Deployment of Sensors in Regular Terrain in Form of Interconnected WSN Units

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Abstract. The cost of algorithm for finding the deployment positions of static sensors in a given terrain is one of the most important issues for sensor deployment. In this paper a new scheme of deployment is proposed considering a regular rectangular terrain. In the proposed algorithm the entire coverage of the terrain is provided by interconnecting a number of predefined WSNs. Each WSN in a normal configuration consists of five sensors as deployable unit, unlike other sensor deployment algorithms, where each sensor is considered as a deployable unit. The efficiency of the algorithm is guaranteed by making deployment decision for a group of sensors together, rather than making decision for each sensor node. A group of sensor nodes already form a WSN, where the sensor at the centre acts as a server-node and the remaining four as client-nodes. The client-nodes are responsible for sensing coverage and any object sensed within the WSN will be reported to the server-node; whereas the server-node is mainly responsible for communicating with the neighboring WSNs. Hence the challenge of the algorithm is to organize the WSNs in a particular order so that interconnection between the WNSs can be established for effective sensing coverage in the given terrain.

Keywords: wireless sensor network, sensor deployment, DIW, WSN deployment, network of WSNs, regular terrain, Interconnected WSN units.

1 Introduction

The entire network of sensors providing sensing coverage in a given terrain can be viewed as an inter-network between a number of small WSNs. Deployment of Interconnected WSNs algorithm or DIW algorithm is proposed for deployment of predefined WSNs in a rectangular terrain. The performance analysis of the algorithm is in terms of number of deployments needed to be done for a given terrain. The predefined WSNs are formed by a sensor at centre, which is the server-node, adjacent with four other sensors, which are client-nodes. Client nodes are homogeneous sensors (with same sensing and communication coverage) mainly used for sensing

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and communication limited to server-node (belong to same WSN) only, hence less energy is consumed and memory requirement is extremely low. Server-nodes are mainly responsible for data communication. The arrangements of sensors within a WSN are done in a way to provide sensing coverage in rectangular region, which can be called as sensing rectangle. The sensing rectangles can be joined one with another to provide a complete coverage in any given rectangular terrain.

The rest of the paper is organized as follows. Section 2 covers the basic topology of the WSNs with the calculations required for its effective sensing coverage and details the assumptions about the environment considered for the algorithm. In Section 3 the objectives of the algorithm are presented and in section 4 few already proposed solutions are discussed. Section 5 introduces the algorithm and in section 6 the complexity of the algorithm is presented. A comparison between the proposed algorithm and LDM algorithm [9] is sited in section 7 and simulated results are shown in section 8. The limitations and future scopes of enhancements of the algorithm are discussed in section 9.

2 Some Preliminaries and Assumptions

In predefined WSN, the five sensors are arranged in a star topology as show in Fig. 1. In the topology, the sensor at the centre of the WSN acts as server-node and is a heterogeneous (sensing range and communication range are different) sensor. The other four are the client-nodes, homogeneous of type (sensing range and communication range are same).

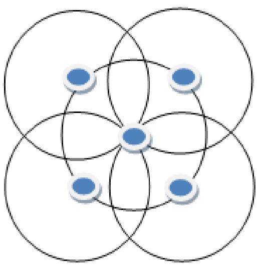

Fig. 1. Topology of WSN

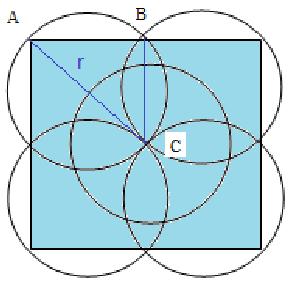

Fig. 2. Calculation of effective coverage area of WSN

Considering the sensing coverage is uniform in all the directions, the sensing area is circular; let it be of radius *r*. Then, the effective coverage of WSN is $8r^2$ as shown in Fig. 2. The effective coverage of a WSN can be calculated as follows-

Let radius of sensor coverage area is r (in Fig. 2)

So if triangle ABC (in Fig. 2) is considered, $where, AB = BC = w$

$$then, w^2 + w^2 = (2r)^2 \quad or, w = \sqrt{2}r$$

Let, s is each side of total coverage rectangle of WSN, then $s = 2w = 2\sqrt{2}r$.

