Network Lifetime Aware Area Coverage for Clustered Directional Sensor Networks

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***Abstract*—The problem of field or area coverage in Directional Sensor Networks (DSNs) presents huge research challenges including appropriate selection of sensors with their active sensing directions in an energy-efficient way. Existing solutions permit to execute coverage enhancement algorithms in each individual sensor nodes, leading to high communication and computation overheads, loss of energy and reduced accuracy. In this paper, we have proposed a novel network lifetime aware area coverage solution, NLAC, for a clustered DSN, where distributed cluster heads (CHs) have the responsibility of determining the number of active member nodes and their sensing directions. The CHs minimizes the overlapping coverage area and energy consumption by switching more nodes in *sleep* state. The proposed NLAC system is fully distributed and it exploits single-hop neighborhood information only. Results from extensive simulations, show that NLAC system offers better performance in terms of covering area and networklife.**

I. Introduction

A Directional Sensor Network is composed of large number of small battery powered directional sensor devices that can sense event and report data to a sink. Unlike an omnidirectional sensor device, a directional one has limited range of communication and sensing capabilities as it can sense and communicate in only one direction or a certain angle. However, it can achieve enhanced spatial reuse of underlying communication channel, reduced radio interference, increased coverage range and subsequently an increase in network capacity overall. Thus, DSNs can increase network performance and they are now being widely used in different multimedia and smart applications like camera sensors [1], [2], ultrasonic or infrared sensors [3], etc.

The problem of area coverage refers to maximizing the sensing area coverage percentage of perception area with minimum number of sensors [4]. It is important for many real-life applications, like battlefield surveillance, security monitoring of historical or vital places, wildlife monitoring in the forests, etc. This problem has already been proved as an NP-hard [5], [6] and usually, heuristic or greedy approaches are used to achieve a near-optimal solution [5]. The area coverage problem becomes a bit more complicated in DSNs since we need to determine the active sensing nodes as well as their sensing sectors [7]. Further, the duplicate coverage area should be reduced to as minimum as possible and the solution to the problem must be energy-efficient so that the lifetime of the network is enhanced.

The existing solutions in literature, addressing the area coverage problem, use different approaches. In [6], [8], [9], the authors solve the area coverage problem using distributed algorithms on voronoi cells to select active nodes and their sensing directions to cover a larger area in the voronoi cell. A centralized solution is also proposed in [6]. In [10], [11] the sensing sectors of each node are divided into small grids and thus the number of active sensing nodes is minimized by reducing the overlapping area using centroid location [10] and virtual force [11] among nodes. In these works, individual nodes use greedy approach [12] to determine their sensing responsibility and the sensing direction exploiting neighborhood information. These fully distributed approaches incur huge computational and communication overheads. Furthermore, in some cases, the computation of voronoi diagram becomes more costly. None of these works consider to evenly distribute the energy level of the nodes to prolong network lifetime. They only try to minimize the number of active sensing nodes to conserve energy, which does not always ensure the enhanced network lifetime.

In this paper, we have developed a network lifetime aware area coverage method, called NLAC, for randomly deployed directional sensor networks. We assume that the NLAC nodes are grouped into clusters and each cluster head (CH) runs the NLAC algorithm to determine the active sensing member nodes and their sensing directions. Each CH selects active member sensing nodes based on the area they covered in a sector and their residual energy values. There is a trade-off among these parameters and nodes that fulfill certain conditions will be active while the others will remain in sleep state. The proposed NLAC is neither fully distributed nor centralized; rather, each CH acts as a centralized controller for its member nodes and the CHs are distributed over the network. Lightweight geometric equations have been developed

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to measure the duplicate area coverage and thus it minimizes the number of active nodes. The key contributions of the work are summarized as follows:

- A novel solution to the problem of area coverage in DSNs, NLAC, has been developed that enhances the network lifetime.
- The proposed area coverage algorithm NLAC runs at the CHs only and thus it is distributed and lightweight. To the best of our knowledge, this is the first work that solves the area coverage problem using an energy-aware algorithm running at CHs.
- We have also developed distributed algorithms to diminish redundant coverage among intra-cluster and inter-cluster sensing nodes, increasing the number of sleep nodes.
- The results of performance evaluations, evaluated in ns-3 [13], showed that our proposed work NLAC achieves better coverage ratio compared to state-of-the-art works in terms of area coverage ratio and network lifetime.

The rest of this paper is organized as follows. We describe related works and motivation in Section II and network model and assumptions in Section III. The details of our proposed NLAC system is presented in Section IV and the simulation results are presented in Section V. Finally, we conclude the paper in VI along with future research directions.

