Area Coverage Optimization in Wireless Sensor Network by Semi-random Deployment

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Abstract: Area Coverage is a difficult problem to solve with a minimum number of sensor nodes for maximum time duration, especially in wide areas. Among the solutions proposed for this problem there is the deployment with its two types random and deterministic. The disadvantages of deterministic deployment are configured in the Area of Interest (AoI) limitation, and random deployment is configured in the non-equitable distribution of sensor nodes on AoI. This problem affects power consumption and connectivity; as a result, it affects the coverage of the area of interest. In this paper we have proposed a third type of hybrid deployment that gathers the advantages and minimizes the disadvantage of the application of the random deployment and deterministic deployment. This type has two steps; the anticipate configuration step and the scheduling process step. A comparative study was done to show the effectiveness of this type to optimize coverage in the vast area of interest less danger and more interests.

1 INTRODUCTION

The advancement in Micro Electro-Mechanical Systems (MEMS) technology has lead to production of thin, cheaper and reliable sensors nodes. A network of sensors suffers from several technical weak points such as communication range, monitoring range, low battery, and network deployment circumstance problems such as the difficulty of building a sensor network in volcanoes, mountains, or in the oceans. The deployment with its two types considered a very effective solution to optimize the problem of coverage in networks of wireless sensors, power consumption, routing, connectivity, and others. Deterministic deployment is effective in very limited areas where man can intervene to troubleshoot, configure, change batteries, and replace or move nodes. Random deployment is effective in unrestricted areas where human intervention is impossible or difficult. Advancement in MEMS technology has lead to production of very thin sensor nodes that are less expensive and yet powerful in terms of storage and processing. Increasing network lifetime by keeping the entire coverage of the area of interest is one of the compromises desired by researchers in their work using deployment. Among the disadvantages of this solution for the random type are the non-equitable distribution of the sensor nodes and the difficulty of applying the process of activating sensor nodes in the network. The necessity of knowing positions (best distribution) and remote-control in geographical areas is mandatory, where human intervention is difficult in certain danger zones. In this paper, we have defined a new type of deployment known as the semi-random deployment. This deployment uses deterministic advantages like knowing the distribution of positions. It also employs random deployment mechanisms of dispersing nodes randomly. The semi-random deployment protocol consists of two steps i.e, the anticipate configuration step and the scheduling process step. The anticipate configuration step consists of the configuration of certain necessary parameters and storing them in the memory only once for the used in the nodes scheduling process. Our simulations show that, the semi-random deployment is efficient compared to existing methods of deployment. The rest of this paper is organized as follows. Section 2 formally defines the problem. Sections 3 reviews some related work. Sections 4 proposes our sensor deployment type. Simulation results are presented in Section 5. The Results Analysis are discussed in Section 6. Finally, the Conclusion is drawn in Section 7.

