HarborSync: An Advanced Energy-efficient Clustering-based Algorithm for Wireless Sensor Networks to Optimize Aggregation and Congestion Control

Ibrahim Aqeel
College of Computer Science & IT, Jazan University, Jazan, Saudi Arabia

***Abstract*—In the ever-evolving landscape of Wireless Sensor Networks (WSNs), the demand for cutting-edge algorithms has never been more critical. This paper proposes an algorithm, HarborSync, to improve stability, energy efficiency, durability, and congestion control in WSN. While selecting cluster heads and backup nodes, HarborSync applies the Optimised Stable Clustering Algorithm (OSCA) and the Weighted Clustering Algorithm (WCA). This fresh method puts the groundwork for better performance by acquainting techniques to intentionally postpone changes in cluster heads and computing priorities. Using the innovative Cluster-based Aggregation and Congestion Control (CACC) features, HarborSync provides enhanced routing, adaptive reconfiguration, efficient aggregation techniques, and dynamic congestion monitoring. Among HarborSync's strengths, stability bears out with a 90% rating, surpassing those of LEACH (78%), LEACH-C (82%), TEEN (88%), and PEGASIS (76%). When it comes to durability, HarborSync scores 88% better than LEACH (75%), LEACH-C (80%), TEEN (85%), and PEGASIS (72%). The HarborSync score is 3.85% for congestion control compared to LEACH and LEACH-C, managing 5.22%, TEEN accomplishing 4.98%, and PEGASIS with 7.32%. Regarding adaptability, HarborSync showcases its versatility, earning an 85% rating, surpassing LEACH (72%), competes with LEACH-C (78%), equals TEEN (90%), and outperforms PEGASIS (68%). In the critical realm of packet loss management, HarborSync demonstrates efficiency with a reduced rate of 6.179%. Therefore, it outperforms LEACH (7.811%), LEACH-C (6.897%), TEEN (4.953%), and PEGASIS (7.973%).**

***Keywords*—Clustering; congestion control; cluster head selection; energy-efficient clustering; wireless sensor networks; energy optimization**

I. INTRODUCTION

To monitor and sense faraway places, WSNs collect data from many tiny, inexpensive sensors [1] and send it to a central station. WSNs are versatile and affordable, making them useful in many fields, including healthcare, emergency response [2], weather prediction, and surveillance missions. On top of that, these networks have the capability to build ad hoc networks, which allow them to operate autonomously in challenging or dangerous environments when human intervention is not an option. The operating longevity of WSNs depends on battery life [3], which can be difficult, if not impossible, to replenish, making energy efficiency a significant concern. Consequently, optimizing network functionality necessitates the creation of algorithms that consume less energy. Various algorithms that minimize energy consumption have been suggested for WSNs in the past few years [3].

When neighboring nodes detect the same or comparable events, clustering becomes an effective method for arranging ad hoc sensors. Congestion and data collisions result from the network's energy being quickly depleted due to individual communication between each node and the base station [4]. To solve this problem, clustering organizes sensor nodes into smaller groups, each with its designated cluster head (CH). Each node uses short-distance transmission to send sensed data to its corresponding CH, and then each CH uses long-distance transmission to aggregate and send the aggregated data to the base station. As a result, CHs use more power while sending messages than other cluster members [5]. It has been suggested that clusters hold CH elections periodically to reduce energy imbalances. To improve the network's lifetime, it is essential to determine the ideal number and size of clusters. As data is transferred from cluster members to cluster leaders [6], an excessive amount of energy is consumed when the number of clusters is minimal. On the other side, many nodes have to use long-distance transmission to talk to the base station when there are many clusters since so many cluster leaders were elected. To maximize energy usage across the network, it is necessary to strike a balance between these parameters [7]. For optimal intra-cluster performance, it is critical to distribute cluster heads evenly over the network. When cluster heads are chosen too closely, clusters don't develop evenly, making efficient clustering difficult since cluster sizes are too small or too big. Overhearing signals and wasting energy can happen in any case. Modern technological landscapes bet on WSNs for environmental monitoring, healthcare, industrial automation, and smart cities, among many others [8]. As these networks become increasingly constitutional to our unified society, there is a compacting need for sophisticated algorithms to heighten their functionality [9]. In response to the increasing challenges run into by WSNs, this research infixes "HarborSync," a novel algorithm. In the era of WSNs, cutting-edge solutions are crucial since these networks must voyage the challenges of guaranteeing constant data transfer [10], minimizing energy consumption, and maintaining network resilience over time.

By strategically expanding upon the Optimised Stable Clustering Algorithm (OSCA), HarborSync uses the Weighted Clustering Algorithm (WCA) to choose accompaniment nodes and cluster heads carefully. This one-of-a-kind combination premises features including priority computing, purposeful delay in cluster head transitions, and the incorporation of Cluster-based Aggregation and Congestion Control (CACC) [11], laying the groundwork for a path-breaking approach. At last, we have an all-inclusive solution that surmounts all subsisting algorithms on various metrics, including stability, energy efficiency, durability, adaptability, congestion control, and packet loss management. Section I of the paper introduces the study subject and provides background information on WSN and clustering [12]. A thorough understanding of the HarborSync algorithm is the goal of the paper's organization. The second section lays the groundwork for the proposed technique and examines the current body of knowledge through a thorough literature study. The new method, HarborSync, is described in full in Section III, along with its components and the design rationale of the proposed algorithms. To demonstrate how HarborSync outperforms well-known algorithms like LEACH, LEACH-C, TEEN, and PEGASIS, Section IV presents the results showing how well the algorithm performs when tested with different evaluating settings. Section V presents the discussion. Key findings are summarised in the conclusion, and additional study and development possibilities are suggested in Sections VI and VII in the future scope section.

