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HDRA: A Haybird Data Reduction and Routing Algorithm

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Abstract

Presently, wireless sensor networks (WSNs) are emerging as a vibrant field of research due to various challenging aspects such as energy consumption, routing strategies, effectiveness, among others. Despite unresolved issues within WSNs, a substantial array of applications has already been developed. For any application design, a primary objective is to optimize the WSN in terms of its lifecycle and functionality. Recent studies on data reduction methods have shown that sensor nodes often transmit data directly (single hop) to the base station (BS). However, a significant concern is that most existing multi-hop routing protocols do not address data reduction before forwarding data to the BS. Consequently, this study introduces a Hybrid Data Reduction and Routing Algorithm (HDRA). The principal aim of HDRA is to prolong the lifespan of cluster-based WSNs. It strives to decrease the packet transmission by sensor nodes, especially when there is minimal change in sensor readings. The findings indicate that HDRA outperforms the LEACH protocol in terms of energy efficiency in sensor networks, irrespective of network type (T, H, or TH) or deployment scenarios (200x200m or 400x400m). Overall, the proposed algorithm enhances network performance by conserving energy and extending network lifespan.

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Keywords: Data reduction; WSN; Cluster; Lifetime

1. Introduction and Related Works

In the current landscape of technological research, Wireless Sensor Networks (WSNs) have emerged as a focal area, predominantly due to complex challenges such as power consumption, efficient routing algorithms, and overall system efficiency. Despite the unresolved challenges in WSN technology, a significant number of practical applications have already been developed. Within the realm of application design for WSNs, these networks typically consist of numerous small, cost-effective, low-power sensor nodes, which facilitate wireless communication over limited distances. These sensor nodes play a pivotal role in monitoring and recording various environmental parameters, including sound, pollution levels, humidity, temperature, and wind, subsequently transmitting this gathered data to a base station [1],[2].

A crucial aspect in wireless communication systems is the single-hop data transmission method to the base station. This approach, which involves direct data transmission from sensor nodes to the base station without involving intermediary relay nodes, is key for ensuring efficient and reliable communication between the endpoint and the central data processing unit [3]. Historically, single-hop data transmission has been a standard practice in WSNs for transmitting data from randomly deployed nodes to a centralized base station [4]. However, this method does come with certain limitations, notably the restricted transmission range of the wireless sensor nodes, which is often constrained by energy considerations. This limitation can pose challenges for sensor nodes that are situated at greater distances from the base station, making direct communication links difficult to establish.

To address these challenges, multi-hop data transmission has been proposed as an alternative strategy. This approach offers several advantages over single-hop communication, particularly in the context of WSNs [5],[6]. In a cluster-based WSN architecture, as illustrated in Figure 1, nodes are organized into clusters, with each cluster typically overseen by a cluster head. The overarching aim in this configuration is to organize the nodes in a manner that maximizes network performance and optimizes resource utilization [3],[4]. In these cluster-based WSNs, a variety of mechanisms and protocols are employed, such as Cluster-Head Selection (CHS) algorithms, routing protocols, and data aggregation techniques. These methodologies are integral to ensuring effective data gathering, processing, and transmission within the clusters [7],[8],[9].

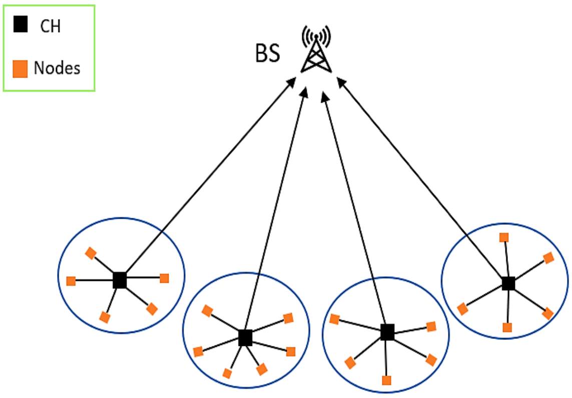


Figure 1: Architecture of WSN-cluster based

In the realm of application development for Wireless Sensor Networks (WSNs), it's critical to factor in the network's lifecycle and functionality. This necessitates a comprehensive grasp of the different phases in the development of a WSN, which include deployment, operation, and maintenance. Prioritizing these aspects is key to enhancing the network's longevity, boosting its performance, and optimizing resource use [7].

Data reduction techniques are central to improving WSN efficiency by minimizing the data transmitted. These strategies involve filtering, aggregating, or compressing data from sensor nodes before it's sent to the base station. By removing superfluous or irrelevant data, these methods help to reduce network congestion, save energy, and extend the network's lifespan. Recent advancements in data reduction have led to designs where sensor nodes transmit data directly to the base station (BS) in a single hop, offering benefits such as lower latency, streamlined network structure, and reduced energy usage [10][11][12][13][14]. However, this can also increase communication overhead and diminish scalability in networks with many sensor nodes.

While single-hop transmission has its advantages, it's important to recognize the limitations of current multi-hop routing protocols [15], [16], [17], [18]. These protocols, typically employed in WSNs, facilitate data transfer through intermediate nodes to the BS. Yet, many do not account for data reduction prior to data forwarding, resulting in the unnecessary transfer of excessive data, leading to higher energy consumption, increased network congestion, and a shorter network lifespan.

In [20], the impact of varying data packet sizes on cluster-based WSN performance was examined. The study concluded that the size of data packets significantly influences the lifespan of WSN clusters, suggesting that the integration of routing protocols with data reduction techniques could enhance performance. Further, [2],[21] investigates the effect of data reduction methods on WSN performance using diverse real-time datasets. Another study [22] introduced a novel clustering algorithm that employs the grey wolf optimizer (GWO) to select Cluster Heads (CHs), evaluating solutions based on projected energy consumption and each node's residual energy.

