Connected Dominating Set based Optimized Routing Protocol for Wireless Sensor Networks

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***Abstract*—Wireless Sensor Networks(WSNs) have problem of energy starvation in their operations. This constraint demands that the topology of communicating nodes should be limited. One of the ways of restraining the communicating nodes is by creating a Connected Dominating Set(CDS) of nodes out of them. In this paper, an Optimized Region Based Efficient Data(AORED) routing protocol for WSNs has been proposed. CDS has been employed in AORED to create a virtual backbone of communicating nodes in the network. The empirical study involving extensive simulations show that the proposed routing protocol outperforms the legacy DEEC and SEP protocols. AORED has increased number of transmission rounds, increased number of clusterheads and reduced number of packets sent to the basestation as compared to DEEC and SEP protocols.**

***Keywords*—Connected Dominating Set; Wireless Sensor Net-works; Energy Efficiency**

I. Introduction

Wireless sensor networks (WSNs) have grabbed attention of researchers in recent years due to their wide range of applications and potential use. A WSN comprises of independent sensor nodes that sense and transfer physical information to the sink. Cheap and small sized sensor nodes cannot be equipped with a large battery source. As these sensors have limited energy, it restricts the sensors to use limited memory, limited transmission power and perform limited computations to increase the lifetime of sensor. Network and data link layers in a sensor node play a vital role in the WSN communication. The energy problem is usually solved by the sensor node by changing its state. Generally, there are three states of sensor nodes i.e. active state, idle state, and sleeping state. The main purpose of active state is to transmit and receive data packets. Active state uses the maximum amount of resources available to the nodes which results in energy consumption. During the idle state, the only task done by the nodes is of sensing without receiving or transferring the data. While in the sleep mode, maximum energy is saved by turning of its radio off by the nodes. Sleep mode consumes the minimum amount of energy as compared to active and idle mode. Another way to conserve nodes' energy is to use energy efficient routing protocols and use limited transmit power if possible that reduces transmission range.

The issue of energy limitation in WSNs has been addressed by using the concept of Connected Dominating Set(CDS) as well. The CDS limits the number of communicating nodes hence reducing the energy consumption. In this paper, a connected dominating set based optimized routing protocol for WSNs has been proposed. Rest of the paper is organized as follows: Related work is presented in section II followed by proposed technique in section III. Section IV presents network model and problem formulation followed by energy consumption in section V and performance evaluation in section VI. Conclusions and future work are presented in the end.

II. Related Work

Routing protocols in WSNs are divided in three major categories; the location based routing, flat routing and hierarchical routing protocols. In case of location based routing protocols, the information of location of the node in WSNs is used to find the distance between nodes. It helps to select the next relay node. The location of node assists the protocol to send data to the specific location, which prevents energy consumption of the whole network. In flat routing protocols, all the nodes play the same role in the network. The BS sends the query to a specific node and that specific node responses to the query. All the nodes send data to neighboring nodes who send it to the BS. The major disadvantage of this routing protocol is that each node sends its data and forwards many other nodes' data to BS. This mechanism drains the energy of the whole network very quickly. In hierarchical routing protocols, group of nodes join together to make a cluster. Among them, there is a cluster head (CH). CH is responsible for receiving data from the nodes. It aggregates and forwards the data to BS. The main drawback of this scheme is CHs high energy consumption due to its additional workload. Random selection of CHs and their rotation from time to time overcomes this issue. However, the formation and selection of CH requires additional energy.

Low Energy Adaptive Clustering Hierarchy (LEACH) [1] is one of the most famous hierarchy based routing protocol in WSNs. Improvements have been proposed on LEACH. One of which is Stable Election Protocol(SEP) [2]. SEP is based on weighted election probabilities of each node to become cluster head according to the remaining energy in each node. Another improvement on LEACH is the Distributed Energy Efficient Clustering(DEEC) routing protocol [3] which selects the CH for the nodes with different levels of the energy. The CH selection is based on residual energy of the node over the average energy of the network. Therefore, the node which has high initial and residual energy has more chances to become a CH for the particular round than the node which has lower energy.