The following are the contributing points that have been addressed in the study based on the proposed algorithm:

1) In this study, a new technique called HarborSync is introduced and proposed; it is particularly made for Wireless Sensor Networks (WSNs). The HarborSync uses the Weighted Clustering Algorithm (WCA) features and the Optimised Stable Clustering Algorithm (OSCA) to choose backup nodes and cluster chiefs.

2) We suggested HarborSync offers Cluster-based Aggregation and Congestion Control (CACC) capabilities to enhance the effectiveness and dependability of data transmission in the network, demonstrating creativity in resolving data aggregation and congestion problems in WSNs.

3) A thorough performance comparison between HarborSync and well-known clustering techniques like LEACH, LEACH-C, TEEN, and PEGASIS is included in the study. This comparative study emphasizes the algorithm's virtues, which shows how it outperforms current techniques in terms of packet loss management, stability, durability, flexibility, and congestion control.

4) One of HarborSync's main benefits is its capacitance to lower power consumption, which is essential for wireless sensor networks. The article hashes out the algorithm's manifested capacity to save power, which bestows the reliability and endurance of WSNs.

5) Panoptic testing equates HarborSync to popular clustering algorithms on many parameters. It raises HarborSync's functionality testing in many scenarios.

II. RELATED LITERATURE

One of the first cluster-based routing concepts for WSNs was LEACH, which was proposed by Heinzelman et al. [3]. LEACH uses a random rotation of the cluster heads to ensure that all sensor nodes use the same amount of power. Because it is not controlled by a single entity, its decentralized nature makes it ideal for networks with many nodes. But, because LEACH is inherently random, specific nodes may experience early energy depletion or an unbalanced energy distribution. In 2003, the same authors introduced LEACH-C [4] as an improvement to LEACH. Resolving some of LEACH's shortcomings, it presents a centralized mechanism for selecting cluster heads. Using parameters like residual energy and distance from the base station, LEACH-C uses a base station to identify cluster heads. This centralized strategy aims to increase the network's lifetime and decrease its energy consumption. Still, problems with centralization and base station connectivity pose a continuing threat. This study offer a new threshold function for cluster head selection that optimizes the LEACH protocol, resulting in an energy efficient clustering method for FANETS [13]. The results from the MATLAB experiments show that the new protocol is more energy-efficient than the current LEACH and Centralized Low-Energy Adaptive Clustering Hierarchy Protocol. It also has a higher packet delivery rate and a lower First Node Death (FND). A referenced study [5] assessed the present clustering routing protocols, categorizing these algorithms into 2 primary types of roting techniques namely data transmission and cluster-construction. The review considered sixteen well-established clustering methods, excluding newer approaches like fuzzy and evolutionary-based methods [14].

In the context of Wireless Sensor Networks (WSNs), this study probed node clustering methods founded on fuzzy modeling. The basal concentrate was on assessing their benefits and drawbacks. Classifying clustering algorithms as fuzzy or hybrid fuzzy-based was one panorama of the inquiry. Diverse methodologies were engaged in a different study [6] to investigate cluster-based routing schemes. Canvassing these techniques fractioned into block, chain, and grid-based methods showcased their benefits and drawbacks. Cluster stability, scalability, energy economy, and delivery time were the valuing retainers [15].

Ramping upon this basis, more research [7] categorized cluster-based routing algorithms as block, grid, or chain-based by probing clustering protocols. The comparative valuations of stream feelers considered factors such as algorithmic complexity, load balancing, cluster stability, delivery time, energy cognizance, and load sensitivity [16]. A paper [9] dealt with the problem of classifying several WSN clustering techniques into heterogeneous and homogeneous networks. This study essayed the advantages and disadvantages of each protocol while describing the network node and resource capacity. The equivalence research admitted Cluster Heads (CHs), complexity, number of clusters, clustering items, and inter-cluster communication [3].

Furthermore, unequal clustering techniques were examined in [10] based on their attributes and objectives. The comparability focused on the clustering process and clustering attributes, forking the techniques into three categories: deterministic, preset, and probabilistic methods. Legion methods were also simulated in order to gauge their energy usage and service life. Heterogeneous and homogeneous networks (Energy-Efficient Stable LEACH) [11] are variations of the LEACH protocol contrived to increase the energy efficiency of the network. The particle swarm optimization (PSO) technique was used in this variation. In the ESO-LEACH model, each node utilizes a probability descent from the ESO algorithm and considers its energy level when selecting a Cluster Head (CH). Based on the current energy levels and node distances, this method depends on a CH with enough energy to subsist the whole round. One substantial drawback of ESO-LEACH is its computational cost. It surpasses that of the original LEACH protocol. It becomes problematic to implement on devices with limited resources, and the protocol would have trouble adjusting to changing network conditions, which would require recalculating the clustering structure from the ground up.

A load-balancing technique was developed in separate research [12] to improve the efficiency of 5G Local Home Networks (5GLHNs). The CFPSO (Cell Attachment using Particle Swarm Optimization) technique was utilized in this process for cell attachment. A separate inquiry examined techniques and approaches for achieving precise time synchronization in femtocell networks [17]. It proposed an intra-cluster synchronization mechanism to improve the accuracy of synchronization. The proposed technique was subjected to empirical testing to assess its consumption of resources and its security features. In addition, another research group has devised an energy-efficient approach for selecting CH (Cluster Head) that considers many criteria, including remaining energy, distance, and node density, utilizing Particle Swarm Optimization (PSO) [18]. Nevertheless, this approach fails to consider the clustering procedure, leading to significant energy inefficiency throughout the network, and fails to acknowledge the creation of clusters. Table I reviews the state-of-the-art literature, showing its advantages and disadvantages.

