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Region Based Cluster Aided Routing Protocol for Environment Monitoring in Heterogeneous Wireless Sensor Networks

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ABSTRACT

Heterogeneous wireless sensing networks (HWSNs) that are limited by their batteries' power consumption might benefit greatly from more efficient routing algorithms. It is essential that routing accounts for the diversity of network nodes to achieve optimal performance. This letter considers sensor nodes with random initial energies and random disparities in data output rate (traffic) to build a realistic clustering-based WSN suitable for heterogeneous sensing applications. The protocol divides the space into numerous zones with different distance thresholds to deal with the hotspot problem that the multi-hop method creates. The advantages of region-divided routing ensure that only qualified nodes compete for the role of cluster's head during the choice phase and that the cluster heads with the greatest remaining energy in the extremely energetic area are selected as the relay node throughout the inter-cluster routing that includes several hops phase. The simulation findings demonstrate that the protocol may efficiently equalize energy consumption throughout the network, eliminate the issue of "hot spots," be used in an energy-diverse system, and lengthen the service life of the network.

1. Introduction

Due to its wide range of practical implications, research into wireless sensor networks (WSNs) has lately gained a lot of traction. Routing methods keep the many small sensor nodes of a WSN in continual communication with one another. The routing protocols of such a network are crucial to its functioning, and these protocols may be broken down into subcategories like "flat routing," "cluster routing," and "location-based routing." When broken down, routing methods for WSNs reveal clustering to be an essential component.

Energy efficiency and scalability are both improved [1]. With sensor nodes' power constraints and the dynamic nature of wireless networks, researchers have taken a keen interest in developing effective protocols for data transmission among sensors. Due to the difficulty of installing and upgrading sensor nodes in dangerous settings, routing continues to be a significant issue in wireless

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communications. Clustering has been studied to keep networks connected, infusing heterogeneity to slow down node deaths, and using evolutionary optimization to determine the optimal network topology are just a few of the ways researchers have attempted to overcome obstacles [2]. Clustering may greatly decrease node energy dissipation and raise the communication burden of cluster leaders in wireless sensor networks (WSNs). The "energy hole" issue may arise from uneven power use amongst nodes in a cluster when a multi-hop communication paradigm is used for clustering. To address this issue, several multi-hop clustering techniques have been introduced recently. Uneven clustering is the primary tool for regulating cluster sizes. Unfortunately, most of these protocols only address homogenous networks [3]. The potential for creating practical applications is greatly expanded in heterogeneous wireless sensor networks (HWSNs).

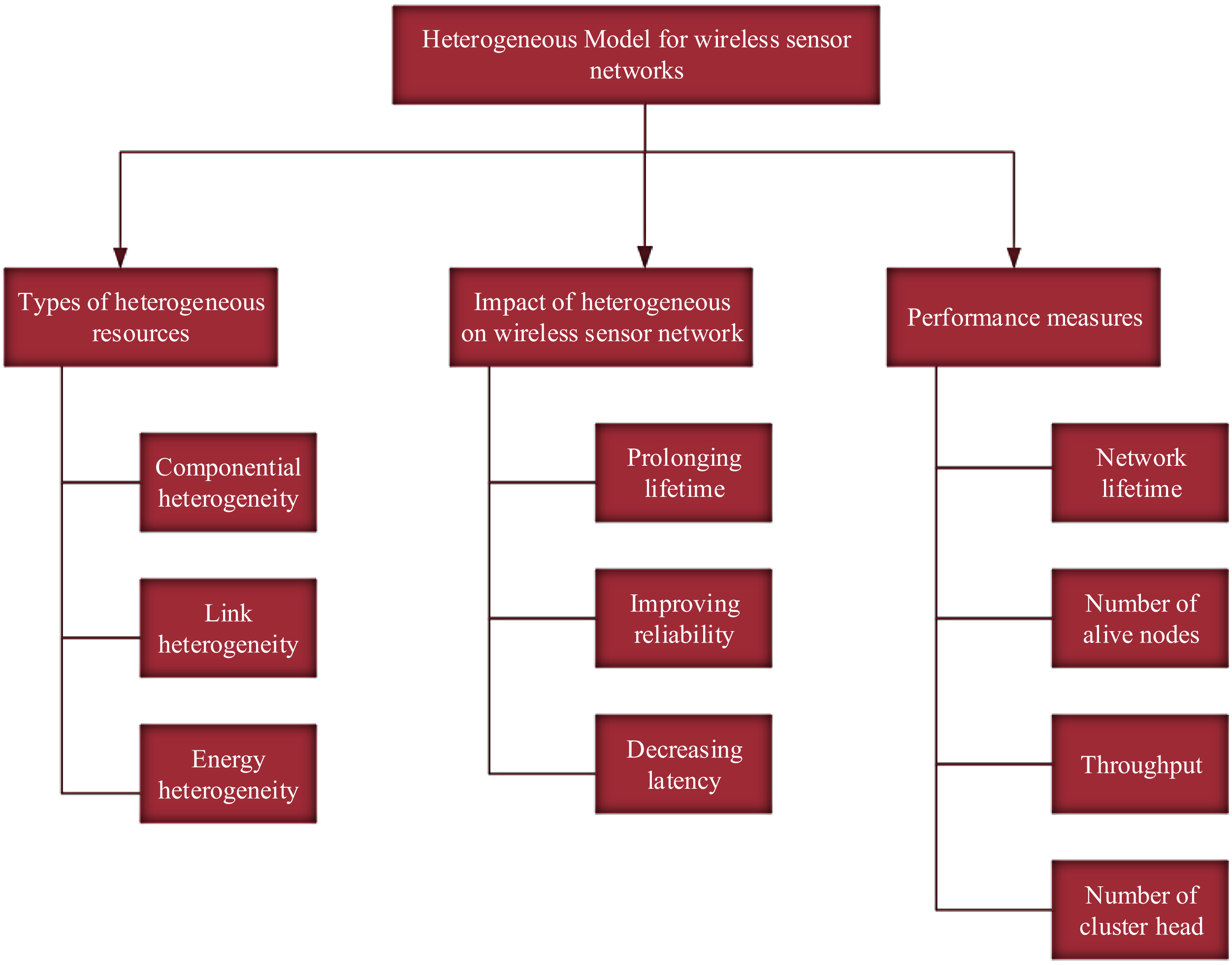

Fig. 1. Heterogeneous Model for WSN

Clusters are formed up of groups of sensor nodes (SNs). The CH is the apex of each cluster. The CH collects information from its SNs and transmits it to a BS. Batteries that power SNs are permanently installed and cannot be removed. One of the biggest issues with WSNs is how much energy they use. Energy-efficient routing protocols need to be developed for mission-critical sensor networks to function effectively [4]. Several clustering-based routing algorithms have been developed for use in wireless sensor networks to improve energy efficiency. Since duties may be distributed among various sensor nodes based on their heterogeneity, installing heterogeneous sensor nodes can further enhance the efficiency of such routing protocols [5].