So, the total coverage area, $A = \left(2\sqrt{2}r\right)^2 = 8r^2$.

Distance between two adjacent WSN canters can be calculated as shown in Fig. 3a and 3b. As per Fig. 3a,

Let *BC*=*w* then, $w = \sqrt{2}r$.

So, the distance between two adjacent WSNs (as shown in Fig. 3b. i.e. distance between *P1* and *P2*) is $2w = 2\sqrt{2}r$. Then the sensing range of server sensor is $t_s = r$, the communication range $t_c \geq 2\sqrt{2}r.$ For the client sensors, it is $t_s = t_c = r.$

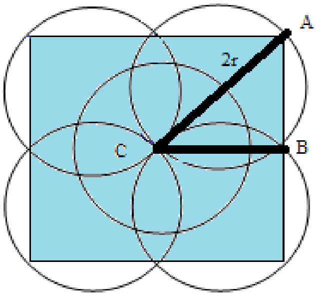

Fig. 3a. Calculation of distance between two deployable positions

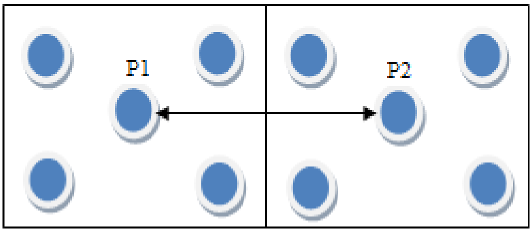

Fig. 3b. Distance between two adjacent deployable positions P1 and P2 calculated as $2\sqrt{2}r$

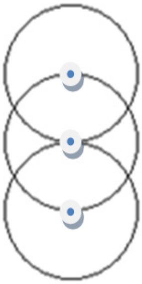

Fig. 4a. Topology of partial WSN-1

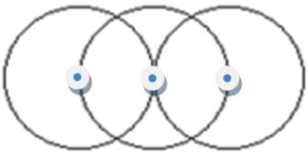

Fig. 4b. Topology of partial WSN-2

Two special kind of WSNs, each consisting of 3 sensors are considered for partial deployments to cover small areas or fragments left after deployments of WSN of 5 sensors or full WSNs. The topologies of partial WSNs as shown in Fig. 4a and 4b are mentioned as partial WSN-1 and WSN-2. The sensor at the center is server-node ($t_s = r, t_c \geq 2\sqrt{2}r.$), and the other two are client-nodes ($t_s = t_c = r$).

The total coverage area by the partial WSN can be calculated as shown in Fig. 5.

$AB = r$ (where r is radius of sensing circle)

$$BC = \frac{r}{2}$$

$$AB = r$$

$$then, r^2 = \left(\frac{r}{2}\right)^2 + (AC)^2 or, AC = \frac{\sqrt{3}r}{2}$$

So, height of coverage area is $\sqrt{3}r$ and length = $6\times(BC) = 6\times\frac{r}{2} = 3r$. Total Coverage = $3r\times\sqrt{3}r = 3\sqrt{3}r^2$.

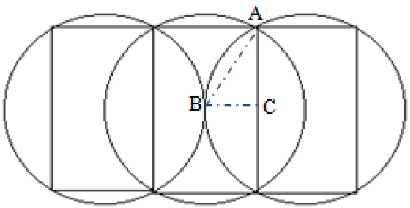

Fig. 5. Calculation of coverage area for partial WSN-2

To keep same alignment with full deployment, the distance between adjacent partial WSNs are kept as $2\sqrt{2}r$. That obviously makes use of $2\sqrt{2}r$ out of $3r$ length. So the actual coverage area = $2\sqrt{2}r\times\sqrt{3}r = 2\sqrt{6}r^2$.

3 Problem Definition and Objectives

The key objectives of this proposed deployment algorithm are as follows-

- Deployment of interconnected WSNs, with a low cost algorithm.
- Complete coverage of the given terrain or AoI [9].
- No effective coverage outside the given terrain or AoI [9].
- Developing algorithm which will deploy the special partial WSNs (as shown in Fig. 4) so that the wastage of sensing coverage can be minimum, i.e. no deployment beyond AoI.

4 Related Works

Different algorithms have already been developed for deployment of sensors in regular terrain, irregular terrain and irregular terrain with obstacles. In [1], [2], [3], [4], [5], [6] and [7], different processes of deployment within a regular rectangular terrain have been proposed. In [1], an irregular shape is partitioned into regular shapes, and then farther sub-partitioned so that the sensors can be deployed. In [2] a fuzzy based key redistribution determining method is used for deployment. In [3], movement assistant principal was introduced for moving sensors from densely deployed area to less densely deployed area. In [4], a unified framework for movement assistant deployment has been proposed. In [5], a “Virtual Rhomb Grid based Movement-assisted Sensor Deployment” algorithm has been proposed, which starts with a rectangular shaped terrain with randomly placed sensors. It partitions the terrain using a virtual rhomb grid (VRG) and moves the sensors on vertices of VRG. In [6], the authors considered a regular shape terrain with holes. They proposed linear-time algorithm to identify the boundary nodes, after a random deployment of sensors in terrain.

An application specific solution is provided in [7], which describes a non-uniform deployment of sensors. In [8], authors consider irregular terrain without any holes, uses robot deployment mechanism for near-minimal number of sensor deployment. In [9] and [10], the LDM algorithm has been proposed for deployment of sensors, routing model and tracking objects and irregular terrain with obstacles has been considered. LDM makes decision for each and every sensor about its deploy-ability, hence reduce performance. A major comparison of DIW and LDM is done in the performance section.

5 Proposed Model

Considering a rectangular terrain the deployment is started from the top-left corner. The number of WSNs to be deployed from left to right is n1 = ⌊ (length of terrain) / (length of each WSN) ⌋. Number of WSNs deployed from top to bottom is n2 = ⌊ (height of terrain) / (height of each WSN) ⌋. So, number of full deployment n1 X n2. The algorithm for full deployment is as follows-

```
algorithm full_deployment(){
    /*let n1 number of WSN to be deployed length-wise;
    let n2 number of WSN to be deployed hight-wise*/
    n1 = floor(length_of_terrain / length_of_WSN);
    n2 = floor(height_of_terrain / height_of_WSN);
    starting_position:=(top_of_terrain+ height_of_WSN/2
    , left_of_terrain+length_of_WSN / 2);
    let, p (point) := starting_position;
    for 1 to n2 do{
          for 1 to n1 do{
          full_deplyment_at(p);
          p.x :=   p.x + 2√2r (with x coordinate)
          }p.y :=   p.y + 2√2r (with y coordinate);
    }
    call partial_deployment();
}
```

The full deployment can leave a small uncovered area at the bottom of AoI and at the right side of AoI. The uncovered areas have to be covered by the partial deployment scheme. The algorithm for partial deployment is as follows-

```
  Algorithm partial_deployment(){
      /*let n1 and n2 number of WSN for partial
      deployment at uncovered area at bottom, length-wise
      and height-wise; let uncovered_bottom_length and
      uncovered_bottom_height are the length and height
      of uncovered area of bottom;*/
      n1 := ceiling(uncovered_bottom_length /2√2r));
      n2 := ceiling(uncovered_bottom_height /√3r));
      partial_deployment of n1 X n2 WSNs at
bottom_uncovered_area.
      /*let n3 and n4 number of WSN for partial
      deployment at uncovered area at right-side, length-
      wise and height-wise; let uncovered_right_length
      and uncovered_right_height are the length and
      height of uncovered area of right side.*/
      n3 := ceiling((uncovered_rihgt_length /√3r));
      n4 := ceiling((uncovered_right_height /2√2r));
      partial_deployment of n3 X n4 WSN at
right_uncovered_area.
  }
```