TABLE I. RELATED LITERATURE

Ref	Advantages	Gaps
LEACH [3]	-The decentralized nature is suitable for networks with many nodes. - Random rotation of cluster heads for energy balance.	- Inherently random, leading to early energy depletion or unbalanced energy distribution.
LEACH-C [4]	- Centralized mechanism improves energy efficiency. - Selection of cluster heads based on residual energy and distance from the base station.	- Centralization and base station connectivity issues pose threats.
EE-LEACH [5]	- Categorizes clustering algorithms into data-transmission and cluster-construction routing techniques. - -Energy efficient clustering for FANETS	- Excludes newer approaches like fuzzy and evolutionary-based methods.
Fuzy based clustering [6]	- Focuses on merits and limitations of fuzzy modelling-based node clustering methods. - Classifies fuzzy and hybrid fuzzy-based clustering methods.	- Limited to fuzzy modeling approaches, excluding other clustering techniques.
heterogeneous and homogeneous clustering [9]	- Classifies cluster-based routing techniques into block, grid, and chain-based methods. - Comparative evaluations cover delivery delay, energy consumption, load balance, cluster strength, and complexity of algorithm.	- Limited information on specific protocols and their evaluations.
unequal clustering protocols [10]	- Classifies WSN clustering protocols into homogeneous and heterogeneous networks. - Comparative analysis considers factors like cluster count, inter-cluster communication, CH count, clustering objects, and complexity.	- Challenges of protocols are outlined but not detailed.
ESO-LEACH [11]	- Explores unequal clustering techniques categorized into probabilistic, preset, and deterministic methods. - Comparative analysis focuses on clustering properties and the clustering process.	- Limited information on simulation results and energy usage.
CFPSO [12]	- Integrates PSO to improve energy efficiency. - Considers energy levels and distances for CH selection.	- High computational cost compared to LEACH. - May struggle with dynamic network changes without full recalculations.
5GLHN [15]	- Improves efficiency in 5G Local Home Networks using CFPSO for cell attachment. - Empirical testing for resource usage and security assessment.	- Specifics of load-balancing techniques not detailed.
OPSO [18]	- Considers multiple criteria like remaining energy, distance, and node density. - Utilizes PSO for CH selection.	- Neglects the clustering procedure, leading to energy inefficiency and lack of cluster creation acknowledgment.

III. PROPOSED METHODOLOGY

Introducing a groundbreaking technique called HarborSync, this research aims to enhance the capabilities of Wireless Sensor Networks (WSN). In dynamic and resource-constrained sensor network contexts, HarborSync aims to improve stability, durability, and congestion control significantly. The algorithm starts by carefully placing sensor nodes inside the target region to set the stage for future network operations.

In order to maximize network efficiency, HarborSync uses advanced methods for both initial cluster creation and continuous maintenance. The ability to delegate obligations inside clusters is a brand-new feature in HarborSync. Each node in a cluster plays a crucial role, including the leader, backup, members, and gateway. By deliberately delaying cluster head changes, HarborSync ameliorates the network’s overall stability. In order to dynamically equilibrate the duties of backup nodes, old cluster heads, and new cluster heads, the system also lets in strategies for prioritizing nodes fitting into their degree and battery life. With features like dynamic cluster reconfiguration, adaptive routing, effective aggregation, and congestion monitoring, HarborSync provides a complete answer to the myriad problems with WSNs. HarborSync coordinates the creation and upkeep of stable clusters while simultaneously negotiating and tracking congestion in real-time. The system inducts adaptive actions, such as dynamic reconfiguration [19] and efficient routing, in reaction to congestion detection to relieve network strain [20]. Finally, among the most innovative WSN algorithms, HarborSync stands out in peculiarity because it can overturn WSNs in terms of congestion control, endurance, and stability. Fig. 1 expresses all the components of the intimated algorithm stages.

