Coulomb's Force Algorithm in Wireless Sensor Network

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Abstract
Wireless sensor network is an emerging and very hot technology these days. Due to recent advancement in semiconductors, networking and material science technologies,deployment of wireless sensor network has become cheaper and easier. Wireless sensor network can simply defined as a network formed by low power devices known as sensor node which monitors the environment or target field and communicate the gathered information to base station or sink node through wireless links using single hop or multi-hop relaying. Node deployment is basic issue of wireless sensor network asit can influence the performance metrics of WSNs connectivity, coverage and Energy consumption. Many deployment schemes have been proposed for wireless sensor networks.In this paper, we have proposed an algorithm to deploy sensor nodes uniformly in the target region. Our proposed algorithm CFA is based on coulomb's law. We have also compared our proposed algorithm CFA with existing algorithm in terms of average moving distance and uniformity.

Keywords
Wireless Sensor Network, Node Deployment Technique, CFA

I. Introduction

The rapid development of wireless communicationhas extensively increased deployment of wireless sensor network. Wireless sensor network has emerged as improvement level of advancement technologies in wireless network and used in wide variety of application such as home automation, habitat monitoring, military application, environment monitoring etc.

It consist of large number of low powered sensor node to monitor the area of interest and to corporately forward their gathered data through network to main location. Sensor node is basic unit of wireless sensor network and its major components are sensors,memory unit, analog to digital converter, radio transceiver, microprocessors and battery. The sensor is a transducer that convert physical parameter such as light, sound, temperature, pressure, humidity and etc. to electrical parameter.So, wireless sensor network provides a bridge between real physical world and virtual world.

In fig. 1, sensor nodes are deployed in target region. These sensor nodes senses the monitored field and acquire the information. The wireless sensor network relays the information from this sensor nodes to one or more collection points.

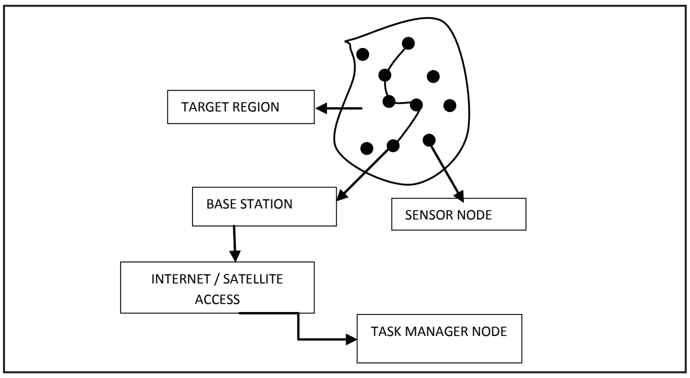

Fig. 1: Sensor Nodes Deployed in Target Region

This collection point are called as base station. Based on the gathered information from different sensor nodes, base station can compute the optimized position of sensor node to reduce the cost and energy consumption of wireless sensor network.Base station can be a simple sensor node with additional computational power and battery life. The information from base station is further relayed to task manager node via satellite link or internet facility. The task manager node represent a work place which is far away from target region where information transmitted by base station is further processed. Based on the results of processed information the necessary action is taken. Sensor nodes can be stationary and movable type.

In wireless sensor network, the deployment of sensor node is a major issue. It affects one basic and important parameter i.e. the number of sensor nodes needed to be deployed in the target region which in turn affects the other important parameters like network coverage, network connectivity and network life time. Minimizing number of sensor nodes needed to be deployed in the target region will decrease the cost of wireless sensor network. Reducing the number of sensor nodes in the target region degrades the network coverage and network connectivity. Network coverage and network connectivity can be improved by increasing the sensing range and communication range of sensor nodes. But increasing sensing and communication range of sensor nodes maximizes the energy dissipation which minimizes the life time of sensor nodes. Energy efficient deployment of sensor nodes needs an optimal localization of sensor nodes in the target region. To solve this major issue, we have proposed an algorithm which uses coulomb's law of electrostatic to find an optimized position of sensor node and to increase the performance of wireless sensor network. Our proposed algorithm can improve the network coverage, network connectivity and network life time.