Apart from these two famous approaches, we see a lot of work done in the recent past to improve the energy efficiency of LEACH. In this regard, [4] presents a new energy-efficient cluster-based routing protocol, which adopts a centralized clustering approach to select cluster headers by generating a representative path. To support reliable data communication, they present a multihop routing protocol that allows both intra- and intercluster communications. In [5], the authors formulate the shortest path routing and the least energy cost routing in wireless sensor networks as L1-norm and L2-norm optimization problems to maintain the maximum network life time. In [6], the authors have proposed to measure the connectivity of sensor nodes and use this parameter for selection of cluster head for forwarding data to BS. In [7], they have used particle swarm optimization with LEACH to increase network life time. In [8], the base station finds the highest energy node among the cluster and mark it as a cluster head for the current time to improve energy efficiency of the network. In [9], the authors propose regional energy aware clustering with isolated nodes for wireless sensor networks. The cluster-heads are selected by the calculated weights based on the residual energy of each sensor and the regional average energy of all sensors in each cluster. In [10], they propose optimum number of cluster heads based on minimizing the dissipated energy in all phases of communication.In [11], The CH selection formula used in [1] is used. However, during re-clustering, a threshold value will be used to decide whether the CH will be replaced or not. Another improvement of leach is proposed in [12]. EELP is proposed for critical applications. Sensor nodes are manually deployed in each room on the floors of the multistorey apartment block. The nodes deployed in the rooms on each floor are assumed as a separate cluster and the node with the highest energy is selected as the CH to decrease the probability of the selection of a node with low energy and to balance the total energy load distribution of the network. In [13], only nodes with maximum residual energy and minimum energy consumption can become cluster heads since each nodes residual energy as well as average energy consumption is considered for the selection of cluster heads. In [14], the first level CHs are elected as in LEACH protocol. After the election of first level CHs, the second level CHs are elected hence introducing two-level hierarchy of CH nodes. The data undergoes multiple hops among CHs thereby increasing network lifetime. In [15], LEACH is improved by introducing master head and shortest path algorithm. Sensor nodes send data to the BS using MIMO. In [16],H-LEACH, the nodes with energy less than to that of the minimum energy required for transmitting and receiving signals is made to die as it lacks energy to do it. Minimum threshold is subtracted from the energy of the node in every round as that much of energy is consumed. Total number of alive nodes are calculated for every round so as to have a track on the life time of the network. In [17], LEACH-MAC, attempts to control the randomness present in LEACHs clustering algorithm by using MAC layer function. This approach makes the cluster head count stable. In [18]LEATCH, a two level hierarchical approach has been proposed to organize a sensor network into a set of clusters, every cluster divided into small clusters that are called Mini Clusters. As the way the clusters are organized, for each mini cluster, we define a Mini Cluster-Head (MCH). Every MCH communicates with the cluster-head directly, it aggregates its mini-cluster information and passes it on to the base station. In [19]P-LEACH, it combines the features of LEACH and PEGASIS [20] to improve energy efficiency in routing. In [21], each node broadcasts a Hello message which contains its identity and energy status with a predefined transmit power. With the received power of Hello messages and the prior knowledge of the transmit power, nodes can estimate the distance among them. Based on distance profiles, nodes create a list of N dominant neighbors. After this, the same steps are performed as that of LEACH. [22] present a comprehensive overview of different approaches under structure-free and structured wireless sensor networks for data collection and aggregation, clustering and routing along with their key issues. In [23], the authors propose to keep the cluster head count optimal using a cross layer approach since this count directly affects the energy efficiency of the network. In [24], they choose clusterheads based on their geographical locations to improve the overall network performance.

The limited power constraint in WSNs demand that the topology of communicating nodes should be limited. This need has urged the researchers to design new algorithms for controlling topology of the network. Connected Dominating Set (CDS) based topology control has received attention to reduce redundant and unnecessary communication overhead. Having such a CDS restricts the main communication tasks to the dominators only. In recent past, many efforts regarding the usage of CDS in wireless sensor networks can be seen. In [25], they consider how to construct a CDS in WSNs. In [26], they summarize the various CDS constructing algorithms both centralized and distributed and compares them. In [27], the authors propose a new degree-based greedy approximation algorithm to construct the CDS and then reduce its size by excluding some of the CDS nodes cleverly without any loss in coverage or connectivity. In [28], they have considered the problem of minimizing the number of CDS vertices that belong to a subset $v \subset V$. In [29], the authors present a novel algorithm based on the Induced Tree of Crossed Cube to reduced the size of CDS. In [30], they have performed a comparative study of major works relating to CDS construction emphasizing on the type of algorithm, technique employed, performance metric used and the outcome achieved.

III. Proposed Technique

In this paper, An Optimized Region Based Efficient Data Routing (AORED) protocol has been proposed in which the whole network field is divided into two regions to optimize the transmission power of sensor nodes. This partition is based on the euclidean distance to BS. AORED employs CHs to send data to base station. CHs in both regions transmit the aggregated data with the same transmission power to BS. CHs that are faraway from the BS, first send data to routing nodes which then relay the data to BS.

A. Procedure

The proposed protocol AORED is based on rounds; each round consist of two phases: setup phase and steady phase. The proposed protocol introduces three additional concepts: Logical formation of two groups, selection of CHs among the

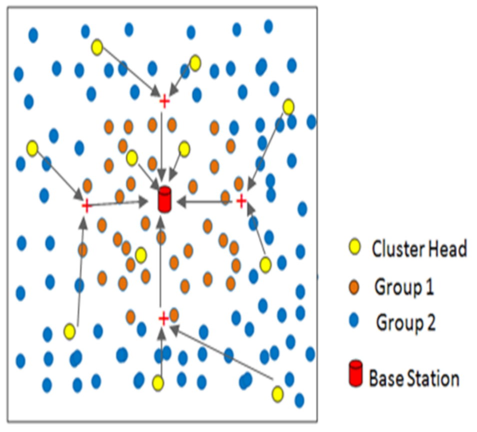

Fig. 1: AORED Communication Scenario

same group and installation of four routing nodes in the center of sensor field (distance measured from the BS). Additional concepts and phases in AORED are discussed in detail below.

B. Groups Formation

The whole network field is divided into fixed logical groups. These groups are homogenous in nature; each group may have different number of sensor nodes. BS is placed in the center of sensor field. The formation of groups requires the distance to BS of each node. If the distance of node to BS is less than or equal to 30% of the network size $100m \times 100m$, these nodes will be the part of group 1 shown in orange color in figure 1. All other nodes that lie at a distance greater than 30% of distance to BS belong to group 2 in blue color.

C. Routing Nodes Installation

The routing nodes have the same capabilities as normal nodes but they are used for a specific purpose. The four routing nodes are placed in the center of the sensor field along the x and y axes. + sign shows routing nodes in figure 1. Routing nodes neither take part in the CH formation nor in any other sensor field operations. They are installed to route the data of group 2 CHs. The group 1 CHs directly communicate to BS with the normal transmission power. In the same way, group 2 CHs also forward the data to routing nodes with the normal transmission power. The routing nodes aggregate the data received from the group 2 CHs and forward it to BS. Before forwarding the data to routing nodes, group 2 CHs calculate the distance to the routing nodes and forward it to the nearest routing node.

In figure 1, the total area is $100m \times 100m^2$ and the BS is in the centre at position of (50,50). Routing nodes are installed at the position of (25,50), (50,25), (75,50) and at (50,75).

D. Setup Phase

In the setup phase, it uses the same mechanism of CH selection as described in [1]

Grouping Phase:
Node $i \in$ N broadcasts ranging probe to BS
BS unicasts reply to i
i calculates distance $di \rightarrow$BS
if $di < 30$ **then**
  if $i_{Energy} > 0$ **then**
    i joins Group 1
  else
    i joins Group 2
  endif
endif

Fig. 2: Algorithm 1

$$T(n) = \begin{cases} \frac{p}{1-(p * rmod(1/p))} & if\ n \in G \end{cases} \quad (1)$$

$$T(n) = 0 \quad if n \notin G \quad (2)$$

In equation 1, p is the percentage to be a CH, G is a group of nodes that have not served as a CH since $1/p$ rounds so far and r is the present round. After a few rounds, the energy of the nodes will be uneven and nodes who have not taken the chance will become the CHs. AORED protocol provides this function to work with specific group. If the region of the node is group 1, then it can be a member of group 1 CH and if the node lies in group 2 region, then it can join the CH of group 2.

E. Steady Phase

In this phase, the communication starts between the nodes and respective CHs according to TDMA slots allocation. All the nodes only communicate through their CHs. Elected CHs broadcast their status using CSMA/CA protocol. Non-CH nodes select their CHs by comparing the strength of received signals from multiple CHs. After creating clusters, all CHs will create TDMA schedule for their associated members and broadcast it. All those nodes whose time slot is not active, are in sleep mode to conserve energy. The group 1 region CHs in this phase aggregate the data and forward it to the BS. On the other hand, the group 2 region CHs aggregate the data and forward it to the routing nodes. After receiving data from many CHs, the routing nodes aggregate the data and forward it to the BS as shown in figure 1.

The algorithm for grouping and steady phase of AORED is given in figure 2 and 3.

IV. Network Model and Problem Formulation

For problem formulation, the network area is divided into two groups: group 1 and group 2. An undirected graph G = (V, E), such that V is the set of vertices and E is the edges of graph G. In this scenario, there are two types of vertices V_{CDS} and V_{nonCDS}. Similarly the edges E are also divided into E_{CDS}

Steady Phase:
if $i \leftarrow$N **then**
TransToCH(i,Datapack)
end if
if $i \leftarrow$CH **then**
CH(i) estimates distance to routing nodes(RN)
CH(i) calculates distance $D_{CH\rightarrow RN}$
$D_{CH\rightarrow RN} = min(d_{i\rightarrow CH})$ *note down the RN that is at the lease distance away from node*
RCV$_{CH}$*(i,Datapack)CH receives data packet from node* i
Aggregate$_{CH}(i, Datapack)$
TransToRoutingNodeCH(i,Datapack)
end if
if $i \leftarrow$Routingnode(RN)**then**
RCV$_{RN}$(i,Datapack)*RN receives data packet from node* i
AggregateRN (i,Datapack)
TransToBaseStation (i,Datapack)
end if

Fig. 3: Algorithm 2

and E_{nonCDS} such that, E = $E_{CDS} \bigcup E_{nonCDS}$. Vertices V of graph G can be defined as $V = V_{CDS} \bigcup V_{nonCDS}$. The CDS nodes are selected from the group 1 region of 30 meters. A Dominating Set (DS) of graph *G* is a subset *D* of *V* such that every vertex in *V / D* is adjacent to at least one member vertex of *D*. A CDS is defined as a subset *D* of *V* such that any node in *D* can access any other node in *D* by a path that lies entirely within *D*, such that *D* induces a connected sub graph within *G*.

Let n number of nodes be randomly deployed in a two dimensional area. The nodes are categorized into three types: Normal Nodes *(NN)*, Cluster Head *(CH)* and Routing Node *(RN)*. *(NNs)* sense the data and transmit to *CHs*. *CHs* forward the data packets to *RNs*. These *RNs* forward the data packets to BS lying at the centre of network field.
According to mathematical models presented in literature, the network's throughput can be maximized using the equation 3.

