

# Multi-Layer Support based Clustering for Energy-Hole Prevention and Routing in Wireless Sensor Networks

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## Abstract

In Wireless Sensor Networks (WSN), a key technique to improve the network lifetime is clustering. Clustering approach divides sensors into multiple clusters consisting one cluster head and cluster members. An energy-efficient clustering protocol is a major concern for reporting sensory data to the sink node. The main issue in clustering protocol is to select appropriate nodes to act as cluster heads and gateways for routing. The existing works consider a single factor in the cluster head selection and routing approach. However, considering only a single metric fails to expose the influence of other factors. This paper proposes a CLUstering protocol for an Energy-Hole Preventive Environment (CLUE-HOPE) called CLUE-HOPE. The CLUE-HOPE divides the network into virtual grids in a distributed manner. In order to reduce the irregularity in cluster head placements, CLUE-HOPE allows the cluster to adjust its size by handling the sensors from and to the neighbor grids. Moreover, it spins the role of cluster head among the cluster members in a distributed manner, and thus it achieves evenly distributed energy load among sensors. A Greedy based Cluster-Head Coordinated Routing (GCCR) is proposed which connects multiple clusters via gateways in a greedy manner and forwards the sensor data to the sink node. The Bit Error Rate (BER) in a received signal of a sensor is directly proportional to the transmission distance. Even though, BER increases in GCCR due to high traffic in the network layer, CLUE-HOPE employs SMAC and, RS and DSSS coded with a non-coherent M-FSK scheme at the lower layers to improve routing performance. Finally, the simulation results reveal that the proposed CLUE-HOPE appreciably improves the clustering performance.

**Keywords:** Bit Error Rate, Clustering, Wireless Sensor Networks

## 1. Introduction

The WSN consist of low cost and low energy sensor nodes with sensing capability<sup>1</sup>. Routing is one of the critical tasks in WSN. The nodes' sense various environmental and physical conditions, and they are equipped with radio transceivers. The transceivers consume a lot of energy during radio transmission and reception<sup>2</sup>. Generally, the routing technique in WSN exploits the technique of clustering sensors into groups. In each cluster, one of the

nodes act as Cluster Head (CH) and other sensor nodes as Cluster Members of the corresponding cluster (CM). The cluster head collects information from sensor nodes and forward the aggregated information to the sink node. High expectation of sensor lifetime is a major concern due to its rechargeable battery power. It is essential to utilize the limited processing speed and memory space of the sensor node effectively.

Generally, many-to-one traffic pattern leads to uneven energy dissipation in WSN. The sensor nodes closer to

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the sink node should forward a large amount of data than others result in fast energy depletion and network partition<sup>3</sup>. Another reason behind the energy depletion is packet retransmission that leads to the latency in wireless communication. The packet retransmission arises due to a high erroneous packet, the energy hole, and the packet drop. The interference and noise lead to erroneous packets that increase the Bit Error Rate, BER. The energy hole refers to the unavailability of a sensor in the current data transmission path due to its complete energy depletion. When working towards the performance optimization of the network layer, the properties of lower layers such as Physical (PHY) and Medium Access Control (MAC) need to be considered in the network operation.

The proposed CLUE-HOPE work aims at achieving energy conservation and timely data delivery in clustering. The proposed work generates a smaller number of clusters and evenly distribute the selected cluster heads to reduce the energy consumption. The grid based CLUE-HOPE divides the network area into equal sized virtual grids in a distributed manner and each grid is considered as a cluster containing one cluster head. It rotates the role of CH among different sensors in a cluster based on its energy<sup>4</sup> and distance to reach the sink node. The grid can self-adjust its cluster size by handling the sensors from and to the neighbor grids with no additional overhead. Each sensor associate with the cluster respective of the distance of a sensor node to the sink node, but it is irrespective to the grid id. The proposed routing technique GCCR provides the routing paths from different cluster heads to the sink node, and it attempts to employ the same set of links after they join. Thus, it reduces the energy consumption of a sensor significantly. Moreover, the proposed work implements the Sensor MAC (SMAC) protocol and, RS and DSSS coded with a non-coherent M-FSK scheme at the PHY to set the radio in sleeping mode fast<sup>5</sup>. These works assist to improve the performance of CLUE-HOPE in the network layer.

## 2. Related Works

The survey on clustering for WSN in<sup>6-9</sup> presents the classification of clustering schemes in detail. It summarizes different clustering protocols for WSN based on their features, techniques, and complexity. The comparative survey between the clustering protocols is presented in<sup>10</sup>. This work discusses the clustering process, such as cluster formation, cluster association, and routing. Mostly, the clustering protocols are divided into two categories such

as centrally controlled cluster formation and grid cluster based protocols.

### 2.1 Centrally Controlled Clustering Protocol

In centrally controlled cluster formation, the sink node controls dynamically formed clusters<sup>11</sup>. The basic idea of grid-based clustering approach is to divide the network into virtual sized grids. Each grid is considered as a cluster, assigned with one cluster head. In the modified version of Low-Energy Adaptive Clustering Hierarchy, LEACH-C<sup>12</sup>, each sensor sends the remaining energy and location information to others in the network. The sink node employs the simulated annealing algorithm to build clusters and select cluster heads in the network. The sink broadcasts the identification of cluster heads and TDMA schedule information to the sensors in the network. The same procedure is adopted in Cluster-Based Energy-Efficient Data Collecting and Aggregation Protocol (CEDCAP)<sup>13</sup> and DUCA in<sup>4</sup>. However, the communication latency and control overhead on centralized clustering protocols is high due to the frequent exchange of location and remaining energy information among sensors.

