Finding Optimal Base Station Locations in Wireless Sensor Network Using Node Partitioning

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Abstract— The optimal Base Station (BS) location can improve the network lifetime in Wireless Sensor Network (WSN). In this paper, we proposed a new approach called node partitioning technique to find out the optimum BS locations. This new approach provides a good insight of BS location problem. An algorithm is also proposed based on this approach in our paper.

Keywords—Wireless Sensor Network, Minimum Enclosing Circle, Node Partitioning, Base Station, Cluster.

1 Introduction
WSN is a network of distributed sensors that can collect information from a physical environment. Low cost sensors are the backbone of a WSN. The improvement in small Scale computational devices has let the foundation for WSN. WSNs can be deployed for Node Tracking Scenarios/ Environmental Data Collection Scenarios/ Security Monitoring Applications [1][6]. The applicability of WSN in the practical domain has succeeded to draw the attention of researchers toward it.

A WSN is constrained by its limited resources. Sensors are driven by batteries and recharging the batteries is not a good option in WSNs. As a result, a great deal of efforts is made in each layer so that the network can be run for the maximum time. In the physical layer finding optimal locations for BS is important since a significant amount of energy is spent in the process of transmission and reception of signals. For a sensor node, most of the energies are spent in the transmission and reception process[1][6]. A small amount of energy is spent for sensing and processing comparing to the energy required for transmission and reception purpose. Thus energy consumption of a sensor node is distance dominated [9]. That is the farthest node will consume more power comparing to the nearest one. Because of the non-uniform distance from the BS, some nodes will die much earlier than other nodes. As a result, connectivity with some parts of the network is lost. For some applications, where connectivity throughout the network lifetime is of maximum priority; this scenario is undesired. That is why, a careful planning on BS locations can lengthen the network lifetime.

In a two tired network, two types of nodes are deployed and responsibility is divided among those nodes. The whole network is divided into clusters [1][6]. The low capable nodes perform sensing and relaying information to the Cluster-Head (CH). The CH, which has a higher capability than the other nodes aggregates the received information and transmit the information to the BS. The CHs consume more power comparing to the macro sensor nodes. The death of a CH can define the end of network operation where connectivity is of primary concern [9]. That is why, surveillance of CHs is very important in a two tired WSN.

This paper is organized as follows. In section II, we review related works. We specify the network model in section III. In section IV, we introduce a bi-partitioning technique and provide an algorithm based on it. We conclude the paper in section V.

2 Related Works

With the help of Particle Swarm Optimization (PSO) Hong et. al [2] tried to find out optimal positions of base
stations. PSO is a searching algorithm which performs well but convergence highly depends on the number of particle selection and number of generations. Pan et. al [9] introduced the concept of minimum enclosing circle to find optimal location for single BS not for multiple BSs. Hou et. al [3] provided a solution for multiple BS location where Aggregation and Forwarding Nodes (AFNs) can communicate with BS in multi hop. Hu et.al [4] worked on anycast routing based on a source based tree. Algorithms for BS locations in WSNs are also proposed in [7]. Our proposed approach can provide a good insight for optimal multiple BSs location.

### 3 Network model

A Two Tired Network is a network where macro-sensors send local information to the CH and CH sends the integrated local information to the BS [9]. A CH is a node which is superior to other nodes inside a cluster in terms of battery power and computational capability. A CH can communicate with the BS if the sum of the information signals transmitted by macro sensor nodes is above a certain threshold level [1]. This indicates that if some of the macro-sensor nodes die inside a cluster communication with that region might be possible if the CH can receive a signal above the predefined threshold level. But if any of the CH dies out, connectivity with that part of the network is lost and this phenomenon defines the end of network lifetime for those networks.

The network architecture is highly dependent on the application type. A significant amount of energy can be saved by choosing a heterogeneous network instead of a homogeneous network and applying clustering concept [1][6]. If we divide the whole network in clusters then each cluster represents a specific region in the network. The macro-sensor nodes are responsible to send the sensed data only to the CH. The CH aggregates all the data received from the macro-sensor nodes under it. The CH is responsible to send the aggregated data to the BS. The communication between the CH and the BS can be in single hop or in multi hop. For the applications, where a quick response is required from the network, direct communication between CH to BS is the desired one. Communication inside the cluster can be also in single hop or in multi hop [1][6]. Generally, communication in multi hop inside a cluster is the preferred one to reduce the energy consumptions of the energy-constrained macro-sensor nodes. In this paper, we investigate a two-tiered heterogeneous WSN, where macro-sensors communicate with the CH in multi-hop and CHs communicate with the BS in single hop and the death of first CH defines the end of operation.