II. Related Works

Recently, in DSNs, the sensing coverage problem has received great attention in both industrial and academic community. The related studies can be divided into three categories: (1) target coverage (2) area coverage and (3) sensing or barrier coverage. Researchers related to target coverage determine a subset of sensors to cover some specific targets or positions [14], [15]. The barrier coverage guarantees the detection of events crossing a barrier of sensors [16], [17]. In area coverage, we need to activate sensors so that a certain or full region falls under the sensing coverage [6], [8], [12]. In this work, our goal is to provide maximum area coverage with a minimum number of sensors, well known as MCMS problem, which is NP-hard problem [12].

In some previous works, such as in [5] and [14], the network lifetime is maximized by finding cover sets among nodes. In [18], the authors first address the directional cover-sets with coverage reliability (DCCR) problem of organizing directional sensors into a group of nondisjoint subsets that can extend network lifetime maximally while maintaining the required coverage reliability.

Concerning to region coverage, in [11] the authors Jing and Jian-Chao used the coverage overlap between the adjacent sensors as the quantity of electric charge and for reducing the overlapped coverage region used Coulombs inverse-square law to change the sensor direction. To increase the sensing field coverage authors in [19] used a hybrid solution of mixing stationary sensors and mobile sensors in a DSN.

In [20] the authors proposed a virtual potential field based method considering the directions and movement of sensors for the coverage enhancement. They mainly focused on the multimedia image sensor networks and proposed linear-relation based algorithm (LRBA) and mechanism-based approximate algorithm (MBAA) since the virtual force causes the adjustment of angular magnitude to be a trouble in coverage problem. The algorithms need to be pairing between two adjacent nodes but some nodes may not find their respective paired partner and thus this is a defect in their algorithm. Ma et al. [7] proposed a group-based strategy, namely, grouping scheduling protocol (GSP) for satisfying given coverage probability requirement by analyzing the deployment strategies in a directional sensor network. A repairing process has given by the authors to mitigate the situation in which a group of sensors are isolated from the sink.

To solve coverage problems, Voronoi-based method has drawn attention of researchers. Li et al. [6] proposed the Voronoi based distributed approximation (VDA) algorithm to make sensors cover the Voronoi edges as more as possible. They consider that most area will be covered if most Voronoi edges are covered; however, this is not definite and may cause more coverage overlap. In [8] the authors use voronoi-diagram to increase the coverage ratio between overlapping nodes. They proposed distributed greedy algorithm that can improve the effective field coverage of directional sensor networks. Considering the coverage contribution of convex polygonal cell of sensors and the coverage overlap of direction select between neighbor sensors, the working direction is adjusted and controlled, so as to improve the overall sensing field coverage ratio in the sensor network environment without global information. In [21], the authors proposed a distributed approach to enhance the overall field coverage by utilizing mobile and direction-rotatable sensors in a directional sensor network. The algorithm makes sensors self-redeploy to the new location and new direction without a global information by utilizing the features of geometrical Voronoi cells.

In [22], the authors present an auto-rotation mechanism of Field of View (FOV) for each sensor node to maximize the coverage area in an interested region. However, finding the overlapping region only for a circle neither cover all cases nor it is able to optimize the number of active nodes. Thus it fails to offer higher network lifetime and better coverage.

The authors in [9], select the direction of the nodes based on voronoi vertices and thus improve the coverage area with minimum number of sensor nodes. They give two algorithms: Intra-cell working direction (IDS) and Inter-cell Working Direction Adjustment (IDA). In IDS the region inside the cell is enhanced and in IDA, the overlapping regions among the coverage of neighboring nodes have been minimized. Besides, they also propose Out-of field Coverage Avoidance (OFCA) to control the direction of sensors outside the boundary. In [10], in order to optimize the network coverage, the authors propose a coverage-enhancing algorithm based on overlap-sense ratio. By adjusting the sensing direction of the nodes, the coverage area is increased with reduced computational complexity. In addition, a modified strategy is presented to shut off redundant sensors to prolong network lifetime.

Though many area coverage algorithms have been proposed [5], [14], [9], [10], very few works utilize the advantages of clustering in the environment considering the energy levels at sensor nodes when selecting active nodes for area coverage problem in DSNs. Our proposed NLAC selects active nodes considering nodes' remaining energy, overlapping ratio and reduce redundancy and computation overhead as calculation in done on cluster heads.