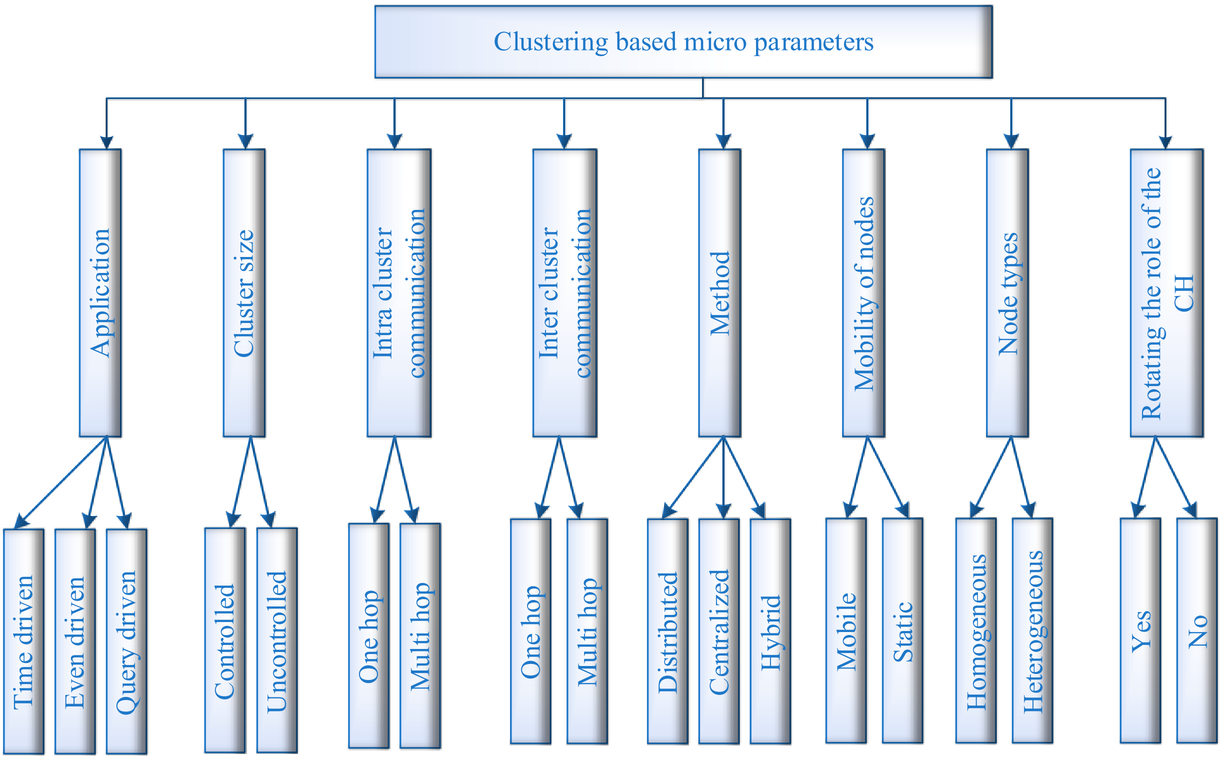

Fig. 2. Clustering Methods and Parameters for HWSNs

In HWSNs, clustering-based routing techniques are mostly utilized to increase the node's lifetime. Various clustering techniques have been developed to efficiently partition a network into smaller, more manageable subnetworks and choose cluster heads for each. Among them is the Improved Technique for Preference Ordering based on Traffic Reliability and Similarity. By factoring in traffic load, starting, and leftover energy of entire nodes in the heterogeneity scenarios, the Ideal-Solution (TARE-TOPSIS) protocol may calculate the chance that every node is regarded as CH. The quantity of clusters and associated probability are calculated only based on coverage and energy. However, data or data packets sent between nodes as well as a base station (BS) are heavily impacted by noise as well as data transmission speeds [6]. Since most sensor nodes in WSNs rely on battery power, preserving that power is a significant difficulty in the field. Clustering is the most often used and effective topology control method because of the benefits it offers in terms of both energy efficiency as well as scalability. Selecting a cluster leader, forming the cluster, and exchanging information are the three primary stages of a cluster-based routing system [7].

2. Related Work

To boost network resilience, the authors of [8] integrated heterogeneity with swarm-based optimization. To obtain a close approximation of the ideal set of cluster heads based on their optimal number, this study made use of the binary particles swarm optimizer with the binary's artificial bee colonies optimizer. A newly revised approach to CHs selection utilizing swarm optimization is provided, with its foundation in the probabilistic concept underlying the heterogeneous protocols SEP, EDEEC, and BEENISH. The best CHs are sought after throughout the swarm's flight thanks to a goal function that represents a healthy compromise between the nodes' starting and ending levels of energy. Concerning stability (FND), the frequency of half-node deaths (HND), network longevity (LND), and energy saving, the protocols developed provide much better results than the industrystandard heterogeneity algorithms SEP, EDEEC, and BEENISH. Selecting CHs in EDEEC and BEENISH with BABC improved those programs by over 20 percent, and compared to the SEP, the BABC-SEP saved 31.66 percent of residual energy.

In [9], an effective cluster-based routing scheme based on Sparrow search is described. The fitness function needed for the clustering algorithm to do its job is derived. Sparrows' feeding and predator-evasion instincts allow them to choose the best cluster leaders and routes to the BS. Extensive experiments have been conducted to verify that the suggested model can be successfully implemented to maximize energy efficiency as well as network longevity compared to other comparative approaches across a wide range of network configurations, including both the number of nodes and the number of network iterations.

For WSNs having multi-level energy heterogeneity, the authors of [10] proposed a routing strategy based on unequal clusters. The sensor area has been divided up into a grid of rectangular cells. First, determine how many clusters are present in every component by equating the power needs of all the cluster nodes. The authors then determine the best configuration in terms of unit count by reducing the total energy required for transmitting data across clusters. Finally, the number of groups in each unit and their sizes are carefully planned according to the energy level of each node. To prevent unfairly punishing the nodes with greater energy levels, a limit is also included. The simulation results demonstrate that their strategy successfully addresses the "energy hole" issue and significantly lengthens the lifespan of the network.

For wireless sensor networks, the team behind the Study [11] suggested the Energy-Aware Gateway Based Routing Protocols (EAGBRP). Their suggested protocol divides the sensing field into five logical regions, each including a subset of the deployed node sensors of a WSN. The BS was set up outside of the sensing region, as well as two node gateways were launched in strategically chosen locations within the sensing area. Each region's CH is chosen separately from the others using a regional weighted election probability. Through simulations, they were able to test their routing system and refine it. Their EAGBRP was put through its paces using simulations of the SEP, M-GEAR, as well as MGBEHA (4GW) protocols to determine its efficacy. Performance is measured by adjusting the network characteristics such as longevity, throughput, and residual energy. The results of the performance investigation show that EAGBRP allows WSNs to outperform all other protocols under consideration in terms of network lifespan and throughput while using the fewest resources.

