International Journal of Scientific Research in Computer Science, Engineering and Information Technology
 | Volume 2 | Issue 4 | ISSN : 2456-3307

Sensor Deployment with Limited Communication Range in Homogeneous and Heterogeneous Wireless Sensor Networks

S. Nagi Reddy[1], Swamy Polgoni[2], Sudarshan Bandi[2]

[1]Associate Professor, Teegala Krishna Reddy Engineering College, Telangana, India

[2]Assistant Professor, Teegala Krishna Reddy Engineering College, Telangana, India

ABSTRACT

We study the heterogeneous wireless sensor networks (WSNs) and propose the necessary condition of the optimal sensor deployment. Similar to that in homogeneous WSNs, the necessary condition implies that every sensor node location should coincide with the centroid of its own optimal sensing region. Moreover, we discuss the dynamic sensor deployment in both homogeneous and heterogeneous WSNs with limited communication range for the sensor nodes. The purpose of sensor deployment is to improve sensing performance, reflected by distortion and coverage. We model the sensor deployment problem as a source coding problem with distortion reflecting sensing accuracy. Traditionally, coverage is the area covered by the sensor nodes. However, when the communication range is limited, a WSN may be divided into several disconnected sub-graphs. Under such a scenario, neither the conventional distortion nor the coverage represents the sensing performance as the collected data in disconnected subgraphs cannot be communicated with the access point. By defining an appropriate distortion measure, we propose a Restrained Lloyd (RL) algorithm and a Deterministic Annealing (DA) algorithm to optimize sensor deployment in both homogeneous and heterogeneous WSNs. Our simulation results show that both DA and RL algorithms outperform the existing Lloyd algorithm when communication range is limited.

Keywords : Sensor Deployment, Homogeneous, Heterogeneous, Source Coding, Coverage.

I. INTRODUCTION

As a bridge between the physical world and the virtual information word, wireless sensor networks (WSNs) collect data from the physical world and communicate it with the virtual information world, such as computers. Proper sensor deployment improves monitoring and controlling the physical environment. To accomplish their tasks, WSNs should address two needs: (i) Sensing in the target area and (ii) Communication between the sensor nodes. WSNs are utilized to collect physical information, such as temperature, humidity, voice and so on. But, the collected data is useless if it cannot be transmitted to the access point (AP) and to the outside information world through the AP node. When sensors are connected by wire lines, the connectivity is provided automatically. On the other hand, the connectivity of WSNs is not guaranteed. In this paper, we consider the sensing and connectivity together and redefine the goal of WSN design accordingly. A huge body of literature exists on the topic of sensor deployment.

The sensor coverage range model assumes that sensors can only monitor the points within a range of Rs. The range Rs is called the sensing range and the coverage area is the area covered by at least one sensor node [1]. Three different connectivity criteria are proposed in [2]. Three movement-assisted protocols, the VECtor-based algorithm, the VORonoi-based algorithm and the Minimax algorithm, are designed to maximize coverage area in [3]. Lloyd algorithm has also been used as a tool to deploy sensors in homogeneous WSNs [1]. The convergence of the Lloyd algorithm has been studied in [4]– [6]. The analysis in [4]-[6] can be applied to the sensor deployment methods in [1]. However, [1] assumes an infinite communication range and ignores the connectivity limitation. When an infinite communication range is assumed, all the nodes in the network are connected to each other. In reality, each node has a limited communication range that will affect the connectivity of the network [7], [8].

A geometric analysis of the relationship between the sensing coverage and the connectivity is proposed in [9]. In [10], the authors have come up with some deployment patterns to achieve both sensing coverage and full connectivity. Unfortunately, given a fixed number of sensor nodes and a finite communication range, connectivity is not guaranteed. When sensor nodes are divided into several disconnected subgraphs, the conventional Lloyd algorithm cannot converge to a proper deployment. The Critical Sensor Density (CSD) in [11] is the number of nodes per unit area, required to provide full sensing coverage when the communication range is limited. When the sensor density is smaller than CSD, we cannot achieve the full sensing coverage. Under such a scenario, coverage may not be the right cost function to optimize. One needs to define an appropriate distortion measure to reflect the sensing accuracy.

Distortion, as an important parameter in source coding can also be used to evaluate the WSN performance. Therefore, one can minimize distortion in WSNs through vector quantization techniques in [12] and [13]. The best possible distortion for a given number of sensors, i.e., the minimum distortion for a given rate, can be analyzed through the rate-distortion theory [?]. Even if the sensor density is larger than CSD, there is no existing sensor deployment algorithm designed to achieve the full connectivity and minimize the distortion at the same time. In this paper, when the communication range is limited, we take both distortion and connectivity into consideration. The existing coverage area model is a special case of our distortion measure. We propose a method, named Restrained Lloyd (RL) Algorithm, to distribute sensor nodes and to minimize distortion with full connectivity.