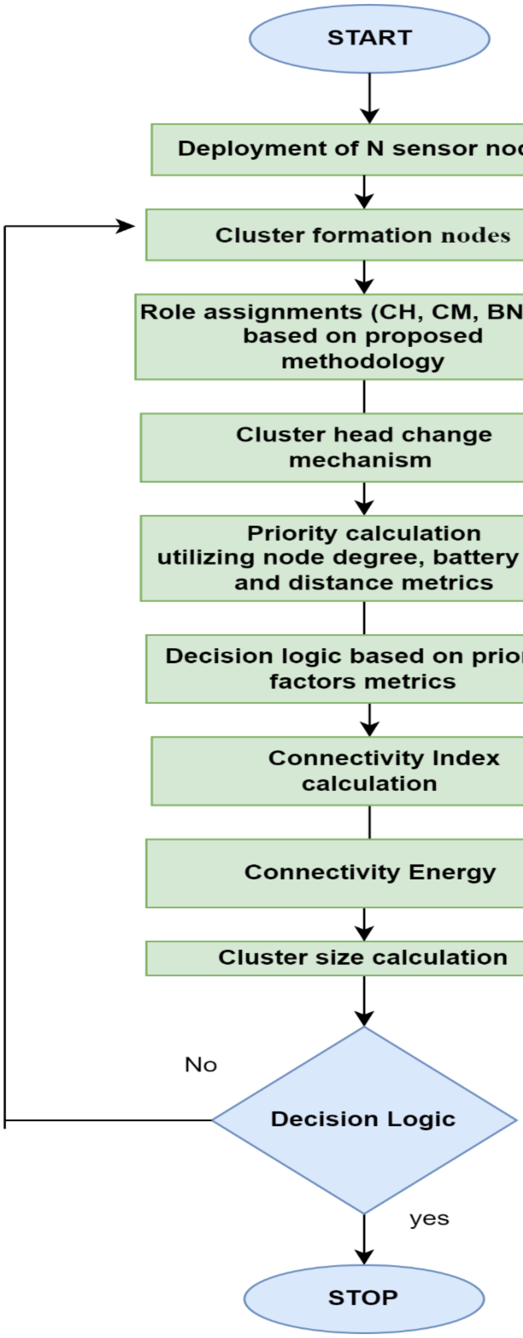

Fig. 1. Proposed methodology.

HarborSync, a urged approach, provides a novel and complex way to wangle wireless sensor networks (WSN). It begins with carefully placing sensor nodes [21] and applies a unique method to cluster formation by picking cluster heads using probability. The system has a unique approach to role assignment that takes into account vital factors, including energy, connectivity, battery life left, base station distance, sensor data quality, and priority calculations. By desegregation adaptive routing, effective aggregation techniques, dynamic cluster reconfiguration, and congestion monitoring, HarborSync offers a stiff real-time congestion control and optimization solution for dynamic and resource-constrained sensor networks.

Algorithm Components:

Initialize Network:

First, in HarborSync's operations, sensor nodes are laid strategically in the interior of the designated target zone. Every network function in the future will be ramped up in this first fundamental step. First, the N sensor node, which is the total number of sensor nodes employed by HarborSync, is consideringly positioned past the target zone.

Cluster Formation and Maintenance:

When it comes to initial cluster construction and continuing maintenance, HarborSync uses unique procedures to take care of it. This strategy aims to maximize the total number of clusters generated while also optimizing the network's overall efficiency [1-2]. Let:

- N be the total number of nodes in the WSN.
- P be the desired percentage of nodes that become cluster heads in each round.
- r be the current round.
- T be the total number of rounds.

The probability p of a node becoming a cluster head in round r can be determined by:

$$p = \frac{P}{1-P\cdot(r \bmod \frac{1}{p})} \tag{1}$$

The expected number of cluster heads ECH in round r is given by:

$$ECH = p \cdot N \tag{2}$$

And the total number of clusters Cover T rounds can be calculated as:

$$C = \sum\nolimits^{T}{}_{R=1} ECH_r \tag{3}$$

In this more complicated case, the predicted number of cluster heads is the total of all rounds, and each round's cluster head selection is based on probability. The total number of clusters is represented by this formula [3].

Roles within Clusters:.

HarborSync inaugurates an innovator role assignment approach, dooming roles such as Cluster Head (CH), Cluster

Member (CM), Backup Node (BN), and Cluster Gateway (CG) based on its unparalleled methodology [4].

$$CH\_Score = w1 \cdot Energy + w2 \cdot Distance\ to\ Base\ Station + w3 \cdot Connectivity + w4 \cdot Remaining\ Battery\ Life + w5 \cdot Sensor\ Data\ Quality \quad (4)$$

Where:

- Energy is the remaining energy of the node.
- Distance to Base Station: is the distance of the node to the base station.
- Connectivity is a measure of the node's connectivity in terms of communication hops.
- Remaining Battery Life is the remaining battery life of the node.
- Sensor Data Quality is the quality of the sensor data if applicable.

$w1, w2, w3, w4$, and $w5$ are weights assigned to each factor based on their relative importance. The weights should sum up to 1 to ensure normalization.

The CH selection process can then be simplified as follows:

$$Select\ CH = argmax_i\ (CH\_Score) \quad (5)$$

This means selecting the node with the highest CH score among all available nodes.

Cluster Head Changes:

To bolster overall stability, HarborSync employs a sophisticated mechanism, strategically delaying cluster head changes within the same cluster.

- $Ttransmit$ be the transmission time for a packet from a cluster head.
- $Tprocess$ be the processing time at the cluster head.

The total delay time for a Cluster Head can be expressed as:

$$DelayTime_{CH} = Ttransmit + Tprocess \quad (6)$$

Priority Calculation:

Utilizing node degree and battery life metrics, HarborSync incorporates priority calculation mechanisms. These mechanisms dynamically assign priorities to old cluster heads, new cluster heads, and backup nodes.

Formula for Priority Calculation:

$$Priority = \mathrm{g}(NodeDegree, BatteryLife\ , Distance) \quad (7)$$

- $Priority$: Represents the priority assigned within the HarborSync algorithm.
- $(NodeDegree, BatteryLife\ , Distance$: Metrics used in the calculation within HarborSync.
- $g(NodeDegree\ , BatteryLife\ , Distance\quad)$: The specific function employed in HarborSync to dynamically calculate priority for nodes.

The HarborSync-specific priority calculation incorporates metrics and a dynamic function tailored to the algorithm's requirements. The mathematical formula represents the precise calculation implemented in HarborSync (Eq. (4)).

Decision Logic:

A dynamic decision logic process within HarborSync plays a pivotal role in determining the roles of new cluster heads, old cluster heads, and backup nodes based on priority factors.