Increasing network longevity and decreasing energy consumption in HWSNs are two goals of the enhanced energy-efficient clustering technique (EEECA) proposed by experts in [12]. The proposed protocol relies on nodes at the standard, intermediary, and advanced levels of network maturity. During the clustering process, they take into account the SNs' starting energy, the number of alive/dead nodes, as well as the remaining energy to determine the CH. Detailed analysis of performance characteristics demonstrates that the suggested EEECA-THWSN reduces energy usage by 25% and increases network lifespan by 25%. The suggested protocol considerably boosts network throughput, longevity, and stability while also enhancing the energy effectiveness of EEECA-THWSN.

In [13], the authors provide a HEB routing protocol known as an enhanced topographical routing method (ATR) for heterogeneity IoT with WSN. Some nodes in the T-HEB protocols utilize direct broadcasts to transmit information to the base stations, while others use clustering. This method uses the energy at each node to determine the three possible topologies for a field whose dimensions are currently unknown. Researchers investigate the communication along with cluster head selection in the Z-SEP protocol, and they create a novel approach for choosing cluster heads according to residual energy as well as distance from the base station. Multi-hop communication links the base stations to the nodes. The T-HEB is compared to its parent protocol in several different assessment circumstances, including when the base station is relocated, the nodes are inverted, and the node energy varies. In this paper, experts evaluate the T-HEB routing protocol in comparison to the well-known Z- SEP and SEP protocols. Evaluate the new protocol against the original using MATLAB 2021a's simulator. The simulation findings demonstrate that the T-HEB protocols I suggest enhance network stability by raising the number of functioning nodes, the pace at which packets are delivered, and the average amount of power used.

For heterogeneous WSNs, [14] introduces a novel non-uniform hierarchical clustering with a dynamic route adjustment method (NHCDRA), which takes into consideration two mobile sinks wandering the perimeter of the sensor field. To do this, NHCDRA creates a hierarchy of sensor nodes of varying sizes. Clusters along the sink's mobility route (border clusters) are maintained relatively big so that a greater number of sensors can be accommodated, and the roles of cluster leaders may be cycled to more evenly spread the workload. In addition, a set of rules for dynamically adjusting routes is established to control the routing pathways caused by the movability of the sinks. These rules ensure that information reaches its destination with the fewest feasible hops and reduce the overall cost of route modification. The simulation results show that NHCDRA significantly improves network lifetime while decreasing data delivery delay.

To address this issue, the authors of [15] presented a Sector Tree-Based clustered routing algorithm for energy efficacy, in which the network topology is partitioned into dynamic sectors (clusters) that maintain a healthy balance of active nodes. Each sector's nodes only talk to their neighbours, and the cluster heads are designated using a combination of candidate node distance to the base station (BS) as well as remaining candidate node energy to create an optimal tree centred on the Kruskal algorithm. STB-EE maximizes the throughput of information packets supplied to the BS by estimating the period in every check for appropriateness. Their simulation findings suggest that compared to power-efficient collecting in sensor information systems (PEGASIS) as well as environmentally friendly PEGASIS-based protocol (IEEPB), the lifetime of a network utilizing STB-EE may be enhanced by roughly 16% and 10%, respectively.

In the realm of Wireless Sensor Networks (WSNs), various research efforts have been directed toward addressing critical challenges for optimal performance. One such study by [17] introduces a novel routing protocol, FFA-RF, integrating a fuzzy-firefly algorithm (FFA) and random forest (RF). This work focuses on optimizing clustering in WSNs, a task known to be NP-hard. By leveraging the FFA for offline tuning and the RF for online routing, the protocol considers both node and application features for enhanced generalizability. While providing a heuristic solution, the study acknowledges the need for further exploration of limitations in diverse network scenarios.

Another noteworthy contribution in the WSN domain is presented by [18], introducing the Residual-Energy-Based Data Availability Approach (REDAA). This approach targets the challenge of maintaining high residual energy and constant data availability in dynamic scenarios. By strategically selecting stable routing paths and employing cluster heads through the integration of Q-LEACH and MH-LEACH algorithms, REDAA aims to enhance network lifetime. However, the study recognizes potential limitations, particularly in highly dynamic scenarios where the effectiveness of REDAA may be influenced by network scale and dynamic node movements.

In the context of multi-UAV-assisted data collection, [19] proposes a start-to-end strategy focusing on the Age of Information (AoI). This approach employs a density-based clustering algorithm to determine data collection points and UAV-SN associations, optimizing SN-CP and CP-UAV associations for minimized AoI. While offering a comprehensive solution, the study acknowledges the complexity of the problem, especially in large-scale deployments and dynamic network scenarios.

Additionally, [20] contributes to the literature with a focus on secure routing protocols in the Internet of Things (IoT) and WSNs. The proposed protocol emphasizes energy efficiency, packet mitigation, congestion management, encrypted data transfer, and surveillance against attacker nodes. However, potential challenges arise due to network isolation and segmentation issues, impacting communication reliability and node resilience in specific scenarios. These works collectively contribute to the growing body of knowledge in WSNs, each addressing distinct challenges with innovative approaches while acknowledging the need for further exploration of limitations.

3. Proposed Methodology

3.1 System Model

A successful CH selection in a multi-heterogeneity scenario may benefit from this section's initial short discussion of the implications of energy along with traffic heterogeneities. The proposed routing protocol is then shown; it selects a CH depending on several parameters, including the initial energy of the nodes, the energy they have left, the amount of traffic, and the average energy of the round.

The RCRP protocol is a revolutionary energy-balanced clustering routing mechanism for WSNs that divides the network into regions. It can even out the network's energy usage and increase the network's lifespan. Here, we'll break down the RCRP protocol into its five component phases to show you how everything works: delineating regions, determining cluster radii, establishing clusters, establishing inter-cluster multi-hop routing, and finally, transmitting data. We assume there to be a sizable number of sensors spread across the network [21]. Also, they're all lined up in a neat square. Furthermore, we assume the following for every node in a WSN:

i. Once deployed, nodes cannot be repositioned in any way. The goal of a sensor network is to have its nodes continuously monitor their surroundings and report back to a central location through wireless communication.
ii. A unique ID is created for each node. And they may combine the duplicate information. It is difficult to replenish the batteries in any of the sensor nodes. The loss of power is the single root cause of node failure.
iii. Each node may dynamically change its transmission power from among a wide range.
iv. Because they lack GPS receivers, nodes have no way of determining their precise location on a global scale. However, the intensity of the signal received may be used to estimate the relative remoteness.