III. Network Model and Assumptions

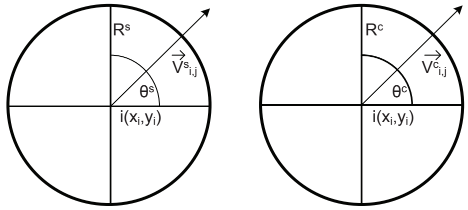
We assume a Directional Sensor Network (DSN) composed of a large set of directional sensor nodes $\mathcal{N}$ in a two dimensional plane. The sensors are deployed with uniform random distribution in an area of $\mathcal{A}$. The DSN has a sink node, to which all sensor devices send their sensed data packets in multi-hop fashion. Each sensor S_i has a fixed and known location (x_i, y_i), determined by GPS or any other localization method [23]. Each sensor device is uniquely identified by its ID, which we assume an integer number. We also assume that all the directional sensor nodes are homogeneous in terms of number of sensing sectors, sensing and communication radius and the initial energy E_0.

We also assume that a clustering algorithm [24], [25], is running in the network that selects cluster heads (CHs) and gateways (GWs) and thereby forms a communication backbone for the DSN. A sensor node can be in either $active$ or in $sleep$ state. When in sleep state, a sensor node periodically wakes up and communicates with its CH to check if there is any new responsibility for the node. What follows next is the sensing and communication model of a sensor node.

A. Directional Sensing Model

Given a DSN with *N* directional sensor devices $1, 2, \ldots, N$. Each sensor has the following characteristics:

- Each sensor has *s* $(s \geq 2)$ sectors, centered at the sensor node with a sensing radius R^s and the sensing angle $\theta^s = \frac{2\pi}{s}$. A sensor can work only at one sector at a given time.
- R^s is the maximum sensing radius and a sensor device cannot sense anything beyond this radius.
- θ^s $(0 < \theta^s < 2\pi)$: the maximum sensing angle which is called field of view (FOV), as shown in Fig. 1(a).
- $\vec{V}^s_{i,j}$ is a directional vector that divides the sensing sector into two equal parts.



(a) Sensing model (b) Communication model

Fig. 1. Sensing and communication models of a directional sensor node

TABLE I
List of Notations

$\mathcal{N}$	Set of all sensor nodes
CM_{CH}	Cluster member node
$D(i,j)$	Cartesian distance between nodes i and j
Ψ_c	The set of communication sectors of any node $i \in \mathcal{N}$
Ψ_s	The set of sensing sectors of any node $i \in \mathcal{N}$
$n_{i,s}$	The set of i's neighbor nodes of sector s $\in \Psi_s$
n_K	List of neighbor CHs of CH K
E_0	The initial energy of node i
E^i_{res}	The residual energy of node i
A_i	Area covered by any sector $s \in \Psi_s$ of any node $i \in \mathcal{N}$
$A_{i,j}$	Overlapping area between node i and j

B. Directional Communication Model

Like sensing orientations, each sensor device has a set of communication sectors, characterized by the following attributes:

- $\theta^c (0 \leq \theta^c \leq 2\pi)$: the maximum communication angle, *i.e.*, the field of view (FOV), as shown in Fig. 1(b).
- $\vec{V}^c_{i,j}$: the directional vector which is the center line of the communication sector, as shown in Fig. 1(b).
- R^c: the maximum communication radius, typically, R^c is twice larger than the R^s [26] and a sensor node cannot communicate with other nodes beyond this radius.

We also assume that each sensor node knows the location of its neighbors. The tasks of sensing and transmission are directional and the reception is omni-directional. Throughout the paper, we follow the notations described in table I.

IV. Design of NLAC System

Given a DSN, where randomly deployed sensor devices are group into multiple clusters, our aim is to maximize the field area coverage in such a way that the network lifetime is enhanced. The difficulty of the problem lies in minimizing the *uncovered* and *overlapped* regions. In NLAC, each CH works as a central controller for its members for determining the active sensing nodes and their sensing directions. The CHs optimize the number of active sensing nodes so that the *coverage overlapping* as well as *uncovered regions* are minimized within and outside the clusters. The CHs also collect, process and transmit data packets toward the sink for all of its members. Therefore, our proposed NLAC system is distributed and it exploits single hop information only centered at each CH. What follows next is the details of the constituent components of the NLAC system.

A. Active Node Selection in a CH

Each CH takes decision to keep a member node in *active* or *sleep* state. A CH has a list of all of its member sensor nodes, CM_{CH}. A temporary list TP_{CH} is also maintained by the CH, initialized to CM_{CH}. When a node i and its sector s is selected by the CH as active, it is moved from TP_{CH} to $AC_{CH} =< i, s >$. In the process of active node selection, the first step is to add the CH itself to AC_{CH} and its sensing direction will be the same as communication direction, i.e., $AC_{CH} = AC_{CH} \cup < CH, s >$, where $s \in \Psi_s$. Since the communication radius is twice larger than the sensing radius of a node, a large portion of the communication sector region of the CH will be covered by this selection. This potentially serves our purpose of activating minimum number of sensors. What follows next, we describe the selection process of cluster member nodes and their sectors for activation.

