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A Novel Approach for Energy Efficient Clustering in Heterogeneous Wireless Sensor Networks

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Abstract
Dynamic clustering is crucial in increasing the sensor network's lifetime. Switching the cluster head is desirable to ensure equal energy expenditure among the sensors, resulting in an improved lifetime. It is invalid for heterogeneous wireless sensor networks (WSNs), and the energy-efficient clustering of randomly deployed heterogeneous sensors is not always perfect. Thus, the sensor deployment also plays a significant role in supporting full-coverage and clustering of a heterogeneous WSN. This paper proposes the Coverage and Heterogeneity aided Energy Efficient clustering Routing (CHEER) protocol to deal with the heterogeneity of sensors. The CHEER protocol operates in three phases such as DIRECT deployment, SURE clustering, and EYE routing. DIRECT is a new deployment strategy that places a set of heterogeneous sensors at specific locations as desired and such a deployment strategy helps to build the SURE clustering. It minimizes the repetitive movement and control message complexity in sensor deployment. SURE clustering supports EYE routing to assign the routing load for sensors according to its communication range and battery energy for achieving a superior network lifetime. Finally, the performance evaluation results show that the CHEER protocol outperforms EEHC in a heterogeneous WSN environment.

Keywords: Heterogeneous sensor network, Deployment, Clustering, Energy-efficient Routing

1. Introduction

A Wireless Sensor Network (WSN) consists of low-powered sensor devices with a short communication range. The sensor lifetime is the major concern owing to its limited battery energy [1]. Clustering is a key technique to limit the energy consumption of the deployed sensors and extends the lifetime of WSN [2]. Organizing the sensors in the form of clusters efficiently utilize the energy for data aggregation. Each cluster selects the Cluster Head (CH) to aggregate the data from Cluster Members (CM). CH sends the aggregated data to the sink node directly or via multi-hop communication. Thus, the clustering mechanism reduces the data communication among sensors, resulting in a high network lifetime [3].
The sensor network is classified as homogeneous and heterogeneous with respect to the functionality of the sensors. In the homogeneous WSN, all sensors have the same processing capabilities. To balance the load among sensors, existing techniques periodically rotate the role of cluster head among them. The clustering in heterogeneous WSN is complex to implement, where the sensors have different sensing and battery energy [4] [5]. Additional energy resources are embedded with the CH devices to improve the lifetime of heterogeneous WSN. In such cases, the rotation of the cluster head is not necessary. An arbitrarily distributed sensors need to cover the entire area for sensing. The coverage reflects how well the sensors monitor and sense the information effectively [6]. Multiple sensors may cover a single area due to the sensor deployment and topology constraints. These devices share the common sensing region and task, and it leads to an inefficient clustering. Thus, a novel design of clustering technique is essential to solve the coverage and connectivity problem jointly. Consequently, the deployment strategy plays a vital role in the formation of clustering over heterogeneous networks. One way to build full-coverage of the clustered heterogeneous network is to relocate the randomly deployed sensors around the sink node in the descending order of its capacity. The routing load is higher for the sensors located closer to the sink, as the sensors located farther away from the sink. Thus, the proposed work employs the idea of deploying the heterogeneous sensor devices along a star segment for attaining energy-efficient clustering.

1.1 Problem Statement

Heterogeneous WSN increases the complexity of energy-efficient clustering, deployment, topology control, and identification of common sensing region. A mixed deployment of low and high sensing devices needs to achieve load balancing and cost of deployment. Moreover, if the sensor devices have different sensing range, the low sensing devices cannot inform its presence to the high sensing devices. It is essential that each sensor should know about its local/ global topology information, and some low sensing devices need to replace with large ones for achieving full coverage for improving the clustering performance. Another problem to form the clustered heterogeneous WSN is the position or deployment of sensors. Most of the existing deployment techniques, formulate the coverage problem into a node intersection problem for maintaining the coverage and connectivity among all the sensors. The intersection area is derived from the common sensing region. However, the fixed sensing range is not practical in a realistic heterogeneous sensor network. If the existing technique for handling the coverage problem is extended to cluster the heterogeneous networks, it leads to *insufficient* energy consumption and shortened *network* lifetime.

1.2 Contributions

The summary of the key contributions of the proposed work:

- The proposed CHEER protocol equalizes the energy dissipation among heterogeneous sensors during routing, by constructing clustered heterogeneous network.
- The proposed work uniformly distributes the heterogeneous sensors along a star segment model by constructing the MaxMin Connected graph in the network.
- MaxMin Connected graph guarantees full-coverage of the network, by distributing the connected sensors in the descending order of its communication range from the center region to the boundary of the network.
- The star structure based deployment strategy supports an energy efficient routing by assigning the routing load for sensors according to its communication range.
- The simulation results show that the proposed CHEER improves the routing performance in terms of throughput, and reduce the energy consumption during both the deployment and routing.

1.3 Paper Organization

The paper is organized as follows: The section 2 discusses the previous works related to the Clustering approach and deployment strategies over heterogeneous sensor network. Moreover, it discusses the problem associated with heterogeneous network. Section 3 talks about the system model and assumptions used in the work. The proposed CHEER is discussed in the section 4. Section 5 shows the experimental results of the proposed CHEER and section 6 concludes the work.

2. Related Works

Homogeneous WSN proposed a variety of energy-efficient clustering and deployment mechanisms for coverage and connectivity. This section reviews these protocols, and summarizes their issues in heterogeneous sensor networks.