### 2.2 Grid Cluster Based Protocol

Unlike the centralized clustering algorithms, the grid cluster based protocols select the evenly distributed cluster heads in the network and rotate the role of cluster head among other nodes in the grid. The proper selection of cluster heads and gateway nodes is a main challenge in grid clustering based protocols. Several works have been proposed for cluster head election and cluster constructing<sup>3,14</sup>. It is necessary to exchange request messages among the nodes within its communication range to determine the appropriate cluster head and grid ID. However, the high load on a cluster head may drain their energy quickly.

### 2.3 Cluster Head Selection Approaches

An alternative cluster head selection approach in<sup>15,16</sup> is based on the node degree which is based on the number of neighboring nodes in the communication range. In the LCM, each node measures the predicted transmission count of its neighboring nodes and derive the priority for these nodes to select the cluster heads and gateways<sup>17</sup>. The predicted transmission count refers the number of

transmissions that the sensor nodes perform. However, complete energy depletion of a node and poor link quality leads to reconstruct the clusters and retransmissions respectively.

In the grid based distributed clustering, the number of cluster heads are determined by the sink<sup>18,19</sup>. The number of grids are decided based on the number of cluster heads required. Hence, a sufficient number of cluster heads are formed to cover all grids. No strategy has been discussed for deciding the optimal number of cluster heads for reducing energy consumption. For example, if the required number of cluster heads decided by the sink is smaller in a large network area, then the number of grids on the network will be smaller. Hence, the distance between cluster member and cluster head will be increased which increases the energy consumption.

The major drawback in the distributed clustering is a communication delay, and the unnecessary delay induced when the sensor associated with the cluster head based on the signal strength<sup>4</sup>. It may also create the following problem. Data transmitted from the cluster member to the cluster head for aggregation may be forwarded via the same cluster member after data aggregation. Thus, the proposed work needs to select the appropriate cluster head and rotate the role of the cluster head among sensors for achieving both the energy consumption and communication delay in clusters.

### 3. Proposed CLUE-HOPE

#### 3.1 System Model

Consider the static WSN as a graph  $G(S, E)$  in a square area of  $XY$ , where  $X$  and  $Y$  represents the Height and Width ( $X = Y$ ).  $S$  represents the sensors and  $E$  represents the direct link between sensors  $E \subseteq S \times S$ . For clustering, network  $G$  is considered as the Grid  $Gr(X/R)$ , where  $R$  represents the communication range of  $S$  and  $|Gr| \& |CH| = (X/R)^2$ . Each  $Gr$  consists of  $(CH, CM)$  or  $(CM)$ , where  $CH$  represents the cluster head and  $CM$  represents the cluster member, and also  $CH$  and  $CM \in S$ . Assume the Sink ( $S_i$ ) is deployed in the center of  $G$ .  $S_i$  provides  $GrID$  to each  $S$ , based on its Location,  $L_s(x, y)$ . Each  $S$  generates a random number between  $0-1$ ,  $R_n S$  and  $S$  which satisfies  $R_n S > \text{Threshold th}(R_n S)$  broadcasts its Residual Energy,  $ResE(S)$  and  $GrID$  in its  $Gr(X/R)$  region.  $S$  with high  $ResE$  announces itself as a  $CH(GrID)$  and  $S \in G$  receives multiple  $CH$  announcement. Let  $d1_{(CH-S_i)}$  and  $d2_{(CM-S_i)}$  be the

distance  $(CH-S_i)$  and  $(CM-S_i)$  respectively.  $CM_i$  joins with the  $CH_i$  which satisfies  $d1_{(CH-S_i)} > d2_{(CM-S_i)}$ . In  $G$ ,  $S$  employs S-MAC for accessing the wireless channel. Each  $S$  has two states  $\langle \text{Active (AT)}, \text{Sleep (SL)} \rangle$  and the transition time of  $S(AT \leftrightarrow SL)$  in MAC layer depends on the functionality in the physical layer, in which RS error correction method with DSSS interference reducing scheme over Non-coherent M-FSK modulation scheme are included.

#### 3.2 Distributed Cluster Formation

The main issue in clustering is the proper selection of nodes to act as  $CH$ 's and  $GW$ 's. The proposed CLUE-HOPE consists of a novel distributed cluster formation mechanism that virtually builds the grid and attempts to evenly distribute the cluster heads for energy consumption. Even though random selection is an easy way to determine  $CH$ s in large scale networks, it may lead to uncovering sensor nodes in the grid region. To avoid this problem, the proposed CLUE-HOPE initially determines the number of  $CH$ s based on the network area and the communication range of sensor nodes. The proposed work divides the cluster formation mechanism into three phases. The optimal number of cluster head election and grid identification are processed in the first phase<sup>4</sup>, and the cluster head selection and data transfer are processed in the next two phases.

##### 3.2.1 Optimal Number of Cluster Heads

The CLUE-HOPE divides the network into virtual Grids,  $GT$ s and selects at least one  $CH$  in each  $GT$  to accomplish the even distribution of  $CH$ s. The sink node selects a sufficient number of cluster heads to cover all grids. Consider the sensor nodes are spread on a rectangular or square area ( $W$ ) with the dimensions of  $X$  and  $Y$  units. Each sensor node estimates the number of clusters required for clustering, and estimates the number of  $GT$ s and its corresponding  $GT$  id. The number of  $GT$  is equal to the number of  $CH$  in the network. Each sensor divides the network area,  $W$  into equally sized grids  $GT$ s virtually. Each sensor node determines the number of  $GT(N_{GT})$  according to its row and column number. Consider  $GT_{row}$  and  $GT_{column}$  are the numbers of grids in one row and column, estimated as follows.

