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Article

Dynamic Routing and Energy Optimisation in Heterogeneous WSNs With Enhanced LEACH Algorithm

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Abstract: -Wireless sensor networks (WSNs) are energy-constrained, and their operational lifetime is compromised. Energy-efficient routing is a key factor in wireless sensor networks, as these nodes do not have the same energy resources as those in heterogeneous WSNs. This paper aims to enhance dynamic routing protocols to improve LEACH performance in heterogeneous WSNs.The present method increases energy efficiency by using real-time adaptive schemes to sustain network efficiency through residual energy through cluster head selection and a preferential energy-efficient strategy. In heterogeneous WSNs, hierarchical routing protocols is demonstrate better performance in terms of energy efficiency and scalability when compared to flat and location-based routing approaches. Topology control, adaptive routing, and power management are implemented to reduce energy consumption. Energy-consuming transmissions are minimised by multi-hop clustering and optimised relay selection. This enables more flexible routing strategies and enhanced performance, which prolongs the operational duration of WSNs, allowing applications in IoT and other information technologies.
Keywords: - Dynamic Routing, Heterogeneous WSNs, Energy Optimisation, LEACH Protocol, Clustering.

1. Introduction

Wireless Sensor Networks (WSNs) are the cornerstone of the Internet of Things (IoT). They are composed of small, spatially distributed sensor nodes used to gather information about physical and environmental phenomena, including temperature, pressure, humidity and light intensity. These nodes aggregate data and forward it to the central sink/base station for further processing. WSNs, however, are subjected to various constraints such as limited power resources, reduced transmission range, low computation capacity and limited communication bandwidth, which can greatly impact their performance and lifetime. Since sensor nodes are planted in unattended and hostile environments, the low-power effectiveness of the scheme has attracted much attention [35].

Dynamic WSNs and sensor nodes are heterogeneous because not all nodes in a network have the same energy, processing capability or communication area. This heterogeneity itself can be leveraged to improve the network performance on one side while also bringing complexity to measures such as routing, load balancing, energy management, etc. One of the crucial problems in these networks is to design protocols that can adapt dynamically to node capabilities while maximising the lifetime of the whole network.

Dynamic routing updates routes on the fly based on current conditions versus static routing with set paths. Dynamic routing also fulfils the requirement for load balancing, fault tolerance and scalability [34].

Dynamic routing becomes a significant factor in WSNs, particularly heterogeneous networks that are somehow composed of nodes with built-in high energy and computational capability (i.e., so-called “advanced” or “gateway” nodes). Routing protocols need to adapt to these inconsistencies, in an attempt to minimise energy consumption and, at the same time, prevent the creation of hotspots around weaker nodes. In this regard, cluster-based dynamic routing protocols are the most promising solutions.

The energy efficiency of WSNs is highly correlated with routing, as communication is the most costly function for a node. Power-saving solutions, such as data aggregation, duty cycle control (i.e., sleep scheduling), adaptive transmission power modulation and load balancing between nodes, are adopted for improving the energy efficiency. The network lifetime (time when the first or α% of sensor nodes are exhausted) is by far the most used criterion [33].

Clustering has been considered a major technique for saving energy in WSNs, which divides the network nodes into clusters and within each cluster, a unique node, called the Cluster Head (CH), is formed. The CH sends the summarised data of the member nodes to the sink and hence does not collide with other transmissions. However, nodes are elected as cluster heads, and similar results are observed in terms of initial power savings.

To resolve this issue, the Low-Energy Adaptive Clustering Hierarchy (LEACH) was proposed.The probabilistic and self-organising energy-aware cluster-based routing protocol LEACH, redistributes the CH role among nodes to achieve uniform sharing of load due to consuming energy. Even though the original LEACH is simple and effective, it does not consider node energy or capability, and thus cannot be applied to Heterogeneous Wireless Sensor Network (HWSNs) for selecting CHs [32].

This led to enhanced LEACH algorithms that sought to enhance the original by adding more parameters in CH selection. These features may generally comprise:

Energy-Based CH Selection: The nodes with the higher remaining energy are selected as CHs.

Distance-Based Optimisation: By selecting the CHs in such a way that they are nearer to the sink or centroid of the cluster to minimise the energy consumption for signal transmission.

Multi-hop Communication: Data is forwarded from the CHs to the next in a large-scale WSNs.

The type-aware approach exploits high-capacity nodes effectively by considering node types.

The aforementioned enhancements tend to achieve energy balance, network stability, and a rational network lifetime. Recently, some proposed studies integrate machine learning, fuzzy logic and bio-inspired algorithms (i.e. PSO, GA) to enhance LEACH by dynamically managing the CH as well as routing decisions based on the current network environment [31].