This paper is organized as follows. Section II presents the related work. Section III discusses the assumptions and the components of the proposed algorithm. Section IV presents simulation experiments and discusses the results, and Section V concludes the paper.

II. Related Work

Many prominent authors have addressed the solution for node deployment problem to improve the network coverage and network connectivity.

Virtual force algorithm,proposed by Zou et al. [1], is incorporated using binary sensing disk model and virtual field concept from robotics. The algorithm uses integration of attractive force and repulsive force to move sensor node from one position to other to expand the sensor field coverage to its extent. A target positioning procedure is also included, basedon a two-step communication protocol between the cluster head and the sensor node within the cluster. First step is to detect the target and second step is to inform about the event to cluster head.

In [2], Xiao et al. proposed a hexagonal grid based deployment algorithm which uses hexagonal grid deployment method and ant colony algorithm for calculating optimize position of sensor nodes. Author initially deployed movable sensor nodes randomly on the target field and then incorporated the proposed algorithm. The proposed algorithm achieve the hundred percentage network coverage and reduce the moving distance of all sensor node.

An improved version of virtual force algorithm [3], proposed by Chen et al., includes some parameters such as boundary condition for sensor nodes, convergence time, threshold distance and etc. which further improves the life time of wireless sensor network. Author have also proposed an exponential version of virtual force algorithm to improve the convergence time and network coverage. At the end of paper, comparison has been done with original virtual force algorithm.

Kribi et al. in their paper [4] address the limitation of virtual force algorithm and proposed a new version of original virtual force algorithm i.e. Dth_Lmax_Serialized_VFA. In original versions of VFA, the exerted forces computed at round r uses the position of sensor node of previous round r-1. But sensor node occupies new position in r round and the calculation of exerted forces is not valid any more.Serialized VFA solve the problem by moving the sensor nodes one by one and to use latest position of sensor node occupied by it. To restrict the energy consumption of sensor nodes due to distance travelled by each sensor node, they have proposed the second algorithm where the movement of each sensor node is restricted by L_max in each round.

Coverage Optimization Algorithm [5], proposed by Han et al., is based on Simplified Virtual Forces-Oriented Particle Swarm with Mutate Mechanism (SVFPS-MA), which will enhance the mechanism of finding the update speed of PSO, control the direction of particle evolution and acquires the high convergence time by removing attraction forces phenomenon from the virtual forces algorithm.

Xiangyu yu et al. proposed an algorithm [6] inspired by Van Der Waals force. In the proposed algorithm, all sensor nodes are denoted as points subject to attractive and repulsive force and sensor nodes moves according to exerted force upon it from all other nodes. Authors have compared their proposed algorithm with traditional virtual force algorithm on the bases of coverage ratio, convergence time and power consumption. The Van Der Waal force algorithm has achieved greater coverage ratio, faster convergence time and consumes less energy than original VFA.

Unlike the above-mentioned virtual force algorithm, this paper proposes an algorithm that finds the best positions of sensor nodes to increase network coverage by using coulomb's law of electrostatic.

III. Proposed Algorithm

In this section, we have introduce our proposed algorithm. Firstly we have presented the networkassumption and definition related with the proposed algorithm and flow diagram of proposed algorithm.

A. Network Assumption

In our proposed algorithm, we are going to make following assumptions:

1. Target region has an area of 100x100 square meters.
2. Target region is obstacle free.
3. Sensor nodes are mobile nodes.
4. Sensing range of sensor nodes is 10 meters and denoted as *SR*.
5. Transmission range of sensor node is denoted by *TR* and is kept as 2**SR*.
6. Threshold distance is denoted by *Dthand* is kept as √3*SR*.
7. Euclidean distance is used for distance calculation between the sensor nodes.
8. To ease the analysis and calculation, binary sensing model is used.
9. Each sensor node computes its location using inbuilt GPS.
10. The probability of equalization of total attractive force and total repulsive force is very less.
11. All sensor nodes have same sensing range and communication range.