Then, a more complex approach, named Deterministic Annealing (DA) Algorithm, is designed to avoid sub-optimal solutions. In many practical situations, different sensors in the WSN have different characteristics such as computational power, sensing range, and sensing accuracy. The deployment and topology control of such heterogeneous WSNs that include the sensor nodes with different communication or sensing ranges, have been studied in [15] and [16]. Similar to [3], three movement-assisted protocols in [15] are designed to avoid coverage hole in heterogeneous WSNs. However, [16] deploys sensor nodes one-by-one and to deploy a new sensor uses the location information of all previously deployed nodes. Also, [16] assumes that sensor can monitor events within a circle with the radius equal to the sensing range. We generalize this model to a sensing accuracy which depends on the distance between the sensor and the event. Our distortion model will include the sensing range model in [16] as a special case in which the distortion is a step function. In such heterogeneous WSNs, weighted Voronoi diagrams [17] rather than conventional Voronoi diagrams [18] will provide the best regions as we will discuss in this paper. An algorithm to construct weighted Voronoi diagrams for a different application has been suggested in [19]. Based on the geometry of the optimal cell partitioning, we will analyze the objective functions in our model and propose the necessary condition for the optimal sensor deployment in heterogeneous WSNs with different sensing abilities.

II. PERFORMANCE EVALUATION

We compare the performance of RL Algorithm, DA Algorithm and Lloyd Algorithm in sensor networks. We provide simulations in three sensor networks: (1) WSN1: A homogeneous WSN in which all sensors have the same cost parameter $\eta i = 1, i = 1, \cdots, 16$; (2) WSN2: A heterogeneous WSN including 2 kinds of sensors: four strong sensors with $\eta i = 1$ and twelve weak sensors with $\eta j = 16$; (3) WSN3: A heterogeneous WSN including three kinds of sensors: two strong sensors with $\eta i = 1$, four medium sensors with $\eta j = 4$ and ten weak sensors with $\eta k = 16$. Sixteen sensors are provided in each sensor network. The AP is chosen from the sixteen sensors randomly. However, when we report the distortion or coverage area for the Lloyd algorithm, we report that of the largest connected subgraph which may not be connected to theAP. Obviously, this will be advantageous for the Lloyd algorithm, but our proposed algorithms still outperform the Lloyd algorithm. We use ten random initial deployments for each algorithm. To have a fair comparison, we consider the same target domain Q as in [1]. Q is determined by the polygon vertices (0,0), (2.125,0), (2.9325,1.5), (2.975,1.6), (2.9325,1.7), (2.295,2.1), (0.85,2.3), (0.17,1.2). The distribution of the events is also the same as [1].

The probability density function is the sum of five Gaussian functions of the form $5\exp(6(-(x - xcenter)$ $2 - (y - ycenter)$ 2)). The centers (xcenter, ycenter) are (2,0.25), (1,2.25), (1.9,1.9), (2.35,1.25) and (0.1,0.1). We use 0.5 as the communication range Rc. Also, when reporting the coverage area using (4), we use 0.25 as the sensing range Rs. In DA Algorithm, the first candidate is accepted at the ith iteration by a probability of $p(i) = \log(i + 1)/\log(N + 1)$, where N is the number of regular iterations. Additional $M = 25$ iterations are used in DA Algorithm to avoid ending with a process that increases the local distortions. Figs. 1a and 1b show one example of the initial and the finial deployments of Lloyd Algorithm in WSN1. Lloyd Algorithm assumes an infinite communication range and requires the global knowledge of the sensor locations. Otherwise, disconnected sub-graphs run Lloyd Algorithm independently and there is no guarantee for convergence. Nonetheless, the calculation of the final distortion only considers sensors in the backbone network. In the final deployment of the example in Fig. 1b, there are four sensors disconnected from the backbone network, resulting in a large distortion D(P) = 2.21. Fig. 1c shows the outcome of RL Algorithm in WSN1. After 500 iterations, the distortion is decreased from 11.30 to 0.60. Simultaneously, the coverage area is increased from 0.15 to 6.26 and the final deployment is connected. Fig. 1d shows the final deployment of DA Algorithm in WSN1. After 500 iterations, the distortion is decreased from 11.30 to 0.32, which is better than that of RL Algorithm. Simultaneously, the coverage area is increased from 0.15 to 6.99 and full connectivity is provided. Unlike Lloyd Algorithm, both RL Algorithm and DA Algorithm guarantee connectivity. Fig. 2 illustrates the performance of the above algorithms for 10 random initial deployments. As can be seen from the figure, unlike other algorithms, the performance of DA Algorithm is not sensitive to the initial deployment. In other words, DA Algorithm avoids most poor local minimum solutions. Fig. 2 shows that DA Algorithm has the best performance among the three algorithms. Fig. 3 compares the final coverage area of RL Algorithm and DA Algorithm with that of Lloyd Algorithm. In most cases, decreasing the distortion results in increasing the coverage area as well. Intuitively, this behavior can be explained by considering coverage area as a hard-decision version of distortion. Next, the relationship between performance (distortion and coverage area) and communication range Rc in homogeneous WSN1 using DA Algorithm is depicted in Fig. 4. Figs. 5a and 5b show one example of the initial and the finial deployments of Lloyd Algorithm in WSN2. As usual, the final distortion only considers sensors in the backbone network. Initially, two strong sensors and four weak sensors are consisted in the backbone network shown in Fig.