In [23] proposed a real-time core network design using WSN-based fixed slot assignments, utilizing direct link single and multi-way routing in WSNs. In [24], a new swarm intelligence optimization method, the dragonfly algorithm (DA), was introduced for energy-efficient CH selection, complemented by the Glow-worm Swarm Optimization (GSO) algorithm for efficient routing. The study [25] introduced the Energy-efficient Data Transmission and Aggregation Protocol (EDaTAP) in Periodic Sensor Networks (PSNs) based on fog computing, implementing clustering-based Dynamic Time Warping (DTW) to reduce redundant data received from sensor devices and decrease data transmission to the base station.

In [26], a dynamic generator polynomial-size for cyclic redundancy check (CRC) was suggested, using a reliable tree-based data aggregation method. While numerous studies, such as [9][27][28][29][30], have focused on data reduction at the node and CH level, they have often overlooked routing considerations when forwarding data to the BS. This paper introduces the Hybrid

Data Reduction Algorithm (HDRA), designed to extend the lifespan of the entire cluster-based WSN. HDRA's primary goal is to reduce the packet transmissions by sensor nodes, particularly when there's no significant change in sensor report values.

2. Proposed Algorithm

In this section, we delve into the details of the Hybrid Data Reduction Algorithm (HDRA), a strategic innovation designed to enhance the operational lifespan of cluster-based Wireless Sensor Networks (WSNs). The fundamental objective of HDRA is to minimize the volume of data packets transmitted by sensor nodes, particularly when the sensor readings exhibit negligible variations. Essentially, HDRA is crafted to evaluate and make critical decisions about the data from sensor nodes before it is transmitted to the cluster head. In scenarios where no significant data change is detected, the algorithm adjusts the update data to zero. Conversely, if a notable change is observed, it necessitates the node to refresh its data transmission to the cluster head. A comprehensive depiction of this proposed algorithm is presented in Fig 2. Accompanying this illustration is the pseudocode, which provides a step-by-step procedural guide, detailing the operational mechanics of the HDRA. This pseudocode serves as a blueprint for understanding the algorithm's workflow and its decision-making process in optimizing data transmission within WSNs.

```
// Proposed Algorithm

1.  Set (X,Y) // Field Dimensions in meters x m X x m
2.  Set "Number of Nodes in the field"
3.  Set Initial _Energy ←1//units in Joules //
4.  Set ENERGY MODEL // "Energy required to run circuity (both for transmitter and receiver) See Table X"
5.  Set NCH←p*Number of Nodes; // "p=0.05 Number of Clusters".
6.  Set Round ←1 // Round of Operation//
7.  Set Alive _nodes ← Number of Nodes ;
8.  Set Number of Transmissions←0;
9.  FOR each NODE (i) do
10. Call NOED(i)Parameters ← Node Structure(i) // Call Node Structure ()
11. SET NOED(i). update Data ← 1 // To Send only first value for Node i at Round 1
12. SET NODE(i). L_ Transmitted Data= [ NODE(i). Sensor Data (1))]// Set the first Raw sensors value [T, H]
    to the last transmitted data at time (t-1)
13. END FOR
14. WHILE Alive _nodes > 0 do
15.   IF Round > 1 // When Round =1 non-reduction mod // Only one time to transmit first value//
16.   FOR each NODE (i) do
17. // Phase Updating data
18.    Set S(t − 1)← NODE (i). L_ Transmitted Data
19.    Read: the current sensor value at t   time (Round)
20. Set S(t) ← NODE (i). Data (Round)
21.   //Calculate the relative differences (R_f)
22. R_f=Abs (S(t) − S(t − 1)) / (S(t) + S(t − 1)) × 0.5)
23. If R_f > Thrd Then
24. Set: NOED(i). update Data ← 1;
   25.     NODE (i). Transmitted Data ← NODE (i). Data (Round)
26. Else:  Set NOED(i). update Data ← 0
27. End if
28. Set Round ← (Round +1)
29. END FOR
30. FOR each NODE (i) do
31.   If NODE(i). update Data==1
32. CALL SELECT_CH () //
33. CALL STEADY-STATE PHASE //
34. Determine // Energy Dissipation for Normal Nodes & Cluster Head //
35. IF NODE(i). E<=0
36. Dead nodes← Deadnodes +1
37. Alive _nodes←Alive_nodes – 1
38. END FOR
39. END WHILE
40. END
```

