Achieving connectivity in an Unstructured Wireless Sensor Network using Optimal Assignment of Mobile Nodes

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***Abstract*—Wireless Sensor Networks (WSNs) have been proposed as a solution to problems in a variety of monitoring applications. Most of the random deployments in sensor networks lack proper connectivity. In this paper, an approach is presented to achieve connectivity in a disconnected random deployment of sensor networks. This can be accomplished by using mobile nodes for establishing connectivity in the network as well as for information gathering. The concept of Steiner point has been used to find the co- ordinates for placing the mobile nodes. The paper proposes a variant of Hungarian algorithm for placing mobile nodes in the field in minimum time. The simulation results indicate that the proposed approach can be effectively used in an unstructured deployment of WSN.**

Keywords-WSN, Mobility, Assignment Problem

I. Introduction

The field of WSNs has emerged over recent years with a wide variety of applications. WSNs have been applied in scenarios such as health-monitoring, industrial and consumer applications. Another application of WSNs is that of intruder detection in remote areas, where sensor nodes continuously monitor any movement in their vicinity [1].

A WSN, typically, consists of a *sensor node*-a PCB (Printed Circuit Board) having a micro-controller, source of power supply, sensors for measuring the physical parameters and a radio transceiver for sending and receiving data. Nodes are deployed over a wide area forming a multi hop network in order to relay the data to a central node commonly referred to as a base station. The base station in a WSN has a dedicated power supply and a higher processing capability. The base station receives the information from the static nodes relayed over the network and processes the data.

There are many constraints associated with the maintainability of WSNs; one of the main constraints is connectivity. In case the node runs out of power it will disconnect from the network, which might have serious consequence on the connectivity of the network. In most of the applications the node once deployed cannot be accessed manually thereby highlighting the importance of maintaining connectivity.

In this paper, the issue of connectivity in the network has been addressed in order to ensure a seamless communication between each node and the base station. In case of a random deployment of sensor nodes, clusters of nodes may be formed which are disconnected from the base station. Such networks consist of clusters of nodes which are connected to each other but may not be connected to the base station. This may lead to a breach of communication between the individual nodes which are part of such clusters and the base station. A mechanism is hence required to ensure that the network remains connected.

The paper aims for an efficient placement of mobile nodes to connect the network. Since the problem calls for a technique of graph augmentation, the concept of Steiner point [2] has been used to determine positions of the mobile nodes with respect to the individual clusters. As mobile nodes themselves are scattered across the area, they must be assigned to points within the field such that the total time for the entire assignment is minimized.

The technique illustrated in this paper can find applications in unstructured deployments where clusters of nodes may be formed leading to a disconnected network. It will be useful in scenarios such as deploying nodes for volcanic activity monitoring, military purposes like object tracking and monitoring environmental conditions in remote areas. The approach also could be adapted with little modification in cases where a deployed network might get disconnected due to malfunctioning of sensor nodes.

This paper is structured as follows: Section II talks about the problem of connectivity in the network and an overview of the techniques to solve them. Section III describes the network architecture explaining the various phases like deployment, discovery, calculation of mobile nodes' positions, optimal assignment of mobile nodes and finally communication to the base station. Section IV illustrates the sequence of events during the simulation along with the results. Section V concludes the paper and highlights the future plans.

II. Background

Achieving connectivity is a significant challenge in WSNs. Connectivity can be achieved by calculating the exact density of nodes required for covering an area. The greater the density, the higher is the chance of attaining connectivity. However in the case of random deployment, covering the entire area becomes a problem due to an uneven distribution of nodes.

This paper proposes the use of mobile nodes to address the problem of connectivity in the case of random deployment. Mobile nodes have been used for data collection as well as for node discovery. Various techniques can be employed for data collection as illustrated in [3]. The concept of mobility

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has already been employed through Data MULEs (Mobile Ubiquitous LAN Extension) and mobile gateways in this regard.

Data collection and transfer to the base station could be accomplished by using a Data MULE which are based on the concept of DTNs (Delay Tolerant Networks). These devices are nothing but miniature mobile computers which roam around the whole field and gather data and remain in motion during most of the lifetime of the network. Data MULES transmit the data to the base station wirelessly through ZigBee, Wi-Fi or Bluetooth, by physically travelling to the base station to complete the data transfer. In [4], an approach to optimally patrol disconnected clusters of static nodes using Data MULES is presented. However, the Data MULES need to be aware of a certain optimal path which they must follow to reach the destination. An attempt has been made in [5] to address this issue.

In cases where the sensor node is at a considerable distance from the base station, a lot of energy is used for multi-hop routing. To avoid such energy losses, a device known as a mobile gateway is used in the field. The primary aim of this device is to act as a mobile base station. In [6], an attempt has been made to reduce the energy consumption due to excessive communication traffic between the static nodes and the mobile gateways.