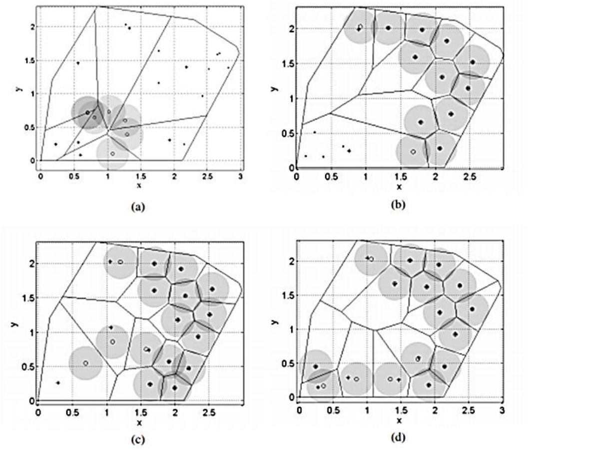

Fig. 1. Sensor deployments in WSN1. (a) The initial sensor deployment and the corresponding Voronoi regions. (b) The final deployment of Lloyd Algorithm after 500 iterations. (c) The final deployment of RL Algorithm after 500 iterations. (d) The final deployment of DA Algorithm after 500 iterations. Sensors in the backbone network are marked by circles. Sensors disconnected from the backbone network are denoted by dots. Voronoi region centroids are marked by stars. The radius of each gray circle is $R_c/2 = 0.25$.

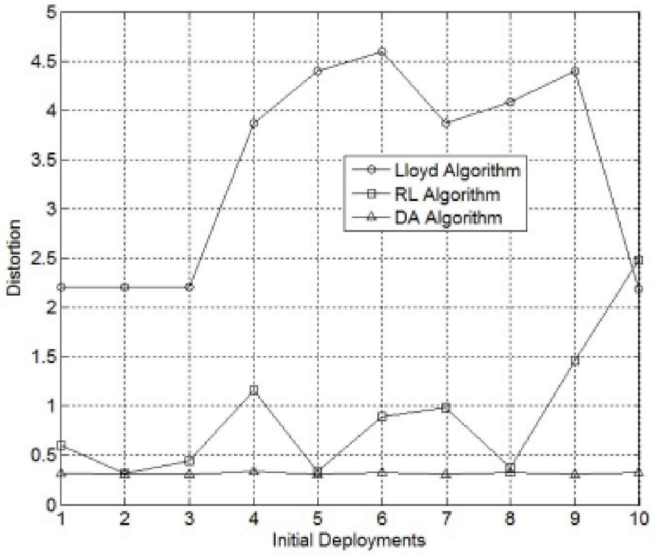

Fig. 2. Comparison of distortion for different algorithms in WSN1.

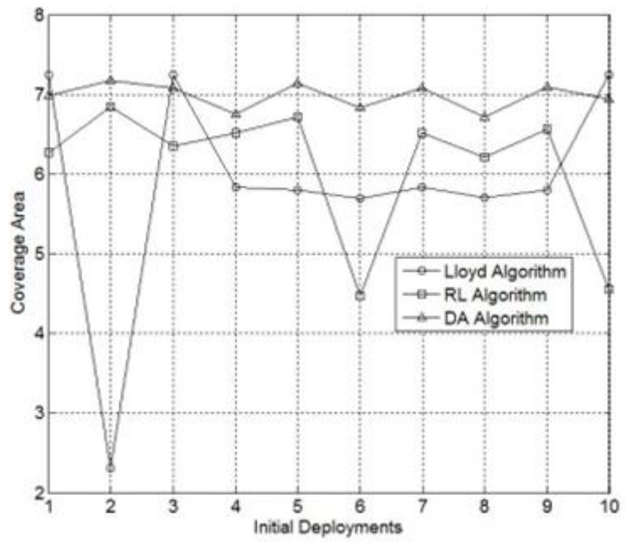

Fig. 3. Comparison of coverage for different algorithms in WSN1.

