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Analysis of Different Sensor Deployment Strategies in Wireless Sensor Network

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Abstract- The Wireless Sensor Network (WSN) is widely used in different applications mostly along with other established or emerging technologies. It is being deployed in small or large scale, permanent or ad – hoc based on the requirement of applications. Most of the WSNs are meant for providing security in vivid forms like intrusion detection, calamity warning, health alert etc. Distribution of the sensors in WSN is playing a major role in satisfying the purpose of the applications. Same approach of sensor distribution is not well suited for all the different kinds of applications because of the need for different sensing probability or detection probability and for different requirements. Few of the applications are well formed with the random deployment of sensors in the application region while few need planned deterministic deployment for achieving better performance such as some applications require dense distribution of sensors in particular sensitive places, which could be contented with relevant distribution methodologies. In this paper, we discuss different existing sensor distribution and deployment methodologies in a broader way. We have also analyzed these methods and summarized it in the table format for the better understanding. This paper also highlights the better distribution and deployment methodology as per current scenario.

Keywords - Sensor deployment, Wireless Sensor Network, Uniform distribution, Gaussian distribution, IoT

I. INTRODUCTION

The Wireless Sensor Network (WSN) plays a vital role in the contemporary human life and is becoming a major component of the smart world. WSN is implemented in different ways for different requirements and vivid applications. Now days it is acting as a backbone of the emerging technology called “Internet of Things” (IoT) [8]. The word “sensors” is uttered by even a child because of their usability in the recent developments. The sensible devices attract the world towards it. WSNs, as other network structures, also face many installation, execution, maintenance and security threats. If the installation is properly done to its perfection, the other threats can be reduced or avoided. The installation part of WSN mainly includes sensor distribution and deployment as per the requirement of the application. Sensor nodes are the major part of the WSN. The specifications of the sensors may vary for different requirements. But the sensor nodes have the common features of limited computing abilities, power and memory. The belief of the researchers was that the sensor node placement need not be well planned or pre-determined, [1] but the algorithms and protocols for the network must be capable of deciding the distribution of the nodes in the network. This has made the sensor placement in the network to be almost always random and non-distribution based approach or uniform distribution. But the fast development of WSN is not satisfied with random deployment and needs different distribution methodologies as per the application. Many researchers have proved that the algorithm based or rule based sensor node placement strategies improve the performance of the WSN. The main advantages of following a defined method of node placement as per the application are the enhancement of Intrusion Detection, better connectivity, fast response, long life time of the network and less maintenance.

In any technological innovations, the intrusions are inevitable. The intrusions are also dissimilar which are to be given more attention to overcome [10, 11]. The Intrusion Detection System (IDS) is only meant for detecting the attacks, not for preventing and thus it enables the alarm which is expected to be true positive to its maximum. The main three parts of the IDS [18] are monitoring component, analysis and detection component which are algorithmic- based and alarm component which alerts the administrator or the responsible authority. There are many IDS proposed and implemented in real time by several researchers especially for the WSN, which are based on different techniques and depend on the network parameters like sensor sensing range, density of the nodes, sensing distance etc. Those Intrusion Detection systems perform very well as per the requirement mainly because of the rule based sensor placement strategies. The intrusions are not harmful always as mentioned in the security systems. In IoT sensors are identifying the intrusion and act according to it. So here the intrusion and intruders are triggering the event in IoT and play a positive role.

When the sensor nodes are placed randomly, few may be away from each other and few may be close to one another, which may affect the connectivity of the WSN. If the network follows certain placement strategy, the distance between the nodes would be calculated based on their coverage limit and the exact number of sensors needed would be known, thus the WSN resource management [12] is highly influenced. The communication and connectivity among the neighboring nodes and to the sink are also improved [3] and due to that the time taken for the overall process is reduced.

Though the words "distribution and deployment" are interchangeably used by many researchers to imply the same meaning for sensor placement and it is not wrong too, they have notably different meanings. In case of WSN, distribution means spreading out the sensors on the area of interest based on some rule, where as the deployment means more than that, i.e. installation of sensors in a particular place with proper configuration and with all needed customization.