Energy Efficient Clustering Techniques

The existing work divides the heterogeneous sensor network into three types. These are computational, energy, and link heterogeneity. To increase the lifetime of the WSN, several protocols are proposed such as Stable Election Protocol (SEP) [7], stable election with Reliable transmission protocol [8], base station initiated clustering [9], and zone based energy efficient routing [10]. Several algorithms are formulated to minimize the energy consumption, according to the heterogeneous cluster structure of sensor networks [11-13]. In these works, every algorithm includes two phases such as cluster setup phase and steady state phase. In [14] [15], the cluster head is selected based on the weighted election probability. This algorithm is based on the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol, where the role of cluster head is rotated randomly.

In the modified version of LEACH-Centralised (LEACH-C) [16], each sensor sends the remaining energy and location information to others in a network. Stochastic Distributed Energy Efficiet Clustering (SDEEC) [17] rotates the role of CH sensor periodically like LEACH. The Clustering For Service Discovery (C4SD) protocol is a service discovery protocol over heterogeneous sensor networks. It aims at reducing the workload of resource constraint sensor devices. This algorithm is based on the local topology information for constructing the sparsely distributed cluster heads.

Techniques for handling coverage and connectivity Problems

The problem in identifying the number of sensors required to cover the network area for achieving the full coverage of a certain region is discussed in [18] [19]. It proposes the exposure-based model to compute the spatial density, according to the physical characteristics of the sensors. The least number of sensors needed to achieve k-coverage regardless of node deployment in [20]. The mechanism used in [21], derives the necessary and sufficient conditions for single covered and connected wireless sensors in grid network topology. The review of the problem of coverage and connectivity in 3D networks is described in [22]. Also, Voronoi tessellation based placement strategy based on of 3D space is introduced in [23]. Another problem in handling the coverage and connectivity is to select a minimum size connected k-cover [24]. It solves the k-coverage problem using a greedy algorithm with a minimum set of sensors. Moreover, the work in [25] optimally solves the best coverage problem using Voronoi. It is not necessary to provide the prior knowledge of the application area and manual tuning of parameters. It supports the heterogeneous network, where deploying sensors with various densities and sensing range. However, the lack of proper relocation of sensors affects the network lifetime.

This section discusses the existing protocols in heterogeneous sensor networks. However, these works are not considering the sensing range to classify the heterogeneous sensor networks. The fixed sensing range is not practical to a realistic heterogeneous sensor networks. Moreover, the existing approaches have been used for solving the coverage and connectivity problems by measuring intersection sensing range among devices. However, these approaches are not suitable for heterogeneous sensor devices. Hence, it is essential to provide energy-efficient clustering with deployment approach as the main criteria in future.

3.System Model

Notations Used

G	Square Network
H	Network Area Height
W	Network Area Width
S	Sensor
E	Direct Link Between Sensors
S_{rg}	Communication Range
n	Total number of S_{rg}s used in different sensors, $\lvert S_{rg}\rvert$
B_e	Battery Energy
$\{C_i\}_{i=1 \text{ to } n}$	n Packed Circles in HW Area
R_i	Radius of Circle
K_n	Number of rounds
M_x	MaxMin Connected Graph
DL	Deployment Leader
Max_{rad}	Maximun S_{rg}

Consider the heterogeneous WSN as a graph G(S,E) and sensors comprising different battery energy (B_e) and communication range (S_{rg}). CHEER uses functions for packing circles into G(H,W) and it simplifies the determination of number of heterogeneous sensors required to cover $\{C_i\}_{i=1 \text{ to } n}$ area that is equal to HW. The radius of the circle (R_i) of each circle is determined using equation (1).

$$R_i = \left\{ n \left({}^{1.414H}/_{2} \right)^2 \Big/ _{|n|} \right\}^{1/2} \quad (1)$$

$$K_n = R_n - \left\{ \sum_{i=1}^{n-1} k_n \left(1.5 * (S_{rg})_n \right) / 1.5 * (S_{rg})_n \right\}$$

where n varies from 1 to $|S_{rg}|$ ……………. (2)

To cover the circle area completely, CHEER splits sensor deployment into multiple rounds. The number of rounds required to deploy the sensors is determined using the equation (2). By applying $(S_{rg})_n$ in the equation (3) and (4) at k_n times, obtain the number of sensors $(S_{rg})_n$ required to cover the circle. $\sum N(S_{rg})_n$ for all k_n , k_n is the total number of sensors in the network.

For k_n=1,

$$N(S_{rg})_n = \left\{ 2\pi \left[\sum_{i=1}^{n-1} \left(|K_{(n-1)}| * 0.5 * S_{rgi} \right) + \left[K * \left(0.5 * (S_{rg})_n \right) \right] \right] \Big/ \left[1.5 * (S_{rg})_n \right] \right\} \quad (3)$$

For k_n=2 to $|k_n|$,

$$N(S_{rg})_{nk} = \left\{ 2\pi \left[\sum_{i=1}^{n-1} \left(|K_{(n-1)}| * 1.5 * S_{rgi} \right) + \left[(K-1) * \left(1.5 * (S_{rg})_n \right) \right] + \left[0.5 * (S_{rg})_n \right] \right] \Big/ \left[1.5 * (S_{rg})_n \right] \right\} \quad (4)$$

Network G is divided into four equal sized square regions. Each region selects a sensor having Max_{rad} as Deployment Leader (DL). Consider each DL is aware of $\sum N(S_{rg})_n$ deployed in the network. Each sensor is connected to other sensors that have high S_{rg} than itself. Each sensor follows the same rule to form MaxMin Connected Graph (M_x). DL measures and moves excessive sensors within M_x to other regions. Each sensor acts as a CH for low sensing devices and they are connected with a star structure. CH aggregates the data received from CMs and send it to the sink. Thus, the proposed work reduces the energy consumption during both the node deployment and routing process.