$$GT_{row} = X/R \quad (1)$$

$$GT_{column} = Y/R \quad (2)$$

$$N_{GT} = GT_{row} * GT_{column} \quad (3)$$

Each sensor node defines its location information as  $(L_x, L_y)$  coordinates, and it identifies the location either by employing the global positioning system or any other localization method. In order to decrease the number of control packets, each sensor identifies its corresponding GT's id using the equation (4) to maintain cluster information constantly. Instead of executing the algorithm at a sink node and inform to the sensor nodes, the proposed CLUE-HOPE allows each sensor node to measure its corresponding GT's id alone, and it reduces the control overhead explicitly.

$$GT = \begin{cases} 1 & \text{for } x < R \text{ and } y < R \\ x/R & \text{for } x > R \text{ and } y < R \\ (y/R) * GT_{\text{column}} + 1 & \text{for } x < R \text{ and } y > R \\ (y/R) * GT_{\text{column}} + (x/R) + 1 & \text{else} \end{cases} \quad (4)$$

### 3.2.2 Cluster Head Election Phase

The CLUE-HOPE select cluster heads in a distributed manner, where sensor nodes in GT make autonomous decisions. To equalize the energy consumption among the sensor nodes in each GT, the CLUE-HOPE employs a mechanism of fair selection of CH in the network<sup>4</sup>. Initially, the sensor nodes are deployed in the network with equal energy.

$$NH_{GT} = \{(3.14R^2)/(X*Y)\}^N \quad (5)$$

The Energy required by a node to act as CH, (ECH) is decided based on the energy consumed by a sensor node in the previous rounds. If the residual energy of a node is greater than the ECH, the node advertises the CH messages to all the sensor nodes in GT. Moreover, the ECH value is a variable and to measure the ECH, the CLUE-HOPE fixes the energy depletion of a node per round. It decides the energy to be depleted by a node based on the network size and  $NH_{GT}$  initially. Where,  $r$  represents the number of rounds.

$$ECH = \text{Initial Energy} - (\text{depleted energy} * r) \quad (6)$$

Only nodes that are not already selected as a cluster head have more energy than others. Therefore, the one of the remaining nodes may become a cluster head at the next round. Moreover, only the nodes that are not already elected as a CH are eligible for the next round. The node's depleted energy varies according to its data aggregation and routing activities. The depleted energy increases with the node's activities, and thus the remaining energy level

of a node is decreased. Thus, only few nodes can satisfy the condition of remaining energy  $> ECH$ , and these nodes broadcast the CH advertisement message to others. The selected CH nodes advertise their message, including its residual energy and GT's id within their grid region. A node may receive more than one CH advertisement messages from different nodes. In this case, the following steps are involved in the selection of CH.

#### Step 1) CH messages with similar GT id

There is a chance for more than one CH in GT, and the CH nodes advertise their messages to others. The CH with the highest energy level is elected itself automatically. The remaining CHs return to their normal state. A node accepts the CH's message with high energy levels and reject the messages from other nodes with the similar GT id.

#### Step 2) CH messages with different GT id

According to the step 1, a node accepts the CH message with the highest energy level. However, it receives more than one message from different GT id. Mostly, the boundary nodes receive more than one CH advertisement message from adjacent GTs, and it decides a CH to join by executing the algorithm of cluster association. Initially, the energy level of all the sensor nodes are same. In this case, the centralized nodes in the GT region announce the CH advertisement and the lower id node among the centralized nodes are selected as a CH. Figure 1 depicts the cluster formation of CLUE-HOPE, where every GT contains one CH and each sensor node in the GT has the same id.

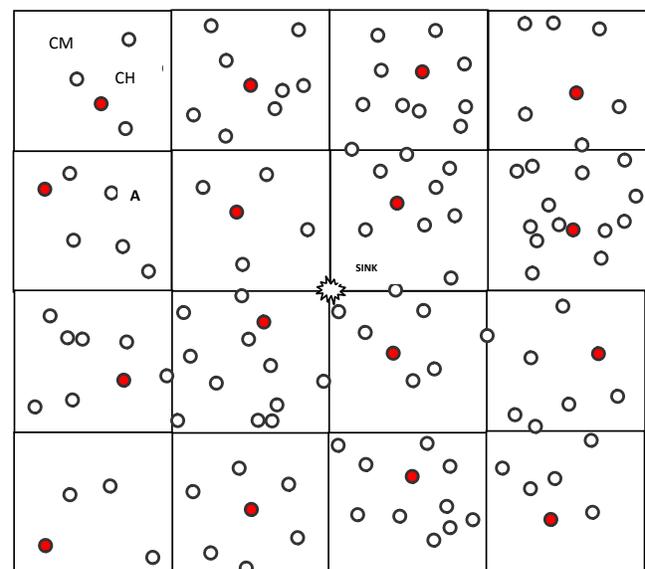


Figure 1. Depicts the cluster formation of CLUE-HOPE.

### 3.2.3 Cluster Association

Once all the GTs are set, CHs are elected, collect data from the non-CH nodes in GT, aggregate, and forward to the sink node. With a grid based structure, the communication process includes an intra grid transmission for data aggregation and an inter-grid transmission for data routing towards the sink node.

In CLUE-HOPE, the data aggregation is one hop process, as the GT's region is equal to the communication range of a sensor node. Generally, non-CH nodes in GT, referred as CM are associated with the CH in its corresponding GT for data aggregation. However, it may increase the transmission cost and lead to high energy consumption. The cluster association is done only within the GT and another reason of high transmission cost is that the CH is not formed on the basis of location information. In order to avoid this, the nodes execute the greedy cluster association algorithm, when it receives more than one CH advertisement with different GT ids. Thus, the nodes after receiving the CH advertisement, determine the CH closer to the sink node associated with it.