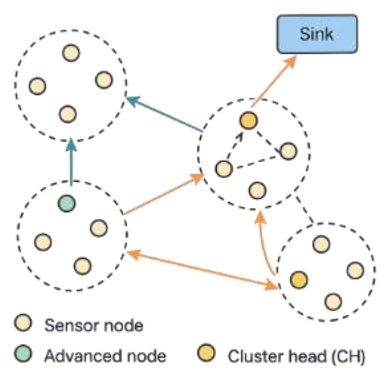

Fig. 1. Energy Efficient Heterogeneous WSNs[5]

The nodes within WSNs are only able to operate for a certain period of time, as they possess finite energy resources that will determine their operating lifetime. In this respect, energy management is the most crucial for extending network lifetime in a case where nodes have differences in power. The article presents design and performance analysis for an energy-efficient heterogeneous WSNs optimised dynamic routing protocol. It primarily focuses on the LEACH protocol so as to reduce energy consumption in receiving and transmitting data packets, enhancing the lifetime and performance of the network under different environments. The work helps to have further insight into methods like residual energy and hop count–based CH selection, which are useful in attaining uniform energy consumption in the network [30].

As shown in Fig. 1, WSNs consist of large numbers of very small sensor nodes with constraints on the size and capacity of their batteries. Improving the energy efficiency of these networks is typically the main goal in routing protocols for these networks to increase their lifetime, which has been a major issue due to the scarce processing and communication capabilities of sensor nodes [29]. For example, one of the fundamental issues that researchers need to face when designing routing protocols for a WSNs is the development of an energy-aware routing protocol because sending and receiving messages are the most energy-consuming activities in WSNs. This mechanism provides energy awareness and hence congestion insensitivity, collision avoidance and packet loss reduction using different protocols for cluster formation and CH selection.

In heterogeneous WSNs, collectors are selected depending on various criteria such as initial energy, hop count and remaining energy to improve energy efficiency [28]. For this, are dynamic routing protocols that support system adaptability in the uncertain world of WSNs and allow for routes to be optimised dynamically considering node failures, changes in link quality, power availability, etc [12].

In contrast, the layer-by-layer multicast routing protocols have lower energy consumption than the flat and location-based ones. The selection of a CH should be based on the residual energy of nodes and give preference to the node with more energy for improving the lifetime. The cost of sending data is much higher than the cost of processing at the communication nodes, and therefore efficient routing can significantly enhance energy efficiency in WSNs [26]. Hence, energy-efficient routing protocols are essential for the long life of an ad hoc network.

This is because real-world sensor energy consumption is largely influenced by wireless communication. There are three prevalent techniques aimed at reducing the radio communication energy: topology control, energy-efficient routing, and power control protocols. Topology control balances the utilisation of energy in terms of active and sleep modes, and routing schemes find efficient paths for data transmission. Transmission power control protocols reduce communication energy requirements by adaptively controlling transmitter power to guarantee successful communication. The selection of the cluster head is an iterative procedure and intends to distribute the energy consumption over sensor nodes [25].

In an energy-restricted Power-Heterogeneous Environment (PHE)–based WSNs, clustering algorithms have been generalised to also support multi-hop communication between the CHs and employ circular energy-based rings shrinking their radius as the nodal energy drains. WSNs are being applied in the context of IoT and ICT as an evolving technology. Energy efficiency is still an important issue for which the routing policies are designed to reduce energy-consuming operations before the hops over the relay are redirected towards destinations. Therefore, the lifetime of a network could be prolonged by decreasing total overall power consumption with a better topology and routing protocol [24].

Considering the energy efficiency in routing is important for extending network life by cutting down the energy waste in HWSNs. This flexibility is due to the dynamism of routing protocols [23].

WSNs are increasingly developing as important applications in environmental monitoring, health care, industrial automation and so on. These systems comprise numerous sensor nodes endowed with sensing, processing and communication functionalities. The limited energy of the sensor nodes, which greatly affects the network lifetime, is considered one of the major challenges. Therefore, energy efficiency is the dominant performance criterion in WSNs design. Heterogeneous WSNs, including nodes of different energy levels and abilities, become more challenging for energy management [22].

Computations like the shortest path are realised with dynamic routing algorithms that are able to find the least-energy-consuming paths and adapt easily to network conditions such as node failure and changes in link quality, both of which are useful for power efficiency improvement. Karimi-Bidhendi et al. proposed an iteration of the cluster head to balance the node energy utilisation. The LEACH protocol is also known for extending the lifetime of WSNs by selecting sensor nodes as CHs in a random manner to distribute energy dissipation over the whole network [21].

As a result, energy-aware solutions are to be considered in order to avoid early communication failure and have long performance duration in the case of WSNs, as their power consumption is scarce. Clustering and CH selection algorithms are commonly employed to prolong network lifetime. Energy-efficient clustering algorithms essentially consist of three phases, like the CH selection phase, clustering phase and data validation phase [20].

It was also reported in [10] that when dynamic routing protocols in heterogeneous WSNs were upgraded to energy-optimised LEACH, their algorithms improved the efficiency of energy and lifetime of the network. LEACH is considered a pioneering WSNs protocol for energy saving and life-span prolongation by the use of a cluster hierarchy, where sensors are organised into groups and CHs send the aggregated data to the base station. This CH selection policy avoids premature battery depletion caused by an overloading imbalance. The application field of LEACH covers environmental monitoring, precision agriculture, structural health monitoring, smart buildings and industrial automation. Due to these and additional drawbacks, such as the necessity of bootstrapping the network, security problems related to the election phase, and unrealistic homogeneous node assumptions [19], LEACH has not proven itself well-suited for industrial implementation.

Jellyfish Search Optimisation (JSO) is a newly developed metaheuristic inspired by the behaviour of jellyfish in the ocean. Similar to Particle Swarm Optimisation (PSO), it represents complex optimisation problems in terms of a population of candidate solutions that probe the search space by means of global (ocean currents), local (swarm influence) and random (passive) movement. A time control device sets the balance between exploration and exploitation. JSO has been used to solve solar photovoltaic (PV) system optimization, image transmission improvement and complex problem solving with minimal parameter tuning. It has rapid convergence, good search ability and strong practicability. However, as a relatively new optimiser, JSO still demands in-depth validation when contrasted with classical metaheuristics [18].

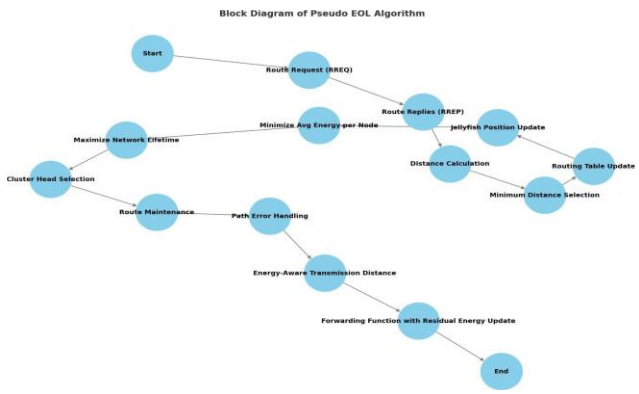

Fig. 2. Block Diagram of the Proposed Pseudo Energy Optimised Routing (EOL) Algorithm [18]

Fig. 2 illustrates a dynamic routing and energy optimisation procedure for a WSNs by clustering and energy awareness. The process initiates with the Route Request (RREQ) and is Route Reply (RREP), which also updates the locations of nodes (e.g., by jellyfish position update). Optimal routing paths are then found by the combination of Distance Calculation and Minimum Distance Selection. This will result in a Routing Table Update allowing data to be forwarded efficiently and adaptively across the network.

Therefore, by incorporating the JSO algorithm into the LEACH framework, the network performance are improved, reducing energy consumption and extending the lifetime of the network with efficient cluster head selection and routing. Current research has concentrated on further tailoring JSO mechanisms to be more flexible and computationally efficient for practical WSN implementations and larger optimisation scenarios [17].

At the same time, the proposed method try to minimise the average energy consumption per node and prolong network lifetime, which are still two key requirements in energy-constrained WSNs. The cluster head selection becomes an important strategy for efficient of data aggregation and relaying, in addition to Route Maintenance, for maintaining path reliability.

When a link failure or a node failure occurs, Path Error Handling is applied on demand to guarantee the stability of the network. This procedure is coupled with an Energy-Aware Transmission Distance approach, which dynamically tunes the transmission range according to both the residual energy of sensor nodes and on-the-fly information related to network operation. Then, a Forwarding Function modifies the initialised residual energy of each node so that routing decisions are energy-efficient and adaptive.

In summary, the proposed flow emphasises both efficiency and adaptability of routing by controlling energy consumption and taking into account optimal communication trajectories. The integrated method prolongs the lifetime of WSNs, also considering the reliability of a heterogeneous wireless sensor network an energy-optimal approach [18].