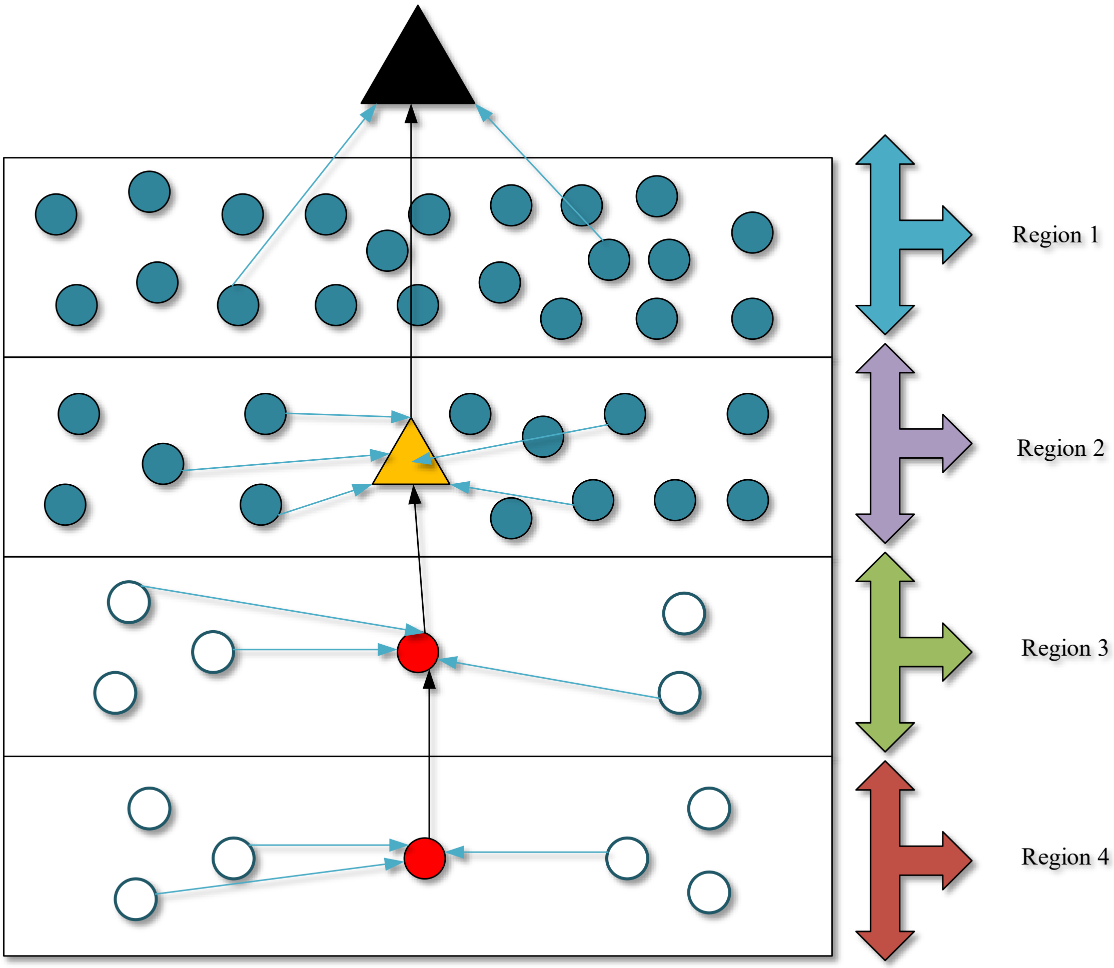

Fig. 3. Region-based Clustering in HWSN

3.1.1 Region Splitting

In RCRP, a base station is responsible for partitioning the network's area into numerous regions based on distance, as well as cluster heads are picked in each region separately to streamline the network structure. The specific approach is as follows: after the network nodes have been deployed, the BS will broadcast the region-divided messages (Region-MSG) over the whole area, making sure to specify the region's radius r. Based on the received signal intensity, nodes determine their distance to BS(d_(i-BS)). Then, they may calculate their region number using the following formula:

$$\text{Region } (i) = \left\lfloor \frac{d_{i-BS} - d_{i-\min}}{r} \right\rfloor + 1 \quad (1)$$

As far as I can tell, 1 is the lowest possible region number, and regions farther left from the base station will have higher region numbers. Using Eq. (1), each node may calculate its unique region number. Due to the immobility of nodes, area partitioning is performed just once after nodes have been deployed. In terms of long-term energy usage, this stage's energy needs are negligible.

3.2 Clustering

After the network space has been partitioned into regions, the cluster radius for each region must be calculated [22]. We investigate the uneven clustering concept in E2RP and suggest the Equation because multihop communication will unavoidably result in the hot spots issue Eq. (2):

$$R_i = \left(1 - c \times \frac{\text{Region}_{\max} - \text{Region}\,(i)}{\text{Region}_{\max}}\right) \times r_{\max} \tag{2}$$

Wherein Z_{region} the maximum number of regions in the area is denoted by max, whereas the region number associated with node i is denoted by region (i). The r_max denotes the largest possible cluster radius in a competition. The coefficient c ranges from 0 to 1, and it is constant. By finding the best possible value for c, we can reduce the network's overall energy footprint and increase its expected lifespan. We will provide the best possible value of c in the simulation section.

Using Eq. (3), we will observe that the distance among areas as well as BS determines the cluster radius. And r_max is the largest possible radius. In [9], we assume that the value r_max describes the best cluster radius:

$$r_{\max} = r_{opt} = 2\sqrt[4]{\frac{2\pi\|A\|E_{DA}}{27N\varepsilon_{fs}}} \tag{3}$$

Since the cluster radii in the same area are uniform in RCRP, its uneven clustering process differs from that of E2RP. It simplifies the process and gets us ready for the multi-hop routing step between clusters in advance.

Without sacrificing too much generality, we'll say that the sensor node is different in its starting charge and traffic frequency (packet sizes). Eq. (4) specifies M_i, the packet's size of each node.

$$M_i = \left(\frac{prksize}{dr}\right) \tag{4}$$

wherein d_r is the traffic density at this node. The prksize controls the top limit of the network's traffic rate (packet size).

$$dr = (1 + \alpha) \tag{5}$$

where α characterized the node i's traffic heterogeneity.

The total amount of messages each node has sent $i(Mbx(i))$ win light of prior iterations of communication,

$$\text{Mbx}\,(i) = \sum_{i=1}^{r} M_i(i) \tag{6}$$

wherein M_i (i) is the packet size of the data delivered to the CH by node i during round r, where r is the round number.

In the current iteration, r, the node i's average traffic rate (T_R) is calculated as

$$T_K(i) = \frac{Mbx(i)}{r} \tag{7}$$

As a result, the average traffic rate (T_R) for a given iteration will be higher for a node with a higher traffic rate (packet size). To achieve a more balanced sleep-wake cycle, paired nodes eavesdrop on one another to learn the energy levels and traffic volumes of their counterparts. As illustrated in Figure 4, after each data transmission cycle, point E with the smallest data velocity (packet length) of 2" " kb will acquire the information regarding the traffic flow of its pairings. This is how the cycle of sleeping and being awake works: Before sending any further messages, each node first calculates its average traffic frequency relative to all previous messages delivered, and then compares this rate to the average traffic frequency of its pair. Second, the currently active node verifies that it has sufficient energy to continue functioning in the network founded on the threshold value. If the present awake node's energy is more than the threshold amount and it has a low traffic rate, it will do environmental sensing and report its findings to CH [23]. Thirdly, the currently awake node will go to sleep after broadcasting its current location and the position of the favoured node amongst its pairs if its traffic rate is higher than the average rate of traffic of any of its pairings. Preferred nodes in pairs wake up to perform data gathering and transmission tasks to CH once they get the current location of the currently awake node. If two or more nodes have the same average traffic rate, the one with the largest residual energy is chosen as the winner. Figure 4 displays how cluster nodes conserve power and regulate traffic by taking turns sleeping and being active.