The approach can plot some of the sensors outside the AoI, which is practically not possible. So, algorithm called *reposition()* will reposition those sensors so that the sensors will be positioned within the terrain and their effective coverage area exactly ends at the border of terrain, so no coverage will be provided outside the terrain.

```
  algorithm reposition(){
      for each WSN whose effective coverage area beyond
      the bottom-border of AoI{
            let h is the height of effective coverage
            area of partial deployment below the AoI;
            deploy the WSN, by h distance upwards;
      }
      for each WSN whose effective coverage area beyond
      the right-border of AoI {
      let w is the width of effective coverage area of
      partial deployment beyond the right border of the
      AoI;
      deploy the WSN, by w distance leftwards;
      }
  }
```

The algorithm guarantees no effective coverage (coverage rectangle) outside the terrain as shown in Section 8, Fig. 10. As a result, the algorithm generates deployment database with X-coordinates and Y-coordinates. The format of the database is as follows-

Table 1. Format of 3 deployment databases for Full-Deployment, for partial-Deployment with WSN-1 and for partial-Deployment with WSN-2

Node ID	**Deployment Position**	
	X-coordinate	**Y-coordinate**

6 Complexity Analysis

Considering a rectangular AoI with no obstacle, with width and height *w* and *h* and the coverage radius of sensors r, DIW construct WSN of side $2\sqrt{2}r$ and area of $8r^2$.

Number of deployments per row is $N = \left[\left(\frac{w}{2\sqrt{2}r}\right) - 1\right]$ (as horizontal and vertical distance between adjacent nodes 2√2r). Number of deployments per column is $M = \left[\left(\frac{h}{2\sqrt{2}r}\right) - 1\right]$.

Total number of deployments in the given AoI of is *(w X h)* = $N \times M = \left[\left(\frac{w}{2\sqrt{2}r}\right) - 1\right] \times \left[\left(\frac{h}{2\sqrt{2}r}\right) - 1\right]$

In worst case, the maximum number of partial deployments at bottom-side and right-side uncovered areas after full deployment will be for 2 rows and 2 columns, i.e. $2 \times \left[\left(\frac{w}{2\sqrt{2}r}\right) - 1\right] + 2 \times \left[\left(\frac{h}{2\sqrt{2}r}\right) - 1\right]$. Considering $h = w$ then total deployment in worst case is $\left[\left(\frac{w}{2\sqrt{2}r}\right) - 1\right]^2 + 4\left[\left(\frac{w}{2\sqrt{2}r}\right) - 1\right]$.

In the algorithms full_deplyment(), partial_deplyment() and reposition() the deployments are done or adjusted row-wise and column-wise. If total number of row-wise and column-wise deployments are m and n respectively, then the cost is $n \times m$. Assuming $m = n$, the cost is n^2. Hence the complexity is $\theta(n^2)$.

7 Performance

The efficiency of the algorithm depends on number of units (WSN) to be deployed. Compare to LDM in [9] and [10], the number of deployments can be definitely reduced as the deployable units in LDM are sensors, whereas in DIW the deployable are WSNs (consisting of 5 sensors).

Considering a rectangular terrain with no holes and pockets, with width and heights are w and h,

Considering homogeneous sensors with the radius of sensor coverage r, for LDM algorithm,

Number of deployment per row, $N = \left(\frac{w}{r} - 1\right)$.

Number of deployment per column, $M = \left(\frac{h}{r} - 1\right)$.

Total deployment = $N \times M = \left(\frac{w}{r} - 1\right) \times \left(\frac{h}{r} - 1\right)$.

Lets assume $w = h$, total number of deployment = $\left(\frac{w}{r} - 1\right)^2$.

For DIW algorithm, total number of deployment (in worst case) considering w=h, is, $\left[\left(\frac{w}{2\sqrt{2}r}\right) - 1\right]^2 + 4\left[\left(\frac{w}{2\sqrt{2}r}\right) - 1\right]$ [as discussed in performance analysis].

For a area 100 X 100, comparison of number deployments of the 2 schemes LDM and DIW, is done below-

Table 2. Number of deployment comparison between LDM and DIW

Radius of sensing area	Number of Deployments		
	LDM	**DIW**	**Gain (less number of deployment)**
10	9801	1317	8484
20	2401	344	2057
30	1045	159	886
40	576	92	484
50	361	61	300

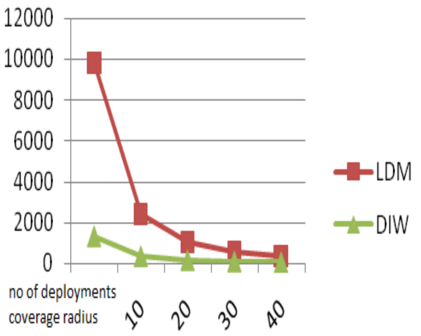

Fig. 6. Comparison of deployment of LDM and DIW

8 Simulated Results

A simple simulator is developed to simulate the DIW algorithm. For example, regular terrain of 500X300 pixels is considered in Fig. 7. The step by step deployment process for the terrain is depicted in Fig. 7, 8, 9 and 10.

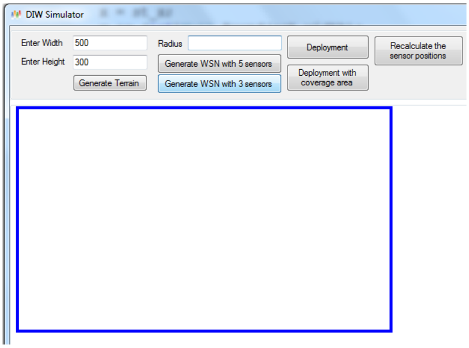

Fig. 7. Creation of rectangular terrain (500X300)