B. Definitions

Definition 1: Binary Sensing Disk Model

According to binary sensing disk model, a sensor node is located at the center of a circle and radius of circle defines the sensing range of sensor nodes.

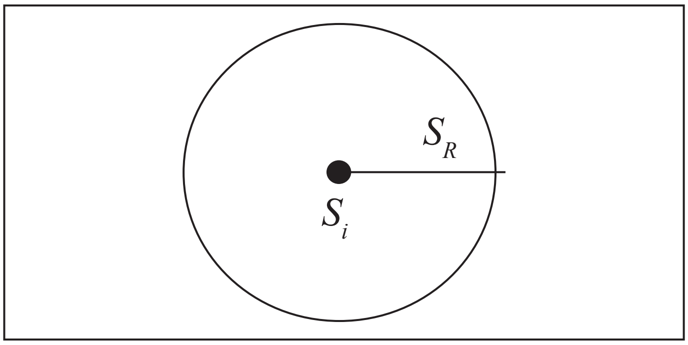

Fig. 2: Binary Sensing Disk Model

Any activity can be detected within an inner disk of radius by the sensor nodes. As shown in fig. 2.

Definition 2: Connecting Neighbour Nodes

A sensor node S_j can be called connecting neighbour nodes to S_i if the Euclidean distance between the both sensor node is less than or equal to 2*S_R. As shown in fig. 3.

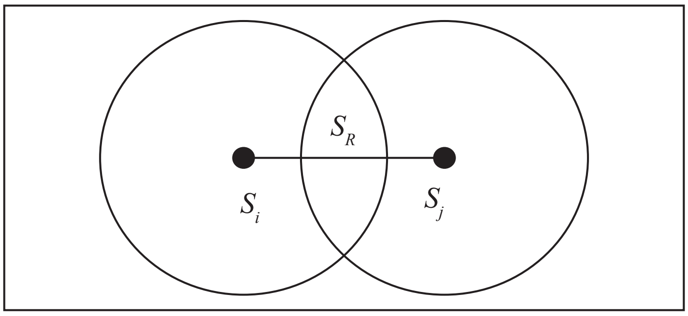

Fig. 3: Connecting Neighbor Nodes

Definition 3: Attraction Force

Attraction force between the two sensor nodes can be found when the Euclidean distance between the two sensor nodes is greater than defined threshold distance. As shown in fig. 4.

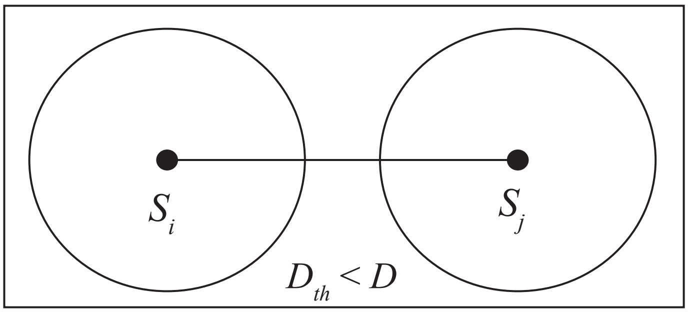

Fig. 4: Attraction Force Between the Two Sensor Nodes

Definition 4: Repulsion Force

Attraction force between the two sensor nodes can be found when the Euclidean distance between the two sensor nodes is less than defined threshold distance. As shown in fig. 5.

Definition 5: Force between the Sensor Nodes.