1) Selection of non-overlapping sectors of nodes: After selecting its own active sector, the CH runs the process of selecting its member sensor nodes and their active sensing direction. The CH first selects the sectors of sensors which can sense a particular non-overlapping communication region of the CH, i.e., no other sensing direction of the member nodes can cover the same region. There might be the possibility that these selected sensors can cover larger area if they sense in other sectors. But, selecting these sectors based on maximum area coverage may leave some region uncovered. Furthermore, since it is difficult to find fully non-overlapping sectors in a dense-deployed environment, we allow a minimum threshold $\alpha\%$ of area coverage overlapping inside the communication region of CH. Then, the CH moves these selected sensor nodes from TP_{CH} to AC_{CH} as follows,

$$AC_{CH} = \{AC_{CH} \cup < i, s > \mid overlap((i, j, s)) = 0, \\ \forall i, j \in TP_{CH} \cup CH, j \neq i, i \neq CH, s \in \Psi_s, j \in n_{i,s}\}, \quad (1)$$

where, the function $overlap((i, j, s))$ returns 0 if node i has less than $\alpha\%$ overlapping with any of its neighboring nodes j for a specific sector s; and, 1 otherwise.

Two nodes i and j will have overlapping area coverage in any of their sectors when the Euclidean distance between them, $D(i, j)$, is less than the sum of their sensing ranges, i.e., $D(i, j) < 2R^s$. Therefore, the aforementioned $overlap((i, j, s))$ function can perform the following inequality test, Eq. 2, to determine whether to return 0 or 1.

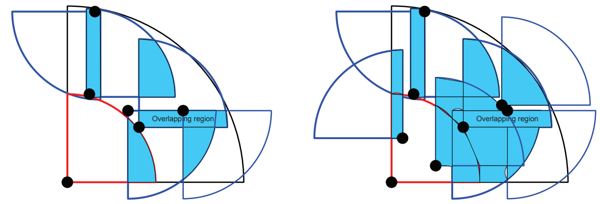
$$D(i, j) < 2R^s \ \&\& \ AO(i, j, s) \leq \alpha \quad (2)$$

Here, the function $AO(i, j, s)$ calculates the area of overlapping region between the nodes i and j in sector s; the details of calculation procedure is described in Section IV-A4.

2) Selection of sectors of nodes having greater than $\alpha\%$ overlapping: Now, the TP_{CH} contains only those nodes that have greater than $\alpha\%$ area coverage overlapping with the neighborhood nodes. At this stage, the proposed NLAC selection process gives higher priority to the nodes having higher residual energy (E_{res}) and to the sectors covering larger amount of non-overlapping region ($ANO_{i,s}$). Therefore, an integrated metric is defined for each sector $s \in \Psi_s$ of each node $i \in TP_{CH}$, as follows,

$$AE_{i,s} = w_1 \times \frac{ANO_{i,s}}{\frac{\theta^s}{2} {R^s}^2} + w_2 \times \frac{E^i_{res}}{E_0}, \forall i \in TP_{CH}, \forall s \in \Psi_s \quad (3)$$

where, θ^s is the angle of a sensing sector, $\frac{\theta^s}{2} {R^s}^2$ is the total area covered by a sector s, E_0 is the initial energy of the nodes, and w_1 and w_2 are the weight factors. The $ANO_{i,s}$ is the area of non-overlapping region covered by sensor i in



(a) Initial situation (b) After selecting active nodes

Fig. 2. Before and after running the ICSS algorithm in CH

sector s, calculated as follows,

$$ANO_{i,s} = A_{i,s} - AO(i, j, s), \forall i \in TP_{CH}, \\ \forall j \in AC_{CH}, \forall j \in n_{i,s}, \forall s \in \Psi_s \quad (4)$$

where, $A_{i,s}$ is the total area covered by sector s of node i inside the communication sector area of CH; the details of this area calculation is found in Section IV-A4. Note that the Eq. 3 measures the value of the metric $AE_{i,s}$ as a weighted linear combination of two submetrics, $\frac{ANO_{i,s}}{\frac{\theta^s}{2} {R^s}^2}$ and $\frac{E^i_{res}}{E_0}$, corresponding to the portion of non-overlapping region covered by sector $s \in \Psi_s$ of any sensor $i \in TP_{CH}$ and the portion of residual energy of a node $i \in TP_{CH}$ has, respectively. Therefore, the metric $AE_{i,s}$ helps us to select the sensor that has higher residual energy and the sector having higher non-overlapping area coverage, which in turn increases the network lifetime as well as decreases the coverage redundancy by judiciously choosing the active sensor nodes in the region.