4. Overview of the CHEER Protocol

An appropriate solution to deal with the characteristic of heterogeneity in sensor devices is proposed. The proposed CHEER is a protocol that operates in three phases. The first phase consists of DIstributed REgion Coverage and conTrolled (DIRECT) deployment strategy, and CHEER protocol performs DIRECT deployment only once at the initial stage. Initially, the network is divided into four equal sized square regions. The DIRECT deployment operates over MaxMin connected graph, that is built based on the principle of connecting randomly deployed sensors in the increasing order of its sensing range. Using MaxMin connected graph, DL sensor relocates the excessive sensors to other regions that have connectivity hole.

The second phase consists of the Star structure (SURE) clustering. The DIRECT deployment strategy ensures that all the regions have adequate number of sensors for achieving full coverage, but there may be a connectivity hole due to the overlapped sensors. From center to the boundary of the network, DL sensor relocates other sensors in the descending order of its sensing range. According to the EnergY Efficient (EYE) routing rule, each sensor acts as both CH and CM. Each CH aggregates the data received from its CMs and sends it to the sink. Thus, the EYE routing assigns the routing load for sensors according to its sensing range and significantly reduces the energy consumption during both the deployment and routing process.

4.1 DIstributed REgion Coverage and conTrolled (DIRECT) Deployment Strategy

Initially, the heterogeneous sensors are randomly located in the network, and the network is divided into four equal sized square regions shown in the figure 1. The DIRECT deployment is performed only once. The sensors having Max_{rad} elect itself as a DL. Only the DL sensor takes responsibility for node deployment, so that it should know all the sensors located in its region. Thus, it creates the MaxMin connected graph, that connects all the sensors in the region.

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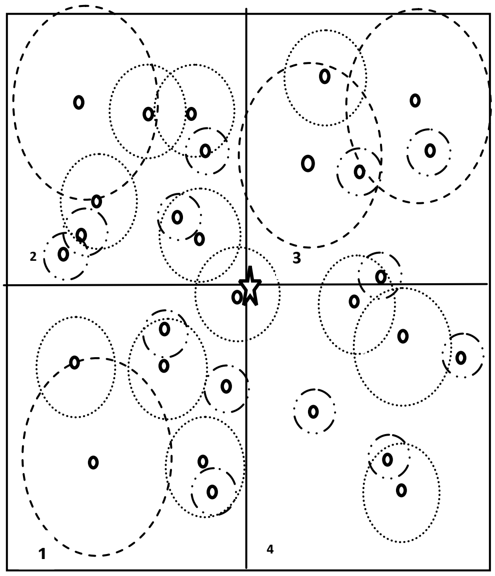

Figure 1: Randomly Deployed Heterogeneous Sensor Network

Every sensor broadcast the hello packet including communication range and location information to initiate the DIRECT deployment session. The design of MaxMin connected graph in turn requires the sensor connection in the ascending order of its communication range. Each sensor selects the neighbor having equal or high communication radio than itself. Moreover, it sends $MaxMin_{join}$ request to the selected sensor to construct the MaxMin sensor connected graph as shown in the figure 2.

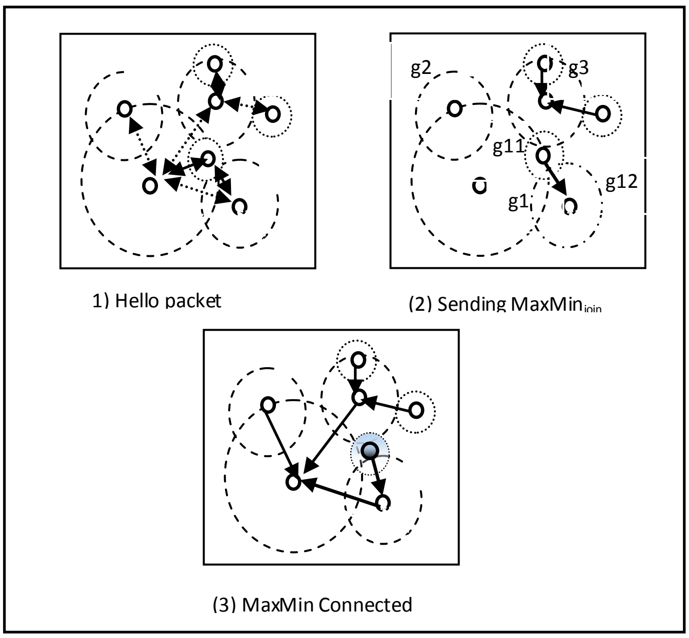

Figure 2: Steps in MaxMin Connected Graph Construction

In the first step, each sensor exchanges the hello packet with its neighbors. In the second step, the least sensing device sends $MaxMin_{join}$ request to the neighbor having a much closer communication radio than it. For instance, there are two sensors located with different communication radios in group g1. The least sensing device in g1 is named as g11 and the rest as g12. The sensor g11 receives a hello packet from both DL and g12. The g11 sends $MaxMin_{join}$ request to g12, as g12 having a much closer communication radio to g11 than DL. Then, g12 joins with the DL sensor by sending $MaxMin_{join}$ request, including its MaxMin graph member list (g11) to build the complete MaxMin connected graph. Each sensor follows the same procedure in the increasing order of its communication radio and completes the MaxMin connected graph successfully.