The threshold is calculated based on the expected network energy consumption every round. To determine the round-trip energy usage (E_"round "), we assume that the sensor nodes are uniformly distributed throughout a KK square area as well as the BS is permanently deployed at the geographic hub of the area. The $N_{tslot} = (Un + pg) - 1$ Each node periodically updates CH with data. We have assumed the worst situation when all nodes transmit prksize every round (the maximum traffic rate allowed in the network). This means that the network's round-total energy consumption may be calculated by

$$\begin{aligned} E_{\text{round}} = \text{ prksize } * (2N_{tslot}E_{\text{elec}} \\ +N_{tslot}E_{DA} \\ +k\varepsilon_{mp}d_{t\_BS}^{4} + N_{tslot}\varepsilon fsd_{t\_CH}^{2}) \end{aligned} \tag{8}$$

for each given set of clusters, k.

Cluster setup starts after every node has been assigned a region number and a cluster radius.

STEP 1: Each node keeps track of its neighbours in a database called Table_Node and sends out its messages, called Node_MSGs, within the radius of the cluster. Node_MSG follows the format shown in Table 1:

Table 1
Node_MSG's Internal Structure

ID	Energy	Region
1	0.37 J	1
2	0.46 J	1
3	0.32 J	2
4	0.42 J	2
5	0.48 J	3

Where ID is the unique identifier of the node in the network, Energy is its current energy level, and Region is its allocated region. Each node exclusively processes messages from its area, discards those from other regions, and modifies the table.

STEP 2: Each node may determine its average energy level relative to its neighbours using the Table_Node. Energy_avg. Let's suppose that each given node N has n neighbours in its Table_Node. stated as $\mathrm{S_N} = \{\mathrm{N_1},\ \mathrm{N_2}, \dots, \mathrm{N_k}, \dots, \mathrm{N_n}\}$, to indicate the kth nearest neighbour node, Nk. Then, the following expression describes Energy_avg: Eq. (9):

$$\text{Energy\_avg}\ (N) = \begin{cases} \frac{1}{n}\sum_{k=1}^{n}\ \text{Energy}\ (N_k) & n > 0 \\ 0 & n = 0 \end{cases} \tag{9}$$

If the node's remaining energy is more than the Energy_avg, it will run for cluster leader; alternatively, it will enter a waiting state until the election is over and then join the cluster with the closest leader. This guarantees that only the most energetic nodes inside the cluster will rise to the top. Since there will be fewer nodes in an energy-diverse network, the complexity of choosing a CH will be reduced, and the node with the least amount of energy will be safeguarded.

STEP 3: Cluster heads are chosen from potential leaders using a time controller method. Assuming H is the ID for a potential node, we can solve for H using Eq. (10):

$$\text{Time}\ (H) = u \times \delta \times \frac{\text{Energy\_avg}\ (H)}{\text{Energy}\ (H)} \tag{10}$$

Where the tstd. wait(u) is a random value between 0.9 and 1, which is the typical waiting time. If you take the average energy of the nodes around H, you get Energy_avg (H). The energy level of the potential candidate node H is denoted by H.

Candidates with more energy in the radius of the cluster area will benefit from the shorter period to wait, as shown by Eq. (10). With any luck, they will be chosen as CHs and will spread the CH_MSG across their cluster's area. Before the waiting period expires, other potential nodes will get the notification and withdraw from the cluster head's election.

STEP 4: A non-CH node will join the cluster led by the CH with the highest signal if it gets messages from several CHs. Once the Join_MSG has been sent, the node will become part of the cluster. A TDMA time window for data transmission is allocated to each member node and broadcast by the cluster head.

Each cluster should now be operational.

3.3 Cluster-Based Routing

The RCRP protocol employs a multi-hop strategy in its intercluster routing phase. The selected routing path should avoid the area with low energy availability so that a cluster head (CH) can process data coming in from the member node along with other region CHs [16]. Both the average energy of the clusters where the next hop sits and the level of energy of the next hop as CH must be sufficiently high for the next hop to be selected.

Multi-hop routing across clusters consists of the following steps:

STEP 1: Each CH broadcasts the information in the CH Inter MSG (ID, Energies, Energy_avg, Region) to its neighbours with a radius of 2r. Each cluster head has a high chance of locating its next hop if the broadcast range is set to 2r, which also helps substantially decrease interference in the wireless channel. If the cluster head M has a region number of 1, then it will use the BS as its subsequent hop; otherwise, it will only keep track of cluster messages from neighbour CHs with a region number of (Region (M)-1) as well as will use the Table_CH to determine the next hop.

STEP 2: In scenarios with up to two entries in Table_CH, the cluster head selects the inter-cluster pair with the highest Energy_avg and designates the one with the largest residual energy as the next hop. This ensures a powerful next hop from a high-energy region, serving as both the cluster leader and relay node. If only one record exists, it is directly chosen as the subsequent transition node. In the absence of an entry for Cluster Head K in Table_CH, K proactively seeks its next hop from neighbouring Cluster Heads with Region Number (Region(K)-1), though this is an infrequent occurrence.

STEP 3: From the perspective of energy equilibrium, we give a threshold for every CH to avoid a situation in which a small subset of CHs with enough residual energy are simultaneously selected as subsequent hop by a large subset of CHs in the same region. The second request will be ignored, and the CH that received the rejection will choose its next hop from among the remaining entries in Table_CH.

Pseudocode for Multi-hop routing across clusters

```
// STEP 1: Broadcast information to neighbours
Function broadcast_CH_Info (ID, Energies, Energy_avg, Region):
    If (Region == 1) then
        next_hop = BS
    Else
        track_neighbors_with_region (Region-1)
        next_hop = determine_next_hop (Table_CH)
    End if
// STEP 2: Select next hop
Function select_next_hop ():
    If (entries_count (Table_CH) <= 2) then
        inter_cluster_pair = choose inter-cluster pair with highest_Energy_avg ()
        next_hop = choose the next hop with the largest residual energy (inter_cluster_pair)
    Elif (entries_count (Table_CH) == 1) then
        next_hop = directly_choose_single_entry (Table_CH)
    Else
        next_hop = proactively_seek_next_hop ()
    End if
// STEP 3: Threshold for energy equilibrium
Function handle_energy_equilibrium ():
    Threshold = calculate threshold ()
    If (small_subset requesting next_hop) then
        If (large_subset →alreadyselected) then
            ignore_second_request ()
        Else
            Handle rejection and choose next_hop (Table_CH)
        End if
```

During the steady-state data transmission stage, every single node will use its allotted TDMA time slot to transmit the information collected to the cluster's head node before entering the rest phase and waiting for its turn. The internal data is combined with relay data from other CHs before being sent on to the next hop by the cluster heads. All information will eventually reach the base stations after being relayed regionally. Due to the high cost and unnecessary energy waste associated with constant reconstruction, we mandated the duration of the stable data transfer period be much longer than the cluster set-up phase.