We cannot conclude that the random placement of sensor nodes is not suitable for WSN at all, because till date many established WSNs have randomly deployed the sensors in their target regions. In this paper we discuss some of the sensor node distribution and deployment techniques which provide better performance in specific applications compared to the traditional random placement.

II. SURVEY ON EXISTING DEPLOYMENT STRATEGIES

Sensor placement or deployment in the application region plays a significant role in case of overall performance of the network. Many researches are being carried out in sensor placements. Charalambos Sergiou and Vasos Vassiliou [7] have set forth the sensor node placement in three different categories namely deterministic, non-deterministic and semi-deterministic node placements. As shown in the figure (1), Grid placement is deterministic where the nodes are placed strictly on the line of a grid (Fig 1a), which is practically less feasible. Biased random placement (Fig 1b) is semi-deterministic where the area chosen is deterministic but the distribution in that area is random which is non-deterministic. Non-deterministic (stochastic) placement (Fig 1c) can either be simple diffusion (e.g. dropped from the airplane) or random (uniform) placement, which are very realistic and easy to use.

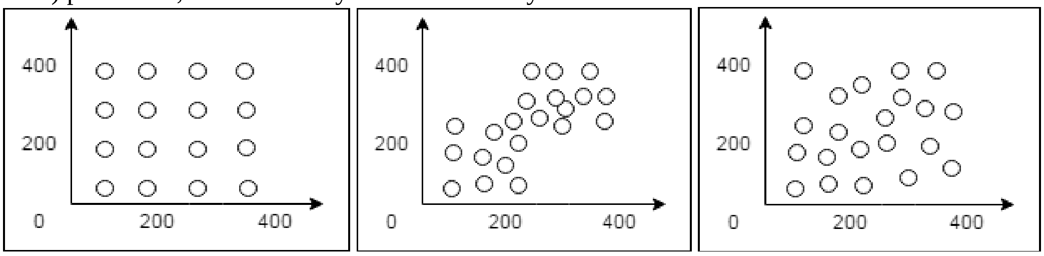

Fig 1a Fig 1b Fig 1c

Fig. 1: Grid placement, Biased random placement and non-deterministic placement

The quality of the deployment for Intrusion Detection is analyzed by [22] Noureddine Assad, et.al, especially for random deployment. It is discussed that the deployment quality of sensors directly depends on the sensing range and node density. The guaranteed sensing quality is analyzed in terms of coverage, checked with mathematical study and measured with single and multiple sensing probabilistic Intrusion Detection models.

An optimal solution for intruder tracking has been proposed by Carlos T. Calafate, et.al [23] with binary detection sensors, mobile sink and IEEE 802.15.4 technology. They combine the tracking algorithm with Mobile- Sink Routing for Large Grids (MRLG) routing protocol and the tracking error is obtained below 10 m, even for irregular mobility patterns. The performance of MRLG protocol is compared with Collection Tree Protocol (CTP) for proving that the proposed approach provides better Intruder Tracking solution.

Srinivasaraju Dantuluri and P. Poturaju [24] have proved their analytical model for Intrusion Detection with respect to intrusion distance and the network parameters like node density, sensing range and transmission range in both homogeneous and heterogeneous WSNs with single and multiple sensing models and verified the correctness. The model helps in selecting critical network parameters to meet the application requirement.

Thomas Clouqueur, et.al have used the path exposure [25] as a measure of the goodness of deployment for target detection. Path exposure is a measure of the likelihood of detecting a target traversing the region using a given path and the better deployment is confirmed with higher exposure. Unauthorized traversal problem has been dealt with Dijkstra's least weight path algorithm and simulations have been done with varied number of sensors deployed. The results are used to evaluate the cost of deployment for varying number of sensors in the area of interest.

Many researchers [5] have projected the optimized sensor node placement based on different genetic algorithms. Omar [6] has proposed a hybrid WSN with both static and mobile sensor nodes and with initial random deployment which has changed the mobile nodes' places with the genetic algorithm for reducing the coverage hole.

