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Coverage Improvement in Clustered Wireless Sensor Networks by Relocating Mobile Nodes based on Waypoints

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***Abstract*—Achieving effective coverage and efficient clustering of sensor nodes are important aspects of wireless sensor networks (WSNs). In this paper we present a novel approach for achieving improvement in both aspects in an integrated manner. Coverage improvement is done based on information exchange by clusters with relocation of mobile nodes between the clusters. Mobile nodes are guided by waypoints between source and destination clusters without use of localization services. The simulation results have been presented which state the effectiveness of the proposed approach. Mobile node relocation has been done in such a way that they could volunteer as future cluster head (CH) and this has been justified by the simulation results. This paper stresses the requirement for considering both coverage and clustering in an integrated manner and proposes a sequential process for WSNs to be followed after initial deployment for effective operation.**

Keywords—coverage improvement; node mobility; mobile nodes; waypoints; sensor networks

I. Introduction

Coverage is an important quality of service (QoS) parameter in WSNs and the quality of the coverage depends on the manner in which the network is deployed. Common envisioned scenarios for deployment of WSNs involve randomly scattering the sensor nodes over the area of interest (AoI). This is necessitated as deterministic deployment is not feasible in many of the envisioned WSNs applications such as battlefield and environment monitoring due to inaccessible terrain and large AoI. Random deployment of sensor nodes cannot attain complete coverage of the AoI unless an excess number of nodes are deployed [1]. In any random deployment, some areas will be well covered with sensor nodes, while other areas will be sparsely populated (coverage holes) [2]. As mentioned, improving the coverage in random deployment of sensor nodes is only feasible by using more nodes than the critical density i.e. minimum number of nodes required to fill the complete AoI or by relocating nodes by providing mobility to some or all nodes.

Organizing the sensor nodes into a clustered architecture is a means to design energy efficient and scalable WSNs. The major objectives around which the clustering schemes have been developed are load balancing, fault tolerance, network connectivity and increase in network lifetime [3]. Many studies have been carried out on improving coverage by relocating mobile sensor nodes to achieve efficient clustering. Largely, the solutions for improving coverage and achieving efficient clustering have been stated independently [4]. In this work, coverage improvement and clustering of sensor nodes are considered in an integrated manner in order to provide WSNs that operate both efficiently and robustly. The contribution of our work is a novel algorithm for relocating sensor nodes between cluster regions, which improves the overall coverage of the network as well as clustering of the sensor nodes in the network. The proposed algorithm decides the nodes to be moved and their destination cluster regions. The movement to the destination region is based on waypoint nodes.

The remaining paper is structured as follows. Section II highlights the related work and Section III presents the network model and the assumptions considered in this work. In Section IV, we present the algorithms for relocating the mobile nodes to achieve coverage improvements and the determination of waypoints for a specific mobile node to reach the destination cluster. Section V gives the simulation results while the conclusions along with future work are given in Section VI.

II. Related Work

Node mobility to improve coverage has been an area of active research with proposed solutions to achieve coverage improvements broadly classified within three categories i.e. area coverage, barrier coverage and target coverage [2, 5, 6]. In [4], the authors stated that clustering and coverage should be considered as an integrated aspect and not separately. They proposed an algorithm for achieving effective clustering by conducting CH elections based on coverage property of the area while coverage improvement was not considered. Relocating mobile nodes to optimize the coverage based on maximum entropy clustering has been presented in [7] where location of mobile nodes is optimized based on particle swarm optimization by the CHs. It was considered that the mobile nodes possess GPS capabilities and the energy consumption and movement coordination for the mobile node have not been considered. Similarly, in [8], a clustering algorithm with coverage preservation objective has been proposed. Clusters are designed such that they possess minimum overlap and thereby achieve energy efficiency and hence lesser dead nodes which results in coverage preservation. Coverage improvement and use of mobile nodes for the same have not been considered. Relocating mobile nodes with assistance of other static nodes acting as waypoints to reach a phenomenon (target) to increase sensing quality in its proximity has been proposed in [6] and this approach is based on virtual forces between the nodes. It assumes that mobile nodes possess GPS for direction guidance. Cluster formation takes place but only around the phenomenon to perform collaborative signal processing. Coverage improvement of the network has not been considered.

In our proposed work, clustering and coverage are considered in an integrated manner**.** To the best knowledge of the authors, this is the first work where coverage improvement is based on clustering. Mobile nodes are relocated such that the CH election and clustering would be based on the relocation and therefore indirectly on the coverage aspect of the network.

III. Sensor Network Model

A. Network Model

A hybrid sensor network made of static and mobile nodes is considered in a square sensing field. The sensor nodes are scattered randomly in the AoI and are not aware of their location i.e. there is no provision of GPS or other location services in the network. There is no power control and all nodes transmit with the same power. The proportion of mobile nodes in the network is considered to be at most 40% of the total nodes deployed. As mobile nodes are more costly than static nodes, it is not feasible to have a large proportion, and also the influence of more than 50% mobile nodes of the total nodes is insignificant in respect to coverage improvement [1]. A sample network layout is shown in Fig. 1. Sensor nodes are considered to have a binary sensor model with a unit disk equal to the sensing range. The entire area within the sensing radius of the sensor node is considered covered. We assume that there exists line of sight between two sensor nodes and a free space radio propagation model is used. Finally, it is assumed that sensor nodes can determine the Euclidean distance between them based on the RSSI and the propagation model.

B. Node mobility model

In this paper we consider that the mobile nodes move following waypoint nodes. The maximum distance moved by a mobile node is considered to be constrained. This way the relocated mobile node would possess sufficient energy for volunteering as a CH in future CH elections in the destination cluster region. A mobile node such as Robomote can move for maximum 20 minutes in full motion and full battery, with a speed of 15cm/sec with a total range around 180m [5]. The results in Section V have been evaluated considering this functional limitation.

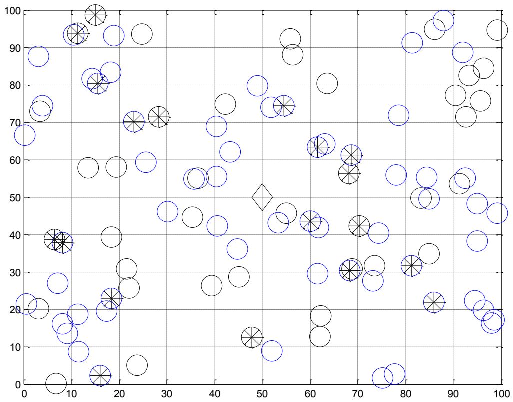

Fig. 1.Random Network Deployment (blue circle - static node, black circle - mobile node, asterisk - CH, diamond center base station)

IV. Proposed Solution

In the proposed solution, the coverage improvement is based on relocating mobile nodes between clustered regions. The CHs have been derived with execution of the LEACH protocol [9]. Coverage contribution of a node is determined based on the number of other nodes with whom it has overlapping sensing radius. The maximum coverage contribution of a node is considered to be 1 and the coverage contribution decreases with the number of overlapping node(s) and the closeness of the overlapping node(s) for a specific node. The total coverage of the network is considered the sum of the coverage contribution of all nodes. A cluster region with coverage contribution equal to the node density is considered as a balanced region and is left untouched. A mobile node within a specific cluster is nominated as a future CH if it has a coverage contribution of 1 and the total number of mobile nodes is greater than 1. Cluster regions are prioritized based on the difference between their node density and coverage contribution into three types: regions with only CHs (empty regions - referred as highest needer region in algorithm), regions with both static and mobile nodes (normal regions) and regions with CH and static nodes only (normal empty regions). Matching of the source and destination CHs is done based on the priority of the region.

The sequence of waypoints is determined for the specific mobile node based on its source and destination allotted cluster information. The objective while determining the waypoints is to maximize the total number of waypoints available for a mobile node. This is based on the reasoning, that the number of more waypoints a mobile node has, the less random would be the path it follows from source to destination cluster i.e. decrease in total distance from start to end point. Nodes which could assist the mobile node are determined as helper nodes in source and destination regions. Waypoints are determined from amongst the helper nodes. This is done in a way such that there is at least one waypoint in destination and source region as well as external waypoints (from other regions) if available. Waypoints issue hello messages at regular interval for the mobile node starting with the waypoint nearest the mobile node. Waypoints issue this message in pairs so that the mobile node could approximate its movement based on RSSI from two waypoints, and multiple messages from the respective sender. An example of an expected path from source to destination for a mobile node has been shown in Fig. 2. The final destination for the mobile node is not a definite point but a region. A mobile node terminates its movement when it receives repeated RSSIs from the final waypoint such that it is within its communication range. This way the node is surely in the destination region, which is the objective of relocating the mobile node. The waypoint based relocation is only evaluated when the direct distance between the mobile node and the destination CH <65m, considering limitations of RSSI reliability for longer distances. The details of matching the cluster regions and determination of waypoints for a mobile node are described in detailed flowchart in Fig. 6 and Fig 7 on subsequent pages.

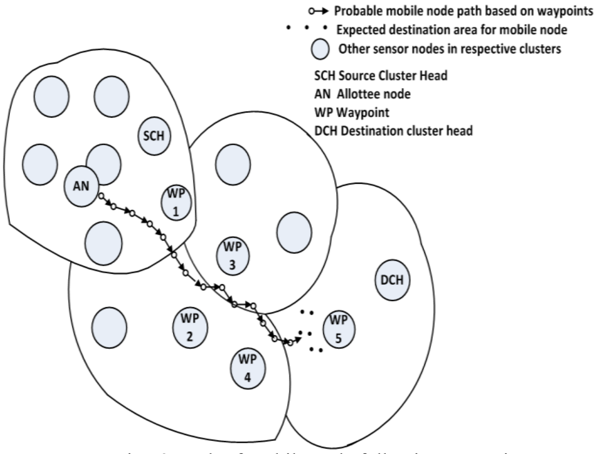

Fig. 2. Path of mobile node following waypoints

A. *Simulation Setup*

The simulation is carried out with variation in the total number of nodes from 100 to 150 in increments of 10. The proportion of the total nodes considered as mobile nodes is increased from 10% to 40 % with increments of 10. The experiment results are mean values for all parameters calculated over 50 runs of the simulation**.** AoI considered with side l and area $l \times l$ ($l = 100$m).

V. Results and Discussions

Based on the simulation results it can be concluded that the full coverage in the network is attained with application of 150 nodes with 40% mobile nodes. With 40% of total nodes as mobile nodes it is observed that coverage of more than 90% is attained for all variation in the range of total nodes as shown in Fig 3. The maximum distance moved by a mobile node for attaining the coverage improvement is shown in Fig 4. It is observed that the maximum distance moved by a node is within the range of 51 to 72m. The direct distance between the specific mobile node and destination cluster head is also shown. It can be observed that the waypoint relocation distance does not differ significantly from the direct distance. It is one third of the maximum distance a mobile node such as Robomote is capable to move as stated earlier. The total distance the nodes move has been shown in Fig 5. It is also to be noted that the Euclidean distance for the waypoints summed together is the maximum distance for a node as calculated in this experiment and shown in the Fig 5. While as elaborated in Fig 2, a mobile node could terminate its movement when it is within communication range of the last waypoint. It is possible that the node may therefore traverse a distance shorter than the presented distance. On the other hand, a mobile node may encounter extra random movement (additional distance) while traversing past the other waypoints and this is the justification for maximum distance moved by mobile node to be considered up to the final waypoint.

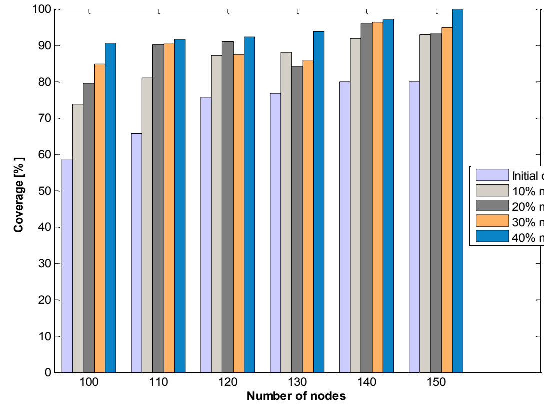

Fig. 3. Coverage improvement with relocating mobile nodes

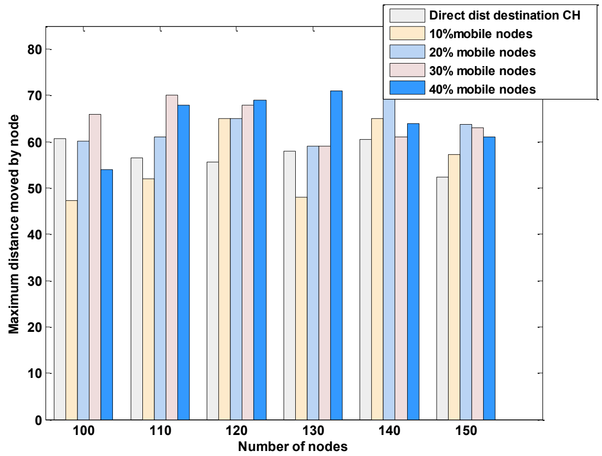

Fig. 4. Maximum distanced a single node for coverage improvement

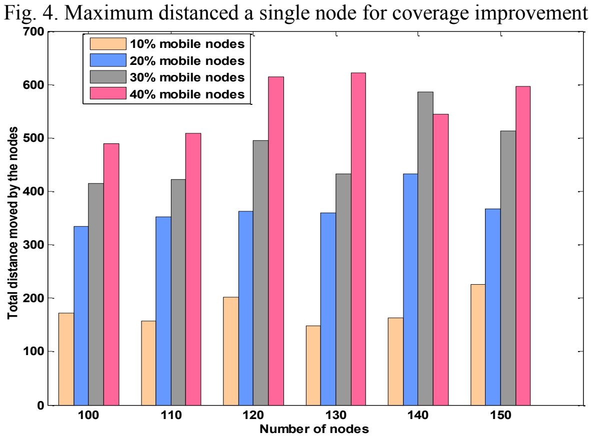

Fig. 5. Total distance moved by all relocated mobile nodes for coverage improvement

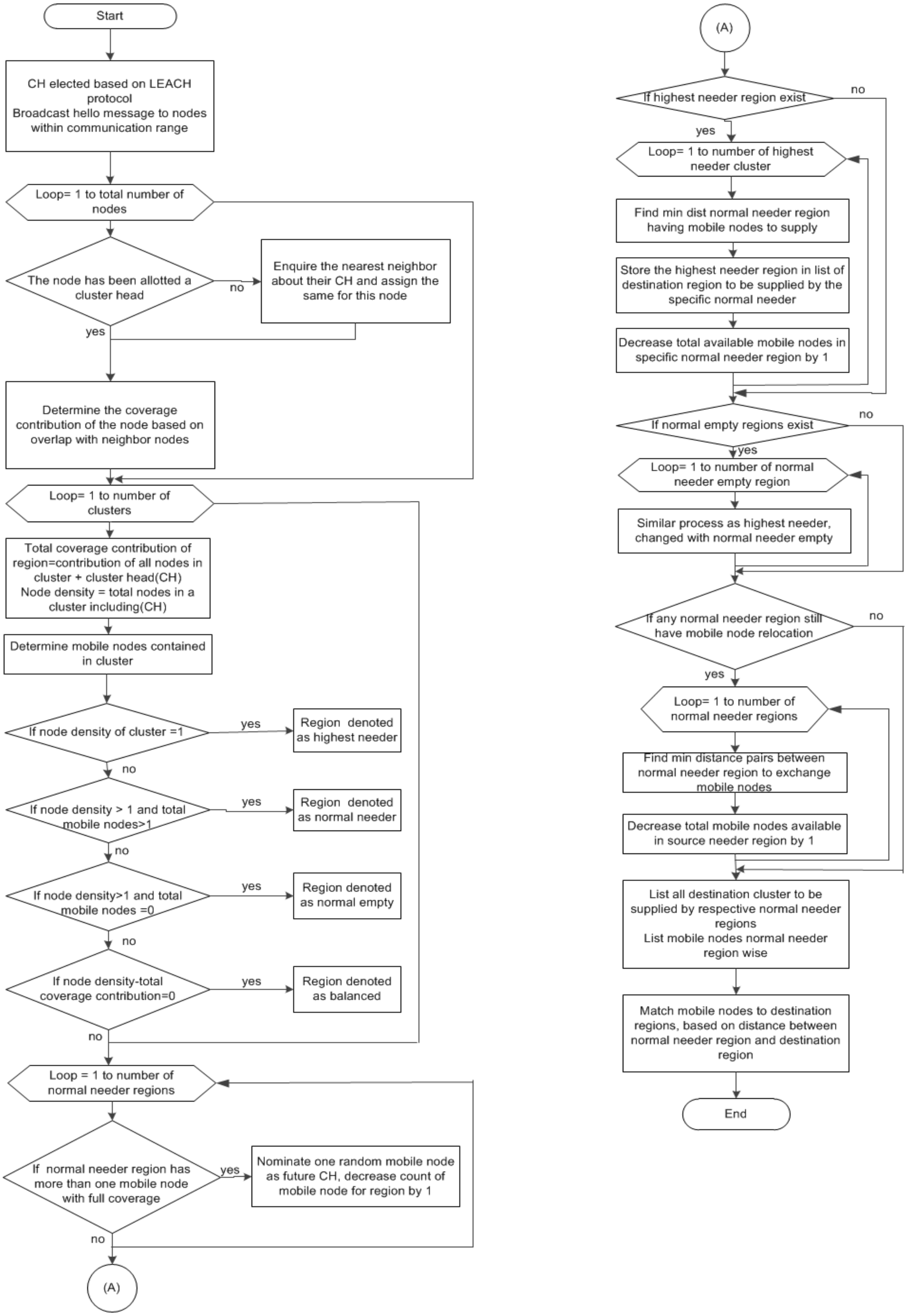

Fig. 6. Matching of clusters for relocating mobile nodes

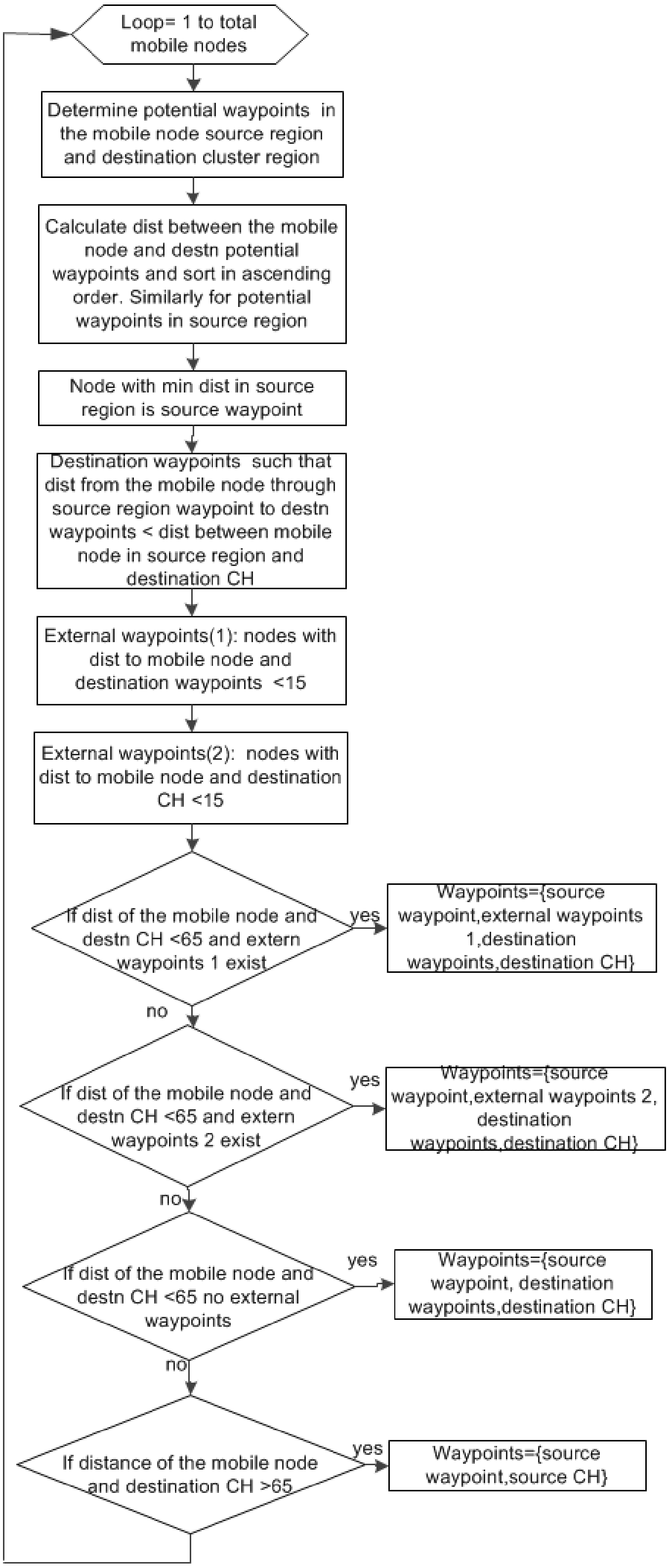

Fig 7. Determination of waypoints for a mobile node

VI. Conclusions And Future Work

It can be concluded that relocating mobile nodes between cluster regions by waypoints is an effective method for coverage improvement. The proposed method justifies that coverage improvement and relocation of mobile nodes can be carried out without use of computationally costly GPS and other localization services. It is also stressed through this paper to consider coverage and clustering of sensor nodes as complementary QoS parameters that should be considered an integrated manner. In the presented work, the focus was on demonstrating coverage improvement for a cluster sensor network. The widely accepted LEACH protocol was used for election of CHs in the initial round. Some mobile nodes have been left in the same original region as future CHs. Relocated nodes could volunteer to be future CHs in the destination cluster region. Hence a clustering algorithm which could function considering these conditions could be explored and it should also replace the LEACH protocol for the initial CH election. It can be concluded that after initial deployment a sequential process of three steps should be followed which are, there should be clustering of nodes, reorganization of nodes for coverage improvement and CH election based on mobile node relocated to destination cluster region and mobile nodes not relocated and nominated as future CHs.

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