An AptDistribution and Deployment Strategy of Sensors for Secured WSN

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Abstract - Wireless Sensor Network (WSN) has become an inevitable part of human life in different structuresand applications with varied network parameters. Sensor node deployment in the application region whether it is indoor or outdoor is a major task as well as plays very remarkable role in the network performance. Node deployment is carried out according to the region where it is applied, either deterministic or non deterministic. Because of the need for different sensing probability or detection probability, same approach of node deployment may not be suited for all the applications. Some of the applications are well formed and give better performance with the uniform distribution of sensors but few need intense distribution of nodes in particular sensitive places especially those applications meant for intrusion detection. Such a promising deployment scheme meant for special applications, which is based on the half-normal probability distribution has been discussed in this paper. The proposed deploymentapproach has been simulated with and without clusters and the results produced show better differentiated intrusion detection probability during the sudden entry of intruder inside the network region with varied number of sensors and sensing range when compared with the performance of uniform distribution.

Keywords- Wireless Sensor Network, Half-Normal Distribution, Intrusion Detection, Detection probability, clustering, Uniform distribution

I. INTRODUCTION

The world has been fascinated by automation in many day to day aspects. The Information and Communication Technology (ICT) has brought many innovations in the form of hardware and software. One of the major contributions which is dominantly used in many intelligent applications from small scale to large scale is WSN. It involves many real-time applications including security, health care, intelligent monitoring and environmental studies. Worldwide in many aspects of WSN development, researches are continuing; including localization, node deployment, routing, scalability, mobility, intruder tracking, sensitivity, coverage and lifetime, among them the sensor node deployment plays a pivotal role. Deployment of sensors in the Region of Interest (RoI) is the first task to be done for any WSN and it is purely application specific, in-door or out-door, smaller and accessible region or larger and inaccessible region. Few important parameters are to be noted before and after deploying the WSN in the RoI, including network and sensing coverage, density of nodes and the deployment model [1]. The communication among sensor nodes and to the sink should be streamlined, so that no area is left uncovered and no sensor is left disconnected. Sensing range of the nodes varies according to the sensor type and should be carefully chosen for any specific requirement. The number of nodes per square meter is the density of nodes; uniform density in the RoI is expected to be maintained for better coverage. There are different deployment methodologies under the major categories of deterministic, non-deterministic and semi-deterministic [2]. Grid placement is deterministic where the nodes are placed strictly on the line of a grid, which is practically less feasible. Biased random placement 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 can either be simple diffusion (e.g. dropped from the airplane) or random (uniform) placement, which are very realistic and easy to use [3]. Few deployments are probability distribution based and few are distribution-free approaches. 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.

The scope of our paper is limited to sensor node deployment which may enhance the intrusion detection of human, animals or vehicles; here we introduce a new distribution based sensor deployment, known to be Half- Normal Distribution based deployment, which is meant for a special application scenario. Half-Normal distribution is a special case of Folded- Normal distribution with mean value zero. The proposed deployment approach has been simulated and has produced better differentiated intrusion detection probability than the uniform distribution. The network parameters including number of sensors, intruder’s starting position and sensing range of sensors are considered. The NS2 simulator as well as Java-tinyOS simulator has been used for testing the performance.

The remaining paper is organized as follows. The next section lists some of the similar work and followed by the explanation of Half-Normal distribution method, algorithm and flowchart followed by simulation results and conclusion.

II. RELATED WORK

In WSN, different methodologies are followed for sensor deployment in out-door and hard –terrain regions. Compared to random deployment, the probabilistic distribution based sensor deployments in hard-terrain application regions are yielding better performance in case of coverage, lifetime of WSN, stability of protocols [4] and intruder detection.

Y.Wang et.al [5] have proved that the Gaussian distribution based sensor deployment in WSN improves the detection probability in protecting a target region. This method provides differentiated detection probability and outperforms the uniform distribution. They have showed theoretically and with simulation that the performance of Gaussian distribution in single sensing and multiple sensing models, with the necessary network parameters including number of deployed sensors.

Omar and Alaa [6] have compared uniform, normal and mixed distributions with suitable simulations and concluded that the normal distribution is showing better performance in terms of intruder detection, average number of transmitted control bits and number of hops and mixed distribution is better for reduced end-to-end delay. It has been proved by [7] that in the multi-terrain environment, the power efficient routing heuristics for maximizing network life time (CMAX, OML) are enhanced by the Normal, Poisson, Uniform and Chi-square distributions in different combinations.

Collaborative beamforming [8] has been proposed which gives better performance in the Gaussian distributed WSN in terms of wider mainlobe and lower chance of large sidelobes when compared to uniform distribution. Q.Yu, et.al [9] have proved that even when the intruder is destroying the sensors in his intruding path towards the target, if sensors are deployed in Gaussian distribution, the detection probability is higher than the uniform distribution. From the paper [10], it is known that the exponential distribution of sensor nodes towards the sink 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.