The force exerted on sensor node S_i due to sensor node S_i can be calculated by

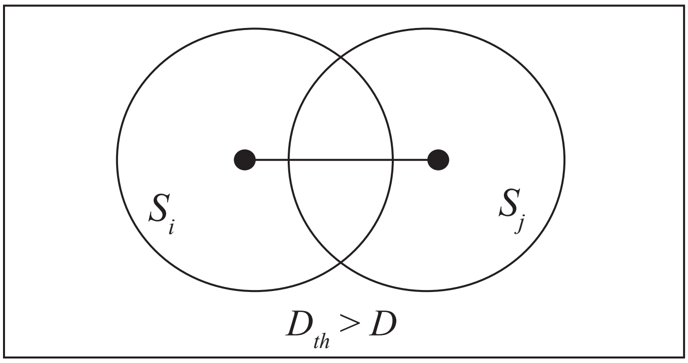

Fig. 5: Repulsive Force Between the Two Sensor Nodes

$$F_i = \begin{cases} \frac{1}{4*\mathrm{pi}*\varepsilon_o}\frac{q_j*q_i}{D_{ij}^2}\frac{x_{ij}\ ,y_{ij}}{D_{ij}}, & D_{th} < D_{ij} \\ -\frac{1}{4*pi*\varepsilon_o}\frac{q_j*q_i}{D_{ij}^2}\frac{x_{ij}\ ,y_{ij}}{D_{ij}}, & D_{th} > D_{ij} \\ 0, & D_{th} = 0 \end{cases}$$

Where the value of q_j, q_i is assumed as 1 and x_{ij}, y_{ij} defines the direction of resultant force and can be written as

$$x_{ij} = x_i - x_j$$

And,

$$y_{ij} = y_i - y_j$$

Where x_i, x_j and y_i, y_j are x-coordinates and y-coordinates of sensor node S_i and S_j.

Definition 5: Total Force exerted on the Sensor Node S_i

Total force exerted on sensor node S_i can be formulated [6] as

$$\vec{F} = \sum_{j=1, j\neq i}^{n} \overrightarrow{F_{ij}},$$

Where n is number of nodes in the region of interest and F_{ij} is force exerted on sensor node S_i by sensor node S_j. The direction of $\vec{F}$ is determined by summation of all individual vector force angle exerted on sensor node S_i [1].

Definition 6: New location estimation of the Sensor Nodes S_i

After calculating total force exerted on sensor node S_i, sensor nodes S_i can redeploy themselves based on magnitude and direction of total force exerted on it by following formula [7]:

$$x_{new} = x_{old} + (\mathrm{sign}F_x) * \frac{F_x}{F_{net}} * \mathrm{maxstep}$$

$$y_{new} = y_{old} + (\mathrm{sign}F_y) * \frac{F_y}{F_{net}} * \mathrm{maxstep}$$