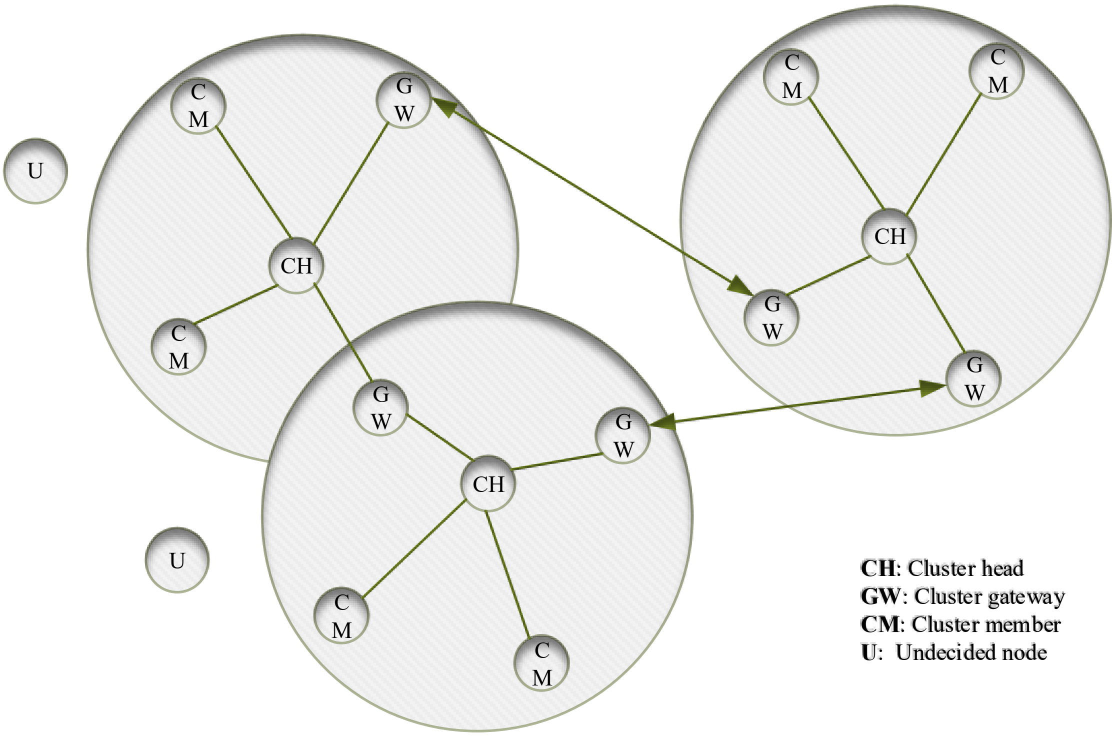

Fig. 4. Routing using Cluster-based HWSN Environment

4. Results & Discussion

This subsection uses NS2 simulations to analyse the efficiency of the RCRP protocol. There are two stages to the experiment. The first step is to find the best value for the parameter c in Eq. (11) by comparing it to other values in the range [0, 1]. The second objective is to evaluate RCRP, LEACH, and E2RP throughout an energy heterogeneous network's lifetime. Table 2 displays the experiment's most crucial variables:

Table 2
Parameters Used in Experiments

Parameter	Value
Network coverage	(0,0) ~ (100,100)m
BS location	(50,150)m
Node Number	100
Initial energy	[0.3,0.5]J
E_{elec}	50 nJ/bit
ε_{fs}	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4
d_0	87 m
E_{DA}	5 nJ/bit/signal
Data packet size	4000bits

In everyday settings including homes, schools, workplaces, and factories, environmental monitoring is crucial for ensuring people's safety and well-being. These spaces need strict regulation of climate conditions, including temperature, humidity, and carbon dioxide levels. In this research, we provide a web-based environmental observing system built on WSN technology. User-friendly interfaces are utilized to reduce the complexity of the WSN IoT system, which consists of sensors, repeaters, and a gateway. The web server operating on the gateway and the accompanying software that offers user-friendly interfaces allow for management of the WSN with the gateway as well as data monitoring. The data dashboard where the visualization is shown is real-time. The system is evaluated at a research institution and two commercial settings. The developed system is tested in three distinct locations: the educational institution of Gävle, a plant that produces ventilation items for kitchens, as well as a mechanical workshop. During the WSN test, many machines were operational in both factory settings. Figure 5 shows the nodes installed near several manufacturing facilities' CNC, wood/steel cutting equipment, and 3D printers. Each experiment is monitored for temperature, relative humidity, and carbon dioxide content. In both the college and the industries, eight sensors with a tree topology have been deployed, and eight repetitions have been connected to the institution's WSN, extending its range from end to end by 400 meters.