Consider node A from the Figure 2. In GT 9, node A receives CH advertisement message from GT 9, 10, and 13. If it joins with the CH of GT 9, it transmits their data to the CH in their grid for data aggregation, but it is longer to the sink node than node A. Thus, it increases the transmission cost during data transmission of aggregated data to the sink node. Thus, the CLUE-HOPE employs greedy clustering in which a node can associate with

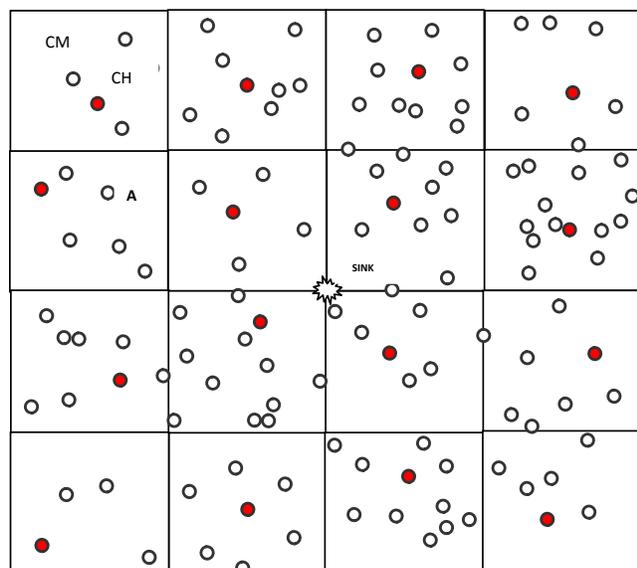


Figure 2. CH Advertisement.

the CH according to the distance to reach the sink node irrespective of the GT id. According to the CLUE-HOPE, each node takes its turn to act as CH. In every round, each CH node broadcast their advertising message to other nodes with an increased broadcasting range to cover nodes in the adjacent grids. In these broadcasts, the CH node attaches the location and GT id information. A node that receives advertisement messages from different CH nodes calculate the distance between CH and sink node, and select the CH that is closer to the sink node rather than it. Thus, it reduces unnecessary transmissions and energy consumption.

In Figure 3, it takes into an account node A and GT 9, 10, and 13 to illustrate the problem in cluster association within the grid region. Data transmitted from node A to CH for aggregation may be forwarded to the sink node via the same cluster member after data aggregation. Consider the distance between CH and sink node as  $d_1$  and the distance between node A and sink node as  $d_2$ . If  $d_1 > d_2$ , the clustering mechanism increases the transmission cost or data traveling distance in  $2(d_1 - d_2)$ . Thus, based on the greedy clustering node A associate with the CH of GT 10 which is closer to the sink node than node A.

The main problem associated with greedy cluster association routing is that it does not guarantee the availability of CH based on greedy clustering. This is called a local maximum problem in which no cluster head is closer to sink node than a sensor. In this case, sensor selects the cluster head, which has minimum distance to the sink compared to others.

### 3.3 Greedy Based CH Coordinated Routing (GCCR)

Each CH collects the data from the CM nodes and sends the aggregated data to the sink node. The data transmissions between CH and sink node may take multiple hops.

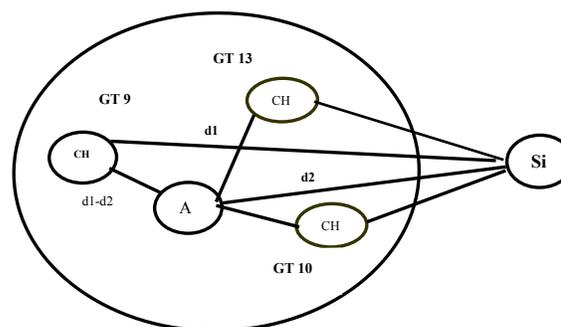


Figure 3. Problem in cluster association.

In existing, the aggregated data forwarding phase follows greedy routing technique. Even though, the greedy routing mechanism includes a minimum number of gateway nodes to reach the sink node, a single path from a cluster head to the sink node may not include other cluster heads. It activates multiple paths to deliver the data to sink node from all cluster heads. An algorithm that provides a trade-off between communication delay and energy consumption is in need. Thus, the proposed CLUE-HOPE provides greedy based CH coordinated routing, GCCR in sensor networks.

If there is an exclusive shortest path from each cluster head to the sink node, it leads to less communication delay, and high energy consumption. To avoid this, the GCCR provides the routing paths from different cluster heads to the sink node, and it attempts to employ the same set of links after they join. These routing paths are named as CH-coordinated routes. Figure 4 shows the greedy based CH coordinated routes to the sink node in the left region of the sink node. In order to discover the CH-coordinated routes to the sink node, GCCR allows each CH to share its location information with adjacent CH nodes. Each CH maintains the location and GT id of adjacent CH sensor nodes in the ADJ\_LIST. The CH nodes, which reach a sink node within a single hop are directly connected. Others select the CH closer to the sink node than itself. Moreover, the CH nodes are either directly connected or connected through the greedy gateway nodes. The gateway nodes are CM nodes in the network irrespective of the grid id.

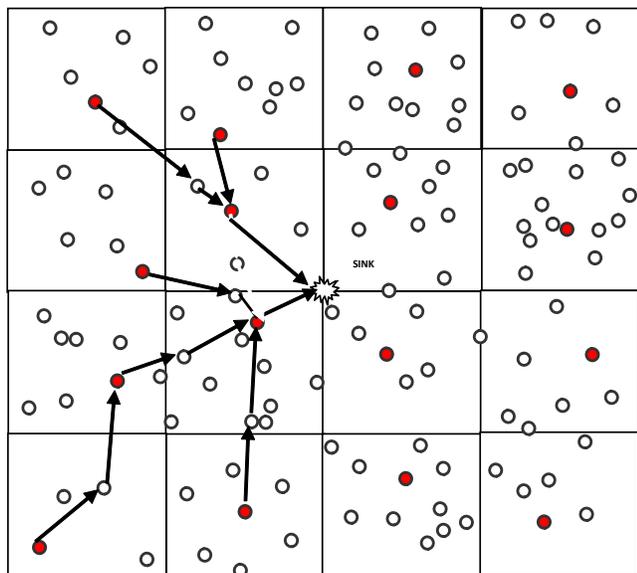


Figure 4. Greedy-based CH coordinated routing.