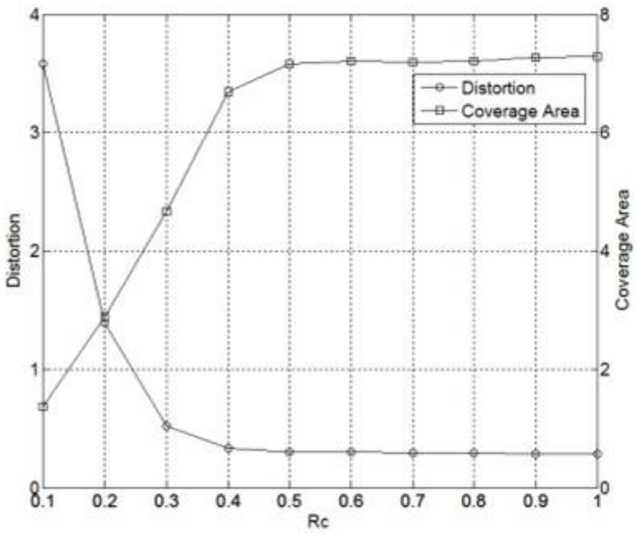

Fig. 4. Relationship between performance and Rc in WSN1.

5a. In Fig. 5b, only one strong sensor and four weak sensors are included in the backbone network, resulting in a large distortion D(P) = 12.67 which is only 0.48 smaller than the initial distortion. Fig. 5c shows the outcome of RL Algorithm in WSN2. After 500 iterations, the distortion is decreased from 13.15 to 5.52. Simultaneously, the coverage area is increased from 0.08 to 1.46 and the final deployment is connected. Fig. 5d shows the final deployment of DA Algorithm in WSN2. After 500 iterations, the distortion is decreased from 13.15 to 1.10, which is better than that of RL Algorithm. Simultaneously, the coverage area is increased from 0.08 to 2.48 and full connectivity is provided. Figs. 6a and 6b show one example of the initial and the finial deployments of Lloyd Algorithm in WSN3. Initially, one strong sensor, two medium sensors and four weak sensors are consisted in the backbone network shown in Fig. 6a. In Fig. 6b, two strong sensors, one medium sensors and one weak sensors are disconnected from the backbone network, resulting in a large distortion D(P) = 19.83. Fig. 6c shows the outcome of RL Algorithm in WSN3. After 500 iterations, the distortion is decreased from 10.96 to 3.22. Simultaneously, the coverage area is increased from

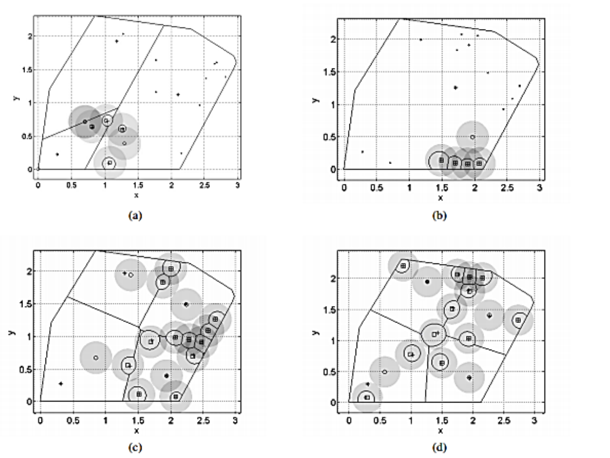

Fig. 5. Sensor deployments in WSN2. (a) The initial sensor deployment and the corresponding weighted Voronoi regions. (b) The final deployment of Lloyd Algorithm after 500 iterations. (c) The final deployment of RL Algorithm after 500 iterations. (d) The final deployment of DA Algorithm after 500 iterations. Strong sensors and weak sensors in the backbone network are, respectively, denoted by hollow circles and squares. Sensors out of the backbone network are denoted by dots. The corresponding centroid for strong sensors and weak sensors are, respectively, denoted by stars and crosses. The radius of each gray circle is $R_c/2 = 0.25$.