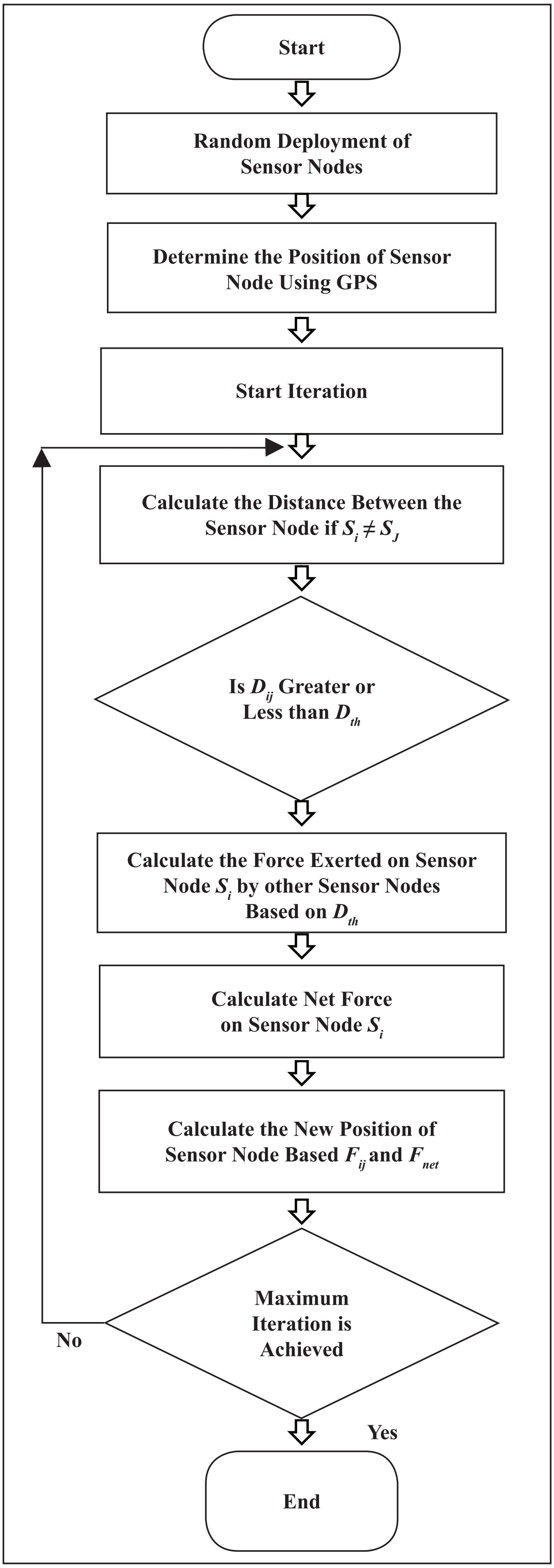

Fig. 6: Flow Diagram of CFA

Where, x_{old} and y_{old} are the old position of sensor node and x_{new} and y_{new} are the new position of sensor node. Maxstep is maximum step travelled in one round by sensor node. F_x and F_y are the force magnitude in x and y direction. F_{net} is the total net force on sensor node S_i and can be calculated as

$$F_{net} = \sqrt{F_x^2 + F_y^2}$$

Our proposed algorithm is distributed algorithm called Coulomb Force Algorithm (CFA) to deploy uniform sensor nodes after initial random deployment. CFA aims to maximize the target area coverage using the combination of attractive and repulsive forces. In distributed algorithm, all sensor nodes run the algorithm and compute their position to ensure uniformly deployment of sensor nodes in the target region. Coulomb Force Algorithm is inspired by coulomb's law and virtual force algorithm. In this algorithm, sensor node are modeled as points subjected to virtual attractive and virtual repulsive force between them. A threshold distance between the sensor nodes is set and sensor node moves in accordance with addition of the force vectors between the sensor nodes [1,6,8].

We apply Coulomb's law to compute the magnitude of resultant forces between the sensor nodes. Coulomb's law describes that force between any two static electrically charged particles. Coulomb's law states that the magnitude of the electrostatic force of interaction between two point charges is directly proportional to the scalar multiplication of the magnitudes of charges and inversely proportional to the square of the distance between them. Coulomb's law can be written in mathematical expression [12] as

$$|F| = K_e \frac{|q1 * q2|}{r^2}$$

Where K_e a constant known as coulomb constant and its value is is 8.987551787×10^9 N m^2 C^{-2}, q^1 and q^2 are the magnitudes of the charges and r is the distance between the point charges.

In CFA, we have assumed that q^1 and q^2 have value equivalent to 1 and r can be defined as the Euclidean distance between the pair of sensor nodes. Then force between the two sensor nodes based on electric field can be calculated [12] as

$$F_{ij} = q_i^E$$

Where E is electric field. The magnitude and direction of the Coulomb force F_{ij} on a sensor node with charge q_i depends on the electric field E. E is calculated [12] as

$$|E| = \frac{1}{4 * pi * \varepsilon} \frac{|q_j|}{{D_{ij}}^2}$$

And D_{ij} is Euclidean distance between the two sensor nodes. p_i is value is equivalent to 3.14. Fig. 6 shows flow diagram to execute CFA.