Many problems may arise during the deployment of an unstructured sensor network. Also the sensor nodes do not have a reliable collision detection mechanism and they do not have knowledge about the network topology. Various techniques to solve the above problems are mentioned in [7].

In this approach, the base station is required to communicate with all the mobile nodes in the network not only for instructing them to occupy particular positions in the network, but also for collecting data about all the clusters and their respective centroids. There is, therefore, a requirement for a technique which enables such a communication over a long range. This can be achieved by using cellular technology. Since cellular technology consumes more power, it is not advisable to use the same for a long duration communication.

In order to save energy, the bulk of data transfer in the network is done through ZigBee [8] although cellular technology is used for communicating with mobile nodes. ZigBee is an IEEE specification which is used extensively in sensor networks due to its low power consumption and longer battery life compared to specifications like Bluetooth or Wi-Fi (Wireless Fidelity). Cellular technology is used mainly during the initial deployment to gather data and to instruct mobile nodes. Cellular technology consists of a variety of standards developed over the years, including GPRS (General Packet Radio Service), EDGE (Enhanced Data Rates for Global Evolution), and so on, which are used for data transfer.

The mobile node communicates on two fronts, with sensor nodes through ZigBee and with the base station through cellular radio. An implementation similar to [9] and [10] could be used in this regard which has both ZigBee and cellular module (GPRS) on the same node.

The concept of Data MULES could be used instead of cellular technology. However, in such a case the mobile node will have to travel quite a distance to transmit data to the base station, which leads to an increase in battery consumption and introduce a considerable delay in the assignment of mobile nodes.

Though the use of cellular technology itself to transfer sensor data from static nodes to base station appears more convenient, it is however power expensive. Cellular technology will put a massive strain on the limited power source of a sensor node for it to be used effectively. Therefore in this paper it is proposed that cellular technology be used only in the initial stages. Once mobile nodes are assigned to positions in the field, the cellular radio can be put to sleep.

Further, for assigning the mobile nodes to the respective positions, the Hungarian method [11] is used. It assigns jobs by a one-is-to-one matching to identify the lowest-cost solution. Each job must be assigned to only one machine. It is assumed that every machine is capable of handling every job, and that the costs or values associated with each assignment combination are known and fixed. The above mentioned algorithm after modification could be used in optimal placement of mobile nodes. The detailed algorithm and the steps involved are explained in the following work [11]. Although [3] mentions some techniques for data collection using mobile elements, the focus of our paper is network connectivity.

The routing algorithm for communication between the nodes and the base station is explained in Section IV.

Assumptions

In this work, the following assumptions have been made:

- The static nodes in the network have already been localized, and have prior knowledge of their global positions. The localization of the nodes can be done using range free techniques such as the APIT (Approximate Point-In-Triangulation Test) algorithm [12].
- The mobile nodes are equipped with a GPS (Global Positioning System) module for localization.
- The mobile node also has a GPRS module with which it can communicate with the base station. The base station using GPRS, can instruct these mobile nodes to occupy certain positions in the network.

III. Network Architecture

The network architecture will be described in 5 phases. The phases are divided according to the sequence of operations which take place in the network right from deployment of the nodes to the final seamless communication establishment between each node and the base station. Subsection A elaborates on the modules that are used for communication and basic assumptions about static and mobile nodes. Subsection B outlines the various steps involved in data collection by mobile nodes. In Subsection C, the exact process of calculating the positions of mobile nodes using the Steiner point algorithm is described. Subsection D illustrates the requirement for optimal assignment of mobile nodes and the Modified Hungarian

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algorithm which is used to accomplish the same. Finally, in Subsection E, the routing algorithm which can be used to send data from the nodes to the base station is presented. It is to be noted that all the phases henceforth are executed only during the initial stage.

A. Deployment Phase

In the field of WSNs, nodes are often deployed without an organized structure. In such cases the nodes are randomly deployed over the area of interest and often lead to cost effective deployment scheme. However, such a deployment can give rise to issues in network connectivity, wherein the static nodes form disconnected clusters amongst themselves.

B. Discovery Phase

The discovery phase involves data collection, i.e., the positions of each individual node along with the centroid of its cluster. Each static node in the network maintains a $discovery$ bit, which is initially set to zero. This work assumes that there are enough mobile nodes to carry out this step initially. The mobile nodes take a random walk and establish contact with any static nodes in the vicinity. Such static nodes are referred to as gateway nodes and facilitate the gathering of information by the mobile node. The $discovery$ bit is required by each static node in the network to determine whether its position has been relayed to the base station or not. This is done to avoid repeating the same sequence of steps if any another static node is contacted by a mobile node in the future. There are three different types of messages which are exchanged, they are:

- $co-ordinate\ request$: It is sent by the gateway to all the nodes in the cluster to gather their co-ordinates.
- $co-ordinate\ response$: It is sent by the node to the gateway containing its co-ordinates.
- $discovered$: It is sent by the gateway to all the nodes in the network to change the $discovery$ bit from default zero to one.