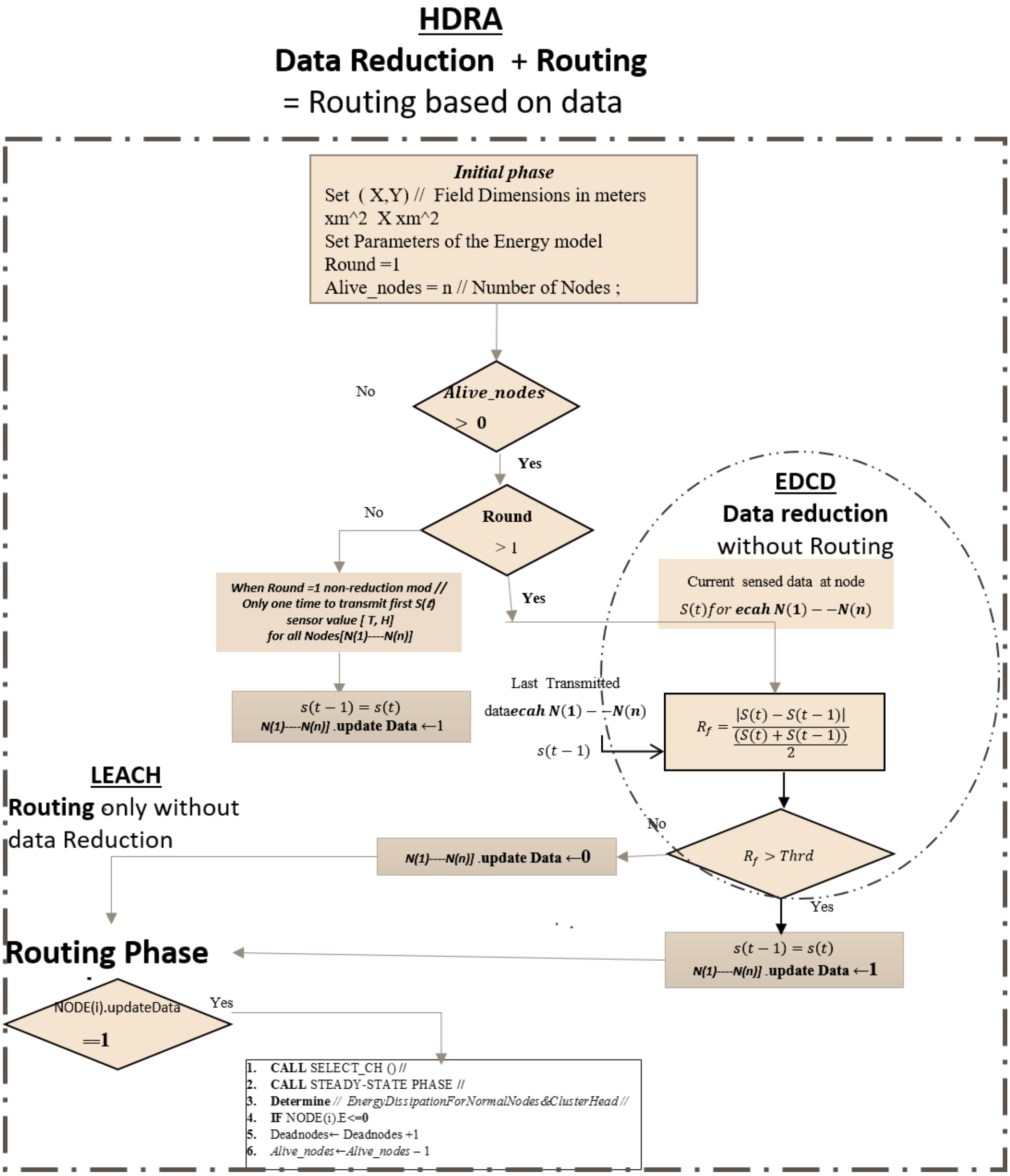


Figure 2: General structure of the proposed algorithm

// STRUCT of NODES //

Parameter	Description
Id	Sensor's ID number
XY	Coordinates of sensor node randomly
Eo	Nodes energy levels
Nrole	Node acts as normal if the value is '0', if elected as a cluster head it gets the value '1' (initially all nodes are normal)
Ncluster	The cluster which a node belongs to
Ncond	States the current condition of the node. When the node is alive its value is =1 and when dead =0
Nrop	Number of rounds node was alive
Nrleft	Rounds left for node to become available for Cluster Head election
Ndtch	Node's distance from the cluster head of the cluster in which he belongs
Ndts	Node's distance from the sink
Ntel	States how many times the node was elected as a Cluster Head
Nrn	Round node got elected as cluster head
Nchid	Node ID of the cluster head which the "i" normal node belongs to
NArea	Area Index
[data T, data H]	GNodeData(AreaRData(NArea).T, AreaRData(NArea).H)
NupdateData	Send only first sample / Values for all nodes without reduction
NL_Transmitted Data	Set the first Raw value[T/ H or TH] to the last transmitted data at time (t-1)

3. Performance evaluation

The performance of the suggested algorithm and cluster-based protocol (LEACH) is examined in this section. The cluster-based protocol and suggested technique can be used with various artificial datasets, as the next subsection explains.

A. System Scenarios

This section describes the system scenarios used in the simulation. The scenarios are designed to assess the performance of the proposed model under different conditions (See Table 1).

- **Scenario 1**: This scenario uses 100 nodes randomly deployed in a field area of (200 × 200 m^2) as shown in Fig.2 The threshold value was set to 0.01, 0.03, and 0. 05.
- **Scenario 2:** This scenario is similar to Scenario 1, but there are 200 nodes instead of 100 as shown in Fig.3. The threshold value was set to 0. 05.
- **Scenario 3:** This scenario has the same number of nodes (200) as Scenario 2, but the area size is 200 × 200 m^2 and 400 × 400 m^2 as shown in Fig.3, and Fig.4. The value of threshold is set to 0.01, 0.03, and 0. 05.

The following are the two cases of the system scenarios:

- **Case 1**: The nodes have only one type of sensor, which is temperature or humidity.
- **Case 2**: There are two kinds of sensors on the nodes: humidity and temperature.