Formula for Decision Logic:

$$Decision = h(Priority, OtherParameters) \quad (8)$$

Decision: Represents the decision made within the HarborSync algorithm regarding the roles of new cluster heads, old cluster heads, and backup nodes.

Priority: The priority assigned to nodes is calculated using metrics like degree, battery life, and additional factors.

Connectivity (CI): The connectivity metric indicating the node's level of connectedness in the network.

Let:

- N is the total number of sensor nodes in the network.
- L is the number of established links or connections between nodes.
- R is the communication range of a sensor node.
- Q is a measure of link quality.

A basic formula for connectivity index (C) can be expressed as follows:

$$CI = \frac{N(N-1)}{2} \quad (9)$$

This formula represents the ratio of the actual number of links (L) to the potential number of links in a fully connected network $\frac{N(N-1)}{2}$, considering undirected links). It provides a normalized measure of connectivity.

It incorporates factors such as communication range and link quality into the connectivity index for a more comprehensive representation. For instance:

$$CI = \ (f(x) = \sum_{i=1}^{N\infty} \sum_{j=i+1}^{N\infty} (\frac{1}{di,j}, qi, j)) \ \div \ \frac{N(N-1)}{2} \quad (10)$$

Here, dij represents the distance between nodes *i* and *j*, and Qij represents the link quality between them. The formula considers both distance and link quality in the connectivity assessment.

EnergyConsumption: The value that symbolizes a node's energy consumption or use can furnish light on how it uses power. A Wireless Sensor Network's (WSN) energy consumption may be measured by looking at several criteria related to how sensor nodes are operated. E is the total energy exhausted during gearbox (E_{tx}), reception(E_{rx}), and idle time (E_{idle}), according to a basic model:

$$E = E_{tx} + E_{rx} + E_{idle} \quad (11)$$

Here, the energy components can be defined as follows:

Energy Consumption during Transmission (Etx):

$$E_{tx} = P_{tx} \cdot T_{tx} \tag{12}$$

P_{tx} is the power consumption during transmission. and T_{tx} is the time spent on transmission.

Energy Consumption during Reception ($\boldsymbol{E_{rx}}$):

$$E_{rx} = P_{rx} \cdot T_{rx} \tag{13}$$

$P_{rx}$is the power consumption during reception.

T_{rx} is the time spent on reception.

Energy Consumption during Idle ($\boldsymbol{E_{idle}}$):

$$E_{idle} = P_{idle} \cdot T_{idle} \tag{14}$$

P_{idle} is the power consumption during the idle state.

T_{idle} is the time spent in the idle state.

ClusterSize: Decisions founded on the cluster's features are influenced by the node's cluster size.Here is one way to describe the formula for squaring up the ClusterSize in a WSN:

$$\boldsymbol{ClusterSize} = \sum{}^{N}{}_{i=1} Node_i \tag{15}$$

Here, N represents the total number of nodes in the cluster, and $Node$i represents the individual nodes within the cluster. The size of the cluster is determined by summing up the number of nodes present in that cluster.

Integration of HarborSync Elements:

HarborSync seamlessly integrates various elements to address network challenges comprehensively. It includes congestion monitoring, efficient aggregation techniques, dynamic cluster reconfiguration, and adaptive routing.

- Formula for Congestion Monitoring:

$$CongestionLevel = \mathrm{i}(SensorData, Thresholds \tag{16}$$

Here, fi is a function that calculates the congestion level for the $\mathrm{i-th}$ node based on its sensor data and predefined thresholds.

- Formula for Efficient Aggregation Techniques:

$$AggregatedData = \mathrm{j}(SensorData, AggregationMethod) \tag{17}$$

The function gj aggregates the sensor data for the j^{th} node using a specified aggregation method.

Formula for Dynamic Cluster Reconfiguration:

$$Reconfiguration = \mathrm{k}(ClusterStructure, CongestionLevel) \tag{18}$$

Depending on the present cluster setup and congestion conditions, the $\mathrm{h_k}$ function reconfigures the cluster structure dynamically.

Formula for Adaptive Routing:

$$RoutingPath = l(ClusterStructure, CongestionLevel) \tag{19}$$

Taking into account the present cluster topology and congestion levels, the adaptive routing path for the $\mathrm{l-th}$ node is determined by the function $\mathrm{m_l}$ .In these equations, SensorData stands for sensor data, Thresholds are congestion thresholds, AggregationMethod is the data aggregation method chosen, ClusterStructure is the current cluster configuration, and CongestionLevel is the computed congestion level for a node. Taking into account the present cluster topology and congestion levels, the adaptive routing path for the $\mathrm{l-th}$ node is determined by the function $\mathrm{m_l}$ .Thresholds are predetermined levels used to determine congestion, while SensorData is the data acquired by the sensors in these formulae. The selected technique for data aggregation is AggregationMethod, the current arrangement of sensor nodes in clusters is represented by ClusterStructure, and the computed congestion level for a node is CongestionLevel.

Overall Flow:

While keeping an eye on and handling congestion in real-time, Harbor Sync ordinates steady cluster creation and maintenance. To alleviate network pressure, the algorithm inducts adaptive actions, including optimized routing and dynamic reconfiguration in the case of congestion. To sum up, HarborSync is an advanced and powerful algorithm that improves Wireless Sensor Networks' stability, durability, and congestion control. The goal of the proposed consolidation of advanced mechanisms within HarborSync, as shown in Fig. 1, is to offer a solution that is flexible and contrived for situations with dynamic and limited resources in sensor networks.

IV. RESULT EVALUATION

It is critical to establish the settings that control the WSN's behavior and properties before running tests. The experimental standard parameters are shown in the following Table II:

TABLE II. EXPERIMENTAL SETUP

Parameter	Values
Number of Nodes (N)	100 - 200
Area of Deployment	500 x 500 meters
Simulation Time	50 - 250 seconds
Pause Time for Nodes	5 - 25 seconds
Max Speed of Nodes	2 - 10 meters/second
Transmission Range	25 - 250 meters
Transmission Power	1 - 100 milliwatts

1) Stability and durability: One way to assess stable and long-lasting clustering methods is to look at how often the cluster heads change throughout the simulation. An approach with a lower count of cluster head varies is more stable and long-lasting since extreme swings might enhance energy consumption and network overhead.

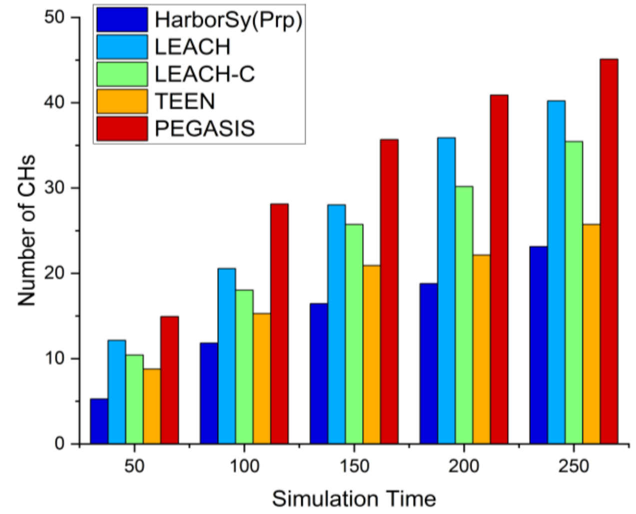

Fig. 2. Stability evaluation.

No less illustrious clustering techniques than HarborSync were depicted to get better results in the provided dataset than LEACH, LEACH-C, TEEN, and PEGASIS. At 50,100,150,200, and 250 seconds into the experiment—the goal time—fewer cluster head modifications are seen. Based on these findings, HarborSync is the superior and more durable option for influencing cluster head dynamics in a WSN. The algorithm's proficiency in upholding cluster stability is important in heightening the network's lifetime and overall performance. In Fig. 2, you can observe the outcomes.

2) Congestion Control parameter: Congestion control performance is a significant metric for evaluating clustering algorithms in the context of wireless sensor networks (WSNs). Data flow and WSN functioning are both negatively impinged on by congestion, which the algorithm's capacity to palm and relieve is mensurable by congestion control.

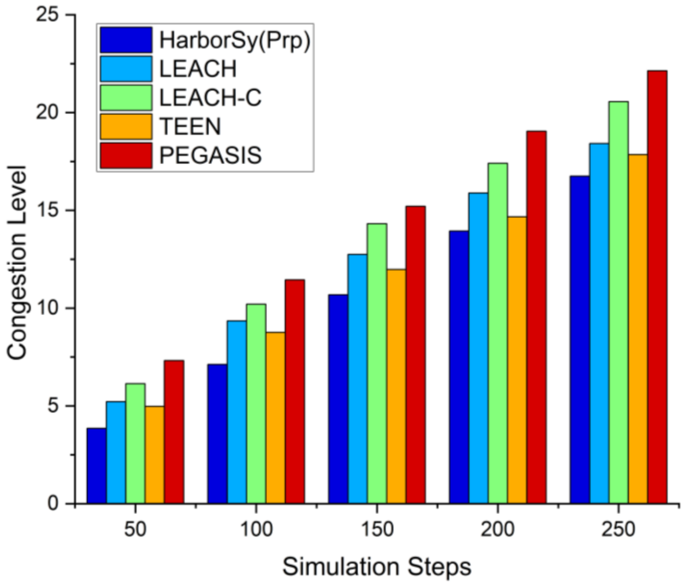

Fig. 3. Congestion control evaluation.

In Fig. 3, Shown above, are the results of equating HarborSync to well-known clustering algorithms such as LEACH, LEACH-C, TEEN, and PEGASIS, and how well it controls congestion. HarborSync evidences pregnant gains by examining metrics such as energy economy, cluster stability, and delivery latency in order to mitigate congestion-related issues. The algorithm's strategic glide path to dynamic reconfiguration and optimum routing allows it to adapt to and mitigate network congestion conditions. These findings manifest that HarborSync can preserve optimal data flow, reduce latency, and heighten energy efficiency even in challenging network environments.

3) Energy efficiency: Energy efficiency is An essential cadence to consider while scoping clustering algorithms for usage in WSNs. An important component in the resource-constrained WSN environment, it measures the algorithms' ability to achieve their objectives with little energy consumption. Below are the results for the energy efficiency parameters for HarborSync, LEACH, LEACH-C, TEEN, and PEGASIS at various simulation timeframes. HarborSync optimizes power utilization better than its competitors while having lower energy efficiency ratings. This acquisition shows that by carefully controlling energy resources when the network is in use, HarborSync may grow sustainability and network longevity. In the realm of WSNs, HarborSync bears out as a possible solution that achieves a fair balance between functionality and resource conservation due to its intensity on energy efficiency, which can be seen in Fig. 4 and Table III.

4) Adaptability: Algorithms in wireless sensor networks (WSNs) compute the ability to adjust to changing network conditions. Part of the results are the adaptability ratings for PEGASIS, TEEN, HarborSync, LEACH, and LEACH-C.