Maximize:

$$d_{total} = \sum_{i=1}^{NN} u_t^i + u_r^i + \int_0^{2\pi} \int_0^r p(\pi r^2) r dr d\theta \qquad (3)$$

Subject to:

$$\sum_{i=1}^{n} u_t^i + u_r^i \leq E_{total} \qquad \forall i \in i \qquad (4a)$$

$$\sum_{c=1}^{CH} \sum_{i=1}^{NN} f_{ci} \leq F \qquad \forall c, i \in n \qquad (4b)$$

$$f_{ci} \leq C_{ci} \qquad \forall c, i \in n \qquad (4c)$$

$$\bar{e}, d_{ci} \geq 0 \qquad (4d)$$

Eq. 3 describes that maximum number of nodes should live for far longer duration in order to increase the throughput. Eq. 4a depicts that energy spent by node i to transmit and receive u bits is upper bounded by total energy given to network. Eq. 4b describes that data flow between *NN* and *CHs* is upper bounded by total flow of the network. f_{ci} is the flow from NN to CH. Eq. 4c elaborates the relation between flow and total capacity of a particular link. C_{ci} represent the total capacity of link.

A. Criterion for CDS Construction

A Connected Dominating Set(CDS) is developed by using extended localized algorithm presented by Dai and Wu in [31]. After establishment of CDS, the length between all the CDS nodes is calculated. The total distance of all the CDS nodes is calculated by using euclidean distance formula between nodes *i* and *j*. CDS formation includes following steps:
Criteria 1: Nodes with the highest degree are identified in the inner region. After that, consider those nodes which have highest degree and then second highest degree. The highest degree nodes are called dominator nodes. The nodes which are adjacent to highest degree nodes are called dominatee nodes.
Criteria 2: Dominatee nodes which are not further adjacent to any other node are called leaf node. The leaf nodes are never included in CDS.
Criteria 3: Dominatee nodes other than leaf nodes are converted to dominator nodes if that dominatee node has only leaf neighbors.
Criteria 4: Node which is a dominatee of two dominator nodes is also converted to dominator node.
Definition 1: A set of nodes $V_{CDS} \subset V$ such that every node $\hat{v}$ belongs to $V - D$, there should be at least one node $\hat{u}$ in V_{CDS} that dominates $\hat{v}$. Furthermore, V_{CDS} are connected to each other.
Definition 2: A CDS,$V_{CDS} \subset V$ of G = (V, E),such that CDS nodes act as RNs and non-CDS nodes act as normal nodes which forward data to RNs. The set of RNs collectively form a random path within CDS through which data is routed to the static sink that exists at the centre of network field.

Definition 3: A CDS, $V_{CDS} \subset V$, such that the random path exists within CDS nodes is converted to a circular path formed by CDS nodes. This circular internal area is optimized to achieve:

$$Maxd_{total} = \sum_{i=1}^{NN} u_t^i + u_r^i + \int_0^{2\pi} \int_0^r p(\pi r^2) r dr d\theta \qquad (5)$$

Consider the example in which nodes are randomly deployed in network field. As the network has two regions, the group 1 region is optimized to achieve the maximum throughput. For this purpose, consider 15 nodes inside group 1 region and then apply the CDS formation rule as discussed above. By searching the first and second highest degree nodes inside the circular region, one finds out that node n_7 has highest degree and node n_{13} has second highest degree. These two nodes are called dominator and thus included in CDS. After completion of first step, the second step is to sort out the dominatee nodes which are adjacent to dominator nodes. The dominatee nodes of n_7 include $(n_4, n_2, n_5, n_6, n_1, n_9)$. The leaf nodes n_5, n_6 are not included in the CDS. Nodes n_4 and n_2 have leaf neighbors, so