4.1.1 Problems in MaxMin Connected Graph Construction

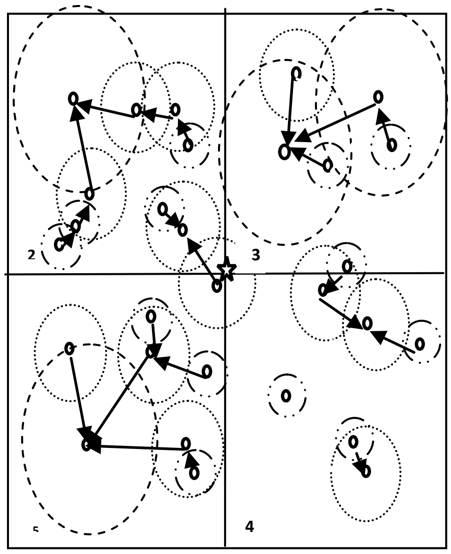

Figure 3: Null and Hot MaxMin Connected Graphs

Each region should be controlled by one DL To take full advantage of DIRECT deployment strategy. However, the heterogeneous sensor network may lead to two different problems in MaxMin connected graph such as Null MaxMin connected graph and Hot MaxMin connected graph. A MaxMin connected graph, that is not joint with the DL sensor is referred as Null MaxMin connected graph, whereas a graph having more than one DL is named as Hot MaxMin connected graph. In figure 3, region 4 and 3 comprises Null and Hot MaxMin connected graph respectively. Even though the region 2 has DL sensor, some sensors do not connect with the DL. So the graph in region 2 is also considered as a Null MaxMin graph.

4.1.2 Null and Hot MaxMin Connected Graph Handling in DIRECT Deployment Strategy

An efficient deployment is possible only when one DL takes deployment decision per region. If two or more DL sensors make deployment decision per region without the knowledge of others, it directs the deployment problem into the iterative relocation of sensors. It is essential to handle both Null and Hot MaxMin connected graph in DIRECT deployment. Before calculating the redundant sensors, each DL sensor needs to know whether the region has Null or Hot MaxMin connected graph. In DIRECT deployment strategy, each DL sends the announcement message, including its connectivity value with the low bit rate but using the high transmission power to cover the entire network.

The end node of the Null MaxMin connected graph is called as Temporary Leader (TL) sensor. When the DL announcement message is received by the leader sensors, they move into the communication range of DL. It solves the problem of Null MaxMin connected graph in region 2 of figure 3 successfully. However, it is not possible to address the problem of Null MaxMin connected graph in region 4, as it does not have at least one DL. The redundant DL sensors should be relocated to Null MaxMin connected graph to solve this problem. For instance, in region 3 of figure 3, DL has high connectivity act as an original DL. It instructs excessive DL sensor to move with its MaxMin connected sensors to region 4, which does not send the DL announcement message in the network. Again, each DL sensor announces its leadership message to the entire region and rebuild the MaxMin Connected sensors. It leads to complete the MaxMin Connected graph in each region.

4.1.3 MaxMin Connected Graph Coverage

Handling of Null and Hot MaxMin connected graph provides complete MaxMin connected graph in each region. However, it does not ensure that each DL sensor has sufficient number of sensors to cover the entire region. Thus, it identifies the required and redundant sensors in each region to relocate. Initially, the DL divides the sensors into different types based on its communication radio. The DL sensor broadcasts the coverage message into the network, and the message includes the number of heterogeneous sensors in each type located on the MaxMin Connected graph. In case of redundant sensors in the MaxMin connected graph, the DL sensor of the corresponding region instructs the excessive sensors in each type to move to other regions based on its requirement. DL sensors execute the same procedure one by one with the knowledge of the decision taken by others in the preceding regions to avoid repetitive deployment. Thus, the DIRECT deployment strategy enables each DL to relocate the excessive heterogeneous sensors efficiently in the network without incurring high movement complexity.

4.2 Star Structured Cluster Formation

Consider the sink node is located at the center point on the network. The SURE clustering assures that the region of interest is covered completely in an energy efficient manner with the use of MaxMin connected graph. SURE clustering is centrally controlled by the DL sensor in each region.

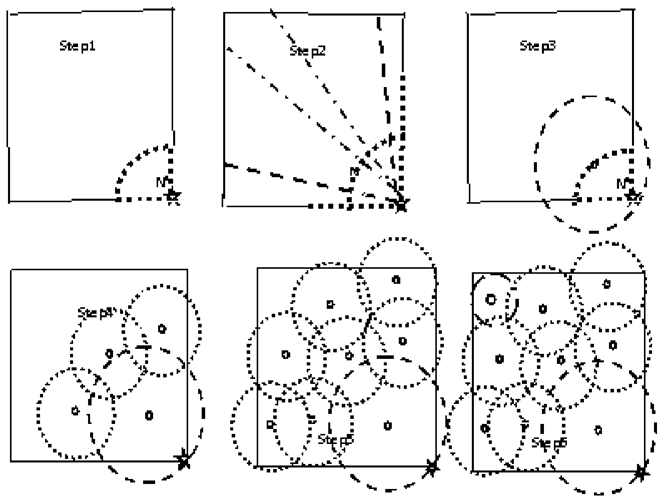

Figure 4: Principle of SURE Clustering

The design of the SURE clustering model takes account of the square region to achieve full network coverage without connectivity hole. For this purpose, it proposes a slicing scheme to divide the area into different quadrant sectors that are the portion of a quadrant enclosed by N^0 angle and an arc. It considers different communication radios equipped with different sensors to decide the radius of an arc. The step 1 of figure 4 implies that the arc drawn with a radius of R and it is centered around a location point of the sink node. The arc touches the region of two points on the different sides of the region. Slice the square region into a quadrant sector using these points along with a sink location and arc. The slicing function is done for all types of sensors in the descending order of its communication range. The result of this slicing operation is called slicing grid. Step 2 of figure 4 shows a slicing grid of a square region.