IV. Simulation Result

In this section, we have compared CFA simulation result with traditional virtual force algorithm.

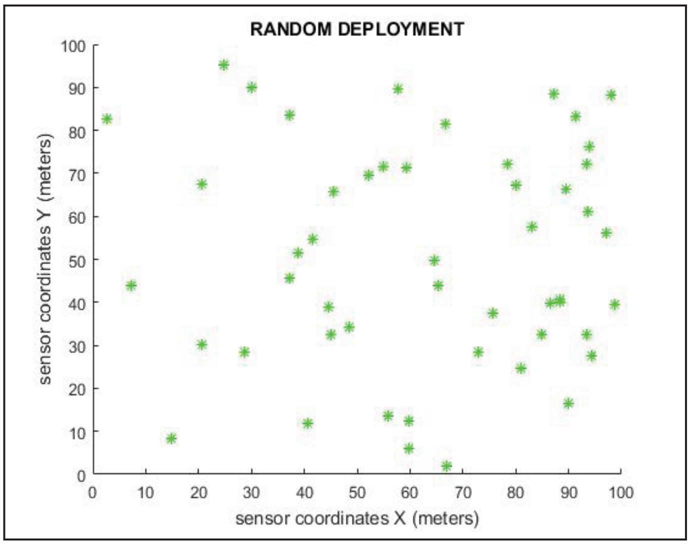

Fig. 7: Random Deployment of N Nodes in Target Area

Fig. 7 shows the random deployment of N = 50 nodes in target area has been shown. The sensing range of sensor node is assumed as 15 meters and the communication range is assumed as 30 meters. The target area covers an area of 100x100 meters.

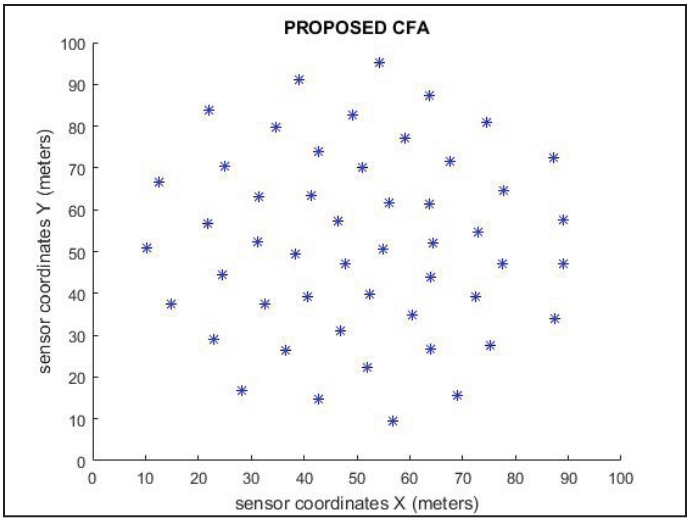

Fig. 8: Redeployment of Sensor Nodes Using Proposed CFA

Fig. 8 shows deployment of sensor node after initial random deployment of sensor node using proposed CFA. CFA uses the Coulomb's law to compute the magnitude and direction of force exerted on sensor nodes S_i by its neighbor sensor nodes S_j.The magnitude and direction of force computed by Coulomb's law is used to move neighbouring sensor node to optimized position based on threshold distance D_{th}. D_{th} is assumed to be 30 m. Based on the forced exerted on sensor node S_i by sensor node S_j, the new location of sensor node S_i is computed. This computation goes on till the distance between two sensor nodes is equal to threshold distance. Fig. 9 shows the movement of each sensor node present in target region based on computation.

Fig. 10 show redeployment of sensor nodes after initial random deployment using Traditional VFA. The main disadvantage of traditional VFA is that few sensor nodes moved outside the boundary of target region based on new position of those sensor nodes computed by traditional VFA. Another disadvantage of traditional VFA is that sensor nodes keeps oscillating after achieving optimized position also.These drawbacks can be seen in fig. 11 where sensor nodes moves outside the target region.

