VIRTUAL FORCE ALGORITHM AND CUCKOO SEARCH ALGORITHM FOR NODE PLACEMENT TECHNIQUE IN WIRELESS SENSOR NETWORK

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ABSTRACT. Wireless Sensor Network (WSN) has become one of the current technologies in the world of information technology. Coverage and connectivity are the main requirement that reflects the performance and quality of services in WSN applications. In WSN applications with a large scale area, the sensor nodes are deployed randomly in a noninvasive way. The deployment process will cause some issues such as coverage hole and overlapping that reflect to the performance of coverage area and connectivity. Node placement model is constructed to find the optimal node placement. Virtual Force Algorithm (VFA) and Cuckoo Search (CS) algorithm approach for node placement technique is analyzed to find the optimal node placement in order to improve the network coverage and connectivity with a minimum coverage hole and overlapping area.

Keywords: node placement, wireless sensor network, virtual force algorithm, cuckoo search algorithm

INTRODUCTION

In recent years, wireless sensor networks (WSNs) have become one of the most promising technologies in sensing application environment. These WSNs provide flexibility in deployment and maintenance, exploiting the ability of wireless networks to be deployed in highly dynamic environments and hence enable sensor networks to be potentially used in a wide range of civilian and military applications, including security surveillance, environmental monitoring, habitat monitoring, hazard and disaster monitoring and relief operations, healthcare applications (Nematy, Rahmani, Teshnelab, & Rahmani, 2010), home applications as smart environments and smart agriculture system (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002). The basic goals of a WSN generally depend on the application and has many functions including to determine the value of the parameter at given location, detect the occurrence events and tracking an object. In an environmental network, sensor nodes can be used to measure the temperature of atmospheric pressure, amount of sunlight and humidity. In a military sensor network, sensor nodes are used to track an enemy as it moves through the geographic area covered by the network. WSN environment consists of a number of sensor nodes and one or more base station spreads across a geographical region of interest area. Each sensor has wireless communication capability and some level of intelligence for signal processing and networking of the data (Fan & Jin, 2010). In addition with integration of sensing, computation, and wireless communication the sensor nodes can sense physical information from the environment, process the information, and report them to the base stations.

There are several constraints in WSN environment especially in random deployment strategy. Due to the random deployment, the sensor nodes are deployed randomly in non-invasive way and will cause a problem such as coverage hole, overlapping and also a connectivity failure (Aziz, Aziz, & Ismail, 2009). Hence, node placement is the fundamentals issue that will affect the performance of the WSN applications and operations and closely related to the coverage area and connectivity (Xiangyu, Weipeng, Junjian, & Xin, 2012). In this research, the node placement technique of Virtual Force Algorithm and Cuckoo Search algorithm is analysed for improving the network coverage area and connectivity in random deployment scheme.

The paper is organised in a few sections. The next section is explaining the node placement technique in WSN using VFA and the modification of the CS algorithm to fit with the node placement. Then, the result is presented and discussions with the conclusion are justified at the end of the paper.

THE NODE PLACEMENT TECHNIQUE IN WSN

Move-assisted deployment node placement technique could be the best adoption in a large region of interest. However, this causes the sensor nodes are not uniformly distributed over the region of interest. In this case, a move-assisted deployment is considered to overcome the problem of the coverage gap, overlapping and connectivity failure in random deployment. Thus, the effectiveness of node placement technique can provide a maximum coverage and continues connectivity in deployment of sensor nodes.

Virtual Force Algorithm

Virtual Force Algorithm (VFA) is a popular approach for a dynamic node placement. VFA uses a force-directed approach to achieve a redeployment of sensor network after an initial random deployment (Wang, Cao, & Porta, 2004; Zou & Chakrabarty, 2003).Jin, Chang, & Jia (2010) also proposed a VFA as a sensor deployment algorithm attempts to maximize the sensor field coverage. Sensor nodes can move towards the required placement using a virtual exerted force. The repulsive and attractive forces of the sensor nodes depend on a threshold distance, D_{th}. When two nodes are close enough, the force is in repulsive pattern which intent to separate them but when two nodes are far from each other, the force become attractive which draws them closer. The repulsive pattern can avoid the redundant coverage or overlapping while the attractive pattern can avoid the coverage holes. The exerted on node *i* by node *j* in the network (denoted by F_{ij}) as the equation below:

$$\overrightarrow{F_{ij}} = \begin{cases} W_a(d_{ij} - D_{th})\alpha_{ij} if d_{ij} > D_{th} \\ 0 \qquad if d_{ij} = D_{th} \\ W_r d^{-1} ij \ , \alpha_{ij} + \pi if d_{ij} < D_{th} \end{cases} \tag{1}$$

where d_{ij} is the Euclidean distance between sensor node *i* and *j*, D_{th} is the threshold on the distance between *i* and *j*, α_{ij} is the orientation (angle) of a line segment from *i* and *j*. Virtual forces allowed sensor nodes to coordinate their movements without the need of any central controller using a distributed algorithm for self-deployment and event-based relocation in dynamic deployment (Jin, et al., 2010).