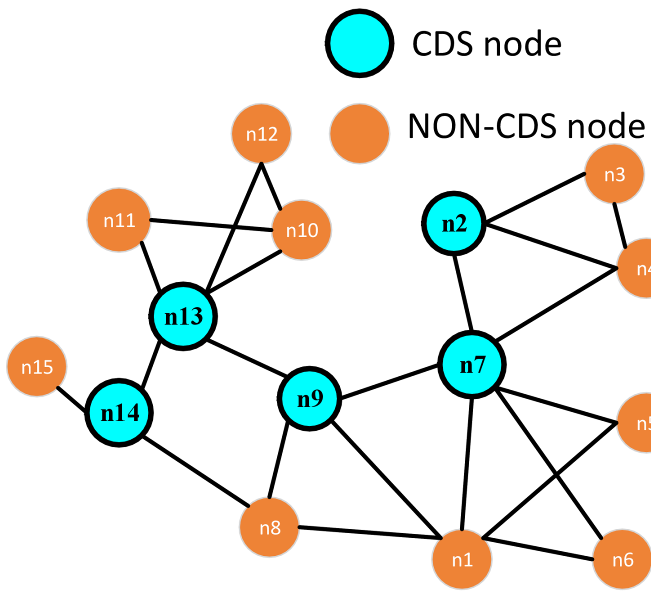

Fig. 4: Construction of CDS

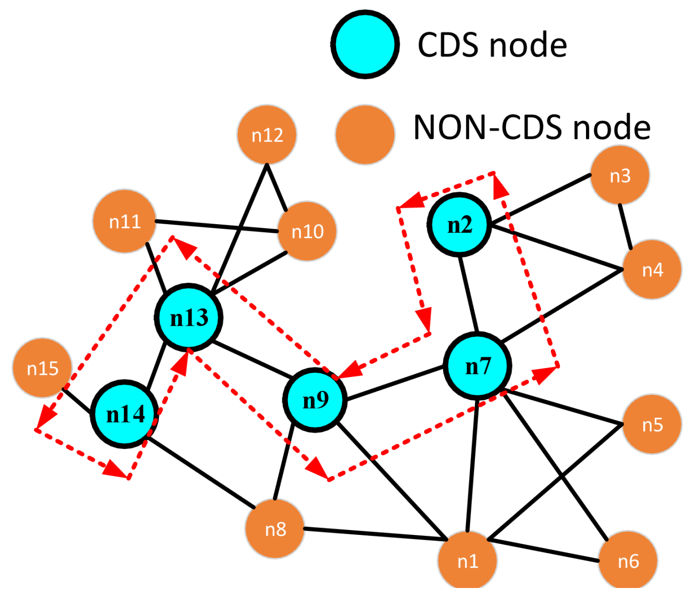

Fig. 5: Random Path formed by CDS nodes

any one of them is included in CDS. Thus, node n_4 is included in CDS. The dominatee nodes n_1 and n_9 have further non-leaf neighbors so these two nodes are not included in CDS.

Consider the second highest degree node n_{13}, and according to criteria 1, the node n_{13} is included in CDS. The dominatee nodes of n_{13} include $(n_{10}, n_{12}, n_{11}, n_{14}, n_9)$. According to criterion 2, nodes n_{10} and n_{12} are leaf nodes and hence these two nodes are not included in CDS. The node n_{14} is included in CDS because it has leaf neighbor that is node n_{15}. Moreover, according to criteria 4, the node which is dominatee of two dominator nodes is also included in CDS, thus node n_9 is included in CDS. After implementation of all the above mentioned rules on the group 1 region of network, we obtain the CDS which includes nodes $(n_2, n_7, n_9, n_{13}, n_{14})$ as shown in figure 4. The Path length (PL) of all the CDS nodes can be calculated as shown in eq 6. Figure 5 shows the random path constructed within CDS.

$$P_L = \{e(n_2,n_7), e(n_7,n_9), e(n_9,n_{13}), e(n_{13},n_{14}) \\ e(n_{14},n_{13}), e(n_{13},n_9), e(n_9,n_7), e(n_7,n_2)\} \tag{6}$$

The length of all the CDS nodes can be computed by adding the length of all links of CDS as follows:

$$P_L = \sum_{\forall e(i,j) \in CDS} length\ (i,j) \tag{7}$$

Where $length(i,j) \in CDS$ is the distance between node i and j. $length(i,j)$ is computed by using Euclidean distance formula:

$$d(i,j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{8}$$

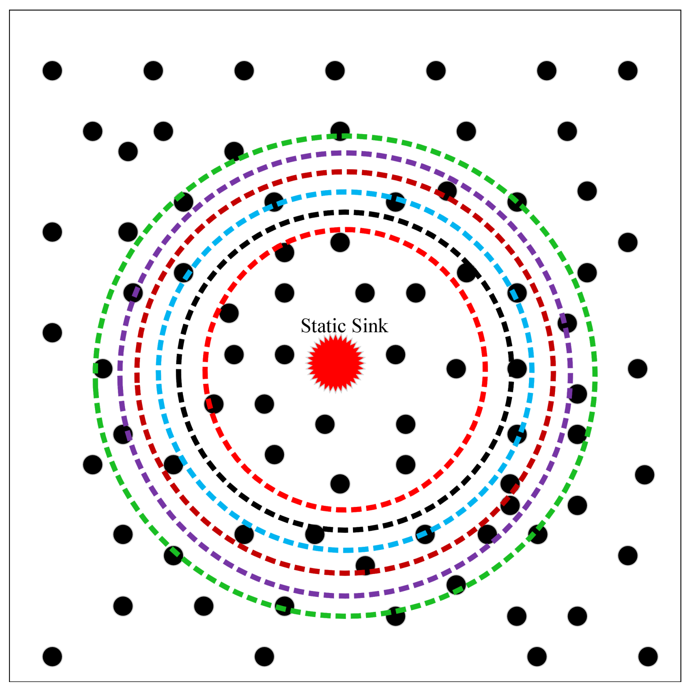

Fig. 6: Conversion of CDS into Circular Shape

In other words:

$$length(i,j) = d\ (i,j) + d(j,i) \tag{9}$$

In this way, total path length of all the CDS nodes is computed by using following equation:

TABLE I: Different values of α

α	r	r = r + α
0	30m	30m
0.2	30m	36m
0.4	30m	42m
0.6	30m	48m
0.8	30m	54m
1	30m	60m

$$P_L = 2 \times \sum_{\forall e(i,j) \in CDS} \textit{length (i,j)} \tag{10}$$

B. Optimized Group 1 Region

Irregular trajectory formed by CDS nodes can be changed to a circular internal area as follows:

Since area of a circle is:

$$A = \pi r^2 \tag{11}$$

Where *r* is a radius of circle. To compute *r*, circumference of a circle is C= $2\pi r$.