Consider the network has three types of sensors. One is DL having Max_{rad} and others are represented as R and R' (Max_{rad} > R>R'). Each type has multiple sensors and places the same kind of sensors in one or more succeeding quadrant sectors (k rounds). Note that the k value varies for each sensor type as shown in the equations 3 and 4. Guaranteeing some degree of overlap among clustered sensors can facilitate the communication between them. To achieve this, the SURE clustering consider cutting down the radio, which is slightly reduced from original communication radio. The cut-down radios of all types of sensors are represented as $CMax_{rad}$, CR, and CR'. It builds first quadrant sector with$CMax_{rad}$. DL is placed at the center point of the arc as shown in the step 3 of figure 4.

Only, the DL sensor has the responsibility to relocate other sensors in each region. The DL sensor draws an arc with a radius of (2k)(Communication radio used in the network> CR) + CR($2k_R$+1) for 1 to k rounds of each sensor type. The arc length of a quadrant sector is shown in the equation 4. It divides the arc into several sub arcs with 2CR length. It places the sensors having R communication radio at the center point of each sub arc as shown in the step 4. For R' type, the DL follows the same procedure. In figure 4, only the second type of sensors is located in two succeeding quadrant sectors i.e. k value of R sensor type is equal to 2 and others are located in only one quadrant sector.

$$\text{Arc length} = (N^0/360^0) * 2\pi R \ldots\ldots\ldots\ldots\ldots (5)$$

To further reduce the energy consumption, the excessive sensor devices in each region could be turned off. Moreover, the CHEER protocol replaces the dead sensors with excessive sensors in the future. Thus, the proposed work guarantees the full coverage and connectivity among all the active sensors.

4.3 EnergY Efficient (EYE) Routing

The proposed SURE model constructs the star structured clusters for energy efficient routing. The design of an energy-efficient clustering in turn requires the sensor distribution in the descending order of its communication range from the center to the boundary of the network. It is because, the low sensing devices are sufficient to cover the border of the network, whereas high sensing devices cover the center point of the network and are highly involved in the data aggregation phase. Thus, the deployment approach for clustering supports efficient energy utilization of sensors during the phase of data aggregation and routing. Sensors located in each quadrant act as CH for the sensors in succeeding quadrant. At the same time, they act as CM for the sensors located in preceding quadrant. Thus, in SURE cluster based EYE routing a sensor can act as both CH and CM other than the DL. Each CH aggregates the information collected from its CMs. It sends the aggregated data to the CH in next quadrant. All the CHs in the network follow the same rule for routing. Finally, the sink node receives the aggregated data from the DL sensors in an energy efficient manner.

4.4 Algorithm for CHEER Protocol

The algorithm 1 demonstrates the CHEER protocol. This protocol includes DIRECT deployment, SURE clustering, and EYE routing. DIRECT deployment takes four equal sized square regions into account and connects all the sensors under DL. DL moves excessive sensors to cover the empty or uncovered regions. DIRECT deployment strategy assures that each DL has sufficient number of heterogeneous sensors to cover the region. It relocates the sensors in descending order of its communication range from center to the boundary of the network. Finally, EYE routing is applied in the SURE clustered network. This leads to distribute the routing load on sensors based on its communication range and improves the network lifetime.

Algorithm for CHEER Protocol
Initialize: Routing Establishment, R_e =1
for all nodes do
If $R_e \leq 1$
DIRECT deployment
SURE Clustering
EYE routing
Else
EYE routing
end for
/*DIRECT Deployment*/
Input: Randomly deployed sensors and four regions (R_g) of network
Output: MaxMin Connected Graph
for i=1 to N do
Broadcast hello packet to sensors in Neighbor_List (NL)
for j =1 to |NL| do
if the communication range of j < i **then**
Sensor j send $MaxMin_{join}$ to sensor i
Form MaxMin Connected graph
end for
Sensor i having Max_{rad} announce DL message into the network
end for
for k=1 to |DL| do
Move excessive DL to Null R_gs
Rebuild MaxMin Connected graph in R_g
Move excessive sensors to other R_g
end for
Ensure: Region of interest is covered completely

/*SURE Clustering*/
Input: Sensors in MaxMin Connected graph
Output: SURE clustered network
for k=1 to |DL| do
Divides the R_g into different quadrant sectors (Q_s)
for n =1 to $|Q_s|$ do
for m=1 to total rounds (k) do
Relocate the sensors in quadrant sector
Build SURE clustering model
end for
end for
end for
for j=1 to k in R_g do
Broadcast hello message to sensors in (k+1) of Q_s
Select CH
end for
Ensure: Guarantees full coverage and connectivity among sensors

/*EYE Routing*/
Input: Connected sensors in SURE clustered network
Output: Energy efficient routing
for j=1 to k in R_g do
if $|CH| \neq 0$ do
for n=1 to |CH|
Receive data from CMs
Aggregate the data
Send to CH in (k+1) Q_s
end for
else
Send data to CH in (k+1) Q_s
end for
Ensure: Improved network lifetime

Algorithm 1: Algorithm for CHEER Protocol

5. Performance Evaluation

NS-2 based simulation model compares the performance of the proposed CHEER with Energy Efficient Heterogeneous clustered scheme (EEHC) [14]. Consider a square area of side length 500m, where all the sensors are randomly deployed. Uses the heterogeneity model, where the sensors having different communication radios such as 75, 50, and 25m, and number of sensors having different communication radios in the network are 12, 20, and 52 respectively. For these three sensor types, deployment is done with 2, 1 and 1 rounds (k) respectively. For sensors with 75m communication radio, the number of sensors deployed in k=1&2 are 4 and 8 respectively. For the sensors having 50 m radio, all the sensors are deployed in only one round. For the last type of sensors, the sensors placed in k=1 is 52. Consider the energy model in which initial energy of each sensor type is 60J, 40J, and 20J respectively. The User Datagram Protocol (UDP) agent is applied to the transport layer. Network traffic is generated using a CBR application agent with the data packet size of 1024 bytes. The simulation time is 600 seconds.