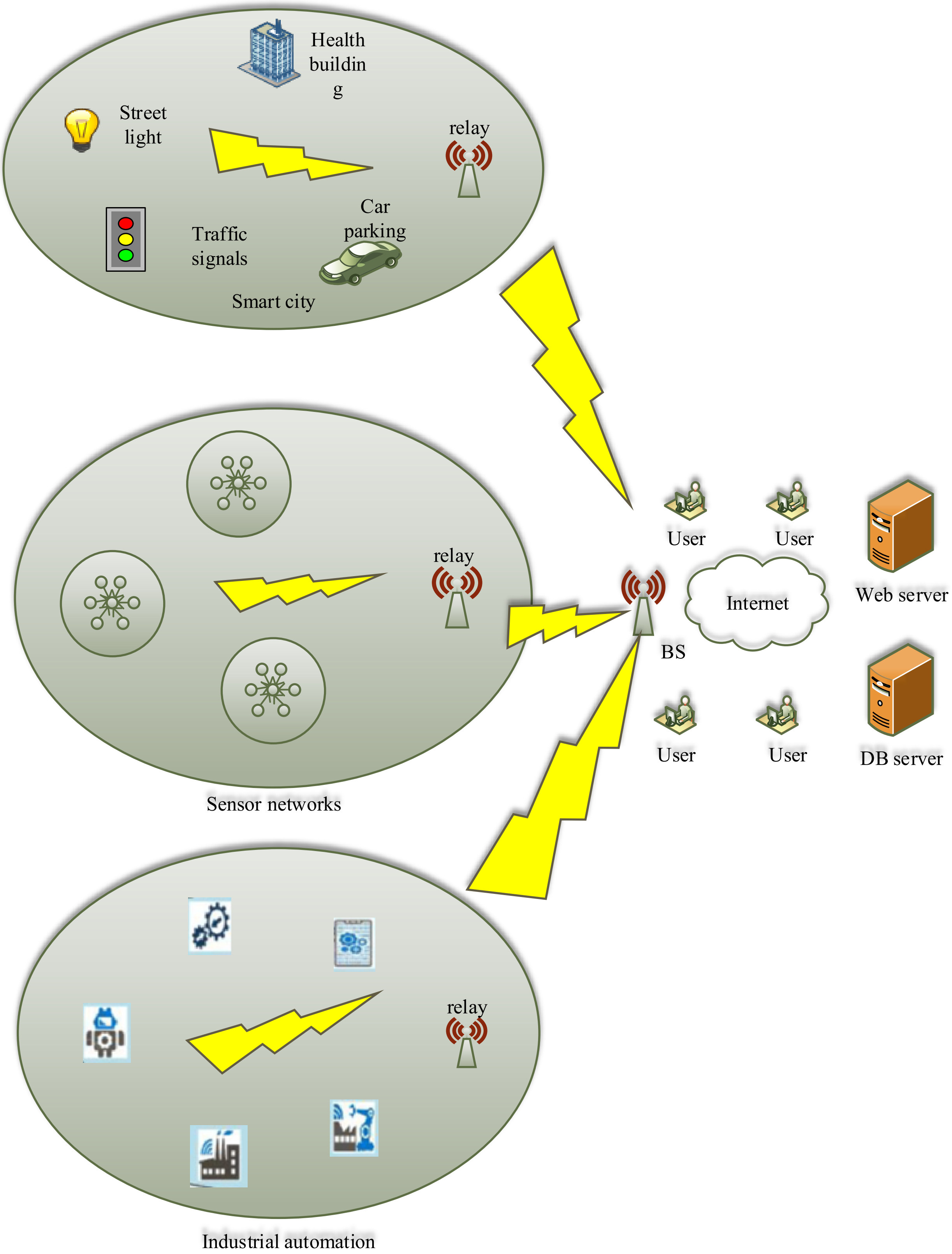

Fig. 5. Simulation of Smart City Application Case Study in HWSN

Below is listed the network's total starting energy, denoted by the symbol (├ E_TIE)

$$E_{TIE} = \sum_{i=1}^{N} E_0(1 + \beta_{ehi}) \tag{11}$$

where β_{ehi} reflects the node's energy heterogeneity value i.

The amount of energy that still exists after something has been used. How well the procedures conserve network resources is reflected by the quantity of power remaining. The typical amount of leftover energy may be calculated using the Eq. (12)

$$RE = \frac{E_0 - CE}{E_0} \tag{12}$$

CE = Average Energy Consumption, where Eo = Average Initial Energy.

Using the LEACH, E2RP, and RCRP routing protocols, the energy consumption for each cycle is shown in Figure 6. By comparing RCRP with LEACH and E2RP, it becomes evident that the former is the most energy-efficient option. Since RCRP is a proactive protocol, it can provide this enhancement. If the measured value is higher than the set threshold, the sensor node will transmit the measured value. Although E2RP also falls within the category of reactive protocols, RCRP's approach to selecting the probabilities of regular nodes, advanced nodes, and super nodes is superior.

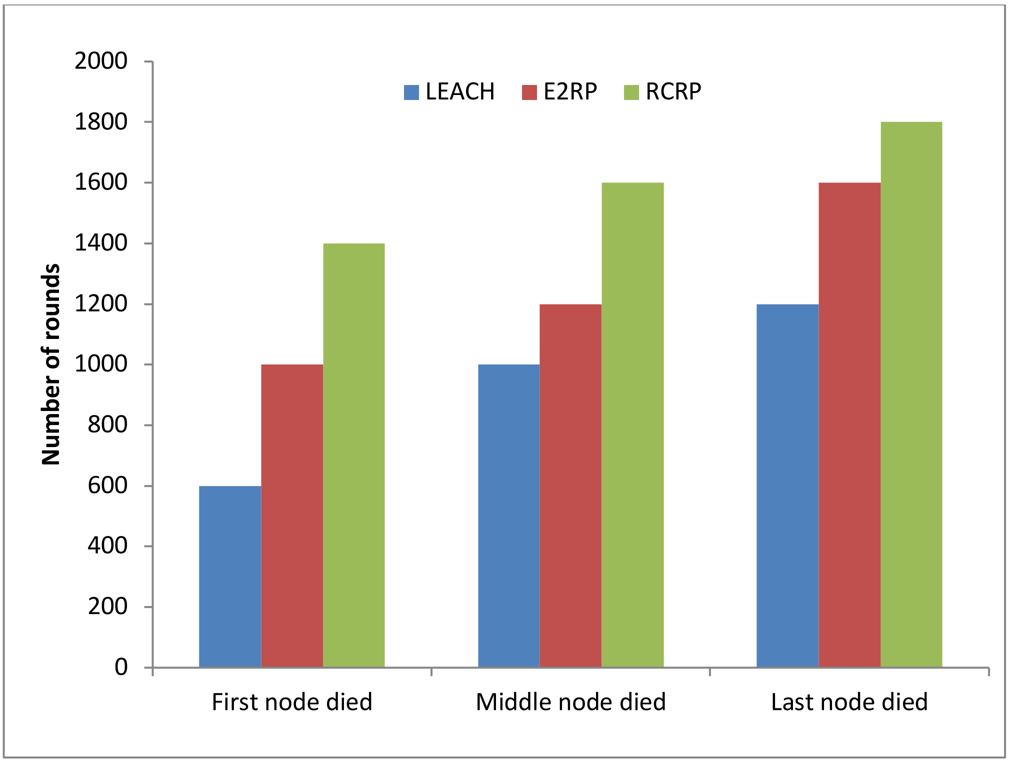

Fig. 6. Comparison of Network Lifetime

The percentage of network nodes that have died after a certain iteration is shown in Figure 7. When a node loses all of its vitality, we say that it has died. Throughput is also impacted by the number of dead nodes.

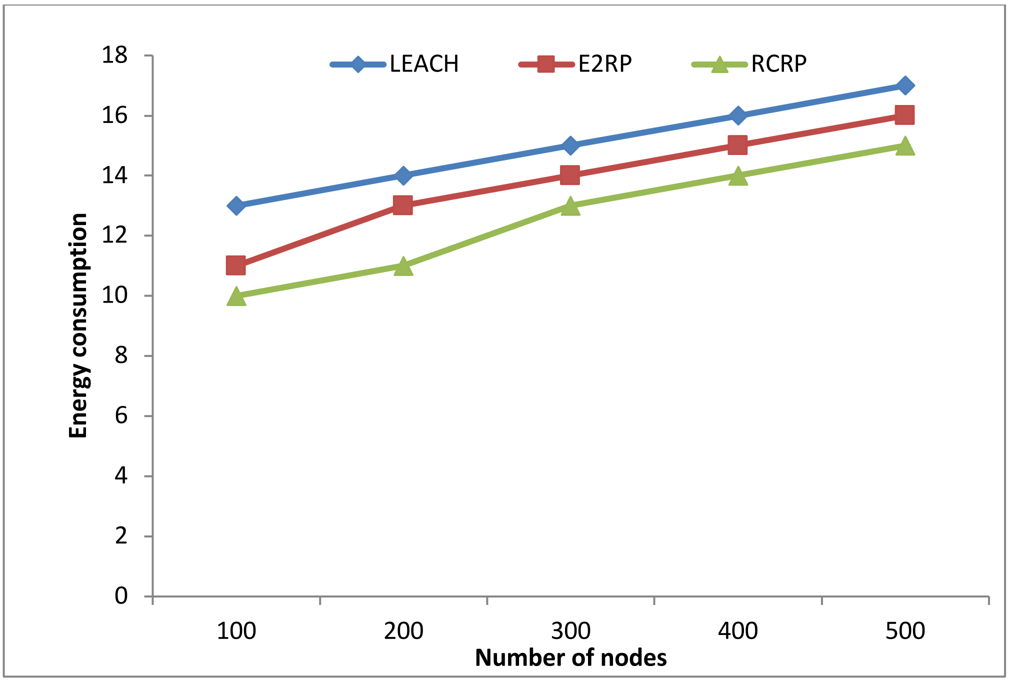

Fig. 7. Comparison of Energy Consumption

Any one of the following measures may be used to characterize the lifespan of a network. The cycle time at which the first node completely runs out of juice. This is the moment at which the final node runs out of energy, and it is also known as the first node dying (or stability period). Instability interval, or "last node dead," describes this condition.