The CH now produces a list $\gamma =< i, s >$, which is a descending order sorted list of nodes and their sectors using the $AE_{i,s}$ values. The CH then checks whether the first entry of γ passes the condition 5, if yes, the node entry $< i, s >$ is moved to the active list AC_{CH}; and, simultaneously, the other entries for that node are removed from the list γ. In the case the condition 5 returns false, the CH goes to the next entry and continues till its communication sector is completely covered.

$$AO(i, j, s) \leq \delta, \quad < j, s > \in AC_{CH} \ \& \ j \in n_{i,s} \quad (5)$$

Note that the condition 5 helps the CH to reduce the sensing overhead by activating a sensor node i and its sector s if it has area overlapping less than a certain threshold δ. The value of the threshold δ may need to be increased (e.g., $\delta = \delta \times 2$) dynamically in the second round if the CH communication sector is not fully covered even if all the entries of γ are checked in the first round. The details of intra-CH node activation process has been presented in Algorithm 1.

3) Determining whether the CH region is fully covered or not: After selecting a new active node, the CH needs to determine whether its communication region is fully covered or not, as stated in line number 17 of Algorithm 1. For this the CH needs to update its covered area each time a new node is added to the active list. The total communication region of a CH can be calculated using Eq. 6:

$$A_{CH} = \frac{\theta^c}{2} {R^c}^2. \quad (6)$$

Algorithm 1 Intra-CH Active Node Selection Algorithm

INPUT: CM_{CH}
OUTPUT: AC_{CH}

$AC_{CH} \leftarrow AC_{CH} \cup < CH, s >$
update AC_{CH} using Eq. 1
update TP_{CH}
for all i $\in TP_{CH}$ **do**
  for all s $\in \Psi_s$ **do**
    Find the value of $AE_{i,s}$ using Eq. 3
  end for
end for
$\gamma \leftarrow$ Desc. order sorted list of $< i, s >$ using $AE_{i,s}$
while ($TP_{CH} \neq \phi$) **do**
  for all $< i, s > \in \gamma$ **do**
    if Eq. 5 returns TRUE **then**
      $AC_{CH} \leftarrow AC_{CH} \cup < i, s >$
      remove all entries of node i from γ
      $TP_{CH} \leftarrow TP_{CH} \setminus i$
    end if
    if Region of CH is fully covered **then**
      Exit
    end if
  end for
  $\delta = \delta \times 2$
end while

Each time a sensor node i and its sector s have been selected to add in the active sensor list AC_{CH}, its corresponding non-overlapping covered area is added to previously computed area using Eq. 7,

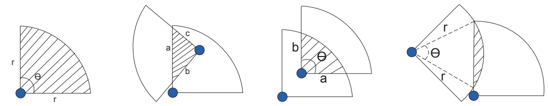
$$A_{CH}^{cur} = A_{CH}^{prev} + ANO_{i,s}, \tag{7}$$

where, $ANO_{i,s}$ is the non-overlapping covered area by sensor i in sector s inside the communication boundary of CH, A_{CH}^{prev} is the covered region of CH before adding the node i in the active list and A_{CH}^{cur} will be the covered region after activating the node i. The process of adding new nodes in the active list will continue till the condition 8 holds.

$$A_{CH}^{prev} \leq w \times A_{CH} \tag{8}$$

The value of $w, (0 < w \leq 1)$, depends on the portion of the region of CH that we want to cover.

4) Overlapping and non-overlapping coverage area calculation: As discussed previously, when a CH attempts to activate a sensor node, it needs to calculate the amount of non-overlapping area covered by that node and the area covered by multiple active sensor nodes of AC_{CH}, i.e., the amount of overlapped area. If a node does not overlap with any other nodes its area can be measured by Eq. 9. When two sensing nodes intersects they may overlap each other in many different ways which can be broadly categorized in three different cases, as shown in Fig. 3. In case 1, the overlapping area is covered by three straight lines; in case 2, the area is covered by two straight lines and one arc; and, in case 3, the overlapping region is covered by one straight line and one arc.