5.1 Simulation Results

The simulation results discuss the different simulation models. In order to facilitate the performance of the proposed CHEER protocol, various performance metrics are evaluated.

5.1.1 Impact of Number of Sensors

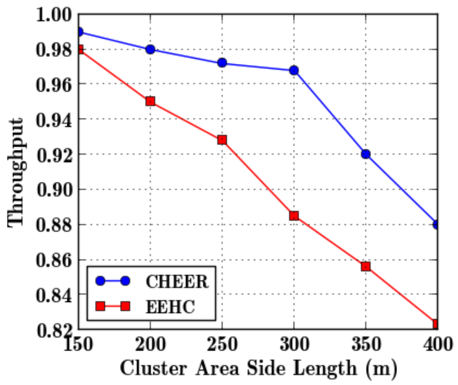

Figure 6: Cluster Area Side Length vs Throughput

The simulation is performed on heterogeneity model where sensors having 50, 25, or 10m communication radio, by varying the cluster area side length from 150 to 400m. Figure 6 shows the values of throughput for different side length and it proves that the performance of CHEER is better than EEHC. The network throughput of CHEER decreases gradually, when varying the network side length from 150 to 250m. On increasing the side length more than 275m, there is a sudden decrease in network throughput. This is due to the fact that using a same heterogeneity model, the 250m side length, and topology is covered almost by 300 heterogeneous sensors. When the number of sensors increases more than 82 (side length > 250m), the number of clusters formed in the network increases. Thus, it decreases the network throughput by 5%.

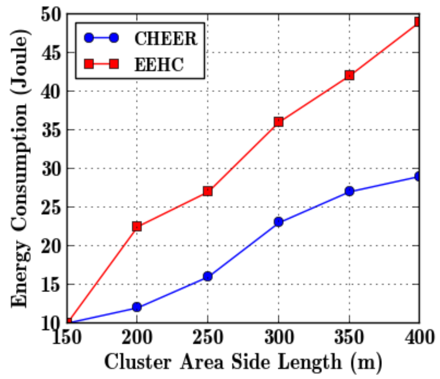

Figure 7: Cluster Area Side Length vs Energy Consumption

Figure 7 shows the comparison of energy consumption of CHEER with EEHC, with varying the network side length from 150 to 400m. The energy consumption of EEHC is similar to the CHEER at a small area. When increasing the network side length, it spent additional energy for reestablishing clusters and leader role rotation, and also to the communication overhead caused by the control packet exchange among sensors. However, CHEER employs a static clustering model, where the CH role is not rotated, thus yielding significant energy savings. For example, with a 150m side length both the CHEER and EEHC consume 10 Joules. However, the energy consumption of EEHC increases in the range of 30% than CHEER at the point of 400m side length.

5.1.2 Impact of Max_{rad}

The impact of Max_{rad} used in the network is simulated on the 500x500m topology with three types of sensors. The alive sensors represent the ratio of the number of sensors that have not yet expanded all of its battery energy to the total number of sensors. Initially, both the CHEER and EEHC achieve similar alive sensors as shown in Fig 8. Increasing Max_{rad} from 25 to 125m, CHEER increases the number of alive sensors compared to EEHC. It is because, CHEER deploys the sensors having Max_{rad} around the sink node and equalize the energy consumption among heterogeneous sensors. Moreover, the Max_{rad} reduces the number of sensors in other types. When the Max_{rad} is 25, both the CHEER and EEHC achieve 0.72 alive sensors, but the CHEER increases it by 8% with 100m Max_{rad} than EEHC.

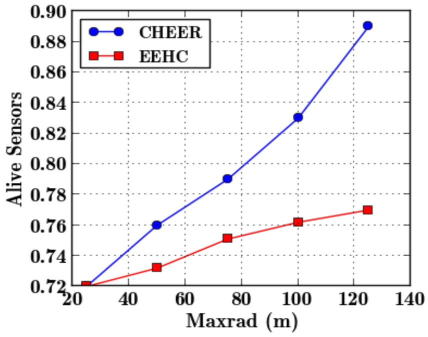

Figure 8: Max$_{rad}$ vs Alive Sensors

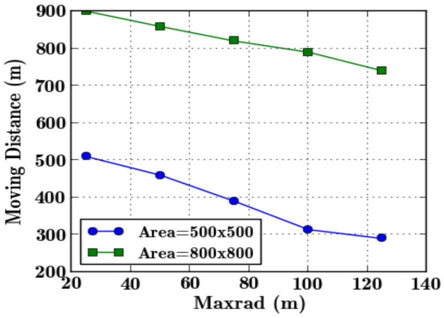

Figure 9: Max$_{rad}$ vs Moving Distance

Sensor moving distance in CHEER is the parameter that represents the distance of moving sensor during DIRECT deployment. To analyze the impact of moving distance on the proposed CHEER protocol, the simulation on 500x500m and 600x600m sensor topology is conducted. The simulation results are shown in Fig 9. From the results, it is observed that the moving distance per sensor decreases with increased Max$_{rad}$. When considering large areas, the CHEER increases the moving distance per sensor. For example, when the Max$_{rad}$ is 25, CHEER achieves 510m moving distance per sensor, but it is increased to 900m when the area is increased from 500x500 to 800x800m.