Where:

$$r = \frac{C}{2\pi} \tag{12}$$

$$C = P_L = 2 \ \times (\sum_{\forall e(i,j) \in CDS} \textit{d(i,j)} \ ) \tag{13}$$

$$r = \frac{2 * (\sum_{\forall e(i,j) \in CDS} \ \ d(i,j))}{2\pi} \tag{14}$$

$$r = \frac{\sum_{\forall e(i,j) \in CDS} \ \ d(i,j)}{\pi} \tag{15}$$

In order to find the optimized value of circular path, equation 15 will be used

$$r = r + r\alpha \qquad 0 < \alpha, < 1 \tag{16}$$

Let the initial value of r = 30 meter. The value of α will be varied from 0 to 1 as shown in table I. AORED protocol has been simulated for different values of α. Figure 6 shows the different circular paths made by *RNs*. The value of α affects the location of RNs. Moreover, the value of α plays a significant role to increase the stability period as well as throughput of network. The value of α is varying as shown in table I. When the value of α is equal to 0, the *RNs* are far from the nodes that exist at the corner of the field. The goal is to find an optimal circular position for *RNs* in order to decrease the transmission distance between CHs in the outer region and *RNs*. When distance between *CHs* and *RNs* decreases, the nodes live for longer duration and hence transmit data packets for longer duration which increases the throughput. By simulating AORED protocol for different values of α, one finds out that at $\alpha = 1$, the stability period as well as network throughput increases. The optimal area of group 1 region can be calculated as follows:

$$A = \frac{(\sum_{\forall e(i,j) \in CDS} \ \ d(i,j))^2}{\pi} \tag{17}$$

V. ENERGY CONSUMPTION

There are three different types of nodes: normal, routing and CH nodes depending upon their role. Energy consumption of these nodes is given in next subsections.

A. Energy Consumption of a Normal Node (NN)

The energy consumption of NN can be calculated as:

$$E_{NN} = \bar{e}_s + \bar{e}_t(d_{NC}) \tag{18}$$

$$E_{NN} = \sum_{NN}^{n} \bar{e}_s + \bar{e}_t(d_{NC}) \tag{19}$$

E_{NN} in equation 18 represents the energy consumption of NN to sense and transmit their own data. $\bar{e}_s$ and $\bar{e}_t$ are the energies required to sense and transmit the data. The distance between NN and CH is represented by d_{NC}. If all the normal nodes are considered in the network, then energy consumption can be represented as in equation 19. Similarly, the energy consumption of NN to forward data to BS can be computed as:

$$E_{NN} = \bar{e}_s + \bar{e}_t(d_{NB}) \tag{20}$$

$$E_{NN} = \sum_{NN}^{n} \bar{e}_s + \bar{e}_t(d_{NB}) \tag{21}$$

where d_{NB} in equations 20 and 21 represents the distance between *NN* and *BS*.

B. Energy Consumption of CH

For CHs, it is assumed that they share equal load from NNs within the cluster. First consider the energy consumption rate for nodes in group 2. Equation 22 depicts the energy consumption of CHs in group 2. However, equation 23 shows the energy consumption of CHs in the group 1.

$$E_{outer}, CH = \bar{e}_s + \bar{e}_t(d_{CR}) + \frac{pn_{outer}}{m_{outer}}[\bar{e}_r + \bar{e}_t(d_{CR})] \tag{22}$$

$$E_{inner}, CH = \bar{e}_s + \bar{e}_t(d_{CB}) + \frac{pn_{inner}}{m_{inner}}[\bar{e}_r + \bar{e}_t(d_{CB})] \tag{23}$$

TABLE II: Simulation Paramters

Parameters	Values
Network size	$100m^2$
Packet Size	1 Byte
Initial Energy	500mJ
Data aggregation Energy Cost	50 pj/bit
Number of Nodes	100
Node Density	0.01
Transmit Electronics	50 nJ/bit
Receiver Electronics	50 nJ/bit
Transmit Amplifier E_{amp}	100 pJ/bit/m^2
Simulation Rounds	3000s

$\bar{e}_r$ is the energy required to receive the data, d_{CR} is the average distance between CH and RN andd_{CB} is the average distance between *CH* and *BS*.

C. Energy Consumption of Routing Nodes (RN)

For RNs, it is assumed that they share equal load from CHs of group 2. Equation 24 depicts the energy consumption of RNs.

$$E_{1,RN} = \bar{e}_s + \bar{e}_t(d_{RB}) + \frac{\sum_{k=2}^{K} pn_k}{m_inner}[\bar{e}_r + \bar{e}_t(d_{RB})] \quad (24)$$

Where d_{RB} is the average distance between *RN* and *BS*.

VI. Performance Evaluation

Extensive simulations have been conducted in MATLAB to compare AORED protocol with DEEC and SEP. AORED outperforms both DEEC and SEP in energy consumption, network lifetime and network stability. The details of simulation parameters and results are discussed in next subsections.