Cuckoo Search Algorithm

The Cuckoo Search (CS) algorithm is a nature-inspired meta heuristic for solving an optimization problem. This algorithm is inspired by the obligate brood parasitism of some cuckoo species and enhanced with a new solution generated by Levy flight to speed up the local search (Yang & Deb, 2009). In CS algorithm, each egg in the nest represents a solution and each cuckoo can lay only one egg (thus representing one solution). The aim of this algorithm is to find a new and potential better solution to replace a not so good solution in the nests.

The CS algorithm is used as an optimization algorithm to search a maximum coverage area in random deployment. The sensor network is assumed deployed using a homogeneous sensor node with a same sensing and communication range. The rules of Cuckoo Search algorithm in order search the maximum coverage area in sensor random deployment is as below:

a) Each cuckoo lays one egg at a time, and dumps its egg in randomly chosen nest. The rule can be interpreted as a set of solution is randomly generated within the range of solutions.
b) The best nest with high quality of eggs will carry over to the next generations. The CS algorithm will find the maximum coverage area and minimum overlapping compare with the fitness value
c) The number of available host nests is fixed. The maximum coverage area and minimum overlapping between nodes is identify and will be abandon if the rule is not fulfill.

SIMULATION SETUP

The simulation experiment is used to stimulate the WSN environment with random node deployment. The simulation was run using MATLAB with dimension 100m x 100m area of deployment. The total sensor nodes was N = 25. This simulation is conducting based on the following assumption parameter:

a) A dynamic sensor nodes are consist of homogeneous node with a same sensing and communication range with a limited movement
b) A dynamic sensor nodes are randomly deployed over an open space area and no obstacle against all nodes.

In each simulation scenario, the sensor nodes are set in a difference group of number nodes: 5 nodes, 10 nodes, 15 nodes, 20 nodes and 25 nodes. The simulation was run in 5 replications for each group of sensor nodes. Table 1, summarize the parameter used in a simulation run of VFA and CS.

Table 1. Simulation Parameter for Virtual Force and Cuckoo Search Algorithm

Parameter	Values	
	VFA	Cuckoo Search
Initial threshold distance, D_{th}	$\sqrt{3}\,R_s$	$\sqrt{3}\,R_s$
Sensing range, R_s	10m	10m
Communication range, R_c	20m	20m
Number of nodes, N	5-25	5-25
Sensor deployment area, xm x ym	100m x 100m	100m x 100m
Lower bound, L_b, Upper bound, U_b	-	100,300
Cuckoo step size	-	0.01
Maximum iteration	-	1000

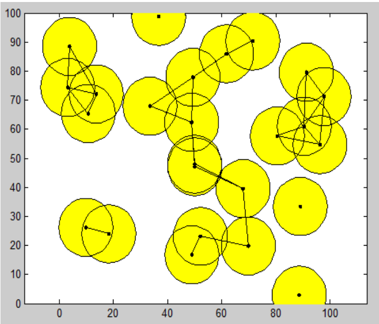
SIMULATION RESULTS

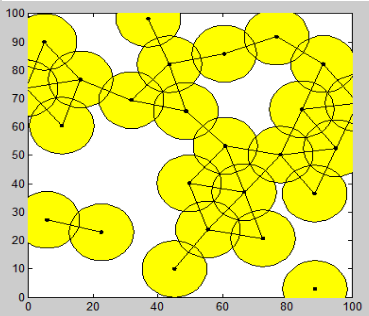
This section discuss the analysis and result of the simulation run in Virtual Force Algorithm and Cuckoo Search algorithm for node placement technique in wireless sensor networks. The following metrics are used as the performance evaluation of the VFA and CS algorithm:

a) Coverage area: The coverage area is defined as a covered area in a region of interest
b) Connectivity: The connectivity is referring to the probability of sensor nodes in the network communicate between nodes based on the distance and communication range.