5.1.3 Impact of Simulation time

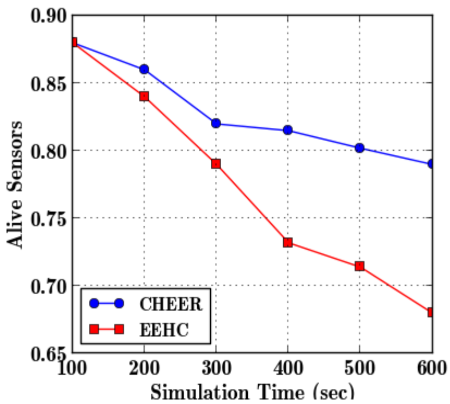

Figure 10: Simulation Time vs Alive Sensors

To analyze the impact of simulation time on CHEER, alive sensors and overhead are measured in equal interval of simulation time. This simulation is conducted on 500x500m network topology. The result of alive sensor and overhead are shown in Fig 10 and 11. The overhead is defined as the ratio of the number of control packets used for routing to the total number of data packets transmitted in the network. Initially, the alive sensors are similar for both CHEER and EEHC.

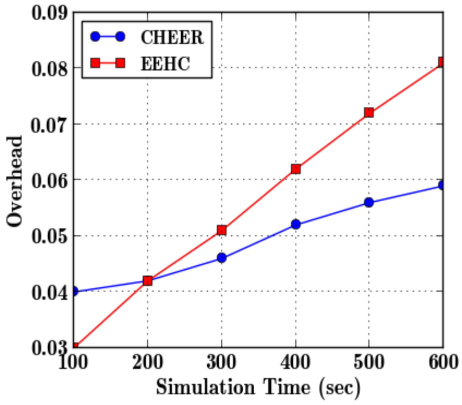

Figure 11: Simulation Time vs Overhead

As the simulation time increases, number of alive sensors in CHEER decreases gradually. However, alive sensors decrease in EEHC, due to the reestablished clustering and role rotation. The message complexity or overhead in EEHC increases gradually. However, CHEER induces high overhead during deployment stage, but after that it increases slowly. Initially, EEHC delivers a packet in the range of 0.03 routing overhead at the point of 100 sec simulation time, but the CHEER achieves 0.04 routing overhead. In EEHC the overhead is increased by 20% compared to CHEER, when the simulation time is increased to 400 seconds.

5.1.4 Number of Cluster types

The cluster type varies based on the number of heterogeneous or different type of sensors used in the network topology of 500x500m. The results of router cost and energy consumption are shown in Fig 12 and 13. The ratio of total number of routers involved in all the regions to reach sink node to the total number of sensors in the network is referred as router cost. As the sensor type or area increases, the number of clusters is also increased. However, increased clusters increases the router cost to reach sink node and the routers deplete their energy quickly.

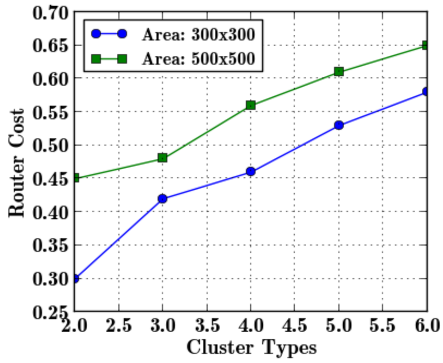

Figure 12: Cluster Types vs Router Cost

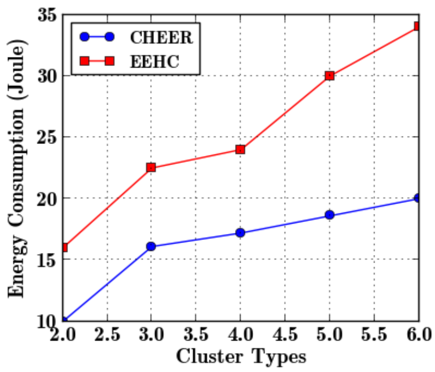

Figure 13: Cluster Types vs Energy Consumption

In the proposed CHEER, the routing load is higher for the sensors located closer to the sink than the sensors located farther away from the sink. Thus, it equalizes the energy dissipation among heterogeneous sensors even under a large scale network. For example, with cluster types 2 and 300x300m area, the CHEER achieves 0.30 router cost, but it increased to 0.58 when the cluster types is 6.

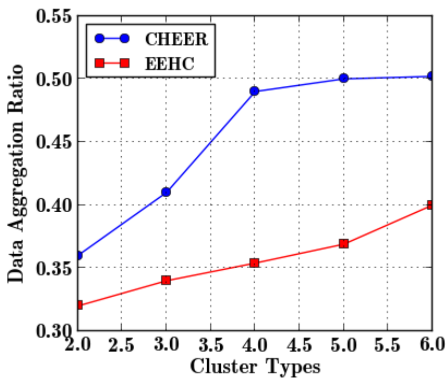

Figure 14: Cluster Types vs Data Aggregation Ratio

The data aggregation ratio is defined as the difference between actually sensed data and originally forwarded packets to the actually sensed data in an entire network. The figure 14 shows the result of the data aggregation ratio by varying the cluster types. When increasing the number of heterogeneous sensors in the network, number of leaders aggregate the sensed data of each sensor also increases. So it increases the originally forwarded packets in the network more than EEHC and thus it decreases the energy consumption in the heterogeneous sensors. However, when the cluster types are increased more than 4, there is no improvement in the data aggregation ratio. The data aggregation ratio of CHEER increases in the range of 10% than EEHC at the point of 2 cluster types.

6. Conclusion

This work proposes a routing protocol for clustered heterogeneous sensor network, called CHEER, to provide energy-efficient routing in wireless sensor networks. The deployment strategy supporting static clustering is paramount to extend the lifetime of the heterogeneous sensor network. The energy efficiency and easy deployment strategy, DIRECT make CHEER a desirable and robust protocol for heterogeneous wireless sensor network. To improve the routing performance and network lifetime, SURE clustering assigns high routing load on the sensors located closer to the sink compared to the sensors located farther away from the sink. AS the CHEER has jointly solved coverage and connectivity problems, it can improve energy efficient routing performance in terms of throughput, data aggregation, and network lifetime. The simulation results show that the CHEER has improved the heterogeneous network lifetime and routing performance by 5.1% as compared with EEHC.