The following are the sequence of events for node discovery, from the individual cluster to the base station:

STEP 1: The mobile node initially establishes contact with the nearest node which is part of a cluster. The node which is contacted by the mobile node now serves as the $gateway$ which employs a one way broadcasting [13] to gather co-ordinates of each node. It broadcasts a $co-ordinate\ request$ packet into the network.

STEP 2: On receiving the $co-ordinate\ request$ packet, a node responds back to the gateway with a $co-ordinate\ response$, and in turn forwards this $co-ordinate\ request$ packet to its own neighbours. This process repeats until all nodes in the cluster have been covered.

STEP 3: On receiving the responses from nodes, the gateway forwards individual positions of the nodes to the mobile node.

STEP 4: On receiving the co-ordinates from all nodes, the mobile node calculates the centroid of the entire cluster. The mobile node in turn relays the data obtained to the base station using cellular network.

STEP 5: The gateway now sends a $discovered$ message back to all the nodes. On receiving this message all nodes will set their $discovery$ bit to one.

STEP 6: The base station now has the information of all nodes in the form of tuples <position of node, centroid of cluster>. The centroid can be used to uniquely identify a given node as part of a particular cluster.

STEP 7: In case another mobile node approaches the above cluster, it will find the $discovery$ bit of the node already set to one, and will move ahead in search of an undiscovered cluster.

The centroid obtained from each cluster is used as an identifier to the cluster.

In [14], the time distribution required for the mobile nodes to visit all the sensor nodes is given.

C. Calculation of the positions of the mobile nodes

On the successful completion of the discovery phase, the base station has obtained the information regarding all the static nodes and the position of the centroid of their clusters. It now seeks to calculate positions for the assignment of the mobile nodes for obtaining connectivity using the minimal number of mobile nodes. To achieve this the concept of Steiner point in geometry is used.

1) Steiner Point: Steiner Point [2] in a graph is an extra vertex, not originally part of the vertex set of the graph, which is introduced into the graph with the aim of making the graph connected in an efficient way. The Steiner Point has the property that the sum of the distances from itself to all the other vertices is minimum. When the Steiner Point is determined with respect to three other vertices, it is also known as the Fermat's point.

Geometrically the construction of the Steiner point is as follows.

- Let the triangle whose Steiner Point is to be calculated be ABC.
- Initially, construct two equilateral triangles on any two out of the three sides of the triangle, wherein the equilateral triangles so constructed have one side common with the original triangle ABC.
- For each of the equilateral triangles, draw a line from its non-common vertex, i.e., the vertex which does not lie on the shared side with ABC, to the vertex of ABC which lies opposite to the shared side.
- The Steiner Point is obtained from the intersection of the two lines.

The Steiner Point with respect to three vertices is calculated in the following way.

- Calculate the barycentrics of the Steiner Points

  f(a,b,c) : f(b,c,a) : f(c,a,b), where

$$f(a,b,c) = a^4 - 2(b^2 - c^2)^2 + a^2(b^2 + c^2 + 4(\sqrt{3})Area(ABC)) \quad (1)$$

where a,b,c are the edge lengths of the triangles and f(a,b,c),f(b,c,a),f(c,a,b) are the barycentric co-ordinates.

- Let A,B,C be the cartesian co-ordinates and let the barycentrics be p, q, r then the cartesian co-ordinates of the Steiner point can be obtained by

$$\frac{pA + qB + rC}{p + q + r} \tag{2}$$

2) Iterative Procedure for connecting clusters: The concept of the Steiner point can now be employed by the base station to calculate positions in the graph which the mobile nodes will eventually occupy. As mentioned earlier, the base station has the knowledge of the centroid of each cluster. The centroid positions can now be used along with the Steiner point to connect the graph in an iterative procedure.

$centroid[i] \leftarrow centroid\ of\ i^{th}\ cluster$

Algorithm 1 Steiner Point algorithm

$c_1 \leftarrow centroid[j],\ where\ j\ is\ index\ of\ base\ cluster$
$n_1 \leftarrow number\ of\ nodes\ in\ base\ cluster$
$S = set\ of\ centroids$
$S = S - c_1$
while S $\neq \phi$ **do**
  $find\ clusters\ 2\ and\ 3\ such\ that\ their\ centroids\ c_2, c_3\ are\ nearest\ to\ c_1$
  $n_2 \leftarrow number\ of\ nodes\ in\ cluster 2$
  $n_3 \leftarrow number\ of\ nodes\ in\ cluster 3$
  $calculate\ Steiner\ Point\ w.r.t\ c_1, c_2, c_3$
  $c_1 \leftarrow \frac{n_1 * c_1 + n_2 * c_2 + n_3 * c_3}{n_1 + n_2 + n_3}$
  $S = S - c_2 - c_3$
end while

The algorithm initially isolates the centroid of the base cluster and stores it in c_1. By comparing the distance of c_1 with all other centroids, it obtains the centroids of two clusters c_2 and c_3 nearest to c_1. It calculates the Steiner point with respect to c_1,c_2 and $c3$. It now sets c_1 to the centroid of all three clusters.