Virtual Force Algorithm

In this research the performance of Virtual Force Algorithm (VFA) is analysed in term of coverage area and connectivity after relocation of sensor nodes in random deployment using a repulsive and attractive pattern. The threshold distance value is set to $\sqrt{3}R_s$ where it is assumed as an ideal distance from each distance of sensor nodes in WSN environment (Li, Zhang, Cui, & Chai, 2012). Figure 1 illustrates the relocation of sensor nodes using VFA approach in random deployment using 25 nodes in area of 100 m x 100 m.





a) Initial random deployment b) Relocation using VFA

Figure 1. Node placement scenario using VFA approach

Coverage Area

VFA approach is proposed to maximize the coverage area and in addition to minimize the coverage hole and overlapping area. The coverage performance in VFA approach is analysed after the relocation of sensor nodes due to the random deployment. In this research, the covered area of each sensor nodes is defined as a disk area with sensing range, R_s. The value of coverage area is as

$$C = \frac{\cup_{i=1}^{N} Acvrd_i}{A} - Ovl \quad (2)$$

where $Acvrd_i$ is the area covered by the sensor nodes i, N is the total number of sensor nodes, A is the total area of region of interest (ROI) and *Ovl* is the overlapping area. Table 2 shows the average results of coverage area using VFA approach with a different number of sensor nodes.

Table 2. Results of coverage area in VFA approach

Number of nodes				
5	10	15	20	25
1374.2	2895.9	3938.5	4735.4	5653.9

Connectivity

Figure 1 illustrated the initial random deployment and VFA approach based 25 nodes deployed in the region of interest with 100m x 100m. The line in Figure 1 represented the connectivity between sensor nodes. The relocation of sensor nodes shows a better result where the overlapping and coverage hole area can be minimize. Thus, the relocation of sensor nodes can improve the connectivity edge where the connectivity intersection between sensor nodes area avoided. From the simulation results, implementation of movement force in range of threshold distance and communication range between sensor nodes in VFA guaranteed the continues connectivity and prevent from the node stacking.

Cuckoo Search Algorithm

In CS algorithm, the metric performance of coverage and connectivity are evaluated based on random deployment of sensor nodes in a group of sensor nodes for a difference number of iteration. In the simulation run, CS algorithm finds the best coverage area for every group number of sensor node in a different number of iterations.

Coverage Area

A fix number of iterations were undertaken and the average result is extracted as depicted in Table 3. The performance of coverage area is gradually increased when the numbers of sensor nodes are increase. Table 3 also shows that the coverage area is static when 5 and 10 sensor nodes are applied regardless total number of iteration.

Table 3. Average coverage area using CS approach

Number of iterations	Number of nodes				
	5	10	15	20	25
10	1570.8	3141.6	4288.5	5089.4	5456.9
20	1570.8	3114.5	4318.5	5216.9	5692.7
50	1570.8	3141.6	4438.7	5197.6	5800.3
100	1570.8	3141.6	4485.6	5365.4	5848.0
500	1570.8	3141.6	4487.8	5497.3	6096.7
1000	1570.8	3141.6	4556.1	5532.8	6275.4

Connectivity

Due to the random deployment of sensor nodes in CS algorithm, connectivity is not guaranteed due to the coverage hole and overlapping in area in the region of interest. There are still some areas with an intersection of connectivity. In this case, it is wasting the energy consumption for transmitting the data between sensor nodes.

CONCLUSION

In this research, the performance of Virtual Force Algorithm (VFA) and Cuckoo Search (CS) algorithm is evaluated based on the metric performance of coverage area and connectivity. A performance evaluation and analysis of the algorithm has been carried out using MATLAB for a 5 replication of simulation runs using a different number of sensor nodes for both VFA and CS algorithm. In CS algorithm the replication of simulation runs is conducted based on the number of iteration. The results presented in previous sections shows that VFA with a repulsive and attractive force pattern can relocate the position of sensor nodes after the initial random deployment. The algorithm shows the improvement of coverage area with a minimum overlapping and coverage hole area. The CS algorithm provide more coverage area in random deployment but there are lot of overlapping and coverage hole area. Thus, the solution provided by CS is not practical and inefficient because of the large overlapping area that will waste a number of sensors. In term of connectivity, the VFA approach exhibits a guaranteed connectivity and the intersection of connectivity is avoided better than CS algorithm. It has been proved that VFA achieve a significant improvement in coverage area and connectivity compared to CS algorithm. Thus, the effectiveness of node placement technique can provide a maximum coverage and continues connectivity in deployment of sensor nodes.

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