Table 1: Simulation Scenarios

Scenario	Number of nodes	Area size	Single Sensor	Mutiple-Sensors
Scenario 1	100	200 × 200 m^2	T	-
Scenario 2	200	200 × 200 m^2	T / H	T & H
Scenario 3	200	400 × 400 m^2 / 200 × 200 m^2	H	-

*Temperature(T) . Humdity (H)

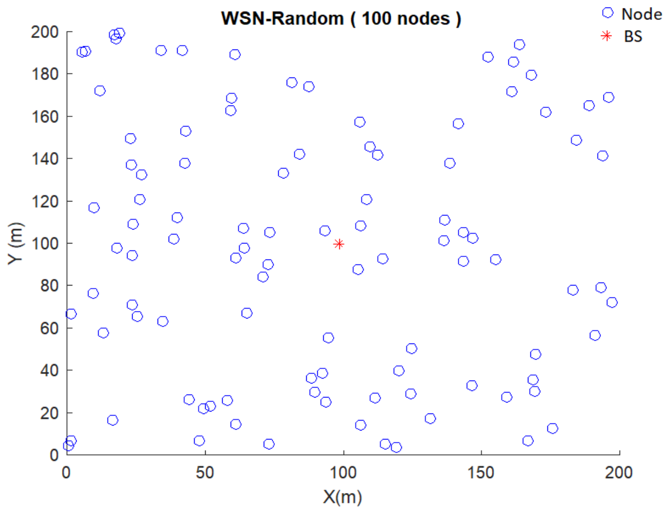


Figure 5: Sensor field area 200m x 200m

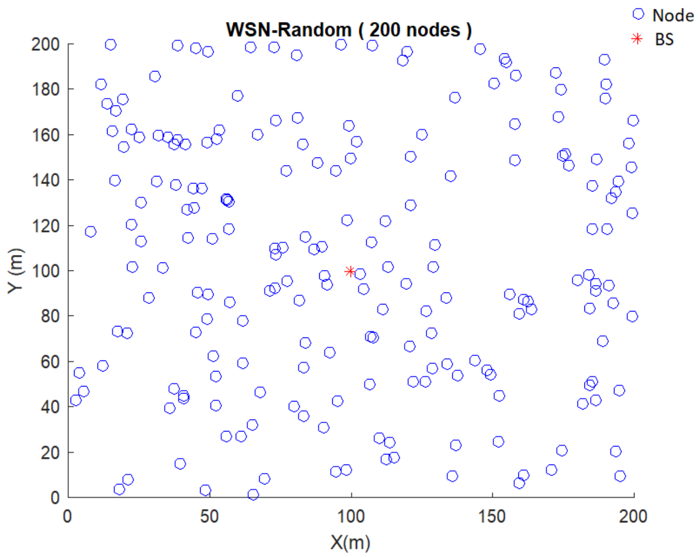


Figure 3: Sensor field area 200m x200m

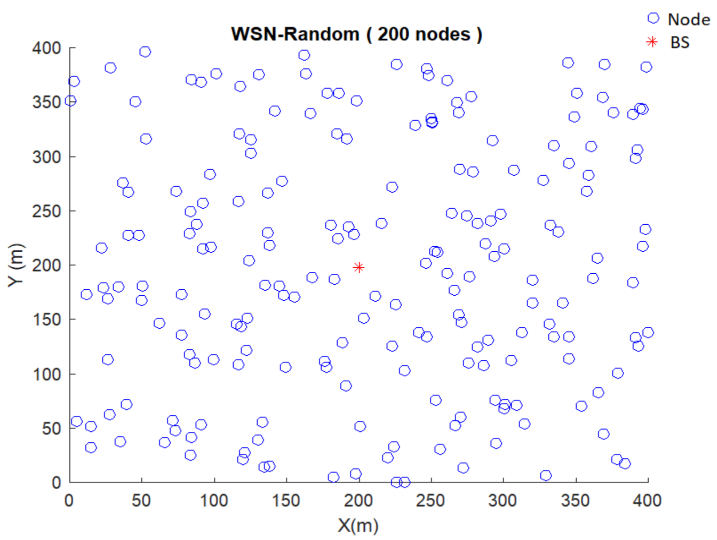


Figure 4: Sensor field area 400m x400m

A. Energy Model

As seen in Fig. 6, we employed Heinzelman's [15] radio energy model in the simulated experiments.

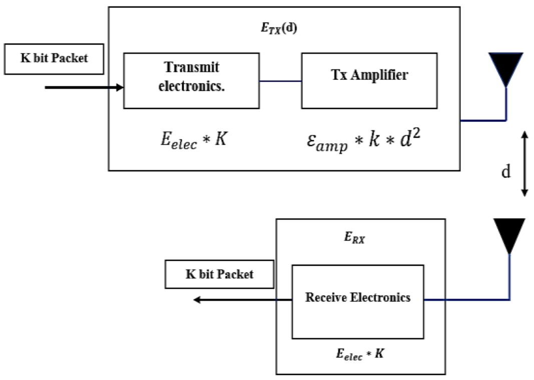


Figure 6: Radio model of the energy consumption.

In order to reach an appropriate amplifier for the transmitter E_b, the model assumes that the transmitter and receiver have energy consumptions of E_elec=50nJ/bit and that the transmitter amplifier has an energy consumption of E_amp=100pJ/bit/m^2. The amount of energy used to transmit a message is shown as.

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \qquad (1)$$

$$E_{Tx}(k,d) = \begin{cases} k.E_{elec} + k.E_{friss-amp}.d^2 & : d < d_{Crossover} \\ k.E_{elec} + k.E_{tow-ray-amp}.d^4 & : d \geq d_{Crossover} \end{cases} \qquad (2)$$

Where, $d_{Crossover}$ threshold is calculated as in Equation (3).

$$d_{Crossover} = \frac{4\,\pi\sqrt{L\, h_r\, h_t}}{\lambda} \qquad (4)$$

consumption of power during receiving,

$$E_{Rx}(k) = E_{Rx-elec}(k)$$

$$E_{Rx}(k) = k.E_{elec} \qquad (5)$$

"Where k is the message of the data packet size, $E_{Tx}$is the energy model for the transmitter, $E_{Rx}$is the energy model of the receiver, $E_{elec}$is the radio electronics of energy, d is the distance between the transmitter and the receiver. All the simulation results in this paper used the model as shown in Table 2."