However, the broadcast of CH's location information to the adjacent grids increases the routing overhead, due to the randomized rotation of the cluster head.

The greedy-based CH coordinated routing technique includes the following steps.

- Step 1:** Each CH elected in the cluster head election phase, broadcast their location and GT id information to the adjacent CHs. Each CH maintains the information of adjacent CHs in ADJ-LIST.
- Step 2:** It ensures that the neighbor list,  $NH_{CH}$  contains sink node and then the node CH directly connected to the sink node. Otherwise, it selects the coordinated CH which is closer to the sink node than itself.
- Step 3:** In case, the coordinated CH is not in the communication range, it selects the greedy node irrespective of the GT id to reach coordinated CH. Thus, it results in CH-coordinated route to the sink node.

**Input:** ADJ-LIST<sub>CH<sub>i</sub></sub> <--- The location and GT id of all the adjacent CH nodes

**Output:** CH - Coordinated route from CH<sub>i</sub>

**For each CH<sub>i</sub>,**

**If** sink  $\in NH_{CH_i}$  then,

forward the aggregated data to the sink node

**else,**

**for** CH<sub>j</sub>  $\in$  ADJ-LIST<sub>CH<sub>i</sub></sub> to |ADJ-LIST<sub>CH<sub>i</sub></sub>| do

**if**  $D_{CH_i-sink} > (D_{CH_i-CH_j} + D_{CH_j-sink})$ ,

Put CH<sub>j</sub> into ---> Coordinated\_CH<sub>i</sub>LIST

**break;**

**end for;**

**for** CH<sub>i</sub>  $\in$  N do

**if** Coordinated\_CH<sub>i</sub>LIST = = empty

Select least  $(D_{CH_i-CH_j} + D_{CH_j-sink})$  CH from ADJ-LIST<sub>CH<sub>i</sub></sub>;

SelectedCH= least  $D_{CH_j-sink}$  CH;

**else**

select least  $(D_{CH_i-CH_j} + D_{CH_j-sink})$  CH from Coordinated\_CH<sub>i</sub>LIST

SelectedCH= least  $(D_{CH_i-CH_j} + D_{CH_j-sink})$  CH;

**end for;**

**for** CH<sub>i</sub>  $\in$  N do

**If** SelectedCH  $\in NH_{CH_i}$

forward the aggregated data to the SelectedCH;

**else**

Select greedy neighbor  $\in NH_{CH_i}$  to reach SelectedCH;

**end for;**

**end for;**

**Algorithm 1:** Algorithm to Determine the Coordinated CH Route to the Sink node

### 3.4 MAC and PHY Layer Aspects to Improve the Network Layer Performance

In order to optimize the performance of the network layer, the properties of lower layers such as physical and MAC need to be considered in the network operation. The greedy cluster association in the network layer may increase the bit error rate, which is indirectly proportional to the signal strength. Even though, this problem arises in greedy cluster association, the data aggregation reduces the bit error rate. To further reduce the bit error rate, effective MAC protocol and error correction scheme should be applied in the lower layers. The proposed scheme employs Sensor-MAC (S-MAC) and it employs a low duty cycle that reduces the energy consumption. The main challenges in the MAC layer are the large amount of data transmitted to the CH nodes and channel collision due to a hidden terminal problem. The CH in GT collects data from multiple homogeneous sensor nodes, but it leads to information redundancy.

It is sufficient to activate only distant CM nodes to aggregate the information for reducing energy conservation, and others are in sleep mode. The randomized rotation of the cluster head and sensor node's state reduces the channel collision induced by the hidden terminal problem<sup>4</sup>. The PHY layer turns off the transceiver, when it receives the status\_change message from the MAC layer. Even the proposed scheme that uses S-MAC enables a low duty cycle; it takes a long time to change the node's state. Moreover, the noise, interference, and distortion cause erroneous packets that increase the BER resulting in retransmissions. Thus, the proposed work employs RS and DSSS coded with a non-coherent M-FSK scheme at the physical layer.

### 3.5 Multi-Layer Architecture of CLUE-HOPE

Figure 5 shows the multi-layer architecture of CLUE-HOPE. It employs RS codes in the proposed work to correct burst errors. The existing techniques enable Forward Error Correction (FEC) in the sensor to avoid retransmission due to packet error. The Reed-Solomon (RS) encoding and decoding technique is better FEC in terms of hardware complexity and quicker transition from sleep mode to active mode in MAC layer<sup>20</sup>. Thus, RS and DSSS coded with a non-coherent M-FSK scheme at the physical layer. As the non-coherent M-FSK modulation scheme exploits Direct Digital Modulation (DDM) technique instead of digital to analog conversion, it reduces the latency during the transition from sleep to active mode in the MAC layer. To improve the interference resistance

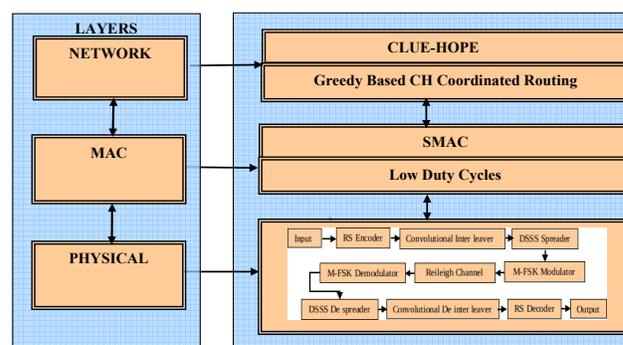


Figure 5. Multi-layer architecture of CLUE-HOPE.

over a wireless channel, the proposed scheme includes Direct Sequence Spread Spectrum (DSSS) scheme<sup>5</sup>.