### 4 Finding Optimal Locations for BSs

Let \( n \) is the number of clusters inside the network; therefore we have corresponding \( n \) CHs. According to the chosen definition for network lifetime, the farthest CH from the BS will define the network lifetime. The following equation for a node’s lifetime gives us this observation:

\[
l(i) = \frac{e(0)}{r \times (a_1 + a_2 \times d^b)}
\]

Where \( r \) is the data rate, \( a_1 \) is a distance independent parameter, \( a_2 \) is a distance dependent parameter, \( d \) is the distance from the node to a destination node or BS, \( b \) is the path loss exponent and is normally 2 or 4 based on the type of environment and \( e(0) \) is the initial energy of the Sensor node.

![Fig. 2 Four possible cases for optimum partition.](image-url)
The lifetime of the network is defined by

\[ L = \min \{l(i)\} \quad (2) \]

If we consider \( a_1 = 0 \) and \( a_2 = 1 \); we can write

\[ l(i) = \frac{e(0)}{r \times d^k} \quad (3) \]

By treating \( e(0) \) and \( r \) as constants we can organize the above equation like this

\[ l(i) = \frac{k}{d^k} \quad (4) \]

Where, \( k = \frac{e(0)}{r} \) which is a constant.

Pan et. al [9] proposed a minimum enclosing circle exists that can enclose all the CHs and center of that circle is the best location for locating a BS. A minimum enclosing circle can be drawn with a set of 2(3) critical CHs. The main idea was to minimize the maximum distance between a CH and a BS. If we want to place multiple BSs we can further reduce the maximum distance by optimally clustering the CHs. From those clusters we can find minimum enclosing circles and choose the centers as the location of BS.

4.1 “ClusterFormation” Algorithm

This algorithm has been proposed in this section:

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ClusterFormation :

1. AB ←The maximum distance formed by CHs A and B inside circle C.
2. R ← A perpendicular line on AB that separates A and B.
3. CD ← The maximum distance formed by CHs C and D inside any cluster.
4. START LOOP.
5. If C, D resides with B
6. Else If CD < AC and CD < AD
7. Transfer D to A’s cluster.
8. Else If inclusion of D makes a distance with some CHs (set S) greater than CD
9. Transfer D to A’s cluster and S to B’s cluster.
10. Else If CD < AD and CD > AC
11. If inclusion of C does not increase distance inside new cluster
12. Transfer C to A’s cluster.
13. Else If inclusion of C makes a distance with some CHs (set S) greater than CD
14. Transfer C to A’s cluster and S to B’s cluster.
15. Else
16. BREAK LOOP.
18 Else If CD < AD and CD > AC
19. If inclusion of C does not increase distance inside new cluster
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20. Transfer C to A’s cluster.
21. Else if inclusion of C makes a distance with some CHs (set P) greater than CD
22. Then
23. If transferring those clusters do not make a distance greater than CD within B’s cluster
24. Transfer C to A’s cluster and P to B’s cluster.
25. Else
26. BREAK LOOP.
27. Else
28. Do steps 10 to 15.
29. Do steps 19 to 24.
30. Select the partition for which distance is less between two CHs.
31. Else
32. BREAK LOOP.
33. Else
34. Repeat step 7 to 33 replacing B with A.
35. END LOOP.
36. RETURN Clusters.

4.2 Correctness of the algorithm for Cluster formation
If A and B are the two CHs at maximum distance inside the minimum enclosing circle C an arbitrary line R that separates the two CHs in two regions. The objective of the line is to form clusters for which the maximum distance between any two CHs is minimized.

From the two clusters formed by line R, C and D are the two CHs that are at maximum distance and reside with B. The possibility of separating the two CHs can be decided from the triangle ACD.