TABLE 2: SIMULATION PARAMETERS

Parameters	Value
Initial Energy of a Node (E_o)	2 Joule
E_{TX}	50 x 10^{-9}
E_{RX}	50 x 10^{-9}
Transmit Amplifier (E_{AMP})	100 x 10^{-12}
Data Aggregation Energy (E_{DA})	5 x 10^{-9}
The percentage of CH (P)	0.5 %
Number of Nodes	Scenario#1-3
Field Area	Scenario#1-3
BS Location	Scenario#1-3
Packet Size (Bits)	500

B. Dataset

In the assessment of the proposed algorithm, a synthetic dataset was constructed, drawing upon characteristics from a real-time dataset. This selection process was guided by the criteria pertinent to the sensor node's operational area. The ensuing artificial dataset was crafted using MATLAB, tailored for sensor node applications, as delineated in the accompanying pseudocode presented below.

// Generate dataset - GNodeData //

---

1. **Input**: temp_node, humdity_node
2. **Output**: dataT, dataH
3. **Set** T ← temp_node; // original data (Temperature)
4. **Set** NSamples ← 200,000 // desired number of samples
5. Call [M, N] ← **size**(T)// returns a row vector whose elements are the lengths of the corresponding dimensions of T//
6. *// Randomly generated Artificial data based on the original temperature values*
7. **Call** dataT ←T (**bsxfun**(@plus, **randi**(M, NSamples,N), M*(0:N-1))) // bsxfun , randi // "*is a matlab function to creates an n-by-n codistributed matrix of uniformly distributed random.*"
8. **Set** H ←humdity_node // original data (*Humidity)*
9. *// Randomly generated Artificial data based on the original Humidity values*
10. **Call** dataH ←H (**bsxfun**(@plus,**randi**(M, NSamples,N),M*(0:N-1)));

End

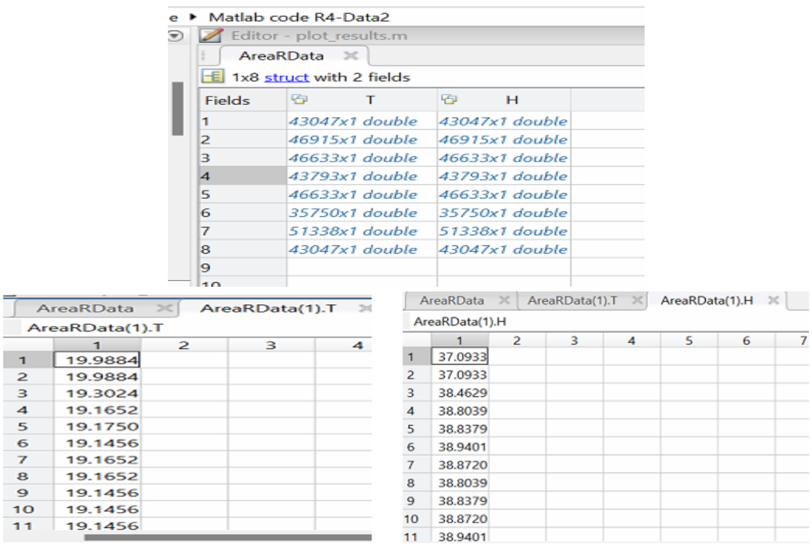
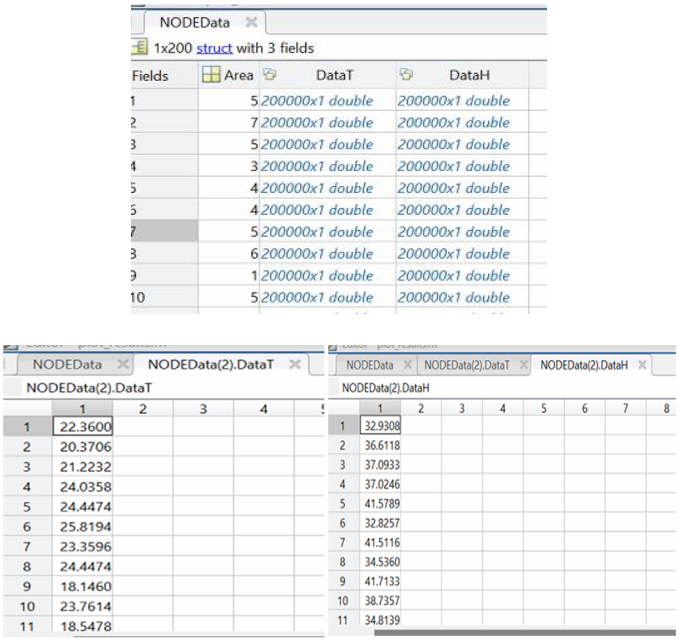


Figure 7: Sample of real-time data



NODEData

1x200 struct with 3 fields

Fields	Area	DataT	DataH
1	5	200000x1 double	200000x1 double
2	7	200000x1 double	200000x1 double
3	5	200000x1 double	200000x1 double
4	3	200000x1 double	200000x1 double
5	4	200000x1 double	200000x1 double
6	4	200000x1 double	200000x1 double
7	5	200000x1 double	200000x1 double
8	6	200000x1 double	200000x1 double
9	1	200000x1 double	200000x1 double
10	5	200000x1 double	200000x1 double

NODEData(2).DataT

	1	2	3	4
1	22.3600			
2	20.3706			
3	21.2232			
4	24.0358			
5	24.4474			
6	25.8194			
7	23.3596			
8	24.4474			
9	18.1460			
10	23.7614			
11	18.5478			