A. Simulation Parameters

All nodes are deployed using the random uniform distribution within the field of $100m \times 100m^2$. The BS is centrally located at the location of (50, 50). Routing nodes are located at (25, 50), (50, 25), (50, 75)and(50, 75). Total number of nodes in the network is 104 including routing nodes.Figure 1depicts randomly deployed network. Each result is an average of 10 simulation runs. Simulation parameters are listed in table II

To evaluate AORED protocol, the following network parameters have been considered:

1) **Stability Period:** observe the network operation until its first node is dead
2) **Network Lifetime:** observe the time period from the start to the death of all the nodes.

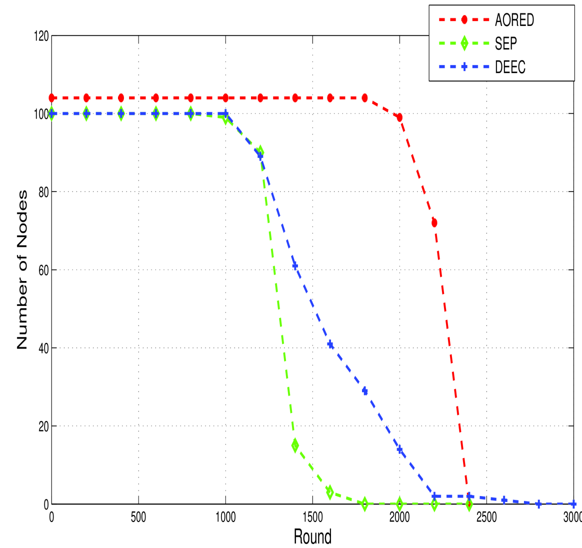

Fig. 7: Number of Alive Nodes

3) **Number of CHs per Round:** observe the number of CHs per round having capability of aggregating the data and sending it to BS.
4) **Number of Alive Nodes:** observe the number of all nodes in WSN that are alive in a particular round.
5) **Variable network size:** observe the behavior of proposed protocol with different network sizes. i.e. $200 \times 200m^2$, $300 \times 300m^2$, $400 \times 400m^2$, and $500 \times 500m^2$ keeping the node density constant i.e. 0.01.

B. Simulation Results

AORED works in rounds as DEEC and SEP. Total rounds used for the experiments are 3000.

Network Lifetime
Figure 7 and 8 show that the AORED has higher network life time as compared to DEEC and SEP. The first node of AORED is dead after 1900+ rounds, whereas in DEEC and SEP, it's 1000+ and 900+ respectively. AORED outperforms the DEEC and SEP in network stability and in network life. Last node of DEEC, SEP and AORED is lifeless at approximately 1674, 1899 and 2371 rounds respectively. AORED has 22% more rounds as compared to DEEC and 24% more rounds than SEP.

$CHSelectionPerRound$
DEEC, SEP and AORED prefer the distributed *CH* selection algorithm. If the algorithm chooses a small number of selected *CHs*, it means each CH forwards more nodes' data. In this way, *CHs* battery diminishes at a fast rate. Selected *CHs* have to perform this additional function of data aggregation and forwarding. If huge number of *CHs* are chosen, it causes overall network energy utilization. Random selection of *CHs* is depicted in figure 9. As there are more rounds in AORED, no. of *CHs* is also increased.

$Packets\ to\ BS$

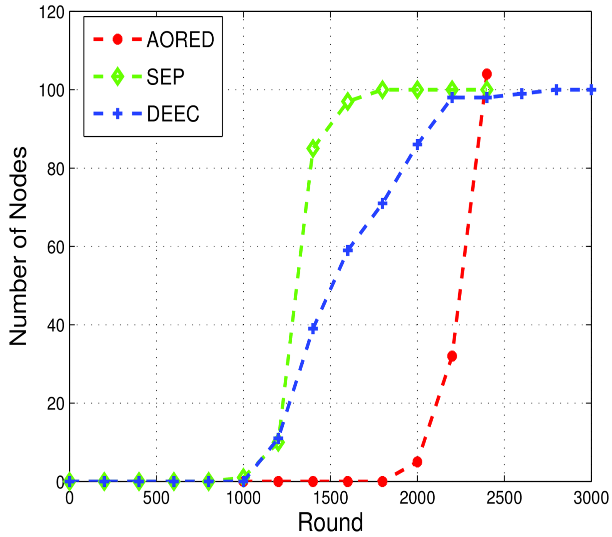

Fig. 8: Number of Dead Nodes

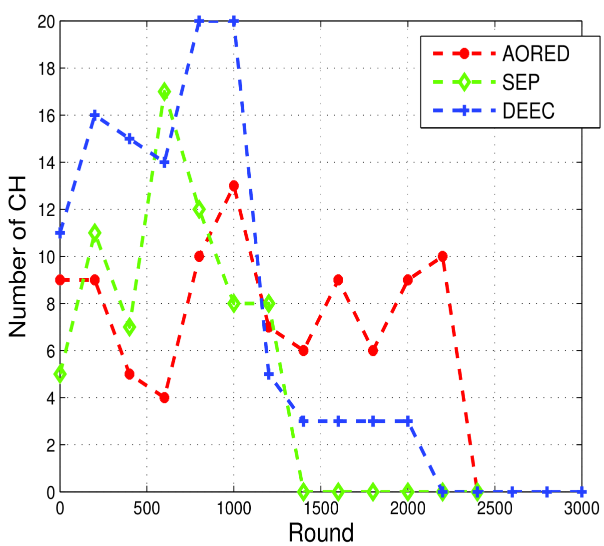

Fig. 9: Increased no. of Clusterheads

In AORED, nodes in group 2 send the data to the Routing(R) nodes. *RNs* after receiving the data from multiple *CHs* aggregate it and send it to *BS*. In this way, almost 50% of packets sent to *BS* are controlled by the *RNs*. Figure 10 shows the impact of packet to *BS* and it can be seen that the no. of packets sent to *BS* in case of AORED have been reduced by 41% as compared to DEEC and 46% as compared to SEP.