References

[1] I.F. Akyildiz et al., “Wireless Sensor Networks: A Survey,” Computer Networks, Vol. 38, No.4, pp. 393-422, 2002

[2] Younis, Ossama, Marwan Krunz, and Srinivasan Ramasubramanian. "Node clustering in wireless sensor networks: recent developments and deployment challenges", IEEE Network, Vol. 20, No.3, pp. 20-25, 2006

[3] Kumarawadu, P.; Dechene, D.J.; Luccini, M.; Sauer, A.,”Algorithms for Node Clustering in Wireless Sensor Networks: A Survey”, In Proceedings of 4th International Conference on Information and Automation for Sustainability, pp. 295-300, 2008

[4] Mhatre, Vivek, and Catherine Rosenberg. "Homogeneous vs heterogeneous clustered sensor networks: a comparative study" IEEE International Conference on Communications, Vol. 6, pp. 3646-3651, 2004.

[5] Mhatre, Vivek, and Catherine Rosenberg, "Design guidelines for wireless sensor networks: communication, clustering and aggregation." Ad Hoc Networks, Vol.2, No.1, pp. 45-63, 2004

[6] Kar, Koushik, and Suman Banerjee. "Node placement for connected coverage in sensor networks" WiOpt'03: Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks. 2003
[7] G. Smaragdakis, I. Matta and A. Bestavros, "SEP: A stable election protocol for clustered heterogeneous wireless sensor networks", In: Proc. of the International Workshop on SANPA, pp. 251-261, 2004
[8] Zhou, Haibo, et al. "A novel stable selection and reliable transmission protocol for clustered heterogeneous wireless sensor networks." Computer Communications, Vol. 33, No.15, pp. 1843-1849, 2010
[9] S. Varma, N. Nigam and U.S. Tiwary, "Base station initiated dynamic routing protocol for Heterogeneous Wireless Sensor Network using clustering", Wireless Communication and Sensor Networks, pp. 1-6, 2008
[10] X. Li, D. Huang and Z. Sun, "A Routing Protocol for Balancing Energy Consumption in Heterogeneous Wireless Sensor Networks", pp. 79-88, 2007
[11] Zhou Haibo, Wu Yuanming and Xie Guangzhong "EDFM: a stable election Protocol based on energy dissipation forecast method for clustered heterogeneous wireless sensor networks", Proceedings of the 5th International Conference on Wireless communications, networking and mobile computing, pp.3544-3547, 2009
[12] Xiaoming Lu, Matt Spear, Karl Levitt and S. Felix Wu, "iBubble: Multi-keyword Routing Protocol for Heterogeneous Wireless Sensor Networks" IEEE INFOCOM, pp. 1642-1650, 2008
[13] Ying Liang and Yongxin Feng, "An Energy-Aware Routing Algorithm for Heterogeneous Wireless Sensor Networks," Ninth International Conference on Hybrid Intelligent Systems, Vol. 2, pp. 275-278,2009
[14] Dilip Kumar, Trilok C. Aseri and R.B. Patel, "EEHC: Energy efficient heterogeneous clustered scheme for wireless sensor networks", Computer Communications, Vol. 32, No.4, pp. 662-667, 2009
[15] Dilip Kumar, Trilok. C Aseri and R.B Patel, "Analysis On Deployment Cost And Network Performance For Heterogeneous Wireless Sensor Networks", International Journal of Computer science & Information Technology (IJCSIT), Vol. 1, No 2, pp. 109-120, 2009
[16] W. B. Heinzelma,"Application-specific protocol architectures for wireless networks", Massachusetts Institute of Technology, 2000
[17] B. Elbhiri, R. Saadane and D. Aboutajdine, "Stochastic Distributed Energy-Efficient Clustering (SDEEC) for heterogeneous wireless sensor networks", Vol. 9, No. 2, pp. 11-17, 2009
[18] Chang, Jau-Yang, and Pei-Hao Ju. "An efficient cluster-based power saving scheme for wireless sensor networks." EURASIP Journal on Wireless Communications and Networking, pp. 1-10, 2012
[19] Adlakha, Sachin, and Mani Srivastava. "Critical density thresholds for coverage in wireless sensor networks." IEEE Wireless Communications and Networking, Vol. 3, pp.1615-1620, 2003
[20] S. Kumar, T.H. Lai, and J. Balogh, "On k-Coverage in a Mostly Sleeping Sensor Network," Proc. ACM MobiCom, pp. 144-158, 2004
[21] S. Shakkottai, R. Srikant, and N. Shroff, "Unreliable Sensor Grids: Coverage, Connectivity and Diameter," J. Ad Hoc Networks, Vol. 3, No. 6, pp. 702-716, 2005.
[22] S. Alam and Z.J. Haas, "Coverage and Connectivity in Three-Dimensional Networks," Proc. ACM MobiCom, pp. 346-357, 2006.
[23] H.M. Ammari and S.K. Das, "Clustering-Based Minimum Energy m-Connected k-Covered Wireless Sensor Networks," Proc. Fifth European Conf. Wireless Sensor Networks, pp. 1-16, 2008.
[24] Z. Zhou, S. Das, and H. Gupta, "Connected k-Coverage Problem in Sensor Networks," Proc. Int'l Conf. Computer Comm. And Networks (ICCCN), pp. 373-378, 2004.
[25] Bartolini, N., Calamoneri, T., La Porta, T., & Silvestri, S. "Autonomous deployment of heterogeneous mobile sensors." IEEE Transactions on Mobile Computing, Vol.10, No.6, pp. 753-766, 2011