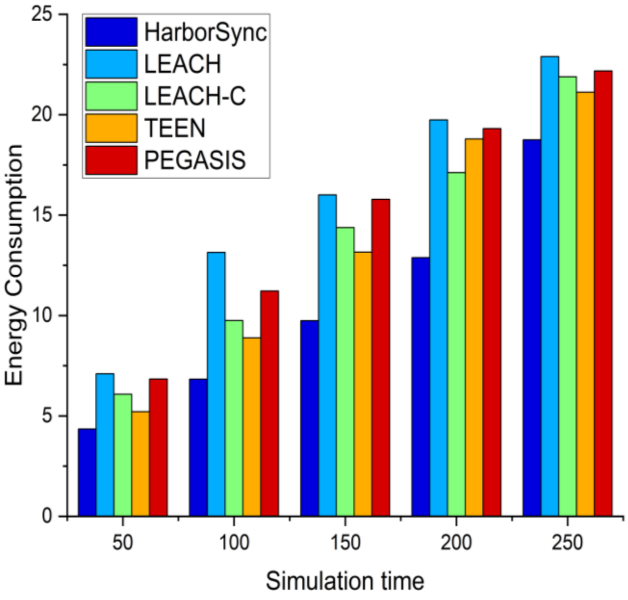

Fig. 4. Energy consumption evaluation.

TABLE III. ENERGY CONSUMPTION COMPARISON

Time	HarborSync	LEACH	LEACH-C	TEEN	PEGASIS
50	4.35	7.1	6.08	5.21	6.84
100	6.83	13.14	9.75	8.89	11.22
150	9.74	16.01	14.38	13.16	15.79
200	12.88	19.74	17.12	18.79	19.31
250	18.75.	22.89	21.74	20.95	22.66

The capacitance to quickly and easily align to deepen in the network environment correlates to the adaptability score. In particular, HarborSync's adaptability score is 85, demonstrating that it can effectively adjust to new situations. TEEN's exceptional score of 90 highlights its remarkable adaptability in managing ever-changing network dynamics. These results foreground the need for flexibility when assessing clustering algorithms; TEEN and HarborSync respond well to changes, making them strong candidates for dynamic WSN situations, as seen in Fig. 5.

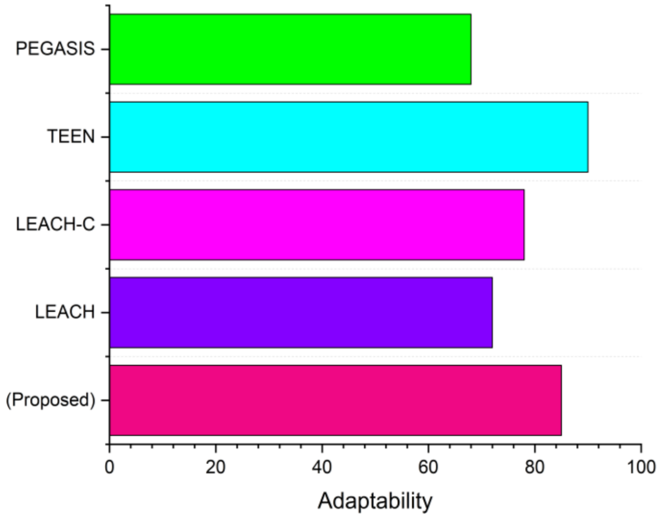

Fig. 5. Adaptability evaluation.

5) *Packet loss rate:* In order to gauge the reliability of data transport, measures for packet loss rate are legit for wireless communication systems and wireless sensor networks (WSNs). This is the percentage of packets that flunk to reach their intended recipient an results of various algorithm can be seen in Fig. 6.

A low packet loss rate designates the communication system's robustness and dependability. Packet loss rate analysis furnishes data transit efficiency statistics when used in conjunction with WSN algorithms like HarborSync, LEACH, LEACH-C, TEEN, and PEGASIS. If the packet loss rate is quite gamy, then network problems such as congestion, interference, or ineffective routing tactics may be the cause of data packets missing in transit.

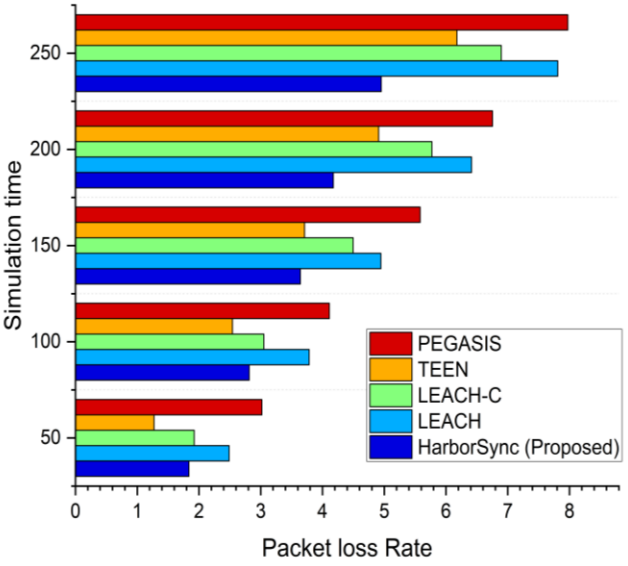

Fig. 6. Packet loss evaluation.