AORED with Variable Network Size
AORED has been tested with increasing network sizes. Table III shows the details of various network sizes, no. of deployed nodes and no. of rounds achieved in each network size. In large network sizes, nodes have been grouped based on 30% of distance to *BS* for that particular network size. e.g. in a $200 \times 200m^2$ network, *BS* is located in the center

TABLE III: Increasing Network Sizes

Sr	Region	Nodes Deployed	Rounds
1	100 ∗100	100	2346
2	200 ∗200	400	2363
3	300 ∗300	900	2480
4	400 ∗400	1600	2661
5	500 ∗500	2500	2663

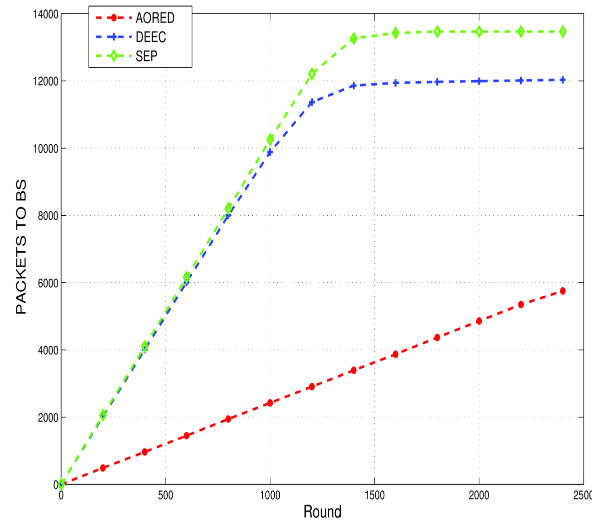

Fig. 10: Packets to BS

of the network at (100,100). Nodes that lie at a distance of $60m(30\% of 200m)$ make group 1 and the rest make group 2. Similarly, in a $300 \times 300m^2$ network, *BS* is located in the center of the network at (150,150). Nodes that lie at a distance of $90m(30\% of 300m)$ make group 1 and the rest of nodes make group 2. Large network sizes follow the same method of group formation. In each network, 0.04% of nodes are routing nodes e.g. in $200 \times 200m^2$ network, there are 8 routing nodes. Similarly, in a $300 \times 300m^2$ network, there are 12 routing nodes and in $400 \times 400m^2$ network, there are 25 routing nodes. Each result is an average of 10 simulation runs.

Table III shows an increase in the no. of rounds for large network sizes i.e. $300 \times 300m^2$, $400 \times 400m^2$, $500 \times 500m^2$. In a $100 \times 100m^2$ network, nodes who wish to transmit a one bit message at a distance use the following communication model:

$$E_{Tx}(k; d) = E_{elec} * k + E_{fs} * k * d^2 \quad (25)$$

if d $\geq d_o$

$$E_{Tx}(k; d) = E_{elec} * k + E_{amp} * k * d^4 \quad (26)$$

Where E_{Tx} in equation 25, and 26 is the energy spent in transmission, E_{elec} is the energy spent in node's circuits and

E_{amp} is the transmit amplifier energy. Therefore, according to the transmission mechanism mentioned in [1] over which AORED protocol has been based, nodes lying at a distance of less than the threshold of 87m transmit using the equation 25 while the nodes at a distance greater than 87m transmit using the equation 26 [1]. In case of AORED, for small network sizes i.e. $100 \times 100m^2$, $200m^2$, $300 \times 300m^2$, nodes in group 1 and in group 2 both lie at a distance of less than the threshold value i.e. 87m hence, they transmit with the same transmission power and die at almost the same time. However, in case of $400 \times 400m^2$ and $500 \times 500m^2$ networks, nodes in group 1 transmit using equation 25 and nodes in group 2 transmit using equation 26 i.e. with high power as compared to the nodes in group 1. Therefore, energy of nodes in group 2 drains out quickly as compared to the nodes in group 1 and that extends the no. of rounds.

VII. Conclusions and Future Work

In this paper, an optimized region based routing protocol has been proposed which focuses on improving the routing process by reducing the communication overhead in WSN. Communication overhead has been reduced by employing CDS that creates a virtual backbone of communicating nodes in the netwok. This paper provides a mathematical model for maximizing network throughput, stability and life. The model is then verified by extensive simuations. Simulation results show that the proposed AORED protocol offers significant improvement in network stability and network life time as compared to DEEC and SEP.
As future work, the same idea of using CDS in AORED can be evaluated by making a certain number of WSN nodes mobile. Furthermore, various other algorithms of CDS construction can be explored by coupling them with the same AORED protocol.

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