After having obtained the Steiner Point with respect to the clusters, optimally connecting it to the cluster is also important. Fig. 1 illustrates the connection between the Steiner Point and the cluster. In order to connect to the cluster, the base station selects a point on the periphery of the cluster such that it is at an optimal distance from the Steiner point itself.

The cluster is initially divided into two regions (region I and region II) based on the line L which passes through the centroid C and L $\perp$ AC. Let the nodes falling in the region (region I) on whose side the Steiner point lies, be part of a set Q. Now, only nodes belonging to set Q are considered.

The Steiner point is located at A(x_2, y_2), the centroid is located at point C(x_3, y_3)

Let D=$max\ distance\ of\ i^{th}\ node \forall\ i \epsilon\ Q$

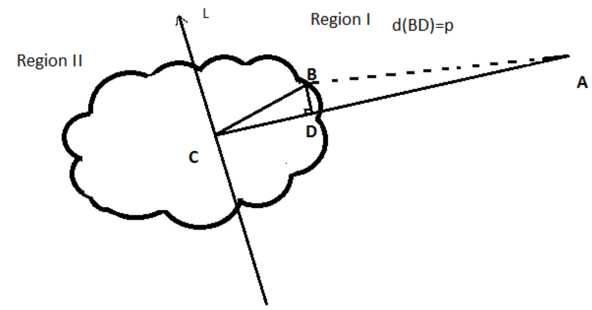

Fig. 1: Cluster Head

let p_i=perpendicular distance of the i^{th} node in cluster to the line joining AC.

Select point B(x_1, y_1) such that,
if, E(i)=$D - d_i + p_i$

then, E(B)=$min\ E(i) \forall\ i \epsilon\ Q$

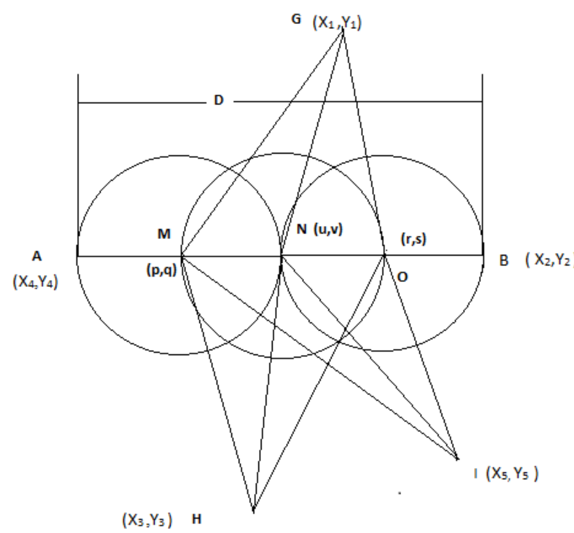

Fig. 2: Bisection of line AB

After the clusterhead is determined mobile node positions are calculated by dividing the line joining the Steiner point to the clusterhead.

In Fig. 2, points A(X_4,Y_4) and B(X_2,Y_2) are the cluster-head and Steiner point respectively. The paper discusses the bisection algorithm to divide line AB. The distance between A and B is D. The slope of line AB is given by:

$$k = \frac{Y_4 - Y_2}{X_4 - X_2} \tag{3}$$

Assuming a spherical range pattern of all nodes, Fig. 2 illustrates the positions obtained after applying the bisection algorithm on line AB.

The mobile nodes are to be placed in such a way that the successor mobile nodes are just within the range of their predecessor. In Fig. 2, the successor N of mobile node M is placed on line AB and in such a way that it is just within the range of mobile node N. However, the predecessor of node M is the clusterhead itself. The given equations express this relation,where d is the range of a mobile node and points (p,q) are the co-ordinates of the final mobile node position.

$$(X_4 - p)^2 + (Y_4 - q)^2 = d^2 \quad (4)$$

$$\frac{Y_4 - q}{X_4 - p} = k \quad (5)$$

On solving equations 4,5 :

$$p = \frac{\pm d}{\sqrt{k^2+1}} + X_4 \quad (6)$$

$$q = \frac{\pm kd}{\sqrt{k^2+1}} + Y_4 \quad (7)$$

In the case wherein the x co-ordinates of points A and B are equal, the slope of line AB is undefined. In this case, the x co-ordinate of the final mobile node position will be equal to that of A and B, and the y co-ordinate can be obtained by adding the range directly to the y co-ordinate of A.