The transceiver receives data packets at the PHY layer. The RS encoder first encodes the input data, and then interleave permutes the encoded data in a predefined manner. The DSSS technique spreads the encoded data bits, and the data sequence modulates the carrier after spreading. The modulated data is transmitted through the Rayleigh channel and it is demodulated by the non-coherent M-FSK demodulator. The DSSS spreads the data sequence. Then, the data sequence is decoded by RS decoder after de-interleaving. Thus, the techniques used in the physical layer reduce the BER and latency during the transition from sleep to active mode in MAC layer, and improves the routing performance.

## 4. Performance Evaluation

The NS-2 simulator is used to compare the performance of CLUE-HOPE with Link aware Clustering Mechanism (LCM)<sup>17</sup> and DUCA<sup>4</sup> over wireless sensor networks. For the simulation of varying node density, the randomly placed nodes of 50 to 250 within the network area 1000 x 1000 m are considered. It simulates an IEEE SMAC protocol with a node communication range of 100-250 m. The initial battery power of the sensor is 2 joules. The User Datagram Protocol (UDP) and CBR application agent are used to transfer data packet size of 1024 bytes. The simulation runs for 500 seconds.

### 4.1 Simulation Results

#### 4.1.1 Impact of Number of Clusters

The simulation is conducted on 100 node topology by varying the network area with the communication range of 100m to analyze the impact of a number of clusters

on the performance of the proposed CLUE-HOPE. The number of clusters is varied based on the network area and communication range of sensor nodes. Figure 6 gives the values of throughput for a different number of clusters. The throughput of two clustering techniques such as CLUE-HOPE and LCM decreases as the number of clusters increases. For illustration, when the number of clusters is 25, CLUE-HOPE delivers 155 Kbps, but the LCM delivers 142 Kbps. The LCM is unaware of the adjacent CH nodes and determines separate paths to the sink node, and so it may invite data collision and increases the packet drop. The CLUE-HOPE put some nodes into sleep state based on the node density, and it reduces the data redundancy and network traffic. Moreover, the selection of merged paths reduces the hop and improves the network throughput than LCM. The proposed CLUE-HOPE increases the throughput in the range of 7% than LCM.

The energy conservation of CLUE-HOPE is compared with DUCA, by varying the network area from 500 x 500 m to 900 x 900 m. Figure 7 shows slight variations in the energy conservation of DUCA protocol, which has been improved significantly by enhancing the performance of the lower layers in CLUE-HOPE. Both the clustering techniques

put some nodes into the sleep state and CH allocate the TDMA schedule only to the active nodes. Thus, both the techniques improve the energy conservation even increasing the network area or number of clusters. But in case of high network traffic, the transition speed of sensor nodes from sleep mode to active mode in MAC layer is decreased in DUCA. To increase the transition speed of a node, the CLUE-HOPE includes SMAC and RS and DSSS coded with a non-coherent M-FSK scheme at the lower layers and it improves the network layer performance and a significant amount of energy can be conserved in CLUE-HOPE. For instance, when the number of clusters is 25, CLUE-HOPE conserves 1.07 joules, but the DUCA conserves 0.95 joules.

In general, the routers involved in the routing are likely drain power quickly, when the number of clusters and router cost increases. The total number of routers involved in all the grids to reach the sink node is referred as router cost. As the nodes in the path deplete their power more quickly, a long path leads to packet retransmissions. In the LCM, the path is determined based on the link quality that takes a long path.

But in CLUE-HOPE, the merged routes are established based on the rule of GCCR in which each cluster head attempts to use the same set of links with adjacent cluster heads. This results in a less hop count to reach the sink node which is shown in Figure 8. However, the LCM performs similar to the CLUE-HOPE, when the number of clusters is small. For example, with 25 clusters both the techniques achieve 0.35 router cost, but the CLUE-HOPE decreases the router cost in the range of 18% than LCM at the point of 81 clusters.

With the increased number of clusters, the control overhead of the CLUE-HOPE and DUCA technique are increased. Even though DUCA is a grid cluster based

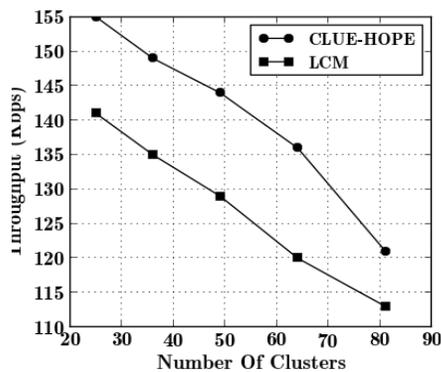


Figure 6. Number of clusters Vs throughput.

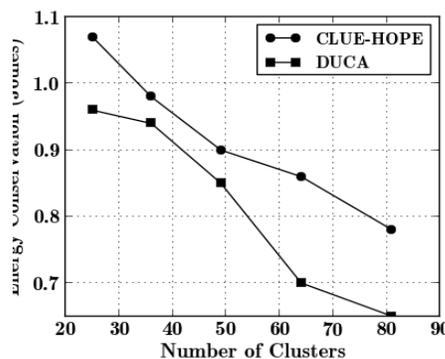


Figure 7. Number of clusters Vs energy conservation.

