# Intra-Cluster Topology Creation in Wireless Sensor Networks

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*Abstract* **-Clustering is proven method for energy efficient topology generation. However, in cluster formation high focus is given on cluster head selection while intra-cluster topology generation is not given much attention. In this paper, we have proposed intra-cluster topology-generation method for heterogeneous wireless sensor network (WSN). For cluster formation, we have used Voronoi tessellation with fix number of cluster heads. We have used leveling method to position the cluster nodes in the network to generate level based intra-cluster topology and exploited the property of variable transmission power of cluster nodes and cluster head.**

## I. INTRODUCTION

Underlying design philosophy of WSN is to create networks that consist of large number of small and low-end devices called sensor nodes. These sensor nodes are made of computing, storage, sensing, communication and power units. Computation and storage units are characterized by their computation speed and storage capacity respectively. Sensing unit is characterized by its sensing accuracy and sensing range, while communication unite is mainly characterized by its communication range and communication rate. Lastly, power unit is characterized by its power capacity. In sensor network, these device-level characteristics are of low ends. They are neither capable enough to handle long distance, high rate communication nor able to process high volume of data at high speed. We can call such units as resource stressed units and devices resource stress devices. While networks that consist of such devices can be called as resource stressed networks. Resource stressed sensor network requires efficient utilization of these scarce resources, which is always the driving factor of every solution provided for wireless sensor networks (WSN) [1].

One of the way through which sensor network has overcome its resource stress-ness is by large number of nodes and their cooperation and coordination. Large number of nodes makes the network deployment dense. This dense deployment makes some nodes to overlap in communication and sensing range. Because of that, nodes make redundant sensing and create unnecessary data communication. Further WSN is application specific, data centric network and it requires data aggregation or data fusion for efficient use of available resources. Dense deployment makes that task hard to achieve efficiently. Many topology control mechanisms effectively organize the sensor nodes of WSN, so that network can achieve efficient data fusion in application specific data collection. Clustering is one of such topology control mechanisms through which WSN creates connected hierarchical network topology.

Normally flat networks consider that nodes in the network are of same type and perform same functionality for entire network life cycle. In clustering this assumption is slightly relaxed and assume that network is consist of heterogeneous nodes, where heterogeneity comes either form hardware or from functionality, or from both. Base on this heterogeneity nodes are divided into cluster heads, gateway nodes and cluster nodes. Task of topology control is to assign the role/functionality to each node of the network. Topology Control decides which node declares itself as cluster head, which nodes join declared cluster heads and become cluster member of that cluster, and which nodes work as gateway between the clusters. Due to dynamic nature of network, topology control mechanism periodically or on certain event adjusts the role of nodes, which in literature putted as cluster maintenance. Further clustering in WSN faces several challenges, such as ensuring connectivity, selecting the optimal frequency of cluster head rotation and computing the optimal cluster sizes.

Recent literature on clustering in WSN is more focus on cluster head selection, while less focus is given on the point that after cluster head is selected from group of nodes how to effectively create intra-cluster topology for selected cluster heads. In this paper, we focus on intra-cluster topology creation for WSN. We have considered heterogeneous WSN in which heterogeneity comes both from hardware and from functionally, resource reach nodes are treated as cluster heads and rest of nodes work as cluster members. We have considered the scenario in which bunch of nodes were dropped in sensor field, in which some of the nodes were resource reach nodes and other were regular nodes with adjustable transmission range. We use Voronoi tessellation for cluster formation between the cluster heads. Voronoi tessellation forms cluster region for cluster head and nodes in that region joints that cluster head. Using leveling mechanism cluster head informs its presence to its cluster members. Cluster members using this leveling information know their relative location in cluster and select their path toward the cluster head.

Rest of the paper organized as follow, section II contains the related work, section III covers our proposed scheme for intra-cluster topology generation, in section IV we have exploited the transmission range of sensor nodes for efficient topology creation and section V discusses the simulation results. We have concluded our paper in section VI with future direction.