Algorithm 2 calculates the co-ordinates of the mobile nodes on a line AB with slope k. Using the maximum range of the mobile nodes, it determines the number of mobile nodes required to connect AB.

Algorithm 2 Bisection Algorithm

```
dist = distance(A, B)
ratio = dist/d
n = ⌈ratio⌉ − 1
for i = 0 → n do
    range = d ∗ (i + 1)
    if A.x! = B.x then
        find p1 p2 using 6
        find q1 q2 using 7
    else
        if A.y < B.y then
            q1 = A.y + range
            q2 = A.y + range
        else
            q1 = A.y − range
            q2 = A.y − range
        end if
    end if
    calculate d11 = distance of (p1, q1) from B
    calculate d12 = distance of (p2, q2) from B
    choose the lesser one as final position
end for
```

Equations 6 and 7 give two sets of co-ordinates (p_1, q_1) and (p_2, q_2) and one of these is chosen as the correct point on the basis of its distance from B. In order to get the next mobile node position, iteratively increase the $range$ in multiples of d.

D. Optimal Assignment of mobile nodes

Since the mobile nodes are scattered all over the network, the base station needs to assign a particular mobile node to one of the previously calculated positions. The mobile nodes use GPS to navigate to their calculated positions and will cease to use GPS on occupying the positions and hence save power. There are implementations like [15] which provide a low power GPS solutions which is useful for saving energy of the mobile nodes. Since it is an assignment problem, a modified form of the Hungarian algorithm is used to achieve this.

Modified Hungarian Algorithm: This approach however demands an algorithm which can minimize the maximum time taken for the simultaneous movement of all mobile nodes from their current positions to the calculated positions. This problem is therefore a BAP (Bottleneck Assignment Problem). The paper uses the technique illustrated in [16] to solve the BAP. This modified hungarian algorithm takes a two dimensional array as input with each element pq having the value of the distance of the current position of the p^{th} mobile node from the q^{th} calculated position. It gives as output n assignments such that each node is assigned to a particular calculated position and also such that maximum time taken for the entire process is minimized.

The algorithm illustrated in [16] follows the following steps

STEP 1: Given a $n \times n$ matrix

$$A = \begin{pmatrix} a_{00} & a_{01} & \ldots\ldots & & a_{0n} \\ a_{10} & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ a_{n0} & a_{n1} & \ldots\ldots & & a_{nn} \end{pmatrix}$$

arrange the elements in non descending order and assign ranks to each element according to its position. Equal elements will have the same rank. Calculate another two dimensional array of size $n \times n$ B with $O(n^2 \log n)$

b_{ij}=rank of element a_{ij}

The above can be done by quicksort algorithm with an input of n^2 elements in .

STEP 2:

Choose α in such a way that

$b_{ij}^{\alpha} \geq n * (b_{ij} - 1)^{\alpha} \ \forall \ b_{ij}$

Set,

$b_{ij} = b_{ij}^{\alpha} \ \forall \ elements \ b_{ij} \ \epsilon \ B$

This can be done in $O(n^2)$

STEP 3: Apply Hungarian algorithm as illustrated in [16] to get the assignment. This is done in $O(n^3)$.

Hence the total complexity for the entire process comes out to be $O(n^3)$, with $O(n^2 \log n)$ complexity for arranging the elements and $O(n^2)$ for setting the values in matrix B and

$O(n^3)$ for the Hungarian algorithm itself. Since the algorithm works in polynomial time, its time complexity is better than a non polynomial time one.

E. Communication

The assignment phase must be followed by the setting up of a communication protocol in the network, so that the nodes can communicate with the base station seamlessly. At this stage, the mobile nodes will occupy the positions as calculated in the previous section. The mobile nodes augment the network by establishing connectivity with respect to cluster nodes and the base station. Hereafter there is a requirement for a routing mechanism to route the data generated from the sensor nodes to the base station. The Ad-hoc On-demand Distance Vector (AODV) is used as a routing protocol in this regard. The advantages of AODV are that it is an *on demand* protocol which creates the route only when required by a particular node and also scales well with increase in number of nodes in the network. An application of AODV to a network consisting of ZigBee (IEEE 802.15.4) along with minimum battery consumption is provided in [13].

In the case presented herein, the base station propagates a one way broadcast message in the network. Each successive node on receiving this message updates the address of its parent node and in turn broadcasts another such messsage with its own address as the source address to its neighbours. This process continues until all nodes in the network know their parent node. If a sensor node is required to send data, it will forward it to its parent node.

