Optimal Placement of Base Stations in a Two Tiered Wireless Sensor Network

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Abstract: - The optimal placement of base stations in a two tiered wireless sensor network (WSN) can reduce the energy consumption of sensor nodes (SN) and thus can improve network lifetime. In our paper, we address the base station location problem and provide a geometrical solution introducing a new concept called node partitioning technique. An algorithm based on the geometrical approach is also provided in the paper.

Key-Words: - Wireless sensor network, Minimum enclosing circle, Node partitioning, Base station, Cluster, Geometry.

1 Introduction

A wireless sensor network (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 the small scale computational devices leads the practical implementation of a WSN which comprises of hundreds and thousands of physically embedded sensor nodes. The basic components of a sensor node are 1) a sensing unit 2) a processing unit and 3) a transceiver unit. The sensing unit could be temperature, humidity, light, smoke, magnetic field, acoustic, passive IR, photosynthetic light sensor. A processing unit typically consists of micro-controller integrated with flash storage, RAM, analog-to-digital converters, digital I/O ports. A transceiver unit includes RF Monolithic TR1000 and Chipcon 1000 and it is the primary consumer of power. The applications of WSN are node tracking scenarios, environmental data collection scenarios, security monitoring etc. [2] [9].

The sensors in a WSN are driven by batteries and recharging the batteries is not a good option in WSNs. Therefore, 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 location of BS is important as energy consumption of a sensor node is distance dominated [14] which means the farthest node will consume more power comparing to the nearest one. Due to 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. In some applications, connectivity throughout the network lifetime is of maximum priority. Therefore, a careful planning on BS locations can lengthen network lifetime.

The whole network is divided into clusters [2] [9] in a two tiered WSN where two types of nodes are deployed and the responsibility is divided among those nodes. The low capable nodes perform sensing and relaying information to the Cluster-Head (CH). The CH, which has a higher capability than 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 [14]. Hence, surveillance of CHs is very important in a two tiered WSN.

This paper is organized as follows: In section 2, related works have been reviewed. The network model has been specified in section 3. In section 4, we introduce a new technique called node-partitioning and provide an algorithm based on it. In section 5, we provide a solution of an existing problem and conclude the paper in section 6.

2 Related Works

Hong et. al tried to find out optimal positions of base stations using Particle Swarm Optimization (PSO) in [5] .PSO is a searching algorithm which performs well but convergence highly depends on the number of particle selection and number of generations. PSO in [5] provides different set of outputs (BS locations) under the same conditions (particle initialization, search space) and for same inputs (CHs locations) during multiple runs which arises confusion for network designers. Pan et. al [14] introduced the concept of minimum enclosing circle to find optimal location for single BS, not for multiple BSs . Hou et. al [6] provided a solution for multiple BS locations where aggregation and forwarding nodes (AFNs) can communicate with BS in multi hop . Hu et.al [7] worked on anycast routing based on a source based tree. Optimal BS locations in two tiered WSN are also investigated in [10] [15-16]. An energy efficient unicast routing protocol is proposed in [11]. A multi cast routing protocol is proposed in [3].

In our paper, we have proposed a new approach that can provide a good insight for optimal multiple BSs location and it does not suffer from convergence issue and also provide the benefits of our proposed scheme

3 Network Architecture

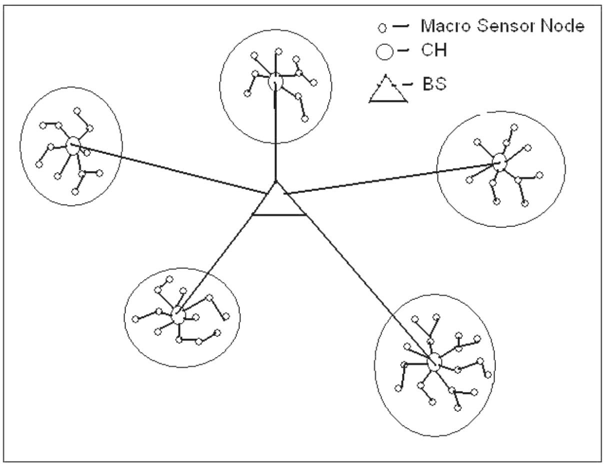

Fig. 1 Two-tiered Wireless Sensor Netwrok (WSN).

In a two tiered WSN, macro-sensors send local information to the CH and CH sends the integrated local information to the BS [14]. The communication between a macro sensor node and the BS is divided into two segments. 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 total power of the information signals that is transmitted by macro sensor nodes is above a certain threshold level [2]. 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 CHs dies out, connectivity with that part of the network is lost and this phenomenon defines the end of network lifetime. Since two types of nodes are deployed for network operation, the network is a heterogeneous network. A detailed explanation of heterogeneity and hierarchy can be obtained from [4], [17].

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]. Techniques to form clusters can be found in [1]. 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 [2][9]. 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 (inter cluster routing) and CHs communicate with the BS in single hop (intra cluster routing) and the death of first CH (N out of N definition) defines the end of network operation.

4 Finding Optimal Locations for BSs

Let n be the number of clusters inside the network which corresponds to n cluster heads (CHs). According to the chosen definition for network lifetime, the farthest CH from the BS defines the network lifetime while data rate is considered as a constant. The following equation for i th CH's lifetime gives us the above observation

$$l(i) = \frac{e(0)}{r \times (a_1 + a_2 \times d^b)} \quad (1)$$

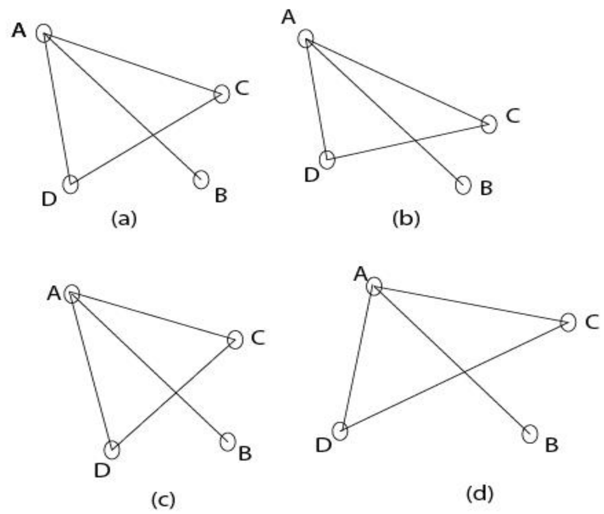

Fig. 2 Four possible cases for optimum partition.

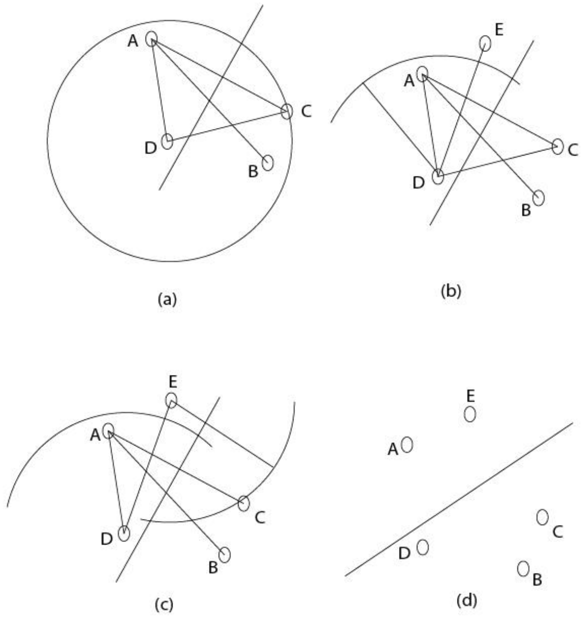

Fig. 3 Optimum partition for case 2.

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 CH to a destination CH 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 CH.

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

$$l(i) = \frac{e(0)}{r \times d^b} \quad (3)$$

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

$$l(i) = \frac{k}{d^b} \quad (4)$$

Expression (4) gives us a clear idea about the impact of variable d . It is observed that the farthest CH from the BS will have the minimum lifetime among all the CHs. According to the chosen definition for network lifetime (N out of N), the farthest CH from the BS also determines the network lifetime. Therefore, minimization of the maximum distance between a CH and the BS ensures the maximization of network lifetime. Pan et. al [14] 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 or 3 critical CHs. The main idea was to minimize the maximum distance between a CH and a BS. For multiple BS locations, we can farther reduce the maximum distance by optimally clustering the CHs and from these clusters, we can find minimum enclosing circles and the centers of those circles correspond to the optimal locations of BSs.

4.1 "ClusterFormation" Algorithm

This algorithm has been proposed in this section:

_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. **Then**
7. **If** CD < AC and CD < AD
8. **BREAK LOOP.**
9. **Else If** CD < AC and CD > AD
10. **If** inclusion of D does not increase distance inside new cluster
    Transfer D to A's cluster.
11. **Else If** inclusion of D makes a distance with some CHs (set S) greater than CD
12. **Then**
13. **If** transferring those clusters do not make a distance greater than CD within B's cluster
14. Transfer D to A's cluster and S to B's cluster.
15. **Else**
16. **BREAK LOOP.**
17. **Else If** CD < AD and CD > AC
18. **If inclusion** of C does not increase distance inside new cluster
19. Transfer C to A's cluster.
20. **Else If** inclusion of C makes a distance with some CHs (set P) greater than CD
21. Then
22. **If** transferring those clusters do not make a distance greater than CD within B's cluster
23. Transfer C to A's cluster and P to B's cluster.
24. **Else**
25. **BREAK LOOP.**
26. **Else**
27. Do steps 10 to 15.
28. Do steps 19 to 24.
29. Select the partition for which distance is less between two CHs.
30. **Else**
31. **BREAK LOOP.**
32. **Else**
33. Repeat step 7 to 33 replacing B with A.
34. **END LOOP**.
35. **RETURN** Clusters.

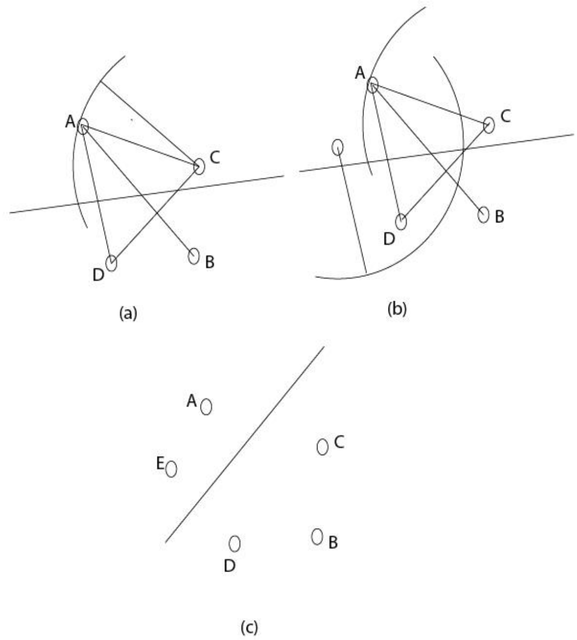

Fig. 4 Optimum partition for case 3.

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 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)). 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.

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 have proposed "MinEncloseCircle" algorithm for computing minimum enclosing circle:

MinEncloseCircle:

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.

4.4 Correctness 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 C1 that can enclose all the CHs (Fig (6(a)). We reduce the circle C1 until a circle C2 is found which goes through a CH (A) (Fig 6(b)). By reducing C2 to C3 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 C3 is the minimum enclosing circle. If the two CHs do not lie on the diameter we reduce the area of the circle C3 to C4 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 :

MultipleBSAlgo

1. Run ClusterFormation
2. For each cluster
   Run MinEncloseCircle

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. The whole idea is illustrated in fig.7.