0.08 to 1.51 and the final deployment is connected. Fig. 6d shows the final deployment of DA Algorithm in WSN3. After 500 iterations, the distortion is decreased from 10.96 to 1.35, which is better than that of RL Algorithm. Simultaneously, the coverage area is increased from 0.03 to 2.07 and full connectivity is provided. Figs. 7 and 8 illustrate the performance of the above algorithms for 10 random initial deployments in WSN2. Figs. 9 and 10 show similar performances in WSN3. The trends in heterogeneous WSNs 2 and 3 are similar to those in homogeneous WSN1.

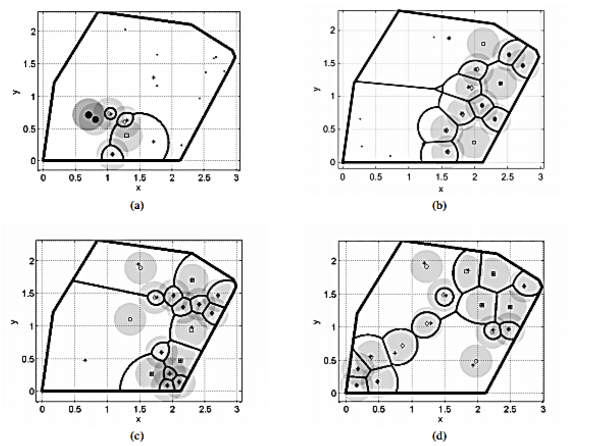

Fig. 6. Sensor deployments in WSN3. Figure (a) The initial deployment and corresponding weighted Voronoi regions. (b) The final deployment of Lloyd Algorithm after 500 iterations. (c) The final deployment of RL Algorithm after 500 iterations. (d) The final deployment of DA Algorithm after 500 iterations. Strong sensors, medium and weak sensors in the backbone network are, respectively, denoted by hollow circles, hollow squares and hollow diamonds. Sensors out of the backbone network are denoted by dots. The corresponding centroid for sensors in the backbone network are denoted by stars. The radius of each gray circle is $R_c/2 = 0.25$.

III. CONCLUSIONS

We studied the deployment of sensors in heterogeneous wireless sensor networks. Similar to homogeneous WSNs, the necessary condition for optimal deployment implies that every sensor node location should coincide with the centroid of its own optimal sensing region. Moreover, we considered a limited communication range for the sensor nodes and modeled the sensor deployment problem as a source coding problem with distortion reflecting sensing accuracy. By defining an appropriate distortion measure, we proposed a Restrained Lloyd algorithm and a Deterministic Annealing algorithm to optimize sensor deployment in both homogeneous and heterogeneous WSNs. Our simulation results show that both DA and RL algorithms outper form the existing Lloyd algorithm when communication range is limited and provide a fully connected network. The DA is not sensitive to initial conditions.

IV. REFERENCES

1. J Cortes, S. Martinez and F. Bullo, "Spatially-Distributed Coverage Optimization and Control with Limited-Range Interactions," ESAIM: COCV , vol. 11 , pp. 691-719, Oct. 2005.

2. X Liu, "Coverage with Connectivity in Wireless Sensor Networks," Broadband Communications, Networks and Systems, pp. 1-8, Oct. 2006.
3. G Wang, G. Cao, and T. F. La Porta, "Movement-assisted sensor deployment," IEEE Trans. Mob. Comput., vol. 5, no. 6, pp. 640-652, June 2006.
4. J C. Kieffer, "Exponential rate of convergence for Lloyd-s method I," IEEE Trans. Inf. Theory, vol. 28, no. 2, pp. 205-210, Mar. 1982
5. X Wu, "On convergence of Lloyd-s method I," IEEE Trans. Inf. Theory, vol. 38, no. 1, pp. 171-174, Jan. 1992.
6. Q Du, M. Emelianenko, and L. Ju, "Convergence of the Lloyd algorithm for computing centroidal Voronoi tessellations," SIAM J. Numer. Anal., vol. 44, no. 1, pp. 102-119, Feb. 2006.
7. C Hu, X. Wang, Z. Yang, J. Zhang, Y. Xu, and X. Gao, "A geometry study on the capacity of wireless networks via percolation," IEEE Trans. Commun., vol. 58, no. 10, pp. 2916-2925, Oct. 2010.
8. H Yousefi-zadeh, H. Jafarkhani, and J. Kazemitabar, "A study of connectivity in MIMO fading ad-hoc networks," IEEE/KICS J. Commun. Networks (JCN), vol. 11, no. 1, pp. 47-56, Feb. 2009