(a) Candidate Sector (b) Case 1 (c) Case 2 (d) Case 3

Fig. 3. Different types of overlapping

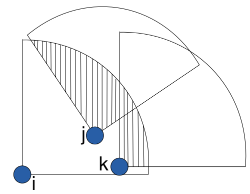


Fig. 4. Coverage area overlapping by multiple nodes

Now, using simple geometry [27], we can calculate the area of a candidate sector that has no overlapping, Fig. 3(a), area bounded by case 1, case 2 and case 3 using Eqs. 9, 11, 12, 13, respectively.

$$A = \frac{R^2\theta}{2} \tag{9}$$

$$s = \frac{a+b+c}{2} \tag{10}$$

$$A = \sqrt{s(s-a)(s-b)(s-c)} \tag{11}$$

$$A = \frac{ab}{2}[\theta - \tan^{-1}(\frac{(b-a)\sin(2\theta)}{(b+a)+(b-a)\cos(2\theta)})] \tag{12}$$

$$A = \frac{R^2}{2}(\theta - \sin\theta) \tag{13}$$

In addition to above cases, we may encounter situations where the overlapping area has two arcs and one straight line or two arcs and two straight lines or two arcs only or four straight lines, etc. In these cases, we will divide the area into two or more separate parts, where each part falls in one of the aforementioned three cases. Thus, we can calculate the area of overlapping region of any shapes.

A node i can calculate the percentage of overlapped area coverage with any of its neighbor node j for any of its candidate sectors s as follows,

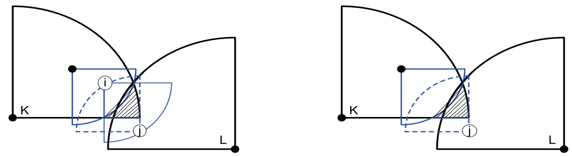
$$\eta_{i,j}^s = \frac{A_{i,j}}{A_i} \times 100\%, \quad \forall j \in n_{i,s}, \forall s \in \Psi_s. \tag{14}$$

where A_i is the total covered area by node i and $A_{i,j}$ is the overlapping area between node i and node j.

In the case, the node i has overlapping coverage with more than one neighbor nodes, it can calculate the total amount of overlapping as follows,

$$AO((i,j,s)) = \sum_{j=1}^{OL} \eta_{i,j}^s, \tag{15}$$

where, OL is the number of neighbors with which the node i has overlapping area coverage in sector s. Please recall that the area of non-overlapping region for any node i can be measured using Eq. 4.



(a) Coverage overlapping (b) Minimizing coverage duplicity

Fig. 5. Area coverage overlapping among members of neighborhood CHs

B. Inter-cluster coverage overlapping reduction

The set of active sensor nodes, produced by the intra-cluster node activation Algorithm 1, for each CH, might have are coverage overlapping with neighbor CHs. In this section, we present an algorithm that minimizes the overlapping regions among neighborhood CHs.

After selecting the active member nodes, a CH K will communicate the list of active sensor nodes and their cartesian locations, $\{AC_K, \{LOC_K\}\}$, with all of its neighboring CHs, n_K. Getting the values from the neighbor CHs, a CH K will determine the member nodes that can be sent to *sleep* state. Each CH K makes a list NC_K of its neighbor CHs that satisfy Eq. 16, in decreasing order of area overlapping.

$$\sum_{\forall<i,s>\in AC_K, \forall<j,s>\in AC_L} AO(i,j,s) \geq \beta, L \in n_K, s \in \Psi_s \quad (16)$$

Note that the Eq. 16 ensures that the CH K only considers those neighbors that have overlapping larger than a threshold value β. The CH K will now take the first CH, L from list NC_K and makes a list SC_K^L of its active member sensor sectors from AC_K that satisfy the condition 17.

$$AO(i,j,s) \neq 0, \quad \forall <i,s>\in AC_K, <j,s>\in AC_L \quad (17)$$

Then, we sort the list SC_K^L, in decreasing order of the amount of area overlapping [1]. Taking sectors $<i,x>$ serially from SC_K^L, K checks is the communication region still fully covered by removing $<i,x>$ from active list, then the CH K give a message to CH L that it want keep the node i in its sleep state. When node K gets a reply OK message from CH L then it will update its AC_K list by actually removing the node $<i,x>$ and give the updated information to all other nodes NC_K. The message passing is necessary here since each cluster head does the calculation individually and may sleep a node which is necessary for others. The whole process will continue checking for each item of SC_K^L and stop when any uncovered region found. In the Fig. 5(a) we find node j of CH L cover some region of CH K. After calculation CH K will sleep its node i as the region covered by node i is covered by other node of K and L shown in Fig. 5(b). The details of the process is given in algorithm 2.

V. Performance Evaluation

In this section, we study the performances of the proposed NLAC system with two state-of-the-art solutions OSECRE [9] and IDA [10]. The comparison among them have been carried out in terms of coverage ratio and network lifetime for varying number of sensor nodes deployed in the network and the number of sectors.

[1]Since K has the location information of active sensors of L, it can easily calculate the list SC_K^L

Algorithm 2 Inter Cluster Node Selection

INPUT: Set of information gets from the neighbor cluster heads n_K^{oc}

OUTPUT:The list of active member sensor nodes AC_K that will be remain active after CH-CH communication.

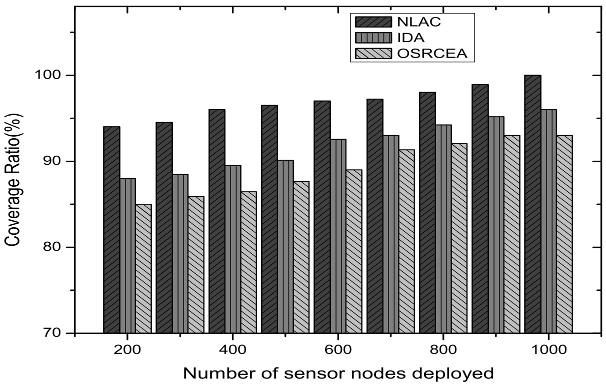
$NC_K = \phi$
for all $L \in n_K$ **do**
  for all $<j,s>\in AC_L$ & $<i,s>\in AC_K$ **do**
    if $AO(i,j,s) \geq \beta)$ **then**
      $NC_K \leftarrow NC_K \bigcup L$
    end if
  end for
end for
$SC_K^L = \phi$
$RV_K = AC_K$
sort the list NC_K based on the overlapping region with K in descending order
for all $L \in NC_K$ **do**
  for all $<i,s>\in AC_K$ **do**
    if (condition 17 true) **then**
      $SC_K^L \leftarrow SC_K^L \bigcup <i,s>$
    end if
  end for
  sort the list SC_K^L based on the overlapping area with L in decreasing order
  for all $<i,s>\in SC_K^L$ **do**
    $RV_K = RV_K \setminus <i,s>$
    if CH is still fully covered by RV_K **then**
      send a msg to S_L
      if gets OK reply message from S_L **then**
        AC_K=$AC_K \setminus <i,s>$
        send the new list to all neighbors NC_K
      end if
    end if
  end for
end for

A. Simulation Environment

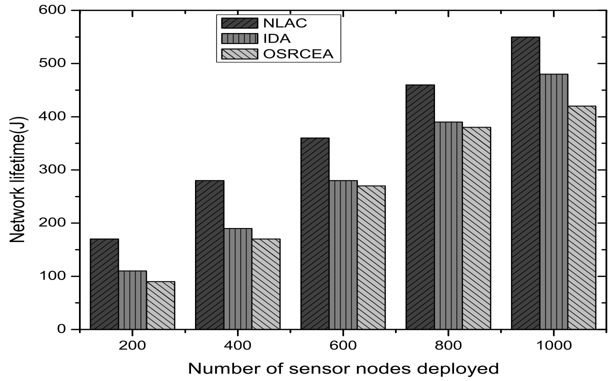
The evaluation has been carried out in ns-3 [13] by simulating the system. Sensors are uniformly deployed in a region of 1000m × 1000m. Each simulation ran for 1000 seconds. The network configuration parameters are shown in Table V-A. We use an existing clustering algorithm [24]. For each graph points the average results of 10 simulation runs has taken.

B. Performance Metrics

- *Coverage Percentage:* The coverage percentage is measured as the ratio of covered area to the total area of the terrain. Coverage is one of the important issues in



(a) Coverage Percentage



(b) Network lifetime

Fig. 6. Impacts of number of sensor nodes

TABLE II
NETWORK CONFIGURATION PARAMETERS

Parameters	**Value**
Simulation Area	$1000m \times 1000m$
Deployment Type	Uniform random
Number of Sensor Nodes	$200 \sim 1000$
Number of Communication and Sensing Sectors	$2 \sim 6$
Number of Field of view	$60^o \sim 180^o$
Transmission Range	$100m$
Sensing Range	$50m$
Initial Energy of a Sensor Node	5 J
Reporting Rate	1 packet/sec
Network Bandwidth	512Kbps
Simulation Time	1000 Seconds

directional sensor network and thus a higher percentage of coverage ratio is expected.

- *Network Lifetime:* The network lifetime is defined as the time difference from the deployment time of the network nodes to the time at which the first node dies out of energy. This is a reasonable assumption in sensor networks [28], [29] since it is expected that the energy of other nodes will also be exhausted some after the first node.

C. Simulation Result

We study the performance of the proposed NLAC algorithm by varying number of deployed sensors and by taking different field of view (FOV) of sensors.

1) Impacts of number of nodes: : By varying the number of directional sensor nodes from 200 to 1000 we measure the performance metrics discussed above. The sectors of sensor is kept at 4 for simulation.

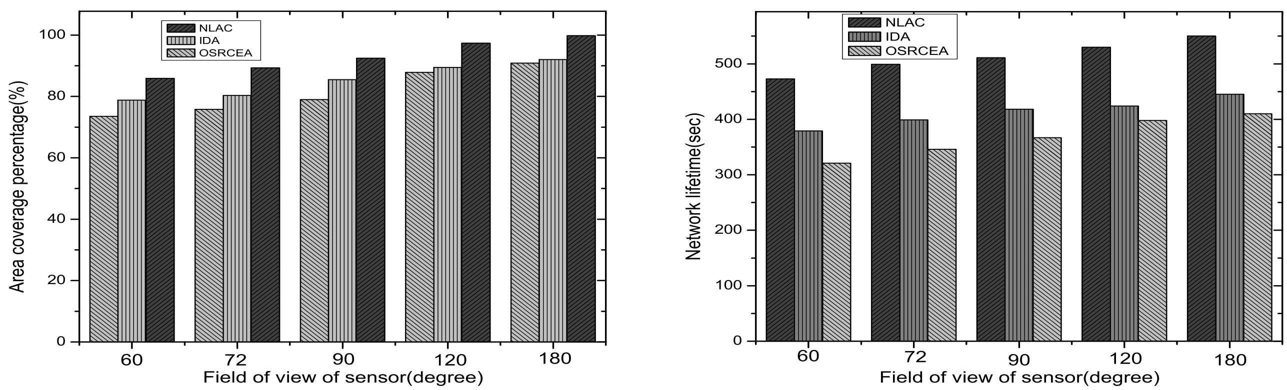
From the graphs in Fig. 6(a) we find a substantial improvement in terms of area coverage accuracy which is measured as the ratio of sensing covered area with total area. Proposed NLAC achieves relatively higher accuracy compared to OSRCEA and IDA. NLAC gives better performance as CH takes the responsibility of being a coordinator to ensure its sensing coverage, and it aggregates information with others. In IDA and OSRCEA, individual sensors are responsible to take decisions, so due to the poor coordination among the nodes they are unable to implement an optimal area coverage. On the contrary, proposed NLCA achieve a better performance as the CHs are playing as controllers for determining active nodes along with their sensing directions; thus, optimal decisions turn more overlapping sensors to sleep mode.

The network lifetime behavior of the algorithms NLAC, IDA and OSRCEA are shown in Fig. 6(b). Network lifetime linearly increases with the number of additional sensors deployed in the network for all studied protocols as it is theoretically expected. But theoretically NLAC system achieves better lifetime compared to the others because NLAC uses clustering approach to reduce network overhead. More explicitly NLAC selects active nodes based on their residual energy, and thereby, enhances lifetime significantly. In IDA and OSRCEA they don't consider the energy level when selecting active nodes. But in NLAC the energy level of nodes are considered and hence, there is balanced energy consumption.

2) Impacts of field of view(FOV): : In this section, we evaluate the performances of the systems by varying the field of view (FOV) from 180^o to 60^o. Varying the FOV gives us different number of communication and sensing sectors, ranging from 2 to 6. In this experiment, 600 number of sensor nodes deployed in the area which is fixed.

The Fig. 7(a) states that the coverage accuracy percentage for NLAC, IDA, OSRCEA increases with an increase in FOV. The high FOV means less sectors. If FOV is high more area can be covered. The graphs also state that NLAC algorithm performs better than OSRCEA and IDA algorithms despite of increasing number of sectors. In NLAC, the CHs run the area coverage algorithm that determines the active sensor nodes and their sensing directions, so that the accuracy percentage is higher.

The comparison of network lifetime offered by NLAC, IDA and OSRCEA algorithms is shown in Fig. 7(b) for increasing number of FOV. The network lifetime linearly decreases with the increasing number of sectors for all the studied protocols



(a) Coverage percentage (b) Network lifetime

Fig. 7. Impacts of field of view(FOV) of sensors

since it increases the probability of activating large number of nodes initially.

VI. Conclusion

In this paper, a network lifetime-aware novel area coverage mechanism, NLAC, has been developed for clustered DSNs. To the best of our knowledge, NLAC is the first approach to solve the area coverage problem using clustering mechanism by taking into account the residual energy level of nodes. In NLAC system, each CH first selects the active nodes and their sensing directions within its covering region to ensure a fully covered communication region. The redundant sensor nodes for overlapping regions among CHs are also minimized by CH-CH communication. The residual energy-aware selection of sensing nodes helps NLAC to achieve balanced energy consumption of network nodes and thereby extending the network lifetime significantly.

In future, we have a plan to focus on extending the work to solve k-coverage problem and provide mathematical analysis on the correctness and accuracy of the coverage algorithms.

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