In [13, 14], the sensor deployment is discussed based on the comparison on radio range (R) and sensing range (r) of the sensors to improve the coverage of the nodes and connectivity among them. Different regular patterns are considered as given. If the radio range is greater than or equal to the sensing range, the hexagonal grid pattern is well suited for better connectivity. If $R >= \sqrt{2}\, r$, then square grid or rhomboid grid pattern promise the good coverage and connection. If $R >= \sqrt{3}\, r$, then the triangular lattice pattern serves better. Few other combinations of R and r are experimented and proved.

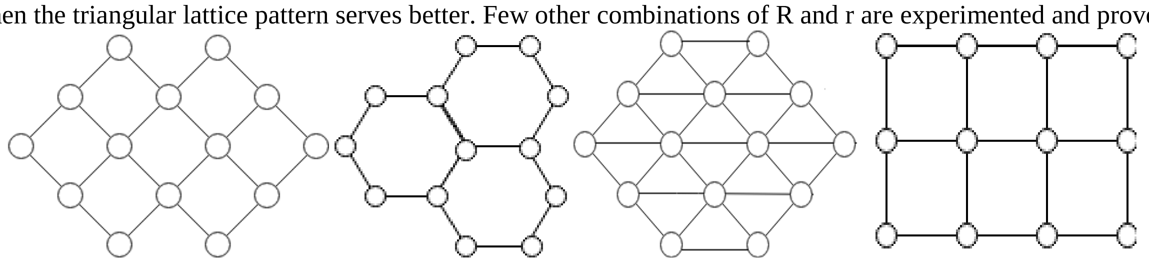

Fig. 2: Rhomboid, Hexagonal, triangular and square grid pattern based node deployment

Naregalkar Akshay et.al [30] has discussed three ways of sensor deployment to minimize the coverage problem and analyzed the relationship among the number of sensors deployed and efficient coverage area ratio. Sensor deployment based on square grid, equilateral triangle grid and hexagonal grid have been taken for analysis and it has been concluded that the performance of the triangular lattice based sensor deployment is good since it has the smallest overlapping area and the grid needs the least number of sensors for better coverage. Also the square grid offers good performance for any parameters but the hexagonal grid based deployment ends up with bigger overlapping area.

In [15], the authors discuss the barrier coverage of WSN with line based sensor deployment strategy which outperforms the Poisson point model, the multiline barrier coverage and the effectiveness of the suitable deployment strategies. The numerical and simulations are proved for guaranteed barrier coverage, [16] in which the sensor deployment is split into multiple rounds which can deal with less placement errors and with less number of sensors.

Mahdie Firoozbahrami, Amir Masoud Rahmani [19] have proposed a deployment model where the nodes are placed on two Archimedean nested spirals in distance less than radio range to assure five coverage and five connectivity. They have analytically proved that the pattern makes use of lesser nodes, consumes less energy and provides more life time and fault tolerance compared to hexagon, square and triangle models.

A virtual force algorithm (VFA) has been developed [21] for sensor deployment which uses a force directed approach to enhance the coverage provided by the initial random deployment. With the VFA, one-time repositioning (not more than one) of sensors, better coverage, less computation time and flexibility are achieved. The authors have combined the proposed algorithm with probabilistic localization algorithm which reduces the energy consumption for target detection.

Three different deployment patterns are tried [26] by Utkarsh and Hemanth, namely regular hexagon based, octagon-square based and a tri-beehive based deployment. K-coverage for all the patterns are analyzed mathematically and examined with simulation and it is concluded that the average coverage of Tri-Beehive node deployment pattern is better than the other two patterns of deployment.

The authors of [27] have developed random, grid and circular deployment of sensors and the comparison is done with the simple shortest path routing algorithm. It is proved that the random sensor deployment has smaller coverage area with more number of nodes deployed with un-equal distances leading to more energy utilization and decreases overall network lifetime. The other two deployments grid and circular have larger coverage area with lesser number of nodes than random, deployed at equal intervals. This has enhanced the network life time with less energy consumption.

Zhang and Zhou [28] have proposed the investigation of irregular equilateral hexagon pattern of sensor deployment and compared with triangle, regular hexagon, square and rhombus patterns. It has been derived that the proposed pattern is best suited when the sensing radius and the communication radius have a different proportion as needed in the application area.

