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 as it 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 communication has 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 consists 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.

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, based on 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. Dih_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 $2\times SR$.
6. Threshold distance is denoted by $D_{th}$ and is kept as $\sqrt{3}SR$.
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. 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 $2\times SR$. As shown in fig. 3.

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.
**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 $S_j$ can be calculated by

$$ F_{ij} = \begin{cases} 
\frac{1}{4 \pi \varepsilon_0} \left( \frac{q_i q_j}{D_{ij}^2} \right) , & D_{th} < D_{ij} \\
-\frac{1}{4 \pi \varepsilon_0} \left( \frac{q_i q_j}{D_{ij}^2} \right) , & D_{th} > D_{ij} \\
0 , & D_{th} = 0
\end{cases} $$

Where the value of $q_i$, $q_j$ is assumed as 1 and $x_i$, $y_i$ defines the direction of resultant force and can be written as

$$ x_y = x_i - x_j \\
y_y = y_i - y_j $$

Where $x_i$, $y_i$ and $x_j$, $y_j$ 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

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

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]:

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

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

![Fig. 5: Repulsive Force Between the Two Sensor Nodes](image)

**Fig. 5: Repulsive Force Between the Two Sensor Nodes**

**Fig. 6: Flow Diagram of CFA**
Where, \( x_{\text{old}} \) and \( y_{\text{old}} \) are the old position of sensor node and \( x_{\text{new}} \) and \( y_{\text{new}} \) 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. \( F_{\text{net}} \) is the total net force on sensor node \( S_i \) and can be calculated as

\[
F_{\text{net}} = \sqrt{F_x^2 + F_y^2}
\]

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

\[
|F| = K_e \frac{|q_1 \times q_2|}{r^2}
\]

Where \( K_e \) a constant known as coulomb constant and its value is is 8.987551787\times10^9 \text{ N m}^2 \text{ 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

\[
|E| = \frac{1}{4 \pi \varepsilon} \frac{|q_i|}{D_{ij}^2}
\]

And \( D_{ij} \) is Euclidean distance between the two sensor nodes. \( \pi \) 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 \( D_{\text{th}} \), \( D_{\text{th}} \) 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.

V. Conclusion
This paper presents 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 less than 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 traditional VFA that few sensor nodes moves beyond the boundaries of target region, this problem does not exist in our proposed CFA.

References

Shekhar Dwivedireceived his B.Tech. degree in AEI from CIITM, Jaipur, India, in 2012, the M.E. degree in wireless communications from BIT, Mesra, Ranchi, India, in 2016. He was assistant professor, with E & C department, MLVTEC, Bhilwara, in 2016 and 2017 respectively. His research interests include Wireless sensor network, VLSI designing.