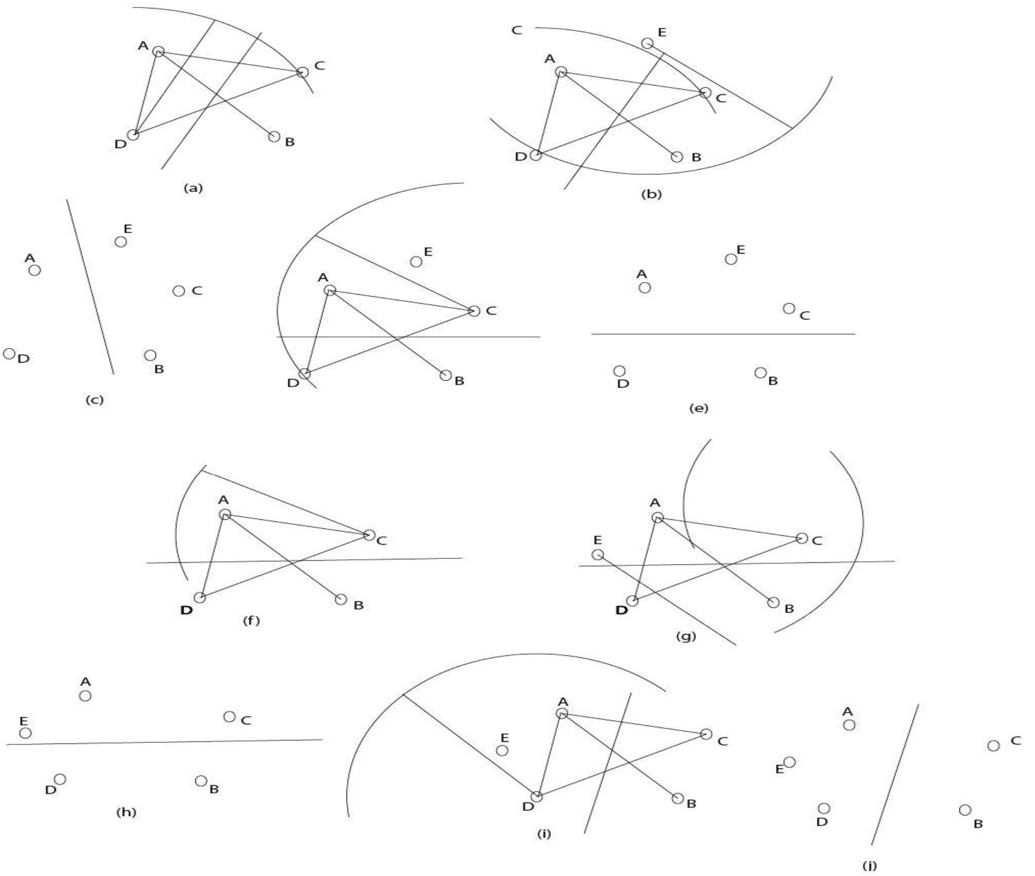

Fig. 5 Optimum partition for case 4.

5 Benefits of Geometrical Solution

Our proposed geometric solution provides us the following benefits:

1. A solution for optimal base station locations based on an optimization algorithm suffers from convergence issue. Our proposed geometrical solution successfully discards the convergence issue.

2. As we do not get same set of outputs for multiple runs of PSO, under same conditions and for same set of inputs, this phenomenon arises confusion. Someone might ask, "Which solution should I take?" Our geometrical approach eliminates this type of confusion.

We argued that if we can produce optimum (minimizing the maximum distance between two CHs) clusters then we can figure out the optimal locations for BSs by finding minimum enclosing circles for each cluster. If the maximum distance between any two CHs is D, then we can find a minimum enclosing circle with radius d and the limit of d is given by

$$D/2 \le d \le \sqrt{3}D/2 \quad \ldots\ldots\ldots\ldots\ldots(5)$$

It can be showed that the maximum distance between a CH and a BS is d. Since we need a set of 2 or 3 CHs on the perimeter of the circle to obtain the minimum enclosing circle, the maximum distance between a BS and a CH is equal to the distance between the center and the perimeter of the circle. For multiple BS locations, we need to form clusters in a way so that the maximum distance between any two CHs inside a cluster is minimized. Notice that inside the clusters the maximum distance between any two CHs may be same or may not be same. Consequently, the area

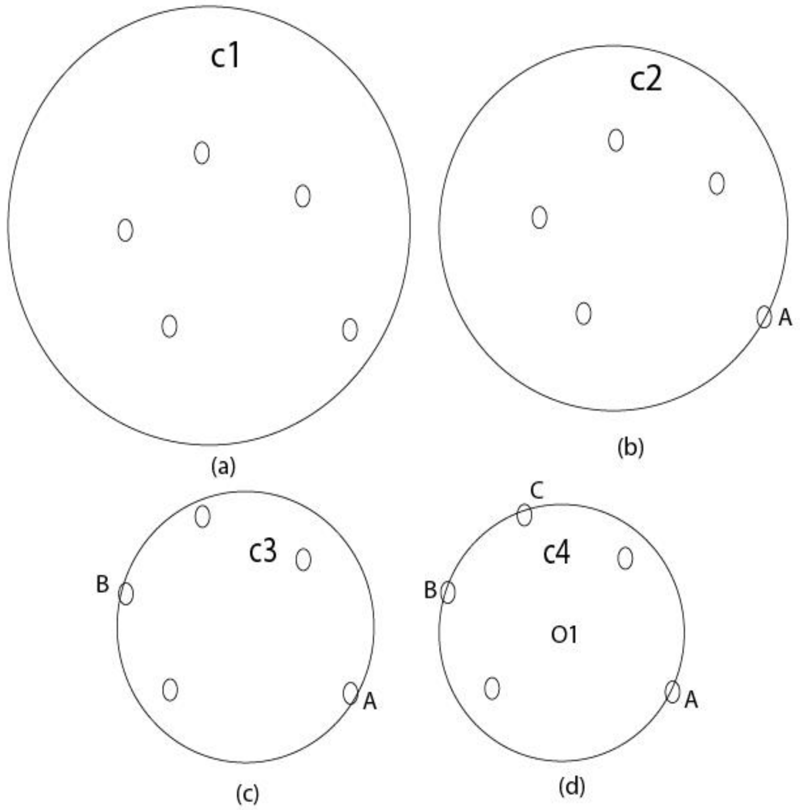

Fig. 6 Minimum enclosing circle.

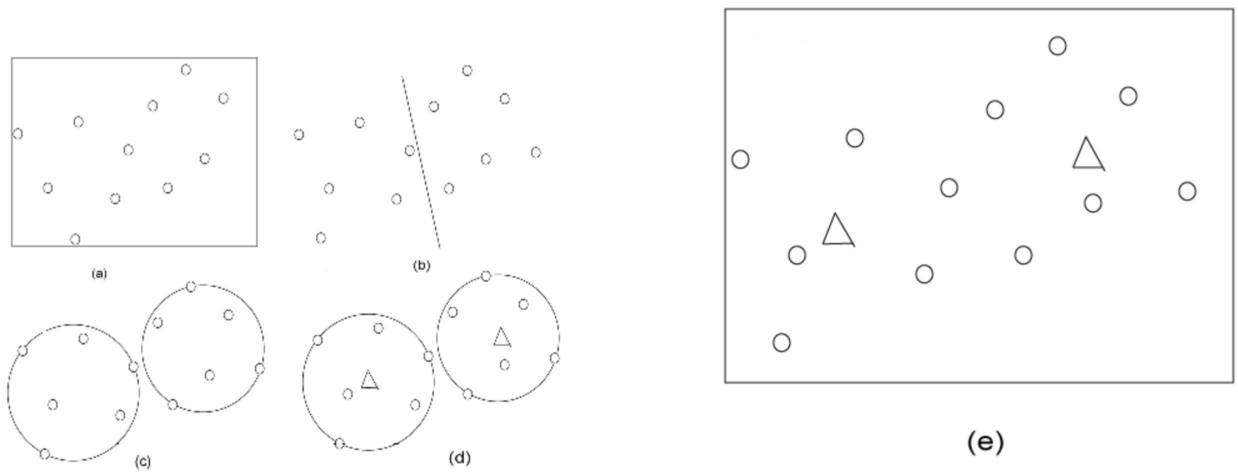

Fig. 7 : Selection of BS locations using node partitioning technique

of the minimum enclosing circles for each clusters are not the same. From the circles, the one with maximum area will determine a fixed optimal position that will not be altered as we run PSO at different times and the point corresponds to the center of that circle. Also, the maximum distance between a BS and a CH is determined from that circle and the distance is equal to the radius (say d_1) of that circle. For the other clusters, if we select a point other than the center of the minimum enclosing circle and if the point does not make a distance with any of the CHs from the cluster greater than d_1, the objective function is satisfied. Hence, we get different results as we run PSO at different times. We take the previous example:

Suppose we form two clusters (cluster A and cluster B) using node partitioning technique. Let C and D are the two CHs inside cluster A make the maximum distance (D1). Inside cluster B, E and F make the maximum distance (D2). Moreover,