NODEData(2).DataH

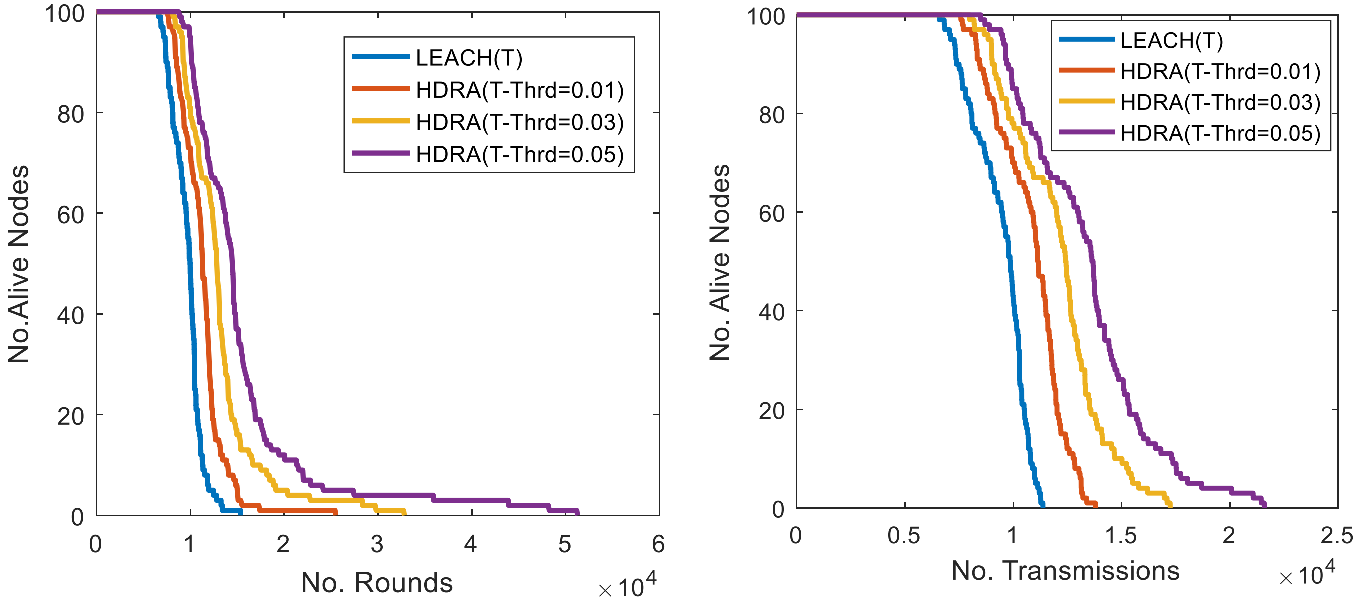
	1	2	3	4	5	6	7	8
1	32.9308							
2	36.6118							
3	37.0933							
4	37.0246							
5	41.5789							
6	32.8257							
7	41.5116							
8	34.5360							
9	41.7133							
10	38.7357							
11	34.8139							

Figure 8: Sample artificial dataset

4. Analysis of the Results

A. Study affect threshold value in Performance of HDRA

In Figure 9, we explore the influence of threshold values on the performance of the HDRA algorithm. This evaluation is conducted within Scenario 1, where the sensor type is set to 'T,' and we vary the threshold values as 0.01, 0.03, and 0. 05. Based on the findings, it is clear that the proposed algorithm produced the highest number of active nodes ever, which means that as many as 21,000 transfers were made. On the other hand, the cluster-based protocol achieves the minimum number of active nodes without considering the updated data status of sensor nodes and issues up to 11,000 messages. Furthermore, using the cluster-based protocol (LEACH) and the proposed HDRA method for Scenario 1, with the sensor type set to temperature, Figure 9-(b) shows the total number of active nodes per round. The findings show that the proposed algorithm extends the network lifetime while keeping in mind the maximum number of rounds is 83000 as compared to 12000 for the cluster-based protocol. The LEACH(T) protocol has the lowest maximum number of transmissions, followed by the HDRA(T-Thrd=0.01), HDRA(T-Thrd=0.03), and HDRA(T-Thrd=0.05) protocols. This is because the LEACH(T) protocol does not perform any aggregation of packets before transmission. To put it briefly, the suggested algorithm reduced energy consumption and enhanced network lifespan performance.



(a) Alive Nodes Per Rounds

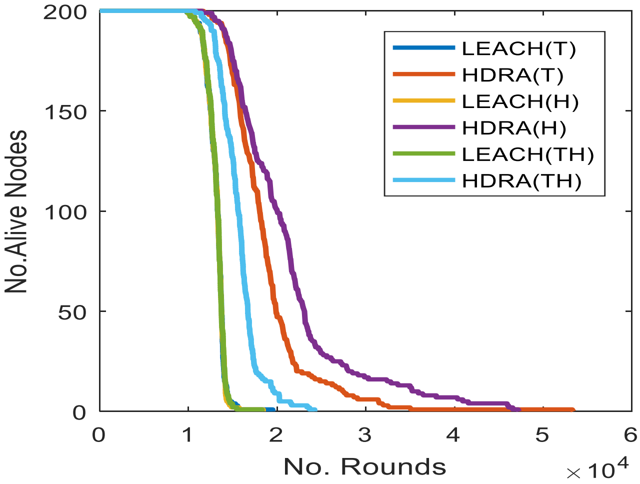
(b) Alive Nodes Per Transmissions

Figure 9: Results of Scenario (1) - (a) Alive Nodes Per Rounds, (b) Alive Nodes Per Transmissions