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2 RELATED WORK

Currently, the use of wireless sensor networks is a major need in various surveillance applications, such as monitoring applications in; the environment, battlefields, borders, forests, intelligent spaces, and in the control of industrial and biological disasters. The main objective of using of the wireless sensors network is how to monitor with sufficient coverage an area of interest with a fewer sensor nodes in a longtime (cardie and Wu, 2004), (C.-F and Tseng, 2005).The guarantee of the perfect coverage leads to guarantee the connectivity of the area of interest (AoI). Coverage is difficult to control, measured and guaranteed using a minimal number of sensors nodes deployed on AoI; so, coverage is an optimization problem. Deployment is one of the solutions proposed to solve this problem. Deterministic deployment is preferred in areas where human intervention is possible to; replace, or to change sensor nodes. On the other hand; random deployment is necessary in the terrain that represents the danger and the impossibility of the intervention of the human being. The treatment of the deployment-based coverage problem is extensively addressed using different domains strategies as: using the scheduling process between the Active / Passive states of the nodes in the network (M. Zaied, 2003), using the geometric angles and distances between the nodes (Aurenhammer, 2001), using the disjoint dominating setsand grid strategies (Shen and Sun, 2006), using the Voronoi diagram and the Delaunay triangulation (Aurenhammer, 2001), using the heuristics (M. Zaied, 2003), and others technics . (Wen-Hwa Liao, 2001) Presents the Glowworm Swarm Optimization (GSO) protocol; a new system process based on random deployment to improve of the nodes coverage. GSO protocol considers each node as a single glowworms transmitter and luminant substance like ”luciferin”. The luciferin force considered as the link between the transmitter node and its neighboring sensors. A sensor node move to the low-density area if necessary. A coverage maximization was achieved when a sensor node can move to the low-density area. The disadvantage of GSM is that the nodes must provide by mobilizers and a GPS position detection system, which quickly depletes the network. (X. M. Guo, 2012) divides the area of interest into grid and the selected sensor node in the next round is there situated in the best case. The goal behind this method is to select a smallest set of nodes to guarantee the target coverage and determine the precise positions for the deployed sensor nodes in the network. This method is not efficient in the area coverage and in the wide area where the monitoring of each point is necessary. (Alduraibi Fahad and Younis, 2016) considers the coverage as an optimization problem, where they dress the problem with the deployment of a smallest set of nodes to maximize the coverage. The authors propose three models optimization models. The first is minimizing the sensor nodes number deployed into the area of interest to attain the high reliability level detection. The second model based on the determination of available nodes positions with nodes number constrain for attain perfect coverage. The third optimization model is to minimize the nodes number deployed in some locations that require low coverage and adjust the nodes number deployed in others locations that require higher coverage. (O. Banimelhem, 2013) the implementation of a genetic algorithm (GA). This algorithm specifies the positions and the number of sensor nodes to be deployed in the zone of interest in order to achieve optimal coverage. The application of this algorithm overloads the nodes by calculations that always leave the nodes in active state, the thing that quickly exhausts the network. The remedy proposed for this is the repetitive deployment of sensor nodes in locations where coverage has reached a minimal threshold, which is not always possible especially in danger zones. In (Shen and Sun, 2006), the different strategies are used to maximize coverage in WSN. These strategies are classified into three categories: (a) Force Based, (b) Grid Based, and (c) Geometry Computational Based. Force-based deployment strategies depend on the mobility of sensor nodes, where; Sensor nodes are forced to move away or approach each other until they reach the perfect coverage. The Force Based strategy uses a virtual force as a repugnant and attractive force. The study in (Howard and Sukhatme, 2002) considers that AoI contains sensor nodes and objects that exert a virtual repulsive force to move the sensor nodes away from the objects and also from each other so that their surveillance areas do not overlap. The sensor nodes will continue to move until they reach the steady state in AoI. This strategy provides coverage and connectivity on AoI, but it is extremely dependent on mobility and complex computations, which quickly depletes the network. The grid-based deployment strategy consists of determining the precise positions of the sensors. This is the strategy in which the coverage is evaluated as the ratio between the points of the covered grid and the total number of points of the grid in the AoI. The accuracy of the assessment is determined by the size of each grid, the smallest in size is the most accurate in the assessment. (Shen and Sun, 2006) mentions three types of grids used in the deployment to provide the best coverage; (A)

Triangular grid, (b) Square grid, and (c) Hexagonal grid. The triangular strategy is the best type because it is the smallest area of overlap, so fewer sensors, then the other types (Sanjay Shakkottai, 2003), and the hexagonal grid is the worst of all, since it has the largest area Overlap. Computational geometry is frequently used to optimize coverage in WSN, (Aurenhammer, 2001) mentions two geometric computational approaches used in deployment to provide the best coverage; (A) Voronoi diagram, and (b) Delaunay triangulation. The Voronoi diagram is the division of the area of interest on locations (sites) so that the points in a polygon are closer to the site in the polygon than the other sites. The Voronoi diagram can be used as a sampling method to determine coverage, and measure the holes of in WSN; the sensors act as sites, if all vertices of the Voronoi polygons are covered, then the AoI is fully covered, otherwise the coverage holes exist. The Delaunay triangle is formed by three sites provided if and only if the sites (Wang and Porta, 2003) circulate do not contain other sites. Delaunay triangulation coverage strategy: it is frequently used in coverage optimization in WSN. The Delaunay triangulation is used to evaluate the worst and best case of coverage (Megerian and Srivastava, 2005). The complexity of these approaches lays in the use of computational complexity geometry methods, which quickly depletes the network.

In (Faten Hajjej and Zaied, 2016), a Flower Pollination Algorithm (FPA) was introduced as a solution for deployment and coverage problem. A deployment approach based on FPA was proposed for the sensor placement problem for WSN. This approach can find the optimal placement topology in terms of Quality of service (QoS) metric. But FPA uses too many parameters to calculate for specify the positions of active nodes, which quickly depletes the network.

3 ASSUMPTIONS

To apply our strategy of area coverage in large areas, which consists of using semi-random deployment by mixing between the two types (random and deterministic), we took into consideration the following assumptions:

1. The subdivision of AoI under sub-areas, in order to cover the vast areas well, to achieve an equitable distribution of the nodes in the geographical area, to control connectivity, and to conserve energy consumption in the network.
2. The deployment of a large number of sensor nodes on each sub-area (sub-zone) by a device on a height a little lower and in calm circumstances around each of the sub-zones z_i, in order to guarantee a good distribution in the network.
3. The nodes used in our study are of two types; the first type is made to have a storage memory more than the ordinal nodes, the second type has the same characteristics of the first but a little heavy than the nodes of the first type.