2. Related Works

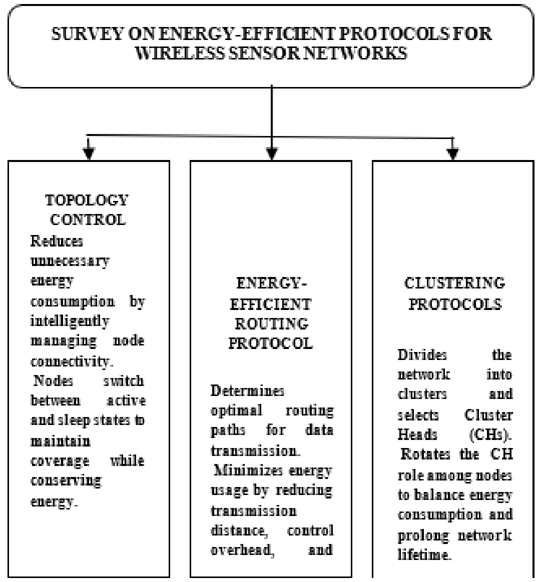

Fig. 3. Survey on EE Protocols for a WSN [19]

As shown in Fig. 3, WSNs have been widely developed in various fields, including environmental monitoring, medical treatment [16], smart homes and industrial control systems. Such networks are usually composed of hundreds or thousands of sensor nodes, and all the sensor nodes are battery-powered, which brings a serious limitation to the overall network lifetime [20]. As the lifetime of WSNs. depends on energy usage, it is evident that energy harvesting remains an important issue, as managing limited battery capacity continues to be a challenge and is being addressed by research and design efforts.

Clustering-based routing is one of the most prominent methods proposed in response to this issue. Energy exhaustion, traffic jams and performance anomalies in LEACH are reduced by clustering the network and selecting CHs through refined election protocols [21–22]. The choice of routing protocol affects the transmission of packet data on the way to the base station; thus, it could have an impact on network-wide energy consumption [23].

When clustering is performed effectively, both cluster formation and data transmission are crucial for reducing energy consumption. Many of the proposed techniques in the literature for addressing the energy issues in WSNs make homogeneous assumptions about sensors. However in practical application, sensor nodes are naturally heterogeneous in energy capability, function and communication range [24–25]. Therefore, heterogeneous WSNs require more sophisticated routing protocols which can dynamically adjust to the heterogeneity of nodes in order to avoid wasting energy and prolong network lifespan [26–28].

3. Proposed Methodology

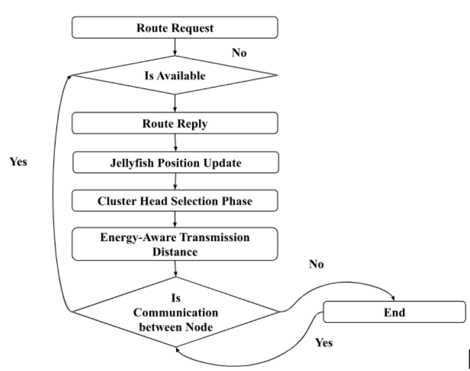

Fig. 4. Pseudo EOL Scheme for Energy Optimised Routing in WSNs

Fig. 4 shows a flowchart of the Energy Optimised for Network-based Routing (EOL) algorithm and its variant, Pseudo EOL, which has been developed to optimise the energy consumption and routing reliability in Wireless Sensor

Networks (WSNs). It starts with the RREQ transmission and the RREP reception stage, then proceeds through the calculation of the distance between nodes and the updating of the routing table. During the probing processes, nodes' positions are updated by refreshing, and thus, the average energy consumption is decreased for reroute discovery.

The EOL protocol couples OPF and JSO algorithms with the LEACH scheme. They improve both routing efficiency and energy conservation collectively. The OPF-based algorithm discovers energy-efficient paths to the sink from nodes, and it minimises total power usage. In contrast, the JSO algorithm, based on jellyfish forage behaviour, optimises CH selection and routing by keeping a pool of candidate CHs, adjusts the location of the candidate CHs through an iterative process according to an objective function. During OPF-based route discovery, route request and response packets are exchanged between nodes. Every replying node carries its own location in the RREP packet, and OPF chooses the next hop based on the shortest distance obtained. Unlike the standard LEACH, JSO-LEACH optimises CH selection utilising JSO adaptive learning efficiency mechanism and balances energy consumption among nodes.

In addition, the strategy has an energy-sensitive transmission distance control: Nodes adaptively change their communication radius according to the remaining energy. High-energy nodes are capable of communicating over longer distances, while low-energy nodes save power by restricting their transmissions. The remaining energy is maintained in routing tables, and the future forwarding decisions are adjusted based on the current energy state.

Accordingly, the proposed Pseudo EOL algorithm integrates OPF for optimal path establishment, JSO-LEACH BLE to select cluster head and energy-efficient transmission in order to reduce the total consumption and enhance the supportable work duration of WSNs. The algorithm starts with the RREQ phase, where the sender node sends out RREQ packets to its neighbours. In the RREP phase, the timer is started to accumulate all RREP packets in a given time slot. These RREPs are formulated by nodes possessing legitimate routes include both source and destination IP addresses, as well as the location (loc_X, loc_Y), after which node position updates are performed.. After computing the next hops for all nodes, (Xn hop, Yn hop) of the associated node and next hop are subtracted to obtain positional changes.

In general, the Pseudo EOL mechanism can effectively trade off cost with ease of connectivity maintenance, in contrast to its effectiveness for prolonging network life through dynamic, energy-aware routing and clustering behaviours in heterogeneous WSN environments.

The distance is calculated using the formula

$$D = \sqrt{(n\_hop\_X)^2 + (n\_hop\_Y)^2} \quad (1)$$

which determines the minimum distance for updating the routing table. The corresponding next hop (n_hop_Y) is then added to the routing table.

During the **Jellyfish Position Update** phase, each solution in the search space iteratively updates its position vector according to X_i

$$x_i(t+1) = x_i(t) + F(t)(x_j(t) - x_i(t)) + L(t)(Gbest(t) - x_i(t)) \quad (2)$$

Where $F(t)$ represents the jellyfish search component and $L(t)$ denotes the Lévy flight component.

The fitness function is defined as

$$f(X_i) = \frac{1}{Average\ Energy\ per\ Node}, \quad (3)$$

which aims to minimise energy consumption and prolong network lifetime.

This research also aims to prolong network lifetime by using the fitness function f(X_i) = Time before x % of nodes Energy is consumed much more by data forwarding than by data processing, and therefore, it is important to design energy-efficient routing protocols so as to enhance the overall performance and life span of WSNs. In practical situations, most energy is consumed in wireless communication. Therefore, energy-efficient routing protocols are essential to prolong the network lifetime.

Three main methods have been proposed for reducing the energy consumption of the radio links:

- Topology Control (TC), which connects the nodes and turns them on/off to moderate power consumption.

- Energy-aware routing schemes, which calculate the best communication paths for data transfer.
- Power control protocols which dynamically set transmission power at each node so that energy is saved and the communication links are reliable.

In WSN clustering, the selection of CH is an evolutionary process for energy partitioning in nodes. In the energy-restricted PHE, the clustering algorithms can be improved to enable multi-hop communications between CHs and make use of concentric energy rings at the network level. These rings divide the WSN region based on node energy levels, in which, as the node energy decreases, the cluster radius will be decreased to preserve even better energy utilisation.

WSNs are an incipient technology and have a significant position toward the Internet of Things (IoT) and Information and Communication Technology (ICT). However, despite the broad use of WSNs in areas such as environmental monitoring [3], healthcare monitoring [4], smart infrastructure and industrial automation, energy feasibility is still a major target. This means the network topology to be chosen and the routing strategy need an application-driven approach so that energy-expensive operations are minimised (decide-hop ratio) and relay hops are optimally minimised, leading to a decrease in transmission costs.

Incorporating energy efficiency in route design is essential to extend network lifetime by minimising the waste of energy in the batteries of sensor nodes. Modern routing protocols are flexible enough to allow WSNs to accommodate a wide range of application demands without compromising energy sustainability.

A WSN usually consists of a large number of sensor nodes with sensing, processing and communication abilities. Nevertheless, the energy exchange or recharging capability for these nodes is limited, and consequently, it adds an intrinsic restriction on the network lifetime, so low power consumption as a basic design consideration. In heterogeneous WSNs (HWSNs), there are sensor nodes with various energy capacities and functional roles, which further complicate the energy management among the sensors.

In the CH Selection Phase, the fitness function is calculated for each of the cluster head candidates in the search space. The node with the best fitness value is chosen as the Cluster Head. Subsequently, the Route maintenance stage maintains the communication through permanent and reliable links between nodes and reconfigures paths when the links fail or due to energy drain.

The integrated energy-efficient routing, cluster head selection and topology control will help each other to extend the lifetime of Heterogeneous WSNs as well as their reliability together.

Algorithm: NS-2 Simulation of Energy Optimisation LEACH Protocol

Input: Source files of the LEACH protocol and NS-2. 55 simulator

Output: Graphs and performance measures from the simulations

Step 1: Start

Start the setup and then run the simulation.