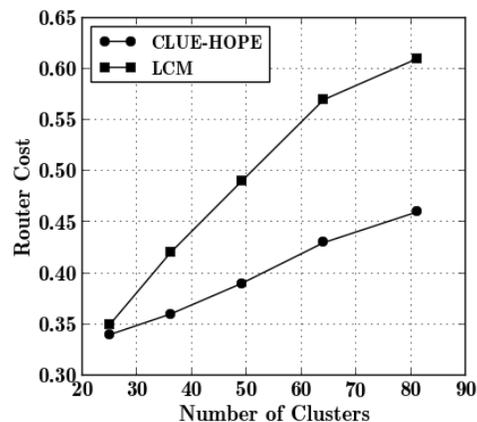


Figure 8. Number of clusters Vs router cost.

protocol, the centralized grid formation increases the control overhead. The Figure 9 illustrates the number of clusters versus overhead. The proposed CLUE-HOPE is not a passive clustering mechanism, but the process of cluster formation and maintenance in a distributed manner reduces the control overhead. The overhead of CLUE-HOPE is reduced in the range of 2% than DUCA.

#### 4.1.2 Impact of Communication Range

The delay induced while the data aggregation of CH is referred as data aggregation delay. Figure 10 shows the comparative results of data aggregation delay between the proposed CLUE-HOPE and DUCA by varying nodes' communication range. It is because, the CLUE-HOPE decides the cluster size based on the node's communication range. The data aggregation delay is similar to the DUCA at 50m, as the number of sensor nodes controlled by a CH is less and fewer time slots are sufficient to aggregate the data from CM nodes. On increasing the cluster size, CH needs to control a huge number of CM in the grid. It increases

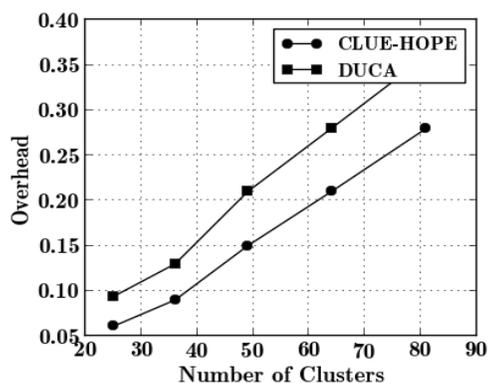


Figure 9. Number of clusters Vs overhead.

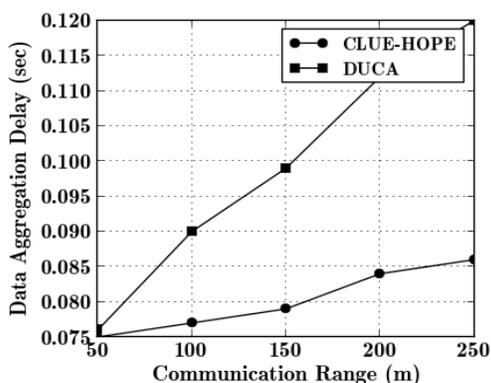


Figure 10. Communication range Vs data aggregation delay.

the data aggregation delay in DUCA, but the CLUE-HOPE increases the delay slightly with increased cluster size. For instance, the data aggregation delay of both the techniques is similar to 0.075 when the communication range is 50. However, in CLUE-HOPE it has increased to 0.085 when the communication range is 250.

The network lifetime is a major concern in the WSN including low energy sensors, and it is shown in Figure 11. The cluster head cooperativeness in routing is defined as the ratio of hop count to the total number of CH involved in the routing. Both LCM and CLUE-HOPE select a highly energetic or highly reliable node as CH, but the CLUE-HOPE increases the cluster-head cooperativeness that eliminates the problem of routing in large clusters. And it improves the network lifetime compared to LCM. The proposed CLUE-HOPE outperforms the LCM under all scenarios, when router cost increases. The LCM determines the routing path from CM to sink node individually, but it leads to multiple paths from a cluster to sink node. However, the proposed CLUE-HOPE connects the adjacent CHs based on the rule of GCCR to reach the sink node, and it increases the cluster head cooperativeness in routing. Thus, the network lifetime of CLUE-HOPE decreases in the range of 7.2% at the point of 250m.

#### 4.1.3 Impact of Node Density

Figure 12 demonstrates the comparative simulation results of data redundancy between CLUE-HOPE and LCM. The increasing node density increases the number of sensors deployed per unit area. Thus, it increases the data redundancy per cluster in LCM. However, the CLUE-HOPE reduces the active nodes per cluster based on the node density and minimizes the data redundancy.

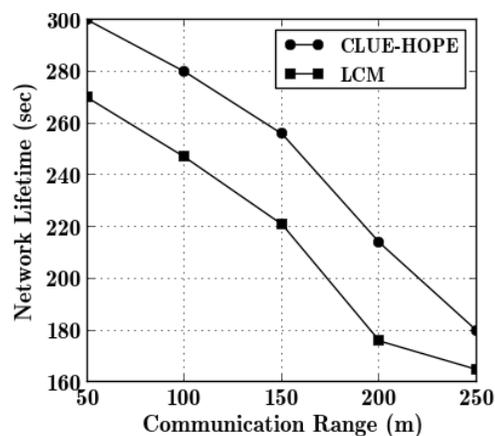


Figure 11. Communication range Vs network lifetime.

However, in a low-density area, the proposed CLUE-HOPE enables all the nodes to active mode and thus it behaves similar to the LCM.