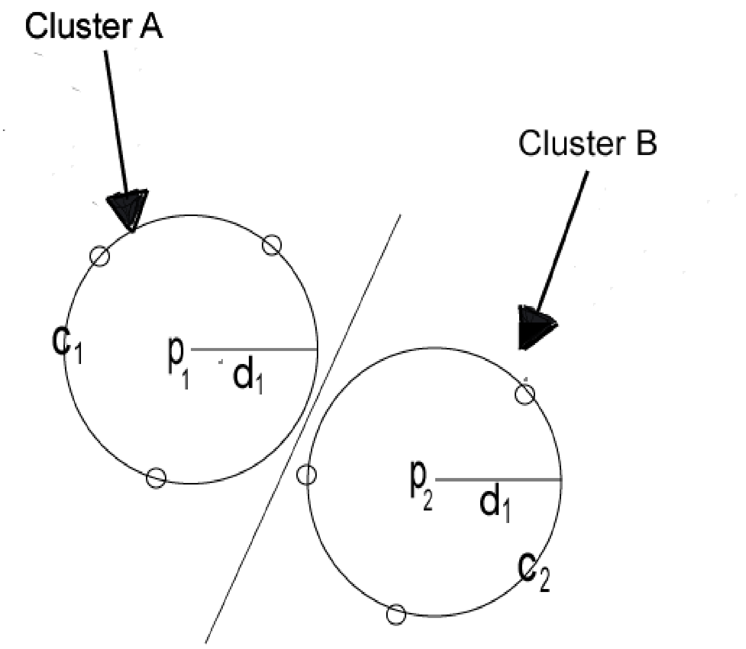

Fig.8 (a) Two circles with same area

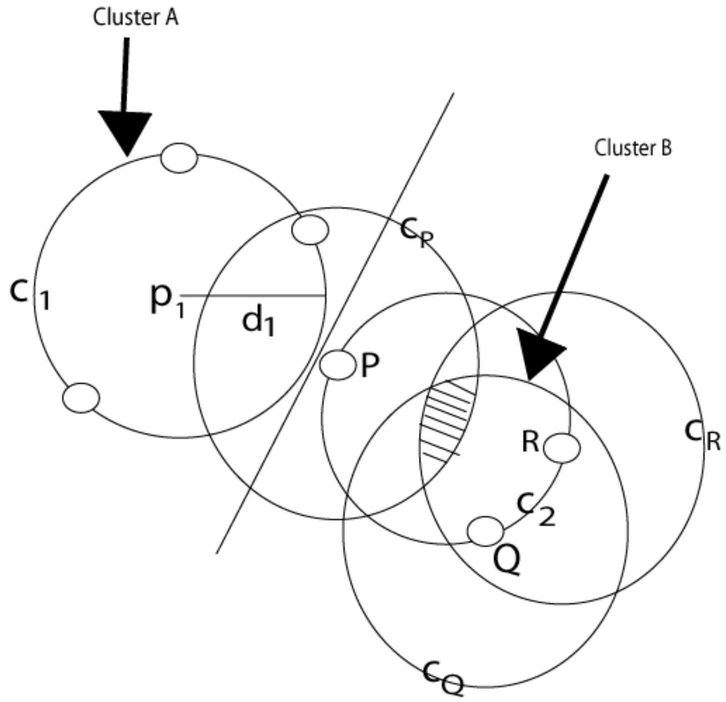

Fig.8 (b) Two circles with different area

expression (5) depends on the arrangement of the CHs. That is why; it is less likely to obtain two minimum enclosing circles with exactly same area. For the case, we get two minimum enclosing circles with same area; it is guaranteed that we are going to get exactly two optimal points as the solution (fig.8 (a)). Otherwise, we have a set of points for which the objective function (maximizing network lifetime) is satisfied.

3. A geometrical approach provides a better insight of the optimal base station locations

problem. Through our geometrical approach we can provide a boundary region for the possible sets of outputs.

Let c1 and c2 are the two minimum enclosing circles for cluster A and cluster B respectively, the area of c1 is greater than c2 and d1 is the radius of the circle c1. Centering the CHs that lie on the perimeter of the circle and taking d1 as the radius if we draw circles then the common region of the circles gives us the optimal set of points. In fig.8 (b) P, Q and R are the three CHs that lie on the perimeter of the circle c2. Centering P, Q and R and taking d1 as the radius we draw circles c_p, c_Q and c_R. The set of points must lie inside the shaded region to satisfy the objective function.

$$Set\ S = C_P \cap C_Q \cap C_R$$

6 Conclusion

In this paper, we have figured out the optimal BS locations through a geometrical approach and provided an algorithm that can take care of the optimal location problem. The energy consumption of a CH increases whenever the distance between CH and BS increases and our algorithm provides a solution to minimize the maximum distance between a CH and a BS. We have also explained a problem that is discovered in [2]. For finding optimal locations for more than two BSs, the concept of partitioning can be used but will require a number of optimal clusters equal to the number of BSs.

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