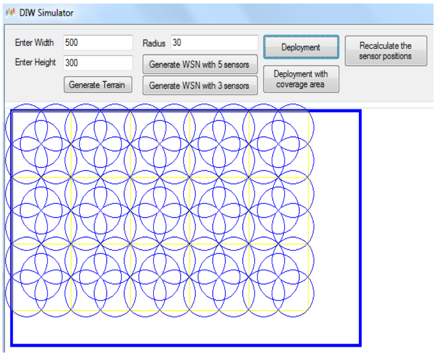

Fig. 8. Coverage after full deployment

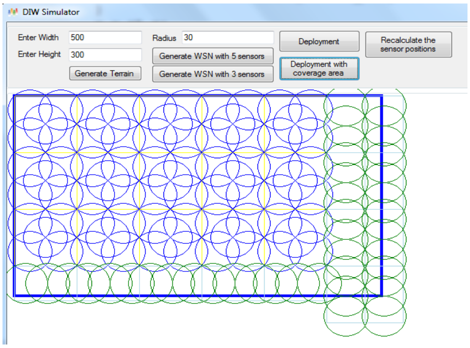

Fig. 9. Coverage after partial deployment

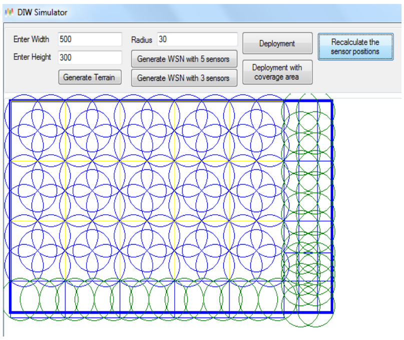

Fig. 10. Coverage after repositioning WSNs

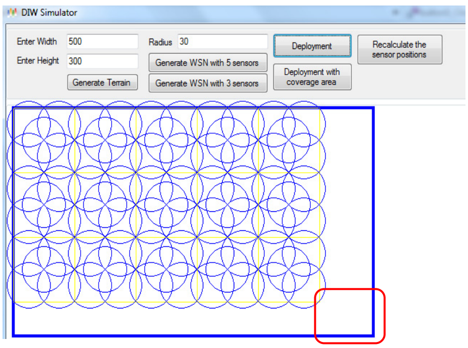

Fig. 11. Deployment ambiguity marked in red colored box

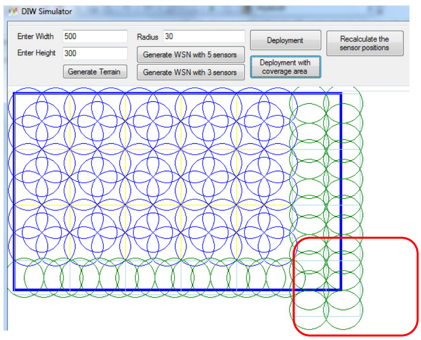

Fig. 12. Resolution of deployment ambiguity in current DIW implementation

9 Conclusions

DIW algorithm is currently restricted to the rectangular terrains. DIW can be further updated to work with irregular terrain with obstacles. Most of the previous algorithms, which start the deployment process from the centre of the terrain, end up with few fragments or uncovered areas at the border of the terrain. One of the key advantages here is that all the fragments will be gathered at a particular side of AoI; so it is easy to address. One of immediate chances of enhancement of this algorithm is in Fig. 11. The uncovered area after full deployment marked in red box can be considered as bottom side uncovered area or right side uncovered area. This can be addressed by right or down partial deployment (deployment ambiguity). Ideally the scheme must be selected so that the number of deployment is minimum. But current implementation always considers it as right-sided deployment as shown in Fig. 12.

References

1. Wang, Y.-C., Hu, C.-C., Tseng, Y.-C.: Efficient deployment algorithms for ensuring coverage and connectivity of wireless sensor networks. In: The Proceedings of First International Conference on Wireless Internet, pp. 114–121 (2005)
2. Zhao, L., Liang, Q.: Fuzzy deployment for wireless sensor networks. In: The Proceedings of the 2005 IEEE International Conference on Computational Intelligence for Homeland Security and Personal Safety, pp. 79–83 (2005)
3. Wang, G., Cao, G., Porta, T.L.: Movement-assisted sensor deployment. IEEE Transactions on Mobile Computing 5(6), 640–652 (2006)
4. Fang, C., Low, C.P.: Unified Framework for Movement-Assisted Sensor Deployment. In: The Proceedings of Wireless Communications and Networking Conference, WCNC 2008, March 31-April 3, pp. 2057–2062. IEEE Publication (2008)
5. Wang, X., Yang, Y., Zhang, Z.: A virtual Rhomb Grid-Based Movement-Assisted Sensor Deployment Algorithm in Wireless Sensor Networks. In: The Proceedings of First International Multi-Symposiums on Computer and Computational Sciences, IMSCCS 2006, vol. 1, pp. 491–495 (2006)
6. Wang, Q., Xu, K., Takahara, G., Hassanein, H.: Deployment for Information Oriented Sensing Coverage in Wireless Sensor Networks. In: The Proceedings of Global Telecommunications Conference, GLOBECOM 2006, pp. 1–5. IEEE (2006)
7. Fang, Q., Gao, J., Guibas, L.J.: Locating and by passing routing holes in sensor network. In: The Proceeding of INFOCOM 2004, Twenty-Third Annual Joint Conference of the IEEE Computer and Communications Societies, vol. 4, pp. 2458–2468 (2004)
8. Chang, C.-Y., Chang, C.-T., Chen, Y.-C., Chang, H.-R.: Obstacle-Resistant Deployment Algorithms for Wireless Sensor Network. IEEE Transactions on Vehicular Technology 58(6), 2925–2941 (2009)
9. Bhattacharyya, C.K., Bhattacharya, S.: LDM (Layered Deployment Model): A Novel Framework to Deploy Sensors in an Irregular Terrain. In: The Proceedings of Wireless Sensor Network, vol. 3, pp. 189–197 (2011)
10. Bhattacharyya, C.K., Bhattacharyya, S.: Tracking a moving object in an irregular area: a guaranteed shortest path routing model. In: The Proceedings of IEEE International Conference INDICON 2009, Ahmedabad, Gujarat, December 18-20, pp. 166–169 (2009)