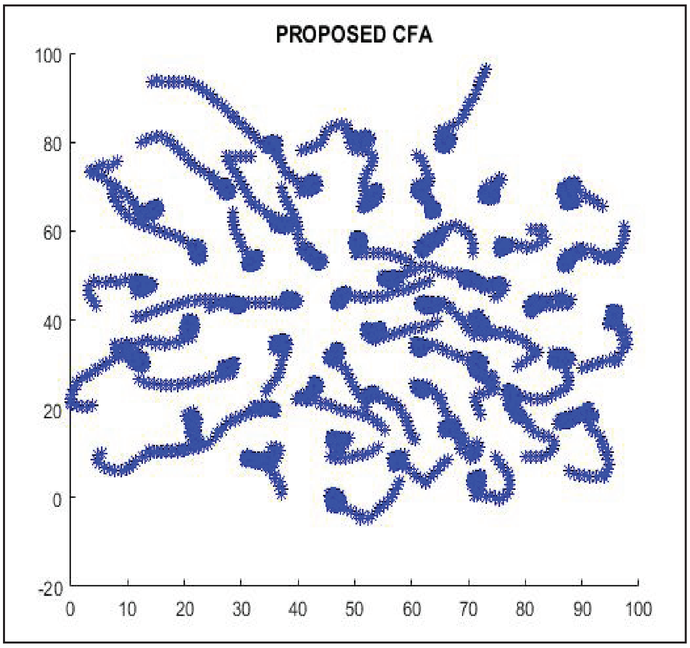

Fig. 9: Distance Moved by Sensor Node in 500 Round Using CFA

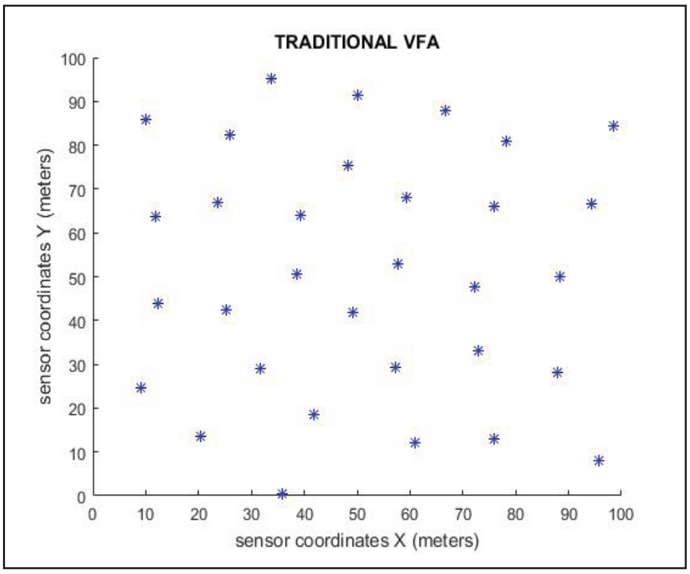

Fig. 10: Redeployment of Sensor Nodes Using Traditional VFA

V. Conclusion

This paper present an algorithm to deploy sensor node uniformly in the target region. This algorithm is based on coulomb's law and virtual force concept. Coulomb's law is used to compute force between two sensor nodes. Based on the computed force, sensor nodes are redeployed on the target region.The performance of CFA in terms of average moving distance of sensor node in target region and uniformity is better than traditional VFA. The average moving distance of CFA is 10.512 meters and of traditional VFA is 14.7096 meters. Average moving distance of our proposed CFA is less than traditional VFA. So, the energy consumed in moving these sensor nodes from old position to new position will also be lessthan traditional VFA. As significant amount of energy is consumed in moving sensor node. Another advantage over traditional VFA is that as seen in the simulation result of traditionalVFA that few sensor nodes moves beyond the boundaries of target region, this problem does not exist in our proposed CFA.

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