Case 1: CD is less than AC and AD (Fig 2(a))
Case 2: CD is less than AC but greater than AD (Fig 2(b))
Case 3: CD is less than AD but greater than AC (Fig 2(c))
Case 4: CD is greater than AC and AD (Fig 2(d))

For case 1, separation of C and D in two clusters is not possible as the distance will be increased farther.
For case 2, D can be transferred to the other cluster to reside with A to minimize maximum distance.
For case 3, C can be transferred to the other cluster to reside with A to minimize maximum distance.
For case 4, any of C and D can be transferred to reduce maximum distance; the choice is made upon farther minimizing the distance inside the clusters.
Same discussion can be made if C and D reside with B.
Partition of C and D is defined by the above 4 cases. If the insertion of a new CH does not make a distance with another CH inside the cluster that is greater than CD then the separation gives the optimum clustering (Fig 3(a), 4(a), 5(a)). But if the insertion of new CH makes a distance greater than CD with any other CH, say E within the new cluster then C can only reside within the cluster if E is transferable to the other cluster(Fig 3(b), 4(b), 5(b)). If insertion of E in the new cluster does not make a distance greater than CD with any other CH then C can reside with B by transferring E to reside with A. Otherwise C and D can not be separated (Fig 3(c), 4(c)). Similar discussion goes with case 3. For case 4, separation of any of C and D can give optimum clustering if separation is possible. If only one of them can change cluster, then that gives optimum clustering.
For the case where both are separable, investigation has to be made by transferring C(D) at a time. From the resulting partitions we take the one for which the maximum distance between any two CH inside the region is minimized. The optimum partitions are indicated in (Fig 3(d), 4(c), 5(e), 5(j)).

By repeating the above process we can achieve the optimum partition that gives us two clusters for which the maximum distance between any two CHs inside a cluster is minimized. At this point two minimum enclosing circles, one for each cluster can provide us with the solution of BS locations and the centers of those circles are the best position for locating BS.

4.3 “MinEncloseCircle” Algorithm
We propose “MinEncloseCircle” algorithm for computing minimum enclosing circle:

MinEncloseCircle:
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1. C1 ← A circle that encloses all the CHs.
2. A ← The first point on the perimeter of the reduced circle C2.
3. B ← The second point on the perimeter of the reduced circle C3.
4. O ← The middle point of AB.
5. C ← The third point on the reduced circle C4.
6. O1 ← Center of C4.
7. If AB is the diameter of C3
8. Then O is the optimal position.
9. Else
10. O1 is the optimal position.

4.4Correctness of the algorithm for minimum enclosing circle
Finding minimum enclosing circle with minimum radius is a well studied problem in computational
geometry. It is always possible to find a circle $C_1$ that can enclose all the CHs (Fig 6(a)). We reduce the circle $C_1$ until a circle $C_2$ is found which goes through a CH(A) (Fig 6(b)). By reducing $C_2$ to $C_3$ at least two CHs(A and B) can be achieved on the perimeter of the circle(Fig 6(c)). If these two CHs lie on the diameter of the circle further minimizing the area of the circle is not possible and $C_3$ is the minimum enclosing circle. If the two CHs do not lie on the diameter we reduce the area of the circle $C_3$ to $C_4$ so that the third CH(C) is achieved on the circle (Fig 6(d)). This is the minimum enclosing circle and further minimization is not possible as we try to reduce the area of the circle at least one of the three CHs will get out of the circle.

Algorithm for multiple BS MultipleBSAlgo :

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MultipleBSAlgo
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1. Run ClusterFormation
2. For each cluster
   Run MinEncloseCircle
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For multiple BSs, we further reduce the maximum distance using optimal (reducing the maximum distance between two CHs inside Clusters) clustering the CHs and from those clusters we find minimum enclosing circles and choose the centers as the location of BS.

5 Conclusions
In this paper, we figured out the optimal positions of BS locations through a geometrical approach and provided an algorithm that can take care of the optimal location problem. Since the energy consumption of a CH increases along with the distance from the BS, the algorithm provides a solution to minimize the maximum distance between a CH and a BS. We integrated the concepts of computational geometry in the field of WSN. For finding optimal locations for more than two BSs, the concept of partitioning can be used but we will require a number of optimal partitions equal to the number of BSs.

References:


