Implementation and Analysis of an Optimal Sensor Deployment Algorithm (OSDA) for WSNs

[1]Kawalpreet Kaur, [2]Tripatjot Singh Panag
[1]Student, [2]Assistant Professor
[1]Department of Electronics and Communication Engineering,
[1]Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, Punjab, India

Abstract— ***Deployment of the sensor nodes is a major aspect in the designing of wireless sensor networks. The coverage, connectivity and lifetime o0f a wireless sensor network is directly affected by the quality of the deployment. In this paper, an optimal sensor deployment algorithm (OSDA) has been presented to cover all the targets with the minimum number of sensors. Starting with a randomly chosen location for the first sensor, the locations for deploying the subsequent sensors are chosen on the basis of the number of targets expected to be covered by deploying the sensor at the selected location. The ability of OSDA to minimize the number of sensors required for covering all the targets has been evaluated under various scenarios and compared with that of random deployment.***

Keywords— ***Deployment, binary model, target coverage, OSDA.***

I. INTRODUCTION

Wireless sensor network (WSN) comprises a number of energy-constrained nodes that are deployed for observing various phenomena of interest. A sensor node consists of a sensing unit, a process unit, a radio transceiver and a power management unit [1]. An important objective of sensor networks is to effectively monitor the environment, detect, localize, and classify targets of interest. The position of sensors affects coverage, communication cost, and resource management. The effective deployment of sensor nodes is the main concern while considering WSN. The sensor nodes in a specific region should be deployed in such a way that they efficiently cover all the targets in surveillance region.

Recently, wireless sensor networks (WSNs) are applied in various fields [2], such as sensing, underwater surveillance [3], and monitoring purposes [4] such as health care [5] with three main objectives: increasing lifetime, targeted coverage and connectivity [6,7].Various methods have been proposed to evaluate the quality of coverage and connectivity achieved by a wireless sensor network[8]. Deploying the sensor nodes to attain the maximum coverage with a minimum number of sensors is a challenging task. Coverage problem [9] can be classified as: area coverage problem (covering the entire region), target coverage problem (covering the specific area of interest) and barrier coverage problem. Two types of sensor node deployments for the coverage are introduced: random deployment (in an inaccessible region) and deterministic deployment (in an accessible region) [10, 11]. Many methods has been proposed to achieve complete target coverage problem [12]. To evaluate the coverage problem, the coverage area was divided into fields [13] and was later extended to grids [14]. This paper proposes an optimal sensor deployment algorithm for covering the targets by employing the minimum number of sensors.

A virtual force algorithmic program (VFA) as a sensing element deployment strategy was planned by Zou [15] so as to boost the coverage for random placement of sensors in order to maximize the sensing element field coverage. Yoon et.al [16] proposed that coverage is the most important performance metrics for detector networks. They explained that random placement is the easiest way to deploy detector nodes, however could cause unbalanced preparation and so they adopted Monte Carlo methodology. The deployment of sensors for the coverage of targets in the grid environment was proposed by Chand et.al [17]. In his, work, he compared his work with ACO-TCAT method in the original form as well as after checking the redundancy. Kumari et.al [18] studied that one major drawback in wireless sensing element network is coverage which shows quality of the network. During this paper, coverage techniques and algorithms employed in these techniques were studied. Coverage Techniques were classified into three groups: space coverage, point coverage and path coverage. Mini et.al [19] presented the paper to maximize the lifetime of the network with the required coverage level. They used artificial bee colony algorithm and particle swarm optimization for sensor deployment problem followed by a heuristic for scheduling. A comparative study showed that artificial bee colony algorithm performs better for sensor deployment problem.

A novel stochastic physics-based optimization algorithm that was both efficient and scalable was implemented by Njoya et.al [20]. The algorithm employed `virtual sensors' which move, merge, recombine, and `explode' during the course of the algorithm, where the process of merging and recombining virtual sensors reduces the number of actual sensors while maintaining full coverage. One of the major challenge of cost effecicient target coverage was accomplished by Jagtap [21] using V-VBAC algorithm that is Voronoi partition based, velocity added artificial bee colony algorithm. He compared his work with the traditional method and the results showed that this algorithm performed better than the classical methods. Wang et.al [22] intended the essential studies on the sensing coverage and therefore the network property from mathematical modeling, theoretical analysis, and performance analysis views. The aim of their analysis was to deliver a scientific study on the basic issues in WSNs and supply pointers in choosing important network parameters for WSN style and execution in observe. There are 3 kinds of sensing models viz. Boolean sensing model, shadow-fading sensing model and Elfes sensing model were examined by Hossain [23]. He investigated the impact of sensing models on network coverage. He additionally investigated network coverage supported Poisson node distribution. A comparative study between regular and random node placement has additionally been bestowed during this paper. This study was helpful for coverage analysis of WSN. Gond [24] explored that one among the basic issues in wireless sensing element network is Coverage and lifetime. Since the sensing element node have a restricted battery powerand once they are deployed, it becomes extremely difficult to replace them. Therefore, economical energy preparations is extremely needed to enhance the coverage and lifetime. During this work, they provided an analytical framework for the deployment of sensors. They also presented the formulation and solution to energy allocation of sensor node according to traffic load in every hop wireless sensor networks. They also presented an algorithm which shows that how much initial energy was required for different sensors which are deployed in different hop WSNs. An improved ant colony algorithm (EasiDesign) was formulated by Li et.al [25] to achieve the approximate solution to the minimum-cost connectivity guaranteed point k- coverage problem. They designed the obstacle avoidance and the routing cost tradeoff strategies to ensure that EasiDesign can work efficiently. Colonoi et.al [26] explored the implications that the study of ants behavior can have on problem solving and optimization. They introduced a distributed problem solving environment and propose its use to search for a solution to the travelling salesman problem.

In this paper, an optimal sensor deployment algorithm (OSDA) is proposed for planned deployment of sensors to solve the point coverage problem wireless sensor networks. A point coverage problem is described as: a finite set of points (targets) in RoI observed by atleast one sensor. The OSDA starts by randomly selecting a location for deploying the first sensor and progresses to identify locations for deploying the subsequent sensors so that all the targets are covered with the least possible number of sensors. OSDA has been implemented and evaluated for different test scenarios. The rest of the paper is organized as follows: Section II presents the basic coverage model. The proposed method for solving the coverage problem is discussed in Section III discusses the results. Concluding remarks in Section IV ends the paper.

II. COVERAGE MODEL

Network coverage of wireless sensor network (WSN) means how well an area of interest is being monitored by the deployed network. It depends mainly on sensing model of nodes. Generally, there are two sensor deployment strategies: (1) deterministic sensor deployment in a controlled and human-friendly environment [27] and (2) random sensor deployment in a dangerous and inaccessible region [28]. For the coverage of the region, we mainly use two types of sensing models: (1) Deterministic sensing model i.e. Boolean sensing [29] (2) Probabilistic sensing model [30].

Binary Detection model – If the event occurs is within the sensing range of a sensor node then the event will be detected, otherwise not. This model ignores the dependency of the environmental conditions (obstacles such as building, plants) and the potency of the emitted signal on the task of sensing. Generally, the area covered by a sensor node is a circle with radius equals to sensing radius of the node.

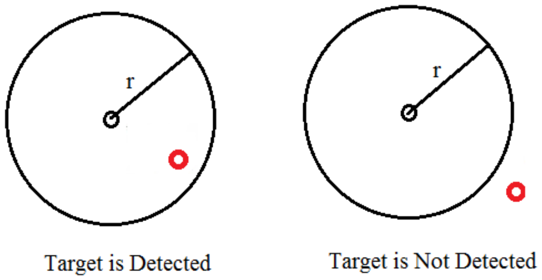


Fig. 1: Detection Criteria of Binary Detection Model

This Equation shows the binary sensor model that expresses the coverage $C_{ij}(x, y)$ of a grid point at (i, j) by sensor s at (x, y)

$$C_{IJ}(X,Y) = \begin{cases} 1, if\ d_{ij}(x,y) < r \\ 0, \text{otherwise} \end{cases} \quad (1)$$

III. PROPOSED WORK

The algorithm of OSDA is proposed so as to cater the problem of covering the targets with minimum number of sensors. OSDA is based on the movement process in all the four directions. In the beginning, n number of targets are randomly generated at the grid points Initially, all the parameters like range of the sensors, dimensions of the area and the number of the targets are defined and thus, saving the data for further evaluation.

In order to cover these targets, an initial random sensor is deployed at any grid point except at the target grid point. The sensor moves from a grid point to another step by step based on the algorithm. If the sensor covers any of the targets, the covered target list is updated that is, the targets that have been covered by the sensor are removed from the list Now, the sensor from that grid point will move to next location (in one of the four possible directions- up, down, left, right) and the next location is determined by counting the number of targets covered by that sensor if it were placed at that location. The next location will be the one where the sensor covers the maximum targets.

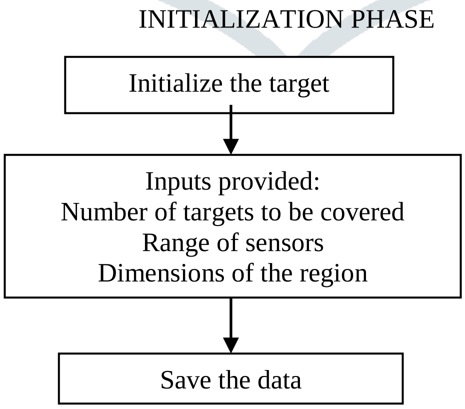


Fig. 2: shows the initialization phase.

Figure 2 illustrates that initially the targets are randomly placed. Certain inputs are to be provided like the number of targets, range of the sensors and the dimensions of the region of interest which is thus saved so as can be used further in the algorithm.

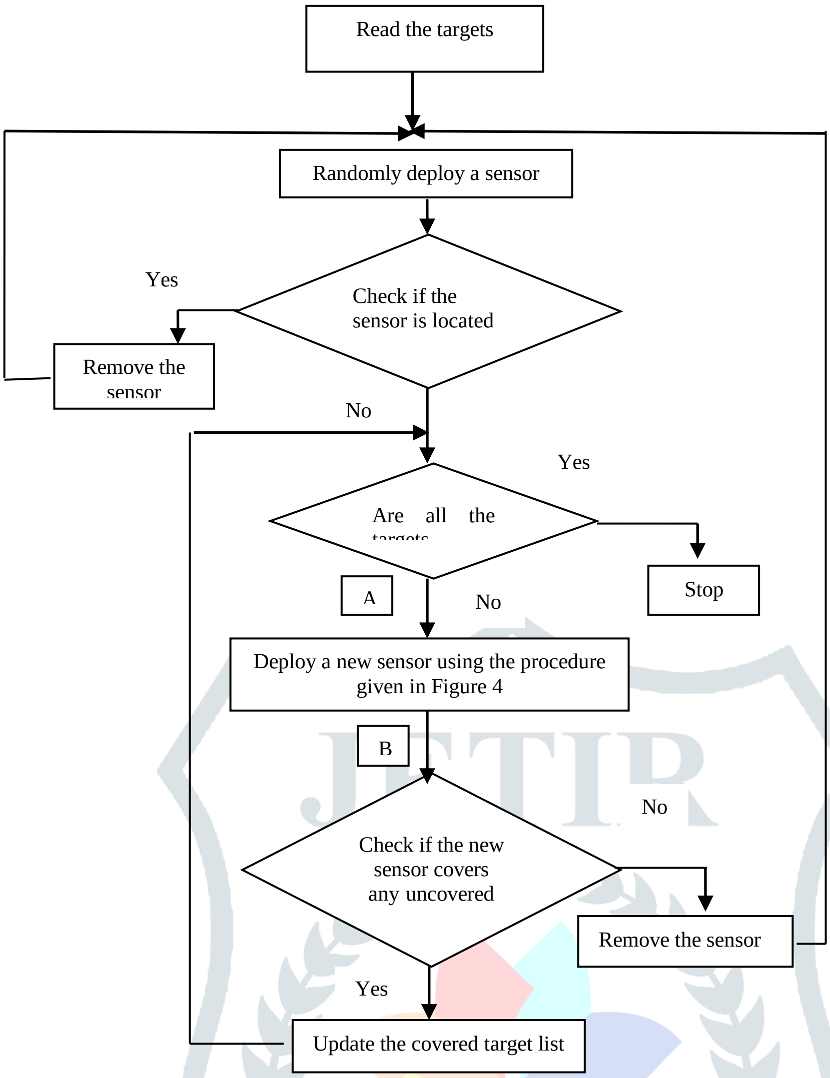
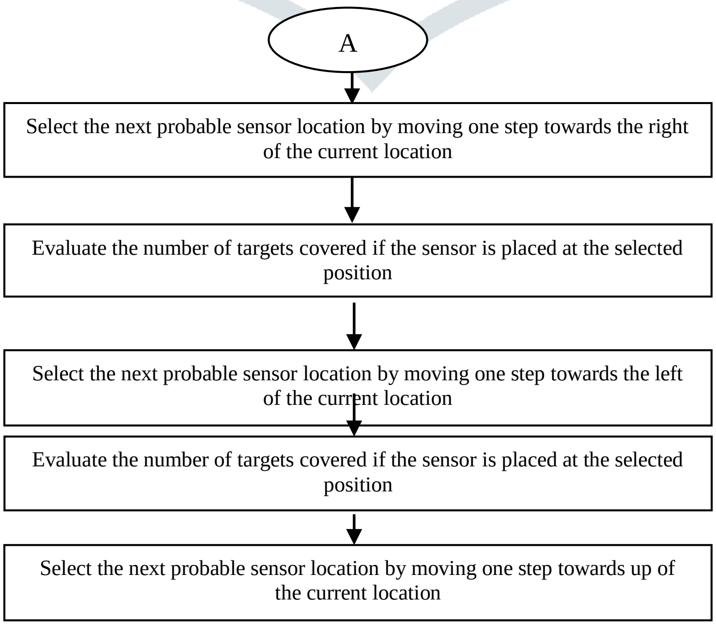


Fig. 3: Flowchart of the proposed algorithm.

Figure 3 shows the algorithm that is to be used in this proposed method. In this method, firstly the saved data is read. A sensor is randomly deployed and checked whether if the sensor is placed at any of the target locations, the sensor is discarded else this sensor is used to check if it covers all the targets. If yes, the process is terminated otherwise the process continues to find the targets covered by the sensor. Then, a new sensor is placed at the location found by the procedure described in Figure 4 to cover the uncovered targets. As the targets are covered, the covered targets list is updated. In case, no new targets are covered, again a sensor is randomly placed and the process continues. The random deployment of sensor is considered in three different cases: (1) when no new targets are covered, (2) sensor is located at the target location, (3) when the sensor moves out of the area of interest.



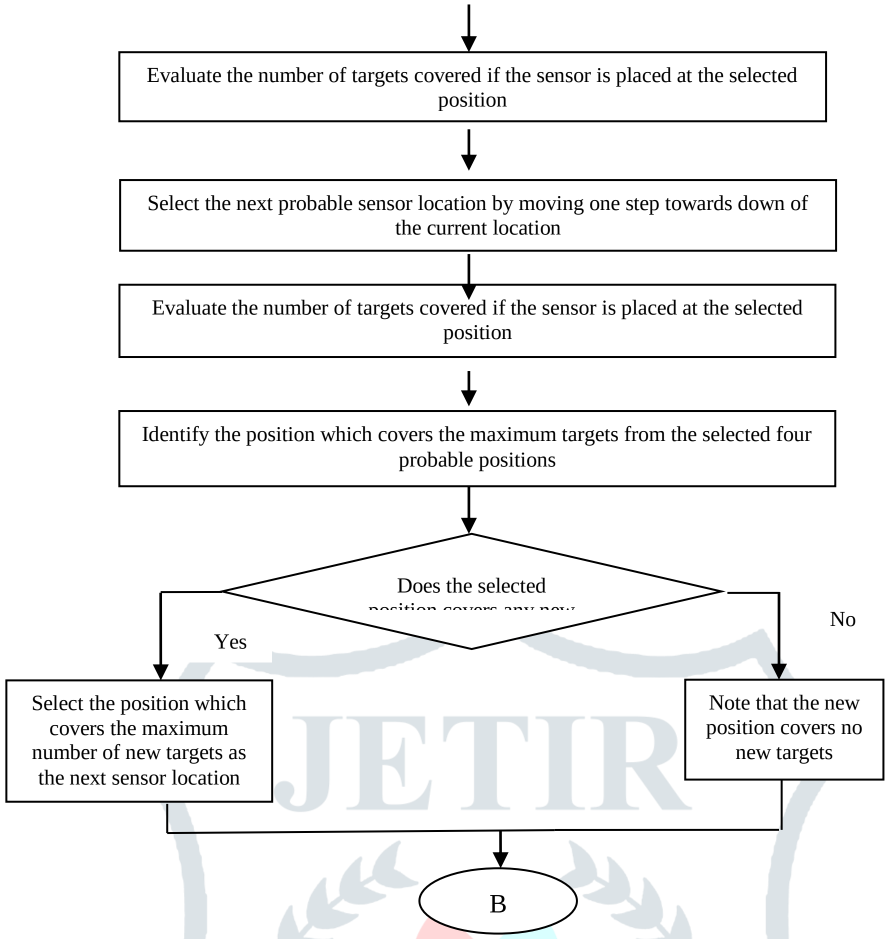


Fig.4: Flowchart describing procedure for deploying a new sensor for finding next location.

Figure 4 describes the process required for the movement of the sensor to the new location in order to cover the uncovered targets. In this process, for the deployment of the sensor, the movement is in one of the four possible directions (up, down, right, left) to find the next grid point for placing the new sensor Firstly, the sensor is moved one step to the right of the current location of the sensor with the distance (2r-1) where r is the sensing range of the sensor. At this location, the number of targets covered by this sensor are evaluated. The sensor is then moved to the left of the current location with a distance of (2r-1). At this selected probable location, number of targets covered by the sensor are examined. The same procedure is followed while moving up and down of the current sensor with a distance of (2r-1). Then the position is identified which covers maximum number of targets when placed at the four probable locations and checked if the new sensor covers any uncovered targets. If so, the probable location is selected as the next sensor location else the procedure is moved to B where a sensor is located randomly and again the process of movement continues. The procedure is carried out till all the targets are covered.

IV. RESULTS AND DISCUSSIONS

In this system, the sensor deployment using optimal sensor deployment algorithm is efficiently done. Firstly, the given area is divided into two-dimensional grid and sensors are deployed in a way to cover all the targets with minimum number of sensors using binary detection model.

In this work, the comparison is made between the optimal sensor deployment and random deployment considering three different configurations i.e. by altering three different parameters which are dimensions of the area, number of targets and the range of the sensors. For each of these configurations, 5 different cases are exhibited for which the algorithms are executed 10 times and the mean of 10 independent results are observed. The three different configurations are as follows:

- Number of targets and the range of sensors are constant whereas the dimensions of the region are altered.
- Dimensions of the area and number of targets are constant and the range of sensors is varied.
- The dimensions of the area and the range of sensors is kept constant but the number of targets are changed.

The results of work done are given below:

Table 1: Showing the effect of variation in total number of sensors of constant range required to cover fixed targets within a varying field of interest.

CASES	AREA	RANGE	NUMBER OF TARGETS	NUMBER OF SENSORS DEPLOYED (Mean of 10 independent executions)	
				OSDA	RANDOM DEPLOYMENT
1	100×100	50	50	2.8	6.1
2	300×300	50	50	16.6	32.2
3	500×500	50	50	26	40
4	750×750	50	50	39	47.3
5	1000×1000	50	50	40.1	47.4

Table 1 illustrates the deployment of sensors of same range for covering a fixed number of targets for different region of interest. It shows the effect of varying area on the number of sensors. It is depicted that for small regions, less number of sensors are deployed but with the increasing area, the number of sensors also increases because as the dimensions of the region keeps on increasing the number of sensors required to cover the targets scattered in the particular region also increases. This effect can be observed by the following graph

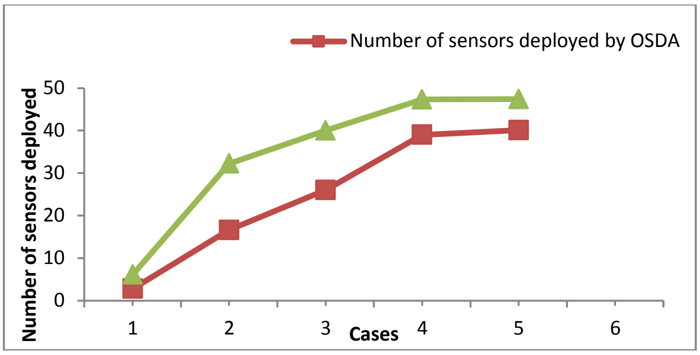


Fig.5: Comparative study of OSDA and Random deployment on varying area when number of targets and sensing radius are constant.

Figure 5 shows the comparison of the two methods. It is evident from the above figure that as the RoI enlarges, the targets are scattered at larger distances due to which the number of sensors needed to cover these targets increases. This is so because the sensing radius of the sensor is kept fixed whereas the space in which the targets are placed is increased. The random method requires large amount of sensors to cover these targets than the OSDA as apparent from the above graph.

Table 2: Showing the effect of variation in the total number of sensors of varying range required to cover fixed number of targets within a fixed area of interest.

AREA	RANGE	NUMBER OF TARGETS	NUMBER OF SENSORS DEPLOYED (Mean of 10 independent executions)	
			OSDA	RANDOM DEPLOYMENT
1000×1000	50	50	38.7	49.6
1000×1000	100	50	24.9	42.4
1000×1000	150	50	19.9	35.1
1000×1000	200	50	11.5	28.1
1000×1000	250	50	9.4	20.8

Table 2 presents the results of the proposed method for covering 50 targets within a region of dimensions, 1000×1000 with different ranges of sensors. It is seen that as sensing radius of the sensors keep on increasing, OSDA requires almost half of the sensors as required by the other method. It can be observed from the above table that within fixed region, as the range of the sensor increases, it covers more targets within that sensing radii due to which the number of sensors required to cover the targets decreases.

Figure 6 given below gives an idea of how the number of sensors required to solve the point coverage problem alters with the changing sensor ranges. A declining curve is noticed for OSDA and random deployment for incrementing detection ranges. This is due to the fact that as the radii of the sensor increases, it covers more targets as compared to low sensing radius.

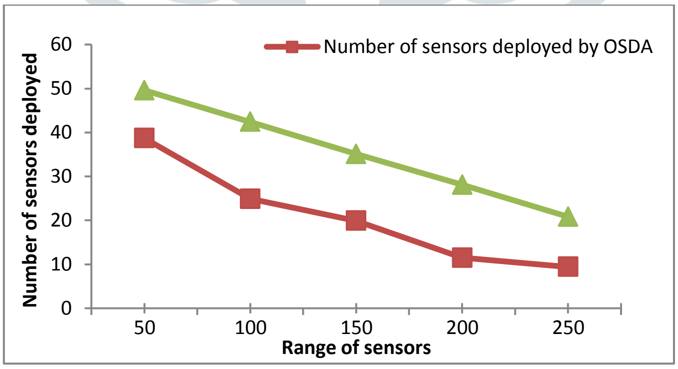


Fig.6: Comparative study of OSDA and Random deployment on varying sensing radius of sensors when number of targets and RoI are constant

Table 3: Showing the effect of variation of the total number of sensors of same range required to cover varying targets within a fixed area of interest.

AREA	RANGE	NUMBER OF TARGETS	NUMBER OF SENSORS DEPLOYED (Mean of 10 independent executions)	
			OSDA	RANDOM DEPLOYMENT
500×500	50	10	7.8	9.4
500×500	50	20	15.6	17.1
500×500	50	30	22	26.9
500×500	50	40	23.1	31.9
500×500	50	50	28.4	42.3

Table 3 depicts the deployment of sensors of same range within a predetermined region. Within region of dimensions 500×500, small number of targets are covered by less sensors whereas for more number of targets, sensors required are more. This is because small amount of targets are scattered in small area due to which they are covered by less sensors rather the scenario is different when the number of targets are increased.

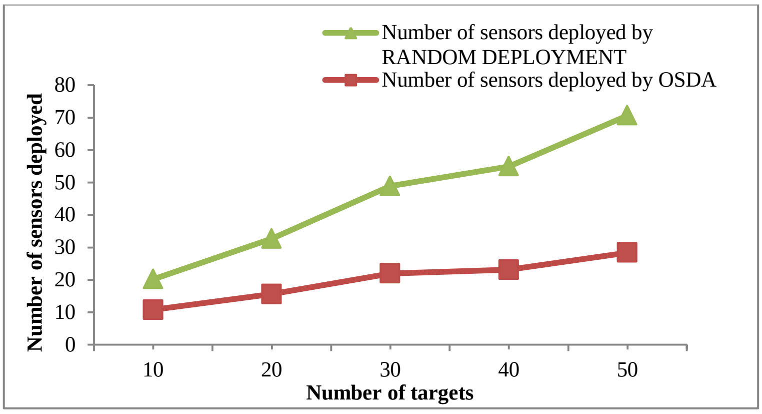


Fig.7: Comparative study of OSDA and Random deployment on varying number of targets when sensing radius and RoI are constant

Figure 7 illustrates the growing curve for the number of sensors needed for target coverage with rising number of targets for OSDA and random deployment. When the number of targets are less, small number of sensors are needed to cover these targets but with increasing targets, number of sensors also increases.

V. CONCLUSION AND FUTURE SCOPE

Coverage is one of the most important measurement for the quality of surveillance that a sensor network can provide. Therefore, the paper emphasizes on the target coverage problem in a wireless sensor network. The methodology based on the movement of the sensors for covering the set of targets with binary detection model is presented. The algorithm proposed, OSDA is so built so as to cover all the targets with minimum number of sensors in a given area. The results are then compared with the random deployment method. In random deployment, the number of sensors required to solve the coverage problem is more than the proposed method.

In the implemented work, it has been concluded that OSDA method is better than the random deployment method for covering the targets under different constraints. Thus, this method requires less number of sensors to cover all the targets and in the Future work, we will try to compare this algorithm with other algorithms with more optimization capabilities.

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "Wireless Sensor Networks: a survey," Computer Networks Journal, Elsevier Science, March 2002, vol. 38, pp. 393-422.

[2] Sohraby, K., Minoli, D., Znati, T., "Wireless Sensor Networks: Technology, Protocols, and Applications," John Wiley and Sons Inc., New Jersey (2007).

[3] Ojha, T., Khatua, M., & Misra, S. (2013). Tic-Tac-Toe-Arch, "A self-organising virtual architecture for underwater sensor networks," IET Wireless Sensor Systems, 3(4), 307–316.

[4] C.-Y. Chong and S. Kumar, "Sensor networks: Evolution, opportunities, and challenges," Proc. of the IEEE 91 (8), 1247-1256 (2003).

[5] Nakamura, E.F., Loureiro, A.A.F., Frery, AA.C, "Information fusion for wireless sensor networks: Methods, models, and classifications," ACM Comput. Surv. (CSUR) 39(3), 9 (2007).

[6] Tripatjot S. Panag, J. S. Dhillon (2015), "Heuristic search algorithm (HSA) for enhancing the lifetime of wireless sensor networks," In proceedings of ICECECE 2015: 17th International Conference on Electrical, Computer, Electronics and Communication Engineering, (pp. 2033-2039). August 20-21, 2015, London, UK.

[7] M. Lu, J. Wu, M. Cardei, and M. Li, "Energy-efficient connected coverage of discrete targets in wireless sensor networks'" Networking and Mobile Computing 3619, 43-52 (2005).

[8] Tripatjot Singh Panag, J. S. Dhillon (2017), "Two stage grid classification based algorithm for the identification of fields under a wireless sensor network monitored area," Wireless Personal Communications (Springer), 95(2), 1055-1074.

[9] MSangwan, A., & Singh, R. P. (2014), "Survey on coverage problems in wireless sensor networks," Wireless Personal Communications, 80(4), 1475–1500.

[10] Y. Gu, H. Liu, and B. Zhao, "Target coverage with QoS requirements in wireless sensor networks," in Proc. Intell.Comput 35–38 (2007).

[11] M. Chaudhary and A.K. Pujari, "Q-coverage problem in wireless sensor networks," Proc. Int. Conf. Distrib. Comput Netw., 325–330 (2009).

[12] Wang, Y.-C., Hu, C.-C., & Tseng, Y.-C. (2008), "Efficient placement and dispatch of sensors in a wireless sensor network," IEEE Transactions on Mobile Computing, 7(2), 262–274.

[13] Slijepcevic, S., & Potkonjak, M. (2001), "Power efficient organization of wireless sensor networks," in Proceedings of IEEE international conference on communications (Vol. 2, pp. 472–476). Helsinki.

[14] Hu, X.-M., Zhang, J., Yu, Y., Chung, H. S.-H., Li, Y.-L., Shi, Y.-H., et al.(2010), " Hybrid genetic algorithm using forward encoding scheme for lifetime maximization of wireless sensor networks," IEEE Transactions on Evolutionary Computation, 14(5), 766–781.

[15] Yi Zou, Krishnendu Chakrabarty, "Sensor Deployment and Target Localization Based on Virtual Forces," IEEE INFOCOM 2003, San Francisco, March-April, 2003.

[16] Yourim Yoon, Yong-Hyuk Kim, "An Efficient Genetic Algorithm for Maximum Coverage Deployment in Wireless Sensor Networks," IEEE Transactions on Cybernetics, vol. 43, no. 5, October 2013.

[17] S. Singh, S. Chand, R. Kumar and B. Kumar, "Optimal sensor deployment for WSNs in grid environment," in Electronics Letters, vol. 49, no. 16, pp. 1040-1041, Aug. 1 2013.

[18] Parveen Kumari, Yudhvir Singh, Yogesh Chaba and Prabha Rani, “Coverage Techniques and Algorithms used in Wireless Sensor Network,” National Workshop-Cum-Conference on Recent Trends in Mathematics and Computing (RTMC) 2011.

[19] S. Mini, S. K. Udgata and S. L. Sabat, "Sensor Deployment and Scheduling for Target Coverage Problem in Wireless Sensor Networks," in IEEE Sensors Journal, vol. 14, no. 3, pp. 636-644, March 2014

[20] A. N. Njoya *et al.*, "Efficient scalable sensor node placement algorithm for fixed target coverage applications of wireless sensor networks," in IET Wireless Sensor Systems, vol. 7, no. 2, pp. 44-54, 4 2017.

[21] A.M. Jagtap and N. Gomathi, “Minimizing sensor movement in target coverage problem: A hybrid approach using Voronoi partition and swarm intelligence,” in Bulletin of the Polish Academy of Sciences, Technical Sciences, Vol. 65, No. 2, 2017.

[22] Zhu, Wang, “Relay Node Placement Algorithm Based on Grid in Wireless Sensor Network," Instrumentation, Measurement, Computer, Communication and Control (IMCCC), Third International Conference IEEE, Beijing, China,2013.

[23] Ashraf Hossain, “Sensing Models and Its Impact on Network Coverage in Wireless Sensor Network,” 2008 IEEE Region 10 Colloquium and the Third ICIIS, Kharagpur, INDIA, December 8-10, pp 447.

[24] Subodh Ku. Gond, Nitin Gupta, “ Energy Efficient Deployment Techniques for Wireless Sensor Networks,” International Journal of Advanced Research in Computer Science and Software Engineering, Volume 2, Issue 7, July 2012, ISSN: 2277 128X.

[25] D. Li, W. Liu and L. Cui, “EasiDesign: An Improved Ant Colony Algorithm for Sensor Deployment in Real Sensor Network System," 2010 IEEE Global Telecommunications Conference GLOBECOM 2010, Miami, FL, 2010, pp. 1-5.

[26] Colorni, A., Dorigo, M., and Maniezzo, V., “Distributed optimization by ant colonies,” Actes de la Premiere Conf. Europeenne sur la vic Artificielle, Paris, France, Elsevier Publishing, 1991, pp.134-142.

[27] De Morais Cordeiro, C., Agrawal, D.P., “Ad Hoc and Sensor Networks: Theory and Applications,” World Scientific, Singapore (2011).

[28] Chakrabarty, K., Iyengar, S.S., Qi, H., Cho, E., "Grid coverage for surveillance and target location in distributed sensor networks,” IEEE Trans. Comput. 51(12), 1448–1453 (2002).

[29] Yuh-Ren Tsai, “Sensing coverage for randomly distributed wireless sensor networks in shadowed environments,” IEEE Transaction on Vehicular Technology, vol. 57, no. 1, pp. 556-564, January 2008.

[30] A. Elfes, “Occupancy grids: a stochastic spatial representation for active robot perception,” in Autonomous Mobile Robots: Perception, Mapping and Navigation, vol. 1, S. S. Iyenger and A. Elfes, Editors, IEEE Computer Society Press, 1991, pp. 60-70.