i. When the first node in a network runs out of juice, this is referred to as "the first node died" (FND).

$$\left(\sum_{r=1}^{r_{\max}} \sum_{i=1}^{N} \begin{array}{l}(\text{Node }(i).E \leq 0, (\text{ dead } = \text{ dead } + 1;\\ \text{if (dead } == 1, \text{first\_dead } = r)))\end{array}\right) \tag{13}$$

ii. Time to 50% node death (TND) is the number of cycles of sensing and communicating required before 50% of nodes die.

$$\left(\sum_{r=1}^{r_{\max}} \sum_{i=1}^{N} \begin{array}{l}(\text{ Node }(i) \cdot E \leq 0, (\text{ dead } = \text{ dead } + 1;\\ \text{if (dead } == 0.5 * N, \text{half\_dead } = r)))\end{array}\right) \tag{14}$$

iii. Round till last nodes died (LND): represents the number of iterations that passed before the last nodes in the network ran out of juice.

$$\left(\left(\sum_{r=1}^{r_{\max}} \sum_{i=1}^{N} \begin{array}{l}(\text{ Node }(i).E \leq 0, (\text{ dead } = \text{ dead } + 1;\\ \text{ifead } == N, \text{last\_dead } = r)))\end{array}\right)\right) \tag{15}$$

iv. In each iteration, the number of living nodes is represented by the variable. (N- dead).
v. A round's death toll is equal to the sum of its dead nodes. (dead = dead),

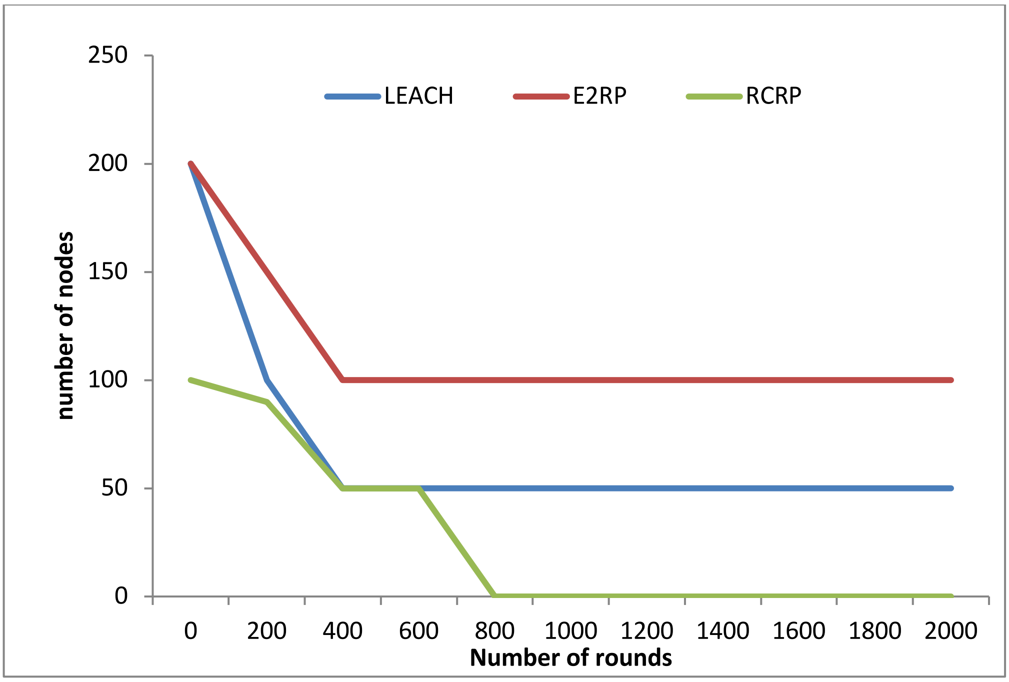

Fig. 8. Comparison of Number of Rounds

These are the primary explanations: In LEACH, the cluster head employs a single-hop transmission technique, which is both energy-intensive and ultimately fatal to the node. The RCRP protocol uses a multi-hop method that's effective in reducing power consumption. The RCRP protocol is similar to the E2RP one in that it uses an uneven clustering technique. In addition, the multi-hop transmission method is provided, and the network architecture is simplified in RCRP thanks to the regional division. The RCRP protocol chooses a cluster leader by calculating the average power of the nodes in a localized area and the node's remaining energy. For a node to qualify as the cluster leader, it must have more energy than the average node within its cluster radius. Unlike the RCRP, LEACH does not take into account the energy factor, and in the E2RP, simply the cluster head's remaining energy is taken into account. Neither LEACH nor E2RP are useful when the network's energy consumption is unevenly distributed. In the inter-cluster routing phase, the RCRP protocol considers distance, average energy, as well as residual energy, while the E2RP protocol only considers residual energy; this can lead to the cluster head using a high residual power yet in a low energy region being selected as the next stop.

The proposed RCRP protocol exhibits advantages in energy efficiency and network lifespan through its innovative region-based clustering and multi-hop routing. However, limitations may arise in highly dynamic environments or scenarios with frequent node mobility. Scalability tests reveal RCRP's ability to handle diverse network sizes, but adjustments may be needed for extremely large-scale deployments. Practical considerations involve potential hardware constraints, necessitating compatibility assessments, and accounting for error rates and interference, emphasizing the need for real-world testing to validate RCRP's robustness across varied conditions.

5. Conclusion

WSN routing algorithms that take into account multi-heterogeneity may aid in maximizing resource consumption in practical settings. In this research, we present a unique RCRP technique for wireless sensor networks, which is effective in an energy-diverse setting. Both the cluster head competitions stage as well as the inter-cluster routing choice stage of the RCRP protocol take energy efficiency into account, streamlining the network architecture via regionalization. The uneven clustering approach is also used by the RCRP protocol to deal with the issue of hotspots. The simulation findings demonstrate that in the energy-diverse environment, the RCRP protocol outperforms LEACH and E2RP. The quality of service in the network will be a focus of our future efforts. The future implications of this study lie in refining the RCRP protocol for improved Quality of Service, facilitating real-world implementations across diverse settings. Ensuring scalability, adaptability, and integration with emerging technologies will be pivotal for widespread adoption and cross-disciplinary applications in fields beyond traditional wireless sensor network scenarios.

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