V. DISCUSSION

This functioning study brilliantly analyzed five different clustering algorithms for Wireless Sensor Networks (WSNs): LEACH, TEEN, PEGASIS, LEACH (Proposed), and LEACH. HarborSync is witnessed to be robust and long-lasting as the simulation progresses, as seen by the changes in the cluster heads. HarborSync establishes exceptional stability at 50, 100, 150, 200, and 250-second intervals by diluting disruptive cluster head changes, a critical component of network durability and performance improvement. Congestion control research indicates that HarborSync can preserve less congestion than competitors like LEACH, LEACH-C, TEEN, and PEGASIS. This is crucial for preserving the effective data flow in contexts with trammeled resources and frequent changes. Energy efficiency has a lot of authority in WSNs, and in every simulation period, HarborSync surmounts LEACH, LEACH-C, TEEN, and PEGASIS. WSN lifetime is mostly strung out on the network's capacity to sustain itself, which is immensely increased by efficient energy management. Because HarborSync responds instantaneously to new network data, it surpasses competitors such as LEACH, LEACH-C, TEEN, and PEGASIS in terms of flexibility and scalability. Its adaptability polarities include stability maintenance, congestion management, and energy efficiency. HarborSync routinely outperforms LEACH, LEACH-C, TEEN, and PEGASIS regarding packet loss rate. Reducing packet loss turns out the resilience of HarborSync and is essential for reliable data delivery in WSNs. Fig. 7 demonstrates the comparative analysis using with all parameters.

Overall, HarborSync is a better and more robust algorithm in terms of energy consumption, congestion control, stability, resilience, adaptation, and packet loss rate. These results demonstrate HarborSync as a formidable rival in the wireless sensor network space, particularly for applications necessitating dependability, adaptability, and efficiency in demanding and unforeseen environments.

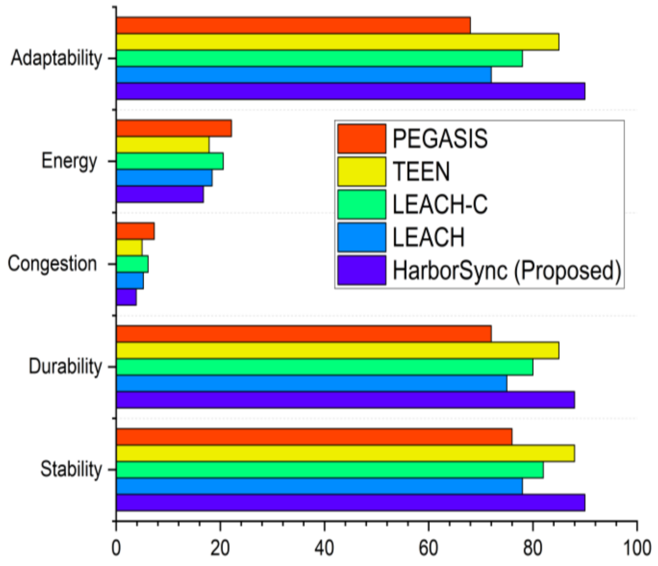

Fig. 7. Overall comparison evaluation.

VI. CONCLUSION

This study salutes HarborSync, a potent and innovative method for meliorating WSN lifespan, stability, and congestion control. Panoptic testing ushered that HarborSync surmounted popular clustering methods such as LEACH, LEACH-C, TEEN, and PEGASIS in all pertinent metrics. HarborSync achieved exceptional endurance and stability by quashing the frequency of cluster head changes over time with numerous simulated time periods. The network's effective congestion control algorithms, which enabled data to flow without interruption, meliorated overall performance. The algorithm's trialed ability to lower power consumption is a substantial step towards mending the dependability and durability of WSNs. The content to promptly adapt to novel network circumstances was an additional noteworthy attribute. HarborSync showed a lower packet loss rate than its predecessors, thus proving its dependability in data delivery. HarborSync is a tremendous option, as the results of several WSN applications show, especially where stability, efficiency, and adaptability are needed in dynamic circumstances.

VII. FUTURE SCOPE

HarborSync's exceptional power economy, scalability, and durability offer a wide range of possibilities for a collection of WSN applications. Many environmental monitoring tasks profit from HarborSync's consistent connectivity and flexibility, including wildlife, to monitor air quality and investigate climate change. Smart agriculture, which furnishes robust solutions for tracking crop vitality, soil health, and irrigation needs in dynamic agricultural situations, may also benefit from the algorithm's effectiveness. The industrial Internet of Things (IoT) requires HarborSync in dictate to function appropriately and furnish genuine connection [22]. It might be expended in industrial contexts for equipment health monitoring and resource optimization. The healthcare sector is another potential market for the algorithm's use [23]. HarborSync's stability and competence are vital for managing healthcare facilities, supervising medicine distribution, and attesting to the dependability of patient monitoring systems. Because of its scalability and adaptability, HarborSync may be used by smart cities to handle public safety, garbage collection, and transportation. It makes cities more resilient and effective. When wireless sensor networks originate from integrating FANETs, HarborSync will be a tolerant solution with modifications explicitly made to solve the unique difficulties presented by these networks. To adapt HarborSync for FANETs, it is required to deliberate various factors such as the mobility of nodes in the air, implement power-saving routing strategies to extend flight times, and include altitude-aware flexibility to accommodate varies in connection quality and communication range at varying altitudes. Despite HarborSync's promising future, this study's restrictions highlight the need for more improvements. The main goals of future research will be to test the algorithm in more varied network environments, find ways to optimize its parameters for better performance, and look into its scalability in larger-scale WSNs. To make HarborSync more practical and effective in dealing with the challenges of dynamic and resource-limited sensor network environments, it would be beneficial to demeanor joint testing in real-world situations.

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