Shaila.K et.al [11] have proposed a probabilistic model for single and multiple sensing Intrusion Detection in 2-D and 3-D homogeneous WSN. They have used the clustering technique where only the cluster head communicates with the sink, thus reducing the number of sensor nodes participating in intrusion detection, this in turn enhances the lifetime of the network. The nodes are redistributed randomly after a certain period of time in order to reduce the early death of nodes. They have proved with simulation that their method of deployment has achieved minimum energy consumption both in 2-D and 3-D network.

In the next section, we discuss the details of the proposed approach.

III. HALF –NORMAL DISTRIBUTION BASED SENSOR NODE DEPLOYMENT

Choice of best suited sensor node deployment for any application region is inevitably essential for the better performance of the network. Here we consider the outdoor application which needs more protection near the target region than the region away from it. Most of the WSN are meant for monitoring and intrusion detection, the purpose has to be solved to the best. When the intruder enters from any boundary and the sensitive region is away from the intruder entry, the scope of detection is more with any kind of sensor node distribution, for instance, uniform distribution. But if any circumstances cause the intruder to enter directly into the network, nearer to the sensitive region, dropped from airplane or faster enough or sudden jumps from dense trees, may not be detected immediately when nodes are uniformly distributed. If more number of sensors are placed near the sensitive region and when sudden movement is sensed by more than one node in the region, further actions like alarm, display on the road side unit are made quicker. The purpose of the WSN is fulfilled when it responds to events in a very short period to avoid any damage to the target entity or region.

The half-normal distribution based sensor node deployment in which more number of nodes are placed near the target region compared to the region away from it. The half-normal distribution ensures varied sensing ability as well as differentiated detection probability. The proposed approach of sensor node deployment has been mathematically verified, implemented with NS2 simulator and compared with the uniform distribution method as well as the cluster-based half-normal distribution method. The deployment is not completed without proper localization and enhanced coverage, so the node localization and intruder localization have also been implemented. The results produced show that the half-normal approach and the cluster-based approach provide better differentiated detection probability and immediate intrusion detection in case of sudden entry of intruder nearer to the target region.

The (truncated) Gaussian distribution [5] is applicable for any closed targets or region to provide better intrusion detection and the same may not be well suited for such above mentioned applications. Uniform distribution is useful for spreading the sensors uniformly, which is good when we need same sensing probability but if the application needs differentiated detection probability, uniform distribution may not satisfy the requirement. The Half- Gaussian distribution [12 and 13], which is a special case of the folded Gaussian distribution [14], can be adopted for such scenarios. The folded Gaussian distribution is a probability distribution related to the normal distribution, where the probability mass to the left of X=0 is folded over by taking the absolute value.

Let X follows the ordinary Gaussian distribution N(0, σ2), then Y=|X| follows a Half- Gaussian distribution, which is a fold at the mean of an ordinary normal distribution with mean zero. With the σparameterization of the normal distribution, the probability density function (PDF) of the Half-Normal is given by,

$f_Y(y;\sigma) = \frac{\sqrt{2}}{\sigma\sqrt{\pi}} \exp\left(-\frac{y^2}{2\sigma^2}\right) y > 0$ Where $E[Y] = \mu = \frac{\sigma\sqrt{2}}{\sqrt{\pi}}$ (1)

The PDF and CDF curves of the half –normal distribution are given in the figure 1.

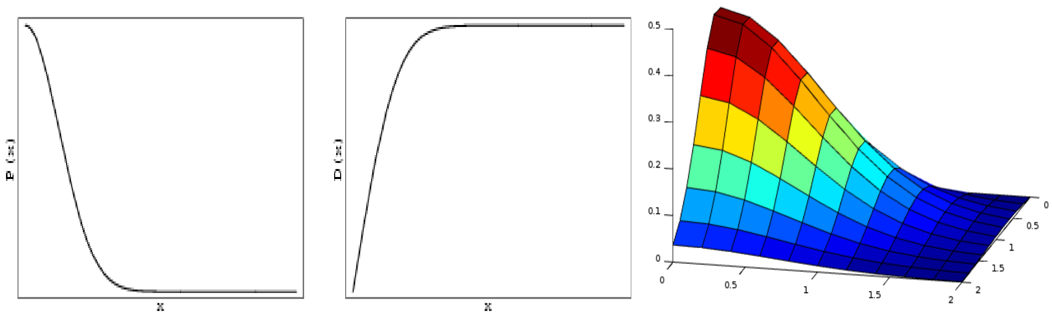

Figure 1. PDF and CDF of Half-Normal Distribution and 3D depiction (Courtesy: archive.lib.msu.edu)

The performance algorithms which were proven for normal distribution are suited for the half- normal distribution with the positive values.The normal distribution truncated at 0 and [15] folded (half) normal distribution give same results for a mean – 0 normal distribution, because any distribution that is symmetric about 0 and has 0 probability of being