjee, Abhishek Kumar, and Radhakrishnan Sujatha. "Energy-efficient cluster head selection through relay approach for WSN." *The Journal of Supercomputing* 77 (2021): 7649-7675.

[9] Shukla, Anurag, and Sarsij Tripathi. "An effective relay node selection technique for energy efficient WSN-assisted IoT." *Wireless Personal Communications* 112, no. 4 (2020): 2611-2641.

[10] Rami Reddy, Mandli, M. L. Ravi Chandra, P. Venkatramana, and Ravilla Dilli. "Energy-efficient cluster head selection in wireless sensor networks using an improved grey wolf optimization algorithm." *Computers* 12, no. 2 (2023): 35.

[11] Shyjith, M. B., C. P. Maheswaran, and V. K. Reshma. "Optimized and dynamic selection of cluster head using energy efficient routing protocol in WSN." *Wireless Personal Communications* 116 (2021): 577-599.

[12] Alghamdi, Turki Ali. "Energy efficient protocol in wireless sensor network: optimized cluster head selection model." *Telecommunication Systems* 74, no. 3 (2020): 331-345.

[13] Madhu, Santanoo, Ravi Kumar Prasad, Prashant Ramotra, Damodar Reddy Edla, and Amruta Lipare. "A location-less energy efficient algorithm for load balanced clustering in wireless sensor networks." *Wireless Personal Communications* 122, no. 2 (2022): 1967-1985.

[14] Kathiroli, Panimalar, and Kanmani Selvadurai. "Energy efficient cluster head selection using improved Sparrow Search Algorithm in Wireless Sensor Networks." *Journal of King Saud University-Computer and Information Sciences* 34, no. 10 (2022): 8564-8575.