In [31], the authors discussed about the random deployment, incremental deployment and movement assisted deployment algorithms and made the comparison and suitability of each algorithm to particular applications.

A. Analysis of the Deployment Strategies:

The below given table (Table 1) discusses various types of node deployment, the specific pattern used in deploying the nodes and the advantages of using them.

TABLE I DIFFERENT DEPLOYMENT STRATEGIES

Type of placement	Pattern	Advantages
Deterministic –Grid based	Hexagonal	Better coverage and reduces the moving distance of mobile sensor nodes [35]
	Square	Fairly good performance for any parameters [34]
	Rhomboid	When $\sqrt{2} <= R/r <= \sqrt{3}$, this pattern provides full coverage (R- Radio range, r- sensing range) [13]
	Octagon square based	Better coverage in K-coverage model with little deviation [26]
	Triangular	Less overlapping of sensing area
	Nested spiral	Less number of nodes and consumes less energy
	Tri-beehive	Better average coverage and connectivity
	Circular	Larger coverage area and less number of sensors
	Irregular equilateral hexagon	Useful if sensing and communication radius have a different proportion
Semi –deterministic	Biased random	Differentiated sensing capability
	Genetic algorithm based	Improved coverage
	Virtual force algorithm	Better target detection
	Barrier coverage (line	Less number of sensors

	based)	
Non- deterministic (Stochastic)	Random	Easy to spread the sensors
	Barrier coverage (random)	Uniform protection

III. SURVEY OF EXISTING DISTRIBUTION METHODOLOGIES

In this section we see some of the statistical distribution method based sensor distribution strategies which are carried out in both the continuous and discrete probability distributions.

The majority of the current application regions to be monitored is huge and needs sensors to be spread randomly all over the area. For instance, the weather monitoring, Tsunami observing applications do not have a single or more targeted entities [3]. These applications can very well follow the uniform distribution of sensors that fall under the non-deterministic category of sensor placement, (Figure 3) which is more effective in terms of the network parameters like sensing distance, number of sensors etc.

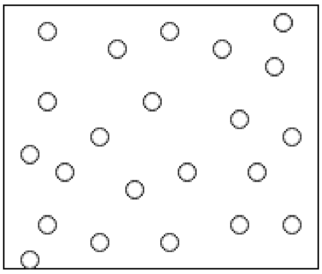

Fig. 3: Uniform distribution

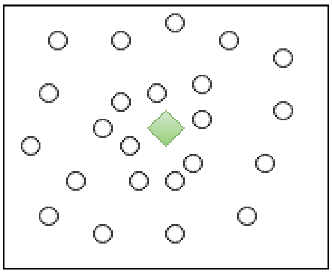

Fig. 4: Gaussian distribution

Few applications which include military surveillance are meant to protect a particular entity, which may be more valuable or sensitive. These applications need more protection in the closer region to the target than the far region. If the same uniform distribution of sensors is used, the sensing or detection probability is same in the whole network and it cannot detect properly if the intruder enters the network from an arbitrary position in the middle or dropped from the air plane. To enhance the better detection probability near the target, a suitable sensor distribution strategy must be adopted. Yun Wang, et.al [2] has proposed the truncated Gaussian distributed WSN which improves the system by providing differentiated intrusion detection probabilities at different locations. Based on the Gaussian (Figure 4) way of distributing sensors, the region nearer to the target is distributed with more sensors with high detection probability than the region outlying and this kind of distribution is considered to be semi- deterministic model of sensor placement. The authors have proved that the performance of the proposed work is better than the uniform distribution with the network parameters including number of sensors, sensing range, deployment deviation, maximum allowable intrusion distance and intruder's starting position. They have derived the detection probability in terms of single sensing and multiple sensing detections. The Gaussian distributed WSN is compatible for any target protecting application than the uniform approach.

T. Shankar, et.al, has [33] used the Multivariate Gaussian Mean Distribution (MGMD) with which the density of nodes is higher in the central region of surveillance and lesser in the region further away. MGMD is the generalization of the univariate normal distribution to higher dimensions and the sensor distribution resembles the normal distribution. The base station is considered to be in the central region and the LEACH algorithm is used to compare the performance with the random distribution. After several rounds of simulations, it is proved that the performance of MGMD is 10-15 % better than random in case of death of first node, alive nodes rate and residual energy rate.