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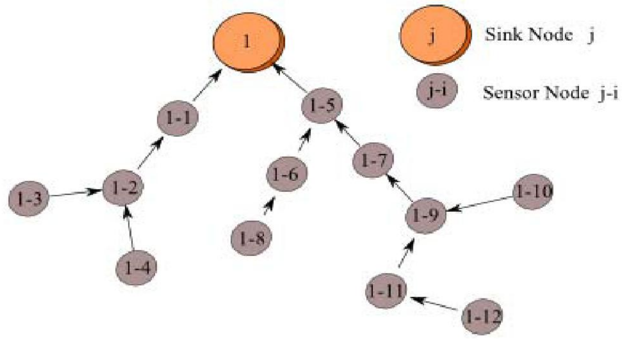

Figure 1. Tree structure for cluster -*1* in WSN

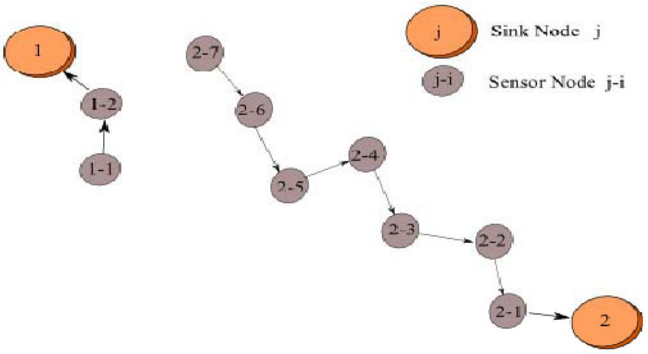

Figure 2. Limitation of tree structure

## II. RELATED WORK

Recent work on clustering in wireless sensor network has intensely been covered in reference [10]. It covers various clustering protocols, their comparison and highlights open issues like node synchronization, optimal cluster size and duty cycle selection, MAC design and connectivity related problems in clustering for WSN. Survey shows that network have achieved inter-cluster connectivity either by gateway nodes or through cluster heads. However, effective mechanism for intra-cluster communication is not discussed in-depth in survey and still it is an open area to work.

Widely used connectivity structure for WSN is tree structure in which nodes are organized as tree, where each node selects one or multiple parents to forward their information towards the sink node. In the case of hierarchical clustering topology, nodes have to send their data to the cluster head. To relay its data toward the cluster head, node from its neighboring nodes selects some nodes as parent nodes and forwards their data to these parent nodes. The parent nodes either only Child's data or their data with child's data send to their parents and process continue until data reaches to cluster head.

Wireless Sensor Network is full of such methods, which generates tree based network topology. COMPOW [2] generates the different routing tables for different transmission range. From these tables node chooses the minimum power routing table that makes network connected. In COMPOW information propagation, delay is high and node chooses sub-optimal transmission range that makes COMPOW inefficient. CLUSTERPOW [3] is improvement over COMPOW, where instead of using common transmission power, node uses minimum transmission power to reach next-hop on the way to destination, but it has problem of infinite loop. Both the COMPOW and CLUSTERPOW use hop count and dynamic transmission range to generate tree topology. Ref. [4-6] use variable transmission power and hop count metric to generate hierarchical tree topology. In next paragraph, we have discussed the problem with these methods while they generate the tree structure.

As shown in previous paragraph, there are many methods to generate tree topology in WSN. Although the base line algorithm is more or less same in all these methods. In which the cluster head broadcasts messages along its information. Nodes which receive this message, consider themselves one hop away from cluster heads.

These receiving nodes increase the hop count in message and rebroadcast the message, nodes that receives this message set their hop count from cluster head and rebroadcast the message again. As shown in Fig. 1, node 1 and node 5 is at one hop from cluster head 1. Now node 1 and node 5 then rebroadcast the message with hop count 2 and node 1-6 and 7 hearing this message set their hop count 2 from cluster head 1. Finally, we have intra-cluster topology as shown in Fig. 1.

This tree structure is simplest to generate but it has limitations. In Fig. 2, we have two cluster heads = {1, 2}, cluster 1 has cluster members = {1-1, 1-2} and cluster 2 has cluster members = {2-1, 2-2, 2-3, 2-4, 2-5, 2-6, 2-7}. In final tree topology, generated base on hop count the hop distance from node 2-7 to cluster head 2 is 7 hops. In this topology node 2-7 and node 1-2 are not in each others communication range. Therefore, node 2-7 has joined the cluster head 2 because it has no other link to other cluster heads. Considering the distance between node 2-7 and cluster heads, node 2-7 is more nearer to cluster head 1 than cluster head 2. However, node 2-7 could not join cluster head 1, due to its limited communication range and lack of awareness that it is near to cluster head 1 than cluster head 2. Therefore, over the time data from node 2-7 has to go through 7 hops to reach cluster head 2, than lesser hop counts to node 1. This makes network to transmit more packets than actually required and that reduces the lifetime of node and the network. To overcome, this problem we have proposed cluster based topology generation method using Voronoi tessellation and cluster leveling.

## III. LEVELING FOR INTRA-CLUSTER TOPOLOGY

As we have shown in section II tree structure on which many WSN protocols work could not, help in achieving minimum hop count to reach cluster head. In addition, because of that, the average path length from cluster nodes to cluster head is more than the minimum possible. That makes network to consume higher energy in data collection from cluster nodes to cluster head and in information dissemination from cluster head to cluster nodes. It happens due to, nodes are not time synchronized, uncoordinated sleep-wakeup and boot up schedule. Other reasons are like declaring its effective coverage area to the nodes in that effective area and cluster nodes have limited transmission

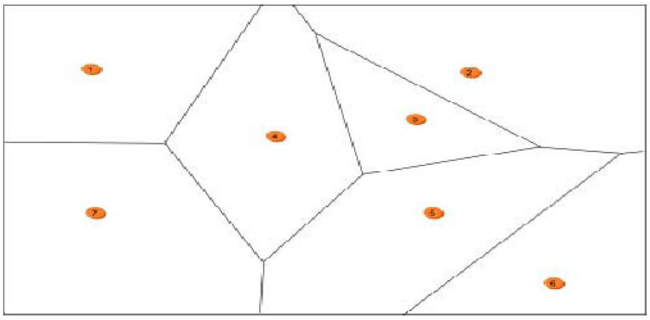

Figure 3. Voronoi tessellation of WSN

range and they do not have information about the nearest cluster heads. We have overcome these problems of cluster head and cluster node by Voronoi tessellation and leveling messages broadcasted by cluster head.

In WSN, many technical aspects of sensor network such as spatial aggregation, target tracking, localization, random sampling and load balancing highly depend on the effective coverage area of sensors. Effective coverage area of node can be defined as the area, which is covered by that node more accurately than any other node in the network. This effective coverage can be defined to be the Voronoi cell for that node. Ref. [7-9] use the Voronoi cells to solve the WSN problems. In the context of sensor networks, a node's Voronoi cell has important properties of linearity and duality. Delaunay triangulation is referred to be the dual of Voronoi Cell. A Voronoi diagram provides effective solutions to the problems related to distance, smallest enclosing circles and nearest neighborhood.

Definition 1 (Voronoi Cell): The Voronoi cell of a node *j* with respect to a set of nodes N, denoted VN(*j*), is the set of points in the plane which are closer to *j* than any node in N − {*j* }.

In order to find the effective area of cluster head in sensor field, we have used the Voronoi tessellation of sensor field base on information exchanged by cluster heads. Nodes that are in the Voronoi cell of cluster head ***j*** are always closer in terms of distance to the cluster head ***j*** than any other cluster heads. Base on location information exchanged between the cluster heads, they can calculate their respective Voronoi cells. We have shown in Fig. 3, example of Voonoi tessellation of sensor fields. Here the circles are the cluster heads and the polygons around them are their respective Voronoi cells. Through Voronoi cell cluster head calculates their effective area and then based on that area they calculate the number of leveling messages required.

Leveling messages are messages through which cluster heads inform its cluster members the approximate metric between cluster head and cluster nodes. Here we have used the general term approximate metric, cluster head can choose any appropriate metric based on system, application and hardware's resources and constrains. In our solution, we have used hop count that is approximate hop distance between cluster head and cluster nodes on that level. Cluster head calculates the number of levels required in its cluster using maximum distance between Voronoi cell boundary and cluster head. Another important parameter that plays key role in defining the number of levels in cluster is the common communication range of cluster member nodes.

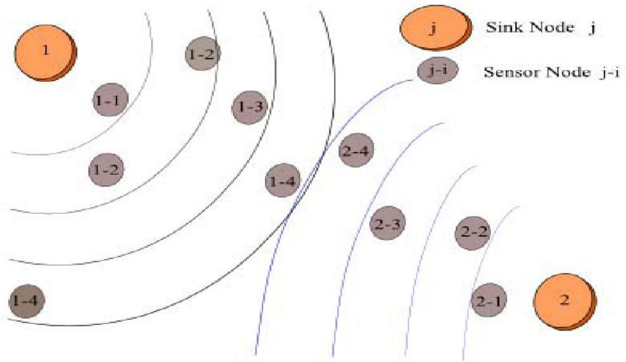

Figure 4. Concentric Levels for Intra-cluster topology generation in WSN

Using following formulation cluster heads calculate their levels. To make the calculation simple. we have taken communication area of cluster head and cluster members as hexagon with side length $l \cdot R$ and $R_{CN}$ respectively and distance between levels $R = R^{l_i}{}_{CH} - R^{l_{i-1}}{}_{CH}$. For simplicity, we are assuming $R$ to be independent of $l$.

$$\beta = \frac{R}{R_{CN}}$$

$$L = \frac{D}{R_{CN}} \tag{1}$$

Here $L$ is the number of levels required for cluster head with distance $D$ between cluster head and farthest point in Voronoi cell. $\beta$ is the ration of $R$ and node's common communication range. The overlapping area $\Delta$ of cluster node at level $l_i$ to level $l_{i-1}$ can be given by following equation.

$$\Delta = \frac{R^2}{4\sqrt{3}}(3\sqrt{3}\beta - 1)(\sqrt{3}\beta - 1) \tag{2}$$

To make network wide connectivity we want that there is at least one node in this overlapping area $\Delta$. This gives the relation between network density and overlapping area $\Delta$.

$$\Delta \cdot \lambda \geq 1$$
$$N = \lambda \cdot A \tag{3}$$

Here $\lambda$ is node deployment density of the network in grid deployment, with field area A and $N$ is the number of nodes in the field. Using above formulation. We have number of levels required for particular cluster head and we can derive the nodes required to cover the given area with given communication range limitations.

To do leveling, cluster head first sets its communication range to base communication range and broadcasts the leveling message. Listening nodes, on first level message set their level to that cluster number. On further level message, node changes its level if the receive level is less

Algorithm 1: Cluster Heads

```
Step1: Get neighboring cluster head information.
Step2: Create Voronoi Cells.
Setp3: Calculate required number of levels.
Step5: Send setup message with full power.
Step6: Set Transmission power for level-i.
Step7: Broadcast level message.
Step8: Repeat Step4-6 for each level
```

than the current node level. Thereafter cluster head gradually increases, the power level to next level and broadcast the level message. This process continues for all the levels calculated by (1). If node receives the multiple level messages, which many nodes could, then nodes choose the level message with the lowest level number and set its level to it. Algorithm for the level formation is given in algorithm 1 and 2. Using this algorithm network forms the leveled topology as shown in Fig. 4.

In Fig. 4, we have two cluster heads = {1, 2}, cluster 1 has six nodes and cluster 2 has 4 nodes. Both the clusters 1 and 2 have four levels. In section II we have shown the problem with tree topology where due to lack of information node 2-7 was not able to get connected to cluster head 1 and is connected to cluster 2 with hop count 7. There the lack of information had increased the hop count of node 2-7 and overall networks average hop count. In our scheme by leveling message node 2-7 receives, the level message from cluster head 1 and comes to know that it is at the second level from cluster head 1. Here due to Voronoi tessellation cluster heads only send level messages to their effective cluster region. Nodes in the network receive level messages from the cluster head that is near to them than any other cluster head in the network. With leveling cluster heads can spread their information in their cluster area, for that they require only linear number of messages, which is same as number of levels in the each cluster.

Level messages are required only at the time of cluster formation so the network has only setup time overhead. Further if cluster head reboots or sets it self up again then it requires only to inform its cluster members. In the case of node reboot, it loses information about the cluster level and cluster head.

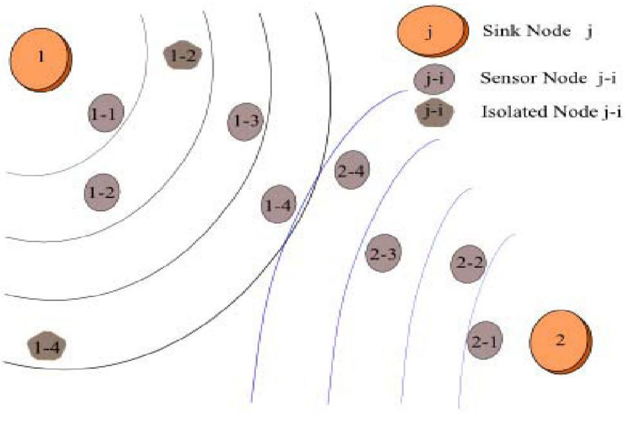

Figure 5. Problem with leveling

Algorithm 2: Cluster Nodes

```
Step1: If hear setup message, listen to level message
Step2: choose minimum level form all level messages
Step3: If no setup message but level message or reboot
Step4: collect neighboring nodes level.
Step5: set ceiling of average neighboring nodes level to
       node level.
```

To reposition the node in the network it only requires to collect the information from its neighbor. From neighbors, node collects information about their level and position itself by taking the ceiling function of average level of neighboring nodes. In the case of node reboot in the halfway of leveling setup time, node checks its level message from the level information collected from the neighbors. If it finds the absolute difference between its level and its neighbor's level to be more than one, then it sets its level to ceiling value of average level of its neighbors.

## IV. CHANGING TRANSMISSION RANGE

In previous section we show that leveling can solve the problem of lack of information, and generate an efficient topology for the dense network. By dense we mean network, which has more nodes than (3). However, in some scenario network can be left with isolated nodes and isolated forests. This happens due to hardware limitations of the network nodes as well as improper scheduling of nodes.

In Fig. 4, we have two cluster heads = {1, 2}, cluster 1 has six nodes and cluster 2 has 4 nodes. Both the clusters 1 and 2 have four levels. Here in cluster 1 we have an isolated nodes and isolated forest. In the Fig. 5, nodes with pentagon are the isolated nodes or root of the isolated forest. There are possible cases in which network falls in this topological structure, like when network has low density of nodes, nodes get clubbed in certain areas due to random deployment or limited transmission range of nodes. These limitations of random distribution and hardware capabilities can be overcome either by the limited mobility or by the adaptive transmission range of nodes.

Still mobility is hard to achieve in small-scale sensor nodes and now a day's hardware are available with

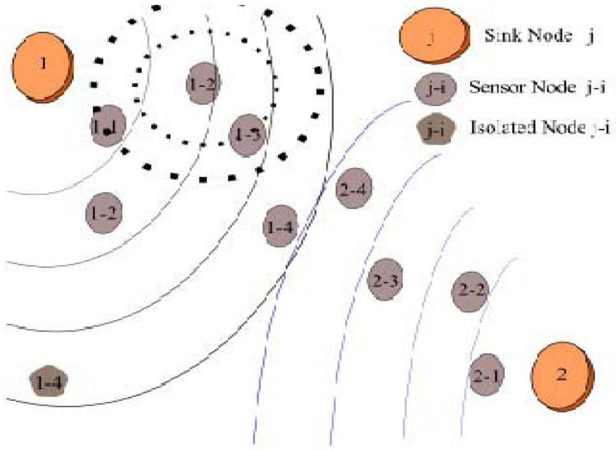

Figure 6. Increase Power Level

Algorithm 3: Change Transmission power for Node

```
Step1: Send hello/help packet with base transmission
       power.
Step2: Listen hello/help packet from neighbors.
Setp3: Nodes with level one less than node's level are child
       nodes.
Step4: Nodes with level one more than node's level are
       parent nodes
Step5: Nodes with same level are neighbors.
Step6: If node has no parent, increase transmission power
       to next level and send help message.
Step7: Nodes if receive high power help message, change
       its power level and send new help message.
Step8: Repeat steps 2 to 7 until get no parent or max count.
```

firmware that adjusts the transmission range without rebooting the communication components. Therefore, to overcome the problem of node isolation, we have chosen adaptive transmission range of nodes. As shown in Fig. 5, network has isolated nodes and forest, in our scheme only isolated node and root of isolated forest need to change their transmission power to be the part of final connected network topology. Therefore, the number of nodes required to change their transmission power is less compare by protocol given in [2], [3], [5]. Protocol for node to change its transmission power is given in Algorithm 3.

Fig. 6, shows that by systematically increase nodes transmission power isolated node and forest become part of the network. Accuracy of decision to change power level of node depends on available hop information. If node makes decision only based on its neighboring node, then it might happen that node has neighboring node which is connected to higher level nodes while node have no parent in that case changing node power is not required, but still node changes power due to lack of information. In our simulation, we have found that in large number of cases 2-hop information is sufficient to make correct decision.

## V. SIMULATION RESULTS

We have used NS-2 for our simulation. We did extensive simulation by varying number of cluster heads and network size. To find the effect of network scaling on our scheme we have changed network size by increasing the number of nodes in the same area and by increasing the network area. We have measured the average path length in hop count and isolated nodes in the network to evaluate the performance of our scheme. We have compared our level based approach with tree based approach and found that with network scaling, our scheme outperforms the tree based approach.

Fig. 7 and 8 show the simulation results in which we have fixed the network area to 200X200 meters and perform simulation to compare isolated nodes and average path length of both the approaches. Fig. 7, shows the isolated nodes in network when network size is increased from 20 to 150 nodes. Further, we have plotted the effect of increasing the number of cluster heads with same network size. In all the scenarios, we found that the number of isolated nodes are higher in tree structure based scheme than in the level structure based scheme.

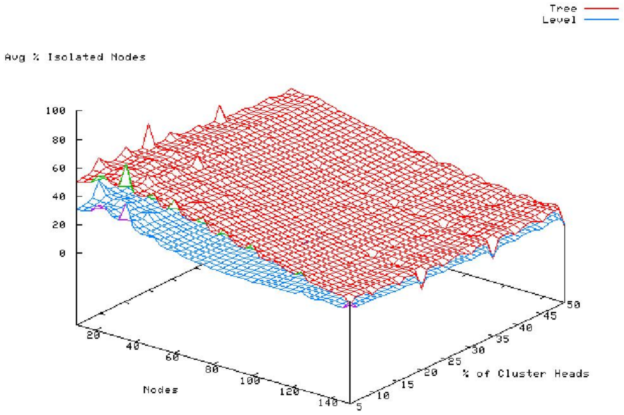

Figure 7. Isolated Nodes

Similar result is found for average path length in network. Fig. 8 shows the average path length in network with the variation of percentage of cluster heads and nodes. It shows with enough node density, scenario shown in Fig. 2 and 4 occur more frequently and nodes select the cluster head that are near to them. This results in average path length reduction in the network.

Further, we checked the effect of increasing the field size on same comparison parameter. We have simulated the scenario by keeping the percentage of cluster heads fixed to 20% of the nodes in the network and found out the effect of field scaling on average path length and number of isolated nodes in the networks. Fig 10 shows the effect of field scaling on isolated nodes in the network. We have changed our field size from 200x200, 300x300, 400x400 and 500x500. In all cases, number of isolated nodes are less in our scheme. With the same field setting, Fig 9 shows average path length of the network, which is affected by the number of nodes in the network. For large field size, tree topology performs better than the level method. There the average path length is smaller than the level based approach. However, as the number of nodes in the network increase, the level method outperforms the tree approach as per the argument given in Fig 2 and 4.

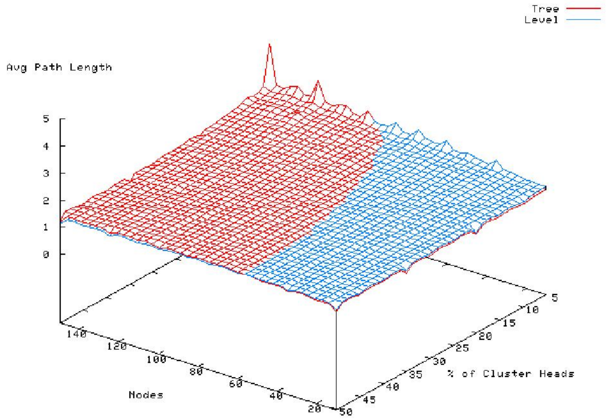

Figure 8. Average path length

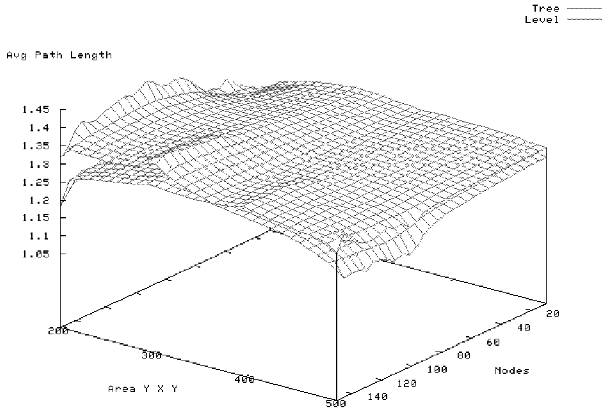

Figure 9. Average path length in 200X200 area with 20% cluster heads.

To show the crossover in path length we have simulated network by gradually increasing the number of nodes in the network and keeping the field size to be 400x400 with 20 percent cluster heads. Isolated nodes and average path length result are shown in Fig. 11. Results show that as the network size increases, the level based approach outperforms the tree based approach and reduces the overall network's path length. With increasing node density, number of isolated nodes reduces in the network. Only far away nodes in the networks remain isolated in both the topology. The scenario we have shown in Fig. 5, cluster head 1 has a level 4 node that is far away in the network.

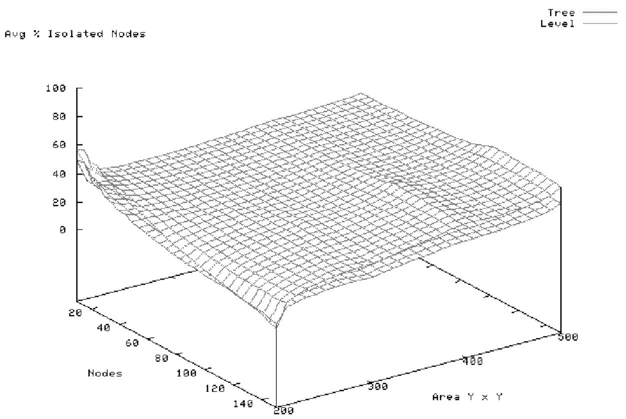

Figure 10. Isolated nodes in 200X200 area with 20% cluster heads.

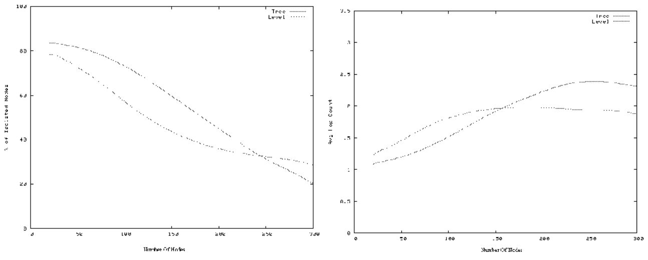

Figure 11. 400X400 area with 20 % cluster heads.

## VI. CONCLUSION AND FEATURE WORK

In this paper, we have proposed level-based intra-cluster topology generation method for the heterogeneous wireless sensor network deployed with fixed number of cluster heads. Voronoi tessellation has been used for cluster formation and within one Voronoi cell, cluster head calculates number of level message required based on nodes common transmission range. Further, we have exploited the property of changeable transmission range of cluster nodes to create efficient intra-cuter topology. We have compared our scheme with the tree based approach and shown that in most of the scenarios our level based method outperforms the tree based approach. We have also shown effect of network scaling on our scheme. Currently we are working on the throughput and network capacity of our generated topology for various traffic patterns.

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