4 DESCRIPTION OF OUR APPROACH

Our protocol consists of two main steps, the anticipate configuration step and the scheduling process step.

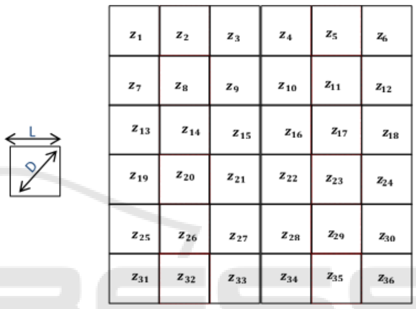

Figure 1: (a) one sub-area, and (b) subdivision of AoI in n sub-areas.

4.1 Anticipate Configuration Step

The area of interest must be divided geographically by n sub-areas of dimension $L \times L$ and diagonal D, as shown in $Figure$1. Anticipate configuration consists of the following steps:

1. The communication radius R_c, and monitoring radius R_s have the following features:

$$R_c = R_s \tag{1}$$

$$R_c = \sqrt{2} \times L \tag{2}$$

   We have taken the case where the communication radius equals the surveillance radius, as shown in relation to equation (1). For a single sensor node to be able to fully cover the sub-area that belongs to it and communicate the collected data to the base station, the communication radius and the monitoring radius would have to be $1.42 \times (thesub - areaside)$, As the relation (2).
2. The nodes used in this study are homogeneous and endowed with a memory capable of storing the following parameters:

- T_{act}: Contains the duration of activation or the time of one revolution.
- T_{att}: Contains the time to wait for the confirmation message by the node that will be active in the next round. The time T_{att}, T_{act} (the waiting time is less than the activation time (the time of one round)) .T_{att},T_{act} times are chosen according to the confidentiality of the task to be performed and the danger of the zone.
- *Num*: Contains the number of the node, this parameter is unique for each node, varied by $1..n$. For each sub-area.
- $Num - zone$: Contains the number of the subzone (sub-area) to be deployed.
- Each node N_i has the ability to generate a random number ρ_i,
- A special node Nsp_i ($sink_i$), it was manufactured for each sub-zone z_i, must be heavier compared to the other nodes of z_i, to fall around the center at the time of deployment. This node must be programmed to be active at the time of their arrival on z_i to allow selecting their neighboring nodes by sending a message *Hello*. The other objective of this sink is the communication of all data collected to the main base station (*BS*).

4.2 Scheduling Process Step

The scheduling process step consists of the following steps:

1. All nodes are passive after deployment except the sinks (special nodes).
2. The special node Nsp_i ($sink_i$) sends a message *Hello* contains the parameter $Num - zone$ to the neighboring nodes, and aims to know the nodes that belong to its own sub-zone. The recipient nodes update their old $Num - zone$ (ie become neighbors of the new Nsp_i).
3. In the first round, the node Nsp_i generates a random number ρ_i and determines the next active node in its own subarea to act as the coverage and transmission of the data harvested according to the following formula:

$$N_i = [\rho_i \times n_i] \quad (3)$$

   Such as:

   - The generate number ρ_i / $\rho_i \in]0..1[$, and
   - n_i represents the total number of nodes deployed in the appropriate sub-zone z_i.
   - $[\rho_i \times n_i]$ represents the integer part of the calculated number $n_i \times n_i$.
4. The node selected to be active in the next round must activate their transmitter and respond with a confirmation message to the transmitter node (a *Hello* message contains the number of the transmitter node). If the transmitter node has not received the confirmation message in a time T_{att}, the latter will remain active until the final exhaustion of their battery.

5 SIMULATION

We compared this type of deployment with the protocols that use deployment and the Active / Passive scheduling process in this case study. The data used in this evaluation are recorded in *Table*1.
To compare our protocol called Semi-Random Deployment Protocol (SRDP) with the protocol named Flower Pollination Coverage Optimization approach (FPCOA) cited in (Faten Hajjej and Zaied, 2016), and mount our improvements over it; we took the same simulation data cited in (Faten Hajjej and Zaied, 2016).The deployment of a number of sensor nodes between 5 and 40; and an area of interest of dimensions 50m 50m; to measure the coverage ratio, and thus to calculate the energy consumed during the 1000 registered primary time units.
To apply our protocol, we divide the area of interest into L-side of sub-areas such that: $L = R_c/1.42 = 15/1.42 = 10.56m$ ie: $25 sub - areas$. The results of simulation are shown in *Figure*2 and *Figure*3.