Maduri Chopde [4] has combined the Gaussian distribution [29] with the Poisson distribution to achieve better differentiated detection probability, which would be always a non-zero value. In case of Poisson distribution [4], the sensor nodes are distributed uniformly and randomly which is not same like Gaussian. So near the target, number of sensors is concentrated because of Gaussian and away from it is uniformly distributed because of Poisson.

But using Poisson distribution, the sensor node deployment is considered in a different way with Saleh H.Al- Sharaeh, et.al. [32]. They have proposed that the sensors are concentrated around the mean with the Poisson distribution and it is suited to use the Poisson in the hard terrain environment such as Airport sensors deployments and the uniform distribution for flat terrains. The 1-D and 3-D distributions are compared for both Poisson and uniform and it has been proved with simulation that the power consumption is lesser than 1D for 3D Poisson and Uniform distributions. The longer life time is achieved due to the fact that the suitable distribution strategy is adopted for the applications.

In some applications especially where the region is uneven with hills or windy, the deployment of sensors which is normally random and uniform, is not maintained as deployed. Instead the sensors move and get collected in some places (Figure 5) because of the nature and they form a different structure which is named as hill distribution by L.Orecchia [9].

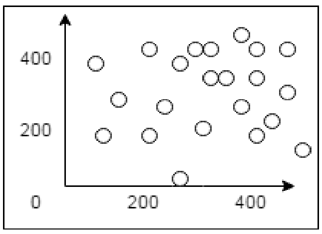

Fig. 5: Hill distribution

This is very common in WSN that the nodes near the sink die faster than other nodes because they are not only sending their own data, forwarding data from other nodes too. This is called the energy hole problem in WSN and it affects the network reliability and the lifetime. From the paper [17], it is witnessed that the exponential distribution of sensor nodes towards the sink in few concentric circular coronas and hybrid routing improves the lifetime of the network as well as reduces the energy hole problem and its performance is better while comparing with uniform distribution.

A distribution free approach to estimate the network coverage intensity has been proposed [20] by Miao Peng and et.al. Here they have taken a small sample of actual deployment and done the statistical analysis to capture the distribution function of the deployment as well as used the kernel density estimator to estimate the deployment. In the sense of coverage the distribution free approach performs better when compared to the uniform distribution.

A. Analysis of Distribution methodologies

In this section we see the consolidation of the available distribution methodologies which are mapped with sensor node distribution and deployment in different applications. Each distribution methodology has been mathematically proved and simulated by the respective researchers. The below given table (Table 2) consolidates the sensor distributions.

TABLE II DIFFERENT DISTRIBUTION METHODOLOGIES

Distribution Methodology	**Placement type**	**Application type**	**Specific requirement taken by researchers**
Uniform Distribution (continuous)	Non-deterministic	Flat region, nor-target oriented	Intrusion detection, Better Connectivity
Gaussian Distribution (truncated Gaussian) (continuous)	Semi-deterministic	Flat region, target oriented	Intrusion detection
Poisson Distribution (discrete)	Semi-deterministic	Hard terrain, target oriented	Better Connectivity, Life time
Exponential Distribution (continuous)	Semi-deterministic	Flat and hard region, target oriented and non-target oriented	Better Life time of the network, reduced energy hole problem
Multivariate Gaussian Mean Distribution (continuous)	Semi-deterministic	Flat region, target oriented and non-target oriented	Intrusion detection, Life time

IV. CONCLUSION

Wireless Sensor Network (WSN) is an emerging technology that deals with many applications. Sensors are the most important devices in WSN and the deployment of the sensors plays a major role in the performance of the network including better coverage, lifetime and Intrusion Detection. In this paper, we have discussed the diverse approaches handled by many researchers for the deployment and distribution of sensors. Each research makes it obvious that the same way of sensor deployment is not suited for vibrant applications and for different needs, hence each deployment methodology has its own adaptability to the specific application in WSN. We have consolidated different existing deployment and distribution methodologies along with the details of advantages and the suitable application types specified by the researchers.

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