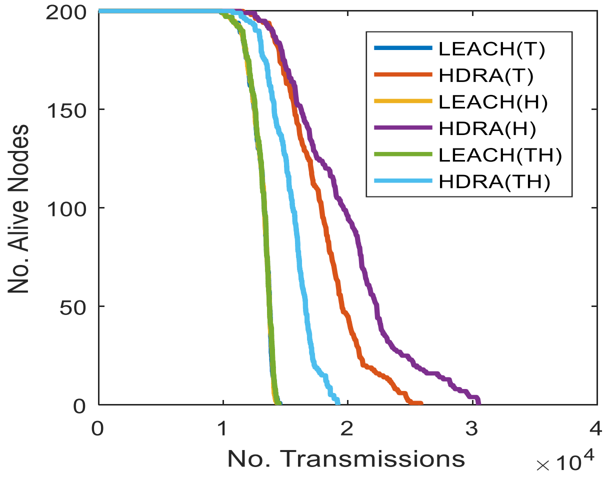
B. Study affect number and type of sensors in WSN Performance

In this section, Figure 10 presented the results of our experiments and provide an in-depth analysis of Scenario (2) - Alive Nodes Per Rounds, Alive Nodes Per TransmissionsResidual Energy Per Transmissions, and Max. No. Transmissions achieved when applying LEACH and HDRA to sensor nodes in various environmental conditions. Specifically, we consider six cases: LEACH(T), HDRA(T), LEACH(H), HDRA(H), LEACH(TH), and HDRA(TH), where 'T' denotes temperature, 'H' represents humidity, and 'TH' signifies the simultaneous monitoring of both temperature and humidity for each sensor node. The results indicate that the maximum number of active nodes, or a maximum of 25000, 30000, and 19000 transmissions for T, H, and TH, respectively, can be observed using the proposed HDRA approach. Conversely, the cluster-based (LEACH) protocol sends up to 15,000 messages and calculates the minimal number of active nodes without taking into account the sensor nodes' updated data status. The outcomes demonstrate that the suggested algorithm performs better in terms of energy savings and network lifetime. It is noteworthy that within the framework of our findings, a node's ability to transmit more packets—despite transmitting fewer times—indicates a longer prospective lifetime because of more effective energy consumption.

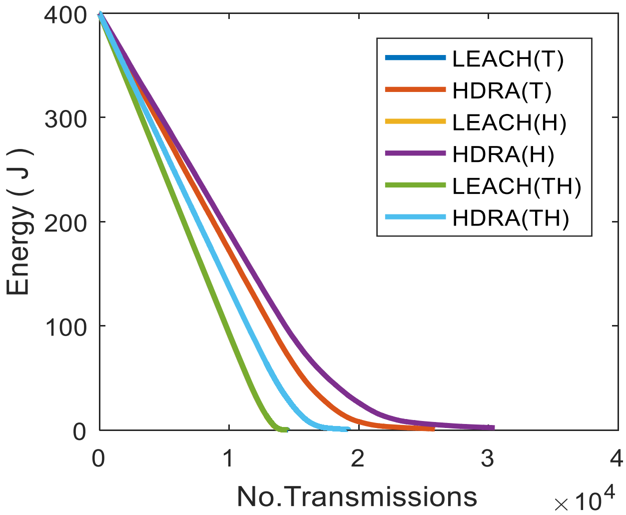
- ***Impact of Single Sensor vs. Multiple Sensors on Network Lifetime*:** Our results provide valuable insights into how the deployment of single sensors as opposed to multiple sensors within a network can significantly influence network lifetime .For example , the newteork with LEACH and HDRA signle sensor (T or H) perform better LEACH and HDRA than Multiple Sensors (TH).
- ***Impact of Sensor Type on Network Performance*:** Our results also highlight the variations in network performance based on the type of sensor used, specifically temperature (T), humidity (H), or a combination of both (TH).



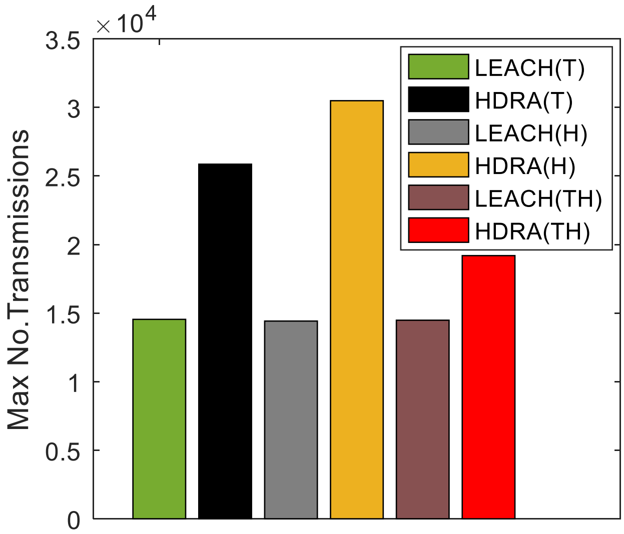
(a) Alive_Nodes _Per Rounds



(b) Alive_Nodes Per_ Transmissions



(c) Residual energy Per Tansmissions



(d) Max. No. Tansmissions

Figure 10: Results of Scenario (2) - (a) Alive_Nodes_Per Rounds, (b) Alive_Nodes_Per Transmissions, (c) Residual Energy Per Transmissions, and (d) Max. No. Transmissions

C. Compare two protocols, LEACH and HDRA, in two distinct deployment Area: 200x200m and 400x400m.

The analysis of energy consumption patterns for different sensor network configurations is crucial in order to optimize the performance and efficiency of wireless sensor networks, Therefore, in this section, we will analyze the energy consumption patterns for different sensor network configurations, specifically focusing on the monitoring of temperature (T), humidity (H), and the simultaneous monitoring of both temperature and humidity. Our primary objective is to compare two protocols, LEACH and HDRA, in two distinct deployment scenarios: 200x200m and 400x400m. Figures 11 and 12 showed the outcomes of Scenario (3) - Average Energy consumed by a Node_per Transmission (J) and Max. No. Transmissions, respectively.

HDRA is a more energy-efficient routing protocol than LEACH in sensor networks, regardless of the network type (T, H, or TH) or deployment scenario (200x200m or 400x40m). Monitoring temperature and humidity simultaneously does not significantly impact energy consumption compared to monitoring these parameters individually. These findings suggest that HDRA is a promising choice for energy-efficient sensor networks in a variety of environmental monitoring applications.

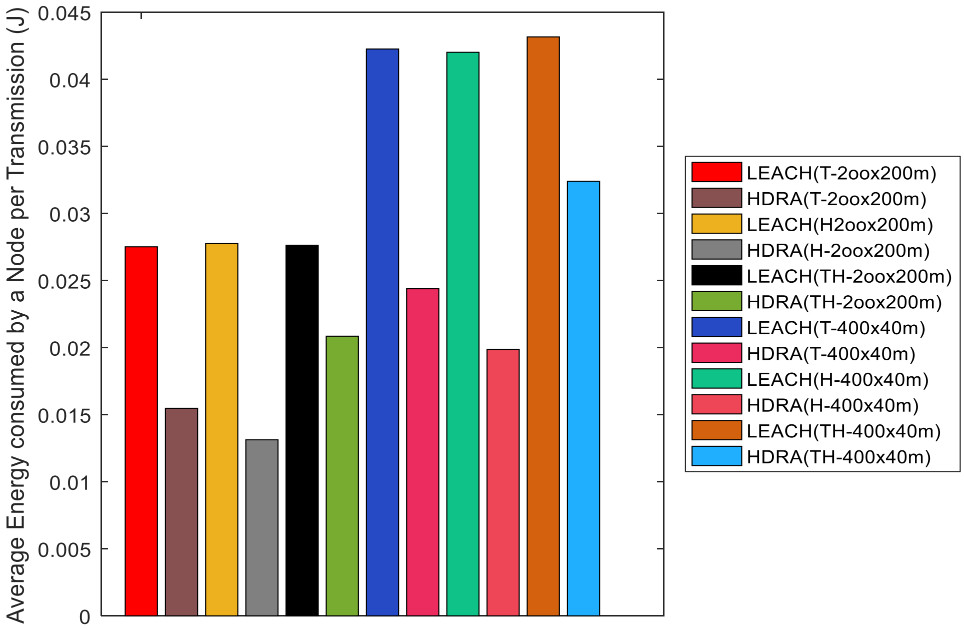


Figure 11: Results of Scenario (3) – Average_Energy _consumed by a Node per Transmission (J)

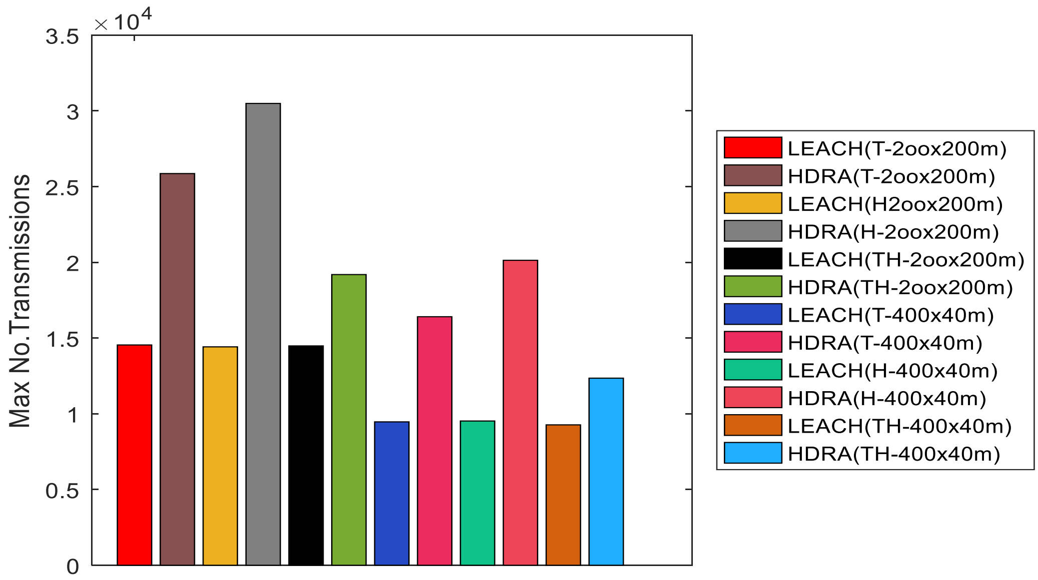


Figure 12: Results of Scenario (3) - Max. No. Transmissio

5. Conclusions

A new hybrid data reduction and routing algorithm (HDRA) was proposed in this research. The primary goal of HDRA is to increase the lifespan of the entire cluster-based wireless network. If there is little to no change in the value of the sensor reports, the goal is to have sensor nodes send fewer packets overall. The findings show that, in sensor networks, HDRA outperforms LEACH in terms of energy efficiency, irrespective of the network type (T, H, or TH) or deployment scenario (200x200m against 400x40m). In summary, from the perspective of the network lifetime, the suggested algorithm enhanced network performance and reduced energy consumption.

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