The energy consumption per cluster head is shown in Figure 13. The node density affects the requirement of energy at a CH. The CH node is responsible for collecting and aggregate packets from multiple CM nodes. Thus, it reduces the energy consumption per cluster head linearly with the node density. However, in a low-density area, the sleep nodes in the network are zero and thus it behaves similar to the LCM.

In LCM, the CH nodes unaware of the node density in its cluster, and multiple transmission in one cluster often degrade communication in a nearby cluster. In the case of high network traffic, it leads to communication interference and packet drop which is shown in Figure 14. To reduce inter-cluster interference, each cluster in CLUE-HOPE put some cluster members into a sleep state based on the node density. Moreover, to reduce inter-cluster interference, the CH nodes in CLUE-HOPE make communication using DSSS. Thus, the performance of CLUE-HOPE is better than LCM.

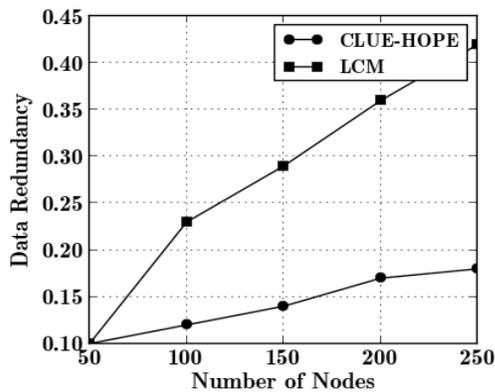


Figure 12. Number of nodes Vs data redundancy.

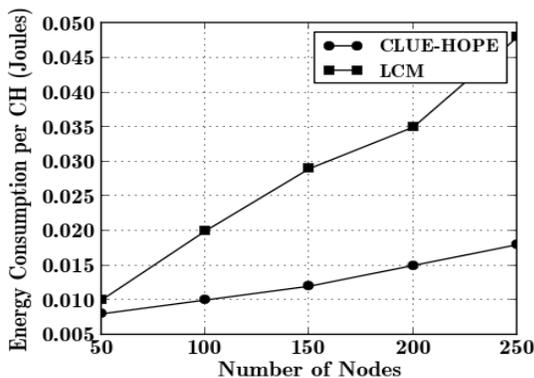


Figure 13. Number of nodes Vs energy consumption.

#### 4.1.4 Impact of Sink Centrality

The sink centrality is defined as the ratio of the distance of the sink node to reach the center point of the network to the half of the network height. The Figure 15 and 16 show the result of varying the sink centrality. In LCM, the router cost is decreased with the sink centrality. It is because, the sink closer to the boundary increases the router count of CH nodes closer to the opposite boundary. However, in CLUE-HOPE, the merged routes are established from

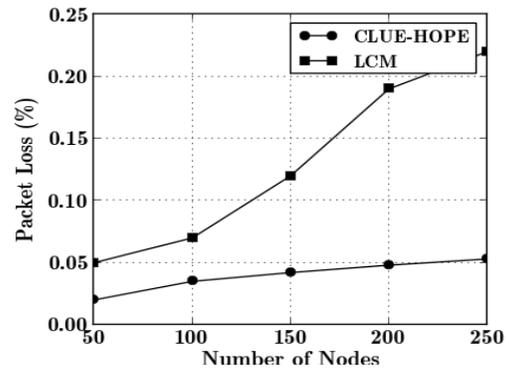


Figure 14. Number of nodes Vs packet loss.

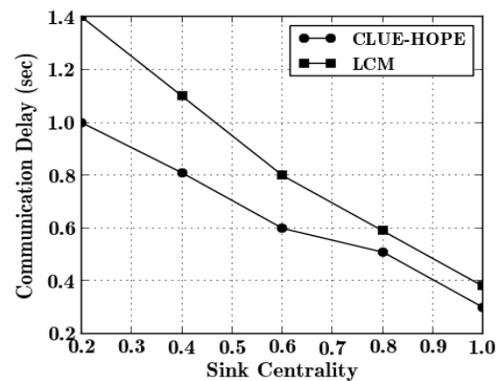


Figure 15. Sink centrality Vs communication delay.

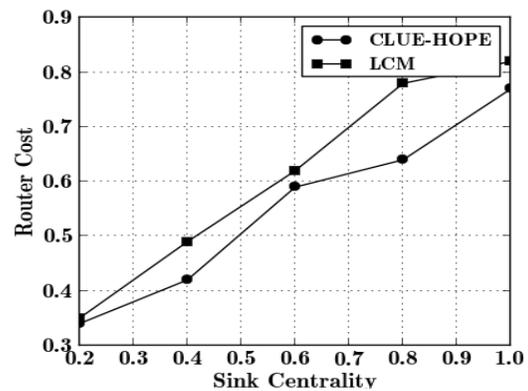


Figure 16. Sink centrality Vs router cost.

CH nodes based on the rule of GCCT. As a result, the communication delay of CLUE-HOPE decreases in the range of 5% than LCM.

## 5. Conclusion

This work has proposed a clustering protocol for an energy-hole preventive environment, called CLUE-HOPE, to provide energy-efficient routing. The grid formation and selection of CH in the distributed manner reduces the control overhead, and the rotation of CH role among the nodes in the grid improves energy conservation in the network. In the proposed work, CLUE-HOPE substantially reduces cluster size variations without spending extra energy in the network. In CLUE-HOPE, the CH selection and rotation mechanism assist to distribute the CHs evenly while the routing is performed on the basis of GCCR. Each cluster in CLUE-HOPE reduces the interference using a direct-sequence spread spectrum in communication, and each node reduces the chance of packet retransmission using an effective error detection mechanism at PHY layer. Simulation results reveal that the proposed CLUE-HOPE achieves better performance in terms of energy consumption, throughput, communication delay, and network lifetime compared to LCM and DUCA.

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