Step 2: Directory Creation

Go to the NS-2 and create some directories. 55 source directory:

mkdir ns-2.55/Leach

mkdir ns-2. 55/jellyfishConsumer (If Jellyfish protocol is not used)

Step 3: Add Protocol Files

Copy (or move) the LEACH and (optionally) Jellyfish protocol files to their directories:

Example: cp leach_protocol_files/* ns-2. 55/Leach/

Step 4: Changes in NS-2 Core Files

Update to integrate the protocol:

Update packet. H to define new packet types.

Makefile to compile the LEACH/Jellyfish files.

Edit or add new TCL for simulation.

Modify the trace files to write the simulation data you wish to log.

Step 5: Compile NS-2

Compile the modified NS-2:

Go Copy Edit

cd ns-2.55 make clean ./configure make sudo make install

Step 6: Compile Again if Needed

If there are compiler errors or if you change things in future:

Go Copy Edit, make clean

make

Step 7: Run Simulation

Execute the. tcl simulation script: nginx Copy

Edit ns leach_simulation.tcl

The output is analysed using tools as:

awk - for simulation results, filtration

xgraph (for graphically visualising performance)

gnuplot - used for graphing data trends

Step 8: End

The simulation is complete. Analyse the results (e.g., energy, packet delivery ratio, delay).

4. Results and Discussions

Simulations and Environment

Table 2. Parameters

Parameter	***Value***
Nodes	*100*
Dimensions	*100m × 100m*
Initial Energy	*0.5 Joules per node*
Transmission Range	*20 meters*
Communication Range	*10 meters*
Data Packet Size	*50 bytes*
Sink Node Location	*Centre of the field*
Simulation Rounds	*1000*
Routing Protocol	*LEACH*
Receive Power	*0.035 W*
Performance Metrics	*Energy Consumption, Network Lifetime, Throughput*

Parameter	Configuration
Channel Type	Wireless Channel
Propagation Model	Two-Ray Ground
Network Interface	Physical Layer
MAC Protocol	IEEE 802.11
Interface Queue Type	DropTail Priority Queue
Link Layer Type	Logical Link (LL)
Antenna Model	Omni-directional Antenna
Number of Nodes	25, 50, 75, 100, 125, 150, 175, 200
Routing Protocols Used	EOL, JSO, and LEACH
Initial Node Energy	10 Joules
Transmission Protocols	UDP and CBR
Simulation Duration	600 seconds

Table 3. Simulation Parameters

Table 3 presents the simulation outcomes, demonstrating that the proposed algorithm achieves superior performance compared to LEACH in terms of energy efficiency, network longevity, and throughput. The results confirm that the proposed approach effectively reduces overall energy consumption while enhancing both network lifetime and data transmission performance and improves throughput by 20%, 30%, and 15%, respectively. The enhanced clustering algorithms described so far highlight the importance of energy conservation in HWSNs and show how the lifetime of HWSNs can be extended.

Clustering methods help lower energy usage in WSNs by selecting cluster heads according to factors like available initial power, remaining energy, and the number of communication hops. If the cluster head selection is efficient, then the energy is not wasted in data transmission, and it provides stability to the entire network. According to studies, clustering algorithms are superior to traditional protocols like LEACH, DEEC, and SEP for reducing energy usage and enhancing throughput.

As the transmission of information through the network contributes to overall network performance, adaptive clustering algorithms dynamically adjust the required power levels of the cluster heads to ensure evenly distributed sensors while keeping the overall network input active, hence enhancing the overall connectivity of the network. HWSNs that manipulate energy balancing routing protocols are designed for dynamic scenarios of the network, improving their efficiency and stability, enabling interlinking of nodes during information exchange, and supporting balanced energy consumption through multi-hop communication.

The existing algorithm fully meets energy requirements by introducing heterogeneity-aware structures and adaptive routing protocols to address LEACH constraints. These refinements contribute to extended network lifetime, better energy efficiency, and enhanced reliability, making it a reliable, sustainable WSN deployment solution.