Table 1: Common data used in the simulations.

Configurations	Value
Area of Interest (AoI)	$50m \times 50m$
Communication Radius (R_c)	$15m$
Sensing Radius (R_s)	$15m$
Deployed Sensor Nodes Number	$5to40$
Time Units	$1000units$

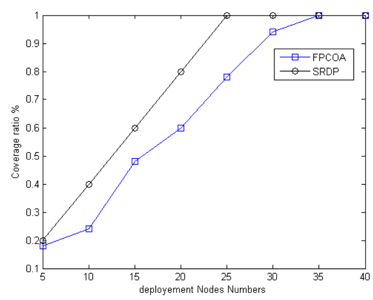

Figure 2: The Comparison of Coverage Ratio with SRDP and FPCOA protocols.

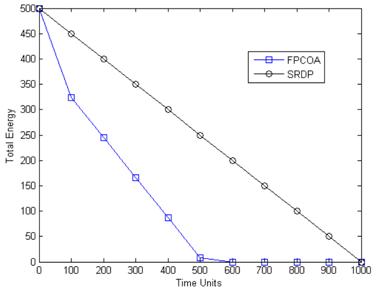

Figure 3: The Comparison of total energy consumption with SRDP and FPCOA protocols.

6 RESULTS ANALYSIS

We simulated the total energy consumption data, thus the coverage ratio in the network for both protocols, the Semi-Random Deployment Protocol (SRDP) and the Flower Pollination Coverage Optimization Approach (FPCOA).

6.1 In Terms of Coverage

The SRDP protocol arrives at a ratio of 1 if the number of nodes deployed reaches 25. On the other hand, the coverage ratio by applying FPCOA arrives at 1 if the number of nodes arrives at 35 nodes as shown in *Figure*2; Which shows a gain at the minimum sensor node number that can be deployed to achieve a perfect coverage of the area of interest. In addition, the network keeps a perfect coverage lifetime more than applies the protocol FPCOA; Because SRDP uses the clustering concept with the activation of a single Cluster-Head by a Cluster to act as a monitoring and communication role of the data captured at the base station.

6.2 In Terms of Energy Consumption

*Figure*3 shows an equitable energy consumption in the network by the application of the SRDP, modeled and proved by the function $Y = 500 - X$. On the other hand, the graph representing the energy consumption of the FPCOA is a graph of the fractions; which shows unfair energy consumption in the network. *Figure*3 shows that the network is exhausted during the 500 prime time units if by applying the FPCOA; On the other hand the network consumes half of their total energy in this time, and it happens to consume their total energy during the 1000 units of prime time. This shows the effectiveness of SRDP versus FPCOA.

6.3 The Advantages of this Strategy Compared to the Previous Scheduling Strategies

1. Not interested in the number of turns for the application of the active / passive process made by each node in the network.
2. Not interested in implementing a process to select the nodes of each subfield (of each cluster) that overloads the node processor and wastes energy and time.
3. Not interested in knowing geographical position, as a result do not need a location system like GPS except in the initial deployment step (anticipate configuration step).
4. Activate a single node in each sub-zone to balance the network in terms of power consumption, guarantee connectivity, and increase the network lifetime.
5. Activation of a single node per sub-zone guarantees full coverage of the area of interest for maximum time without having to implement strategies for measuring coverage.
6. Each asset plays a dual role; a monitoring role and a communication role.
7. The compromise between the two types of deployment brings benefits and minimizes their disadvantages.

7 CONCLUSIONS

In this paper, we proposed a new type of deployment based on anticipate configuration that serves to initialize some parameters help to balance energy consumption, offer connectivity and serves in the entire coverage of the area of interest, thus helps to avoid the different scheduling process and clustering processes used in the sensor network implementation without affecting the connectivity. The subdivision of the area of interest in small areas of diameter equal to the monitoring radius R_s, and putting $R_s = R_c$ provides fair resource consumption in the network, thus guaranteeing connectivity in AoI throughout the network lifetime. The generation of a random number by each node helps to select the next active node for each subfield without the need for different active / passive mechanisms used for this purpose. Using memory settings helps to avoid too much computation and to save energy. The coverage considering $R_s = R_c$ is shown to be effective in area coverage when we subdivide the AoI in subareas of diameter D, ($R_s = R_c = D$), in contrast in previous protocols proposed in (Faten Hajjej and Zaied, 2016), (Yang, 2012).The only inconvenient is the use of memory parameters that it will be processed in the upcoming works.

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