IV. RESULT

The testing and simulation of the proposed algorithm as discussed in Section III is done using Omnet++ simulator [17]. The MiXiM framework of Omnet++ is used in this regard. The modules and flow is as shown in Fig. 3. Once the base station node has the cluster information, it will calculate the positions of the mobile nodes. The algorithm begins initially by choosing the cluster which contains the base station node and it is designated as the base cluster. The nearest two clusters with respect to the base cluster are determined. The Steiner point is calculated with respect to three clusters. The centroids of the three clusters are taken as the three vertices of a triangle. If the Steiner point does not lie within any of the three cluster, the cluster head is calculated with respect to the Steiner point. Otherwise, if the Steiner point is within the range of the three clusters, the cluster head is calculated by choosing a pair of nodes belonging to two different clusters with the least distance. Using the bisection algorithm the mobile node positions are calculated. As all the three clusters are now connected, a bigger cluster comprising of all the three clusters is now formed. This bigger cluster is now designated as the base cluster for the next iteration. This process repeats until all clusters are exhausted.

After all the mobile node positions are determined, the modified Hungarian algorithm as illustrated in Section III(D)

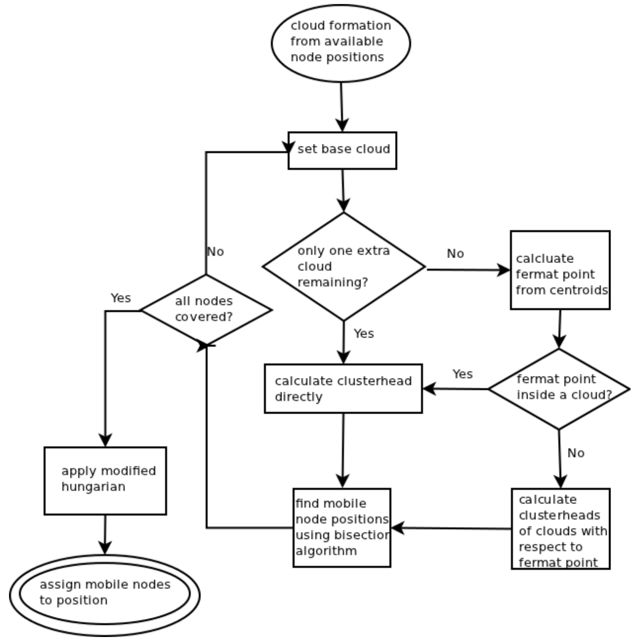

Fig. 3: Flowchart

will be applied to the given scenario to assign the mobile nodes to their respective positions.

Once the network is connected, AODV routing technique is used to form the path from every sensor node to the base station. Sensor nodes will send data using multihop communication to the base station using the route obtained using AODV.

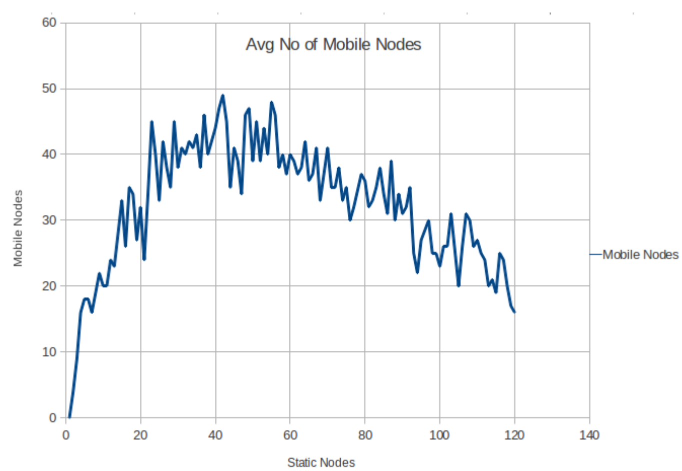

Fig. 4: Mobile nodes vs Static nodes

In order to determine the relation between the number of static nodes to the number of mobile nodes, a graph between the average number of mobile nodes required for a particular number of static nodes has been illustrated in Fig. 4.

In Fig. 4, the graph was generated by simulating the average number of mobile nodes required for a particular number of static nodes spread across an area of 1000m X 1000m with

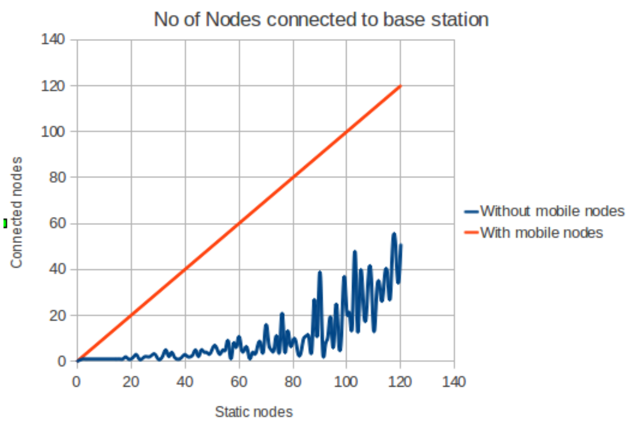

Fig. 5: Connected nodes vs Static nodes

each node having a range of 103.7m.

It can be inferred from Fig. 4 that the number of mobile nodes required to connect the network keeps increasing. Initially as the network is sparse, with an increase in the number of static nodes, the number of mobile nodes also increases. Gradually as the density of static nodes increases, the number of mobile nodes stabilizes. With further increase in density of static nodes the number of mobile nodes starts to decline. This is due to the fact that with an increase in density of static nodes there are lesser number of disconnected clusters formed and hence a lesser number of mobile nodes required.

Fig. 5 plots the number of static nodes deployed in the network to the number of static nodes connected to the base station. The straight line denotes the number of static nodes connected to the base station after mobile nodes have been deployed.

It can be seen that with the use of mobile nodes all the static nodes are connected to the base station. Whereas, without the use of mobile nodes there are static nodes which are unconnected to the base station. The number of nodes connected to base station keep increasing as the network becomes more dense.

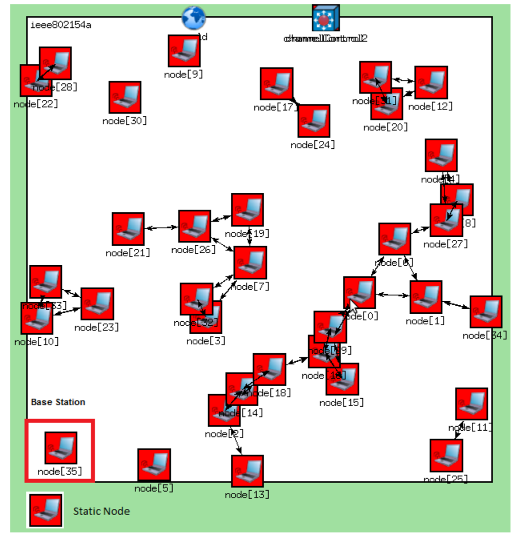

Fig. 6: Before assignment of mobile nodes

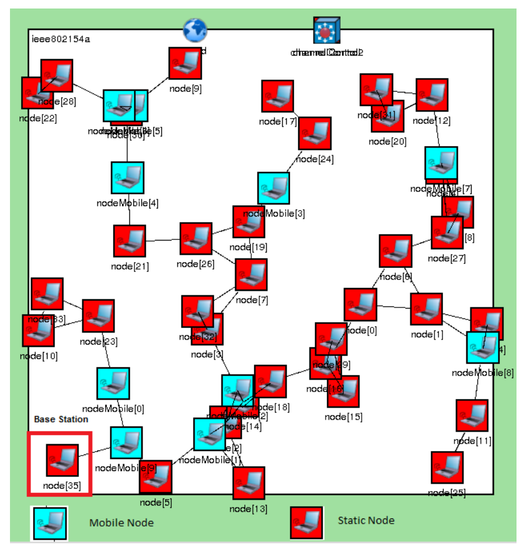

Fig. 7: After assignment of mobile nodes

Scenario

The algorithm has been simulated for a number of combinations of area and network size. One such scenario is illustrated in Fig. 6., which depicts a network of 36 nodes randomly deployed over an area of $700m \times 700m$ with the range of a node being 103.7m. The node 35 is designated as the base station.

Fig. 6 shows the screenshot of Omnet++ simulation with 36 nodes. As shown in the figure, clusters of nodes are formed which are disconnected from the base station. From Fig. 6 it is clear that none of the clusters are connected to the base station and hence the packet delivery is null.

Fig. 7 shows the screenshot of the simulation after applying the algorithm. The resulting network is connected to the base station with ten mobile nodes.

Once the mobile nodes are placed, the connectivity is established between all the nodes and the base station.The simulation results show that the base station received packets from all the nodes in the network, hence it can be inferred that all the nodes in the network are connected with the base station.

After the assignment of mobile nodes, the throughput has been measured as indicated in Table 1. The data in Table 1 is obtained by varying the delay time. Delay time refers to

TABLE1 : Throughput

Delay Time	Sending Rate(B/s)	Receiving Rate(B/s)	Throughput
0.5s	700	415.5	59.3
1s	350	230.5	65.8
2s	175	147.5	84.2

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the time interval between two successive transmissions of a sensor node.

ZigBee uses Carrier Sense Multiple Access (CSMA) to send a packet, so that it doesn't interfere with any of the transmission occurring in the vicinity. This causes hold up of some packets in the network thereby affecting the throughput. The throughput before deploying the mobile nodes is zero. The results in Table 1 show the throughput for different delay times after deploying the mobile nodes.

From the simulation results it is clear that the connectivity is established by optimally assigning mobile nodes in the network.

V. Conclusion and Future Work

The paper addressed the problem of connectivity in unstructured WSNs by using mobile nodes. The network architecture suggested in the paper is suitable for connectivity issues in large area WSNs. The paper uses ZigBee for majority of the communication leading to low power consumption and hence a low cost solution. Using this approach the number of mobile nodes required for connectivity are found to be minimal. The placement of mobile nodes has been optimised using a variant of the Hungarian algorithm and hence saves time. The throughput can be further improved by solving the problem of bottlenecks which arise at some points in the network. The plan for future work includes solving the problem of bottlenecks so as to improve the performance. optimised using a variant of the Hungarian algorithm and hence saves time. Considering large scale WSNs the approach suggested here can find many applications in sensor networks.

The future extension of this work consists of performance improvement in the network by removing bottlenecks and addressing the localisation issues. The throughput can be further improved by solving the problem of bottlenecks which arise at some points in the network. The plan for future work includes solving the problem of bottlenecks so as to improve the performance.

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References

[1] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Computer Networks*, vol. 52, no. 12, pp. 2292 – 2330, 2008. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1389128608001254

[2] Encyclopedia of triangle centres. [Online]. Available: http://faculty.evansville.edu/ck6/encyclopedia/ETC.html

[3] M. Di Francesco, S. K. Das, and G. Anastasi, "Data collection in wireless sensor networks with mobile elements: A survey," *ACM Trans. Sen. Netw.*, vol. 8, no. 1, pp. 7:1–7:31, Aug. 2011. [Online]. Available: http://doi.acm.org/10.1145/1993042.1993049

[4] C.-Y. H. Chih-Yung Chang, Chih-Yu Lin and Y.-J. Ho, "Patrolling mechanisms for disconnected targets in wireless mobile data mules networks," in *Parallel Processing (ICPP), 2011 International Conference on*, October 2011, pp. 30 – 41.

[5] R. Sugihara and R. Gupta, "Improving the data delivery latency in sensor networks with controlled mobility," in *Distributed Computing in Sensor Systems*, ser. Lecture Notes in Computer Science, S. Nikoletseas, B. Chlebus, D. Johnson, and B. Krishnamachari, Eds. Springer Berlin Heidelberg, 2008, vol. 5067, pp. 386–399.

[6] W. Seino, T. Yoshihisa, T. Hara, and S. Nishio, "A sensor data collection method with a mobile sink for communication traffic reduction by delivering predicted values," in *Proceedings of the 2012 26th International Conference on Advanced Information Networking and Applications Workshops*, ser. WAINA '12. Washington, DC, USA: IEEE Computer Society, 2012, pp. 613–618. [Online]. Available: http://dx.doi.org/10.1109/WAINA.2012.133

[7] F. Kuhn, T. Moscibroda, and R. Wattenhofer, "Initializing newly deployed ad hoc and sensor networks," in *Proceedings of the 10th annual international conference on Mobile computing and networking*, ser. MobiCom '04. New York, NY, USA: ACM, 2004, pp. 260–274. [Online]. Available: http://doi.acm.org/10.1145/1023720.1023746

[8] Zigbee alliance. [Online]. Available: http://www.zigbee.org

[9] S. H. Yujie Zhang, "The design of network coordinator based on zigbee and gprs technology," in *Proceedings of the 2012 International Conference on Computer Science and Electronics Engineering*, 2012.

[10] W. Z. Hujing, "Design of remote intelligent home system based on zigbee and gprs technology," in *Consumer Electronics, Communications and Networks (CECNet), 2012 2nd International Conference on*, 2012.

[11] H. W. Kuhn, "The hungarian method for the assignment problem," *Naval Research Logistics Quarterly.*, 1955.

[12] T. He, C. Huang, B. M. Blum, J. A. Stankovic, and T. Abdelzaher, "Range-free localization schemes for large scale sensor networks," in *Proceedings of the 9th annual international conference on Mobile computing and networking*, ser. MobiCom '03. New York, NY, USA: ACM, 2003, pp. 81–95. [Online]. Available: http://doi.acm.org/10.1145/938985.938995

[13] A. Bhatia and P. Kaushik, "A cluster based minimum battery cost aodv routing using multipath route for zigbee," pp. 1 –7, dec. 2008.

[14] H. Z. Qinghai Gao, "Improving probabilistic coverage and connectivity in wireless sensor networks: Cooperation and mobility," 2010.

[15] T. Horng-Wen Lee, Meng, "A low power gps receiver architecture," in *Global Telecommunications Conference, 1999. GLOBECOM '99*, 1999.

[16] E. S. Page, "A note on assignment problems," *Computer Journal 6*, p. 241243, 1963.

[17] Omnet++, discrete event simulation system. [Online]. Available: http://www.omnetpp.org