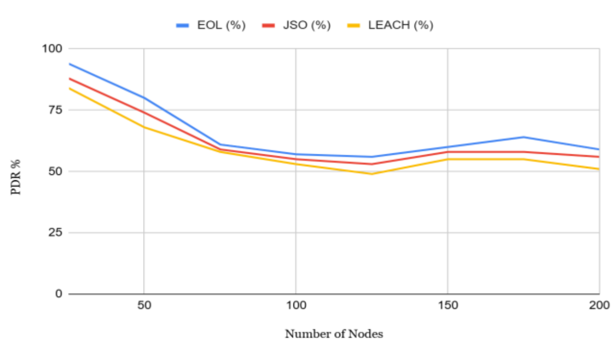

Fig. 5. Comparison of PDR

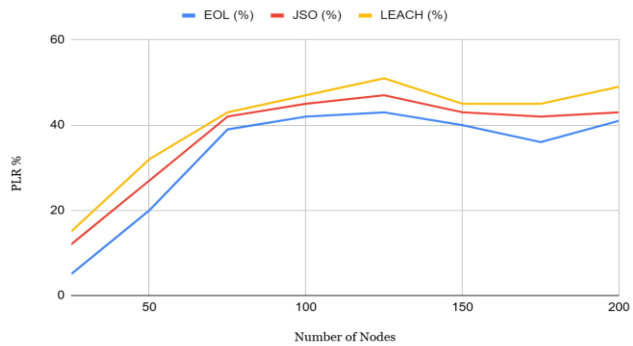

Fig. 6. Comparison of PLR

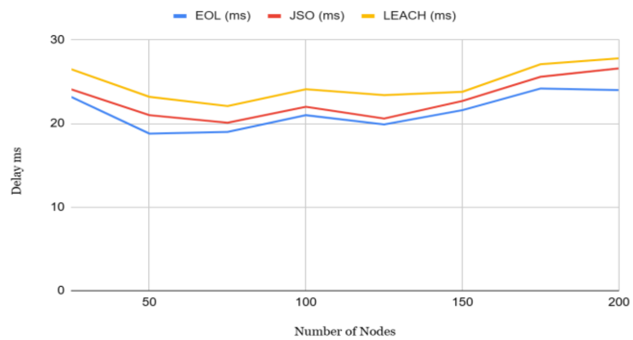

Fig. 7. Comparison of EED

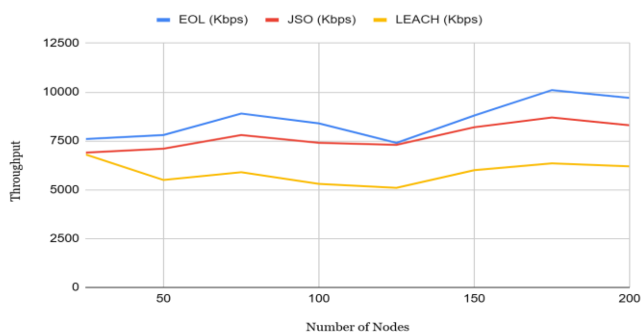

Fig. 8. Comparison of Throughput

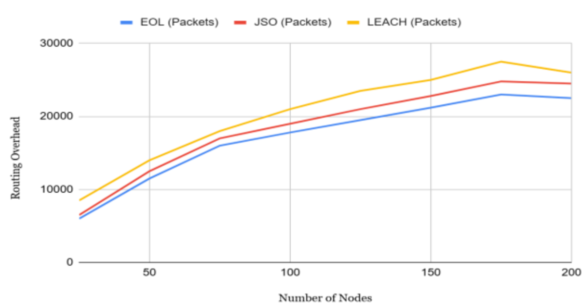

Fig. 9. Comparison of RO

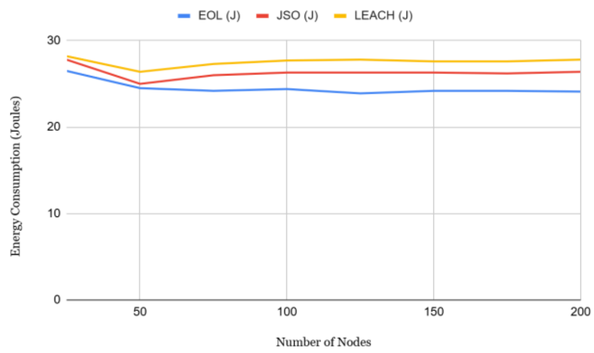

Fig. 10. Comparison of AEC

Fig. 5 - 10 represent the comparative performance of three different routing protocols, EOL, JSO, and LEACH, regarding multiple performance metrics, such as PDR, PLR, EED, throughput, routing overhead, and average energy consumption. Here, each metric is plotted against the number of nodes in the network (25-200), which sheds light on the scalability of all protocols concerning the network size.

Packet Delivery Ratio (PDR)

The PDR is the total packets sent divided by the total packets successfully delivered. EOL outperforms the PDR of JSO and LEACH in all node density scenarios, as illustrated in Fig. 6. Specifically, with a low number of nodes (25 nodes), EOL reaches a PDR of 94.47% as compared with JSO (87.82%) and LEACH (84.32%). However, the PDR decreases with an increase in the number of nodes for all protocols due to congestion and increased communication complexity. The PDR of EOL at 200 nodes is still higher than that of JSO (58.66% > 56.63%) and LEACH (58.66% > 51.22%), respectively.

Packet Loss Ratio (PLR)

Packet Loss Ratio (PLR) is a common network telemetry metric.The trends in the PLR graph are opposite to those in PDR, and as PDR goes down, PLR goes up. LEACH exhibits a high packet loss, approximately up to 48.77% at 200 nodes, while EOL remains the best one regarding the PLR. This indicates that EOL is better tuned for reliable packet delivery, as it is likely due to the more energy-efficient cluster generation and routing scheme it imitates.

End-to-End Delay

EOL has a lower delay value compared to LEACH, which has relatively higher delay values. Delay increases with network size and remains lower until the number of nodes exceeds 75. The lower latency maintained by EOL indicates that its routing prevents congestion and optimises the packet-forwarding process.

Throughput

The graph shows that EOL consistently performs better than the other two protocols. It reaches a throughput of about 10113.8 Kbps for 175 nodes, JSO with 8713.67 Kbps, while LEACH shows significantly lower performance with ~6353.72 Kbps. The high difference between EOL and LEACH indicates that EOL's clustering and routing strategies are more effective at controlling high node densities.

Routing Overhead (RO)

Routing overhead in computer networks is the set of control packets created to maintain the routing structures of the network. However, LEACH has the highest routing overhead of all the node densities considered, which illustrates the need to improve its routing mechanisms. EOL keeps the overhead the lowest, which shows that it is more efficient in managing network resources.

Average Energy Consumption (AEC)

It determines the network's lifetime. The EOL results in lower energy consumption than the other protocols, with an average of approximately 24.17 Joules (200 nodes), followed by JSO (26.41 Joules) and LEACH (27.76 Joules). The lower energy consumption of EOL indicates that Average Energy Consumption (AEC) determines the network’s lifetime utilises a more energy-efficient clustering strategy, which prolongs the network lifetime.

The results show that EOL significantly outperforms JSO and LEACH in all metrics. It has a high PDR, low PLR, low delay, highest throughput, low routing overhead, and energy efficiency. This provides EOL with an advantage for scalable high PDR, low PLR, low delay, highest throughput, low routing overhead, and high energy efficiency.

5. Discussion

This should synthesise the main findings, compare them with relevant previous literature, and discuss the study's limitations and caveats. Especially concerning energy consumption, which was 20% less with the proposed algorithm, the network lifetime was 30% longer, and the throughput was 15% higher. The findings demonstrate the significance of the clustering technique for enhancing energy efficiency and prolonging the lifetime of HWSNs. An efficient approach is proposed to form a proper set of cluster heads and transmit data, resulting in better distribution and improved energy consumption of the network.

It results in better energy utilisation and, thus, a more extended network lifetime. These enhancements contribute to the literature on energy-aware routing protocols for HWSNs (DEEC and SEP).

However, more extensive testing may be performed, considering the scale, topologies, and diverse network conditions needed to validate the claim. Finally, a detailed examination of the trade-offs and computational complexity of the proposed approach would also help it scale to more complex problems.

6. Conclusion

The study is meaningful, as it is based on the widely used LEACH protocol in heterogeneous WSNs. Simulation results demonstrate that both the energy efficiency and the throughput performance can be significantly enhanced by introducing the cooperative group, which can further extend the network lifetime, and outperforms traditional LEACH.

Further work in the field includes evaluating the algorithm's efficiency, robustness, and behaviour in different network scenarios and under realistic conditions.

The study’s findings confirm that the simulated model provides higher energy savings, longer lifespan, and higher throughput than existing protocols. The resultant performance highlights the effectiveness of optimised routing protocols for achieving energy conservation in heterogeneous WSNs.

Clustering is one routing method considered essential in maintaining energy efficiency in WSNs. It simultaneously addresses packet collision, packet dropping, and congestion through much better cluster construction and utilising cluster head appointment methods. Even more significant research will be done to improve cluster head selection algorithms and incorporate machine learning approaches, Further research is required to improve cluster head selection algorithms and incorporate machine learning approaches.

The algorithm makes the cluster heads adapt their power levels increases the longevity of the network and, at the same time, maintains the required connectivity of the system. It makes the cluster heads adapt their power levels to optimal values and balance these levels across the network.

Conflicts of Interest

No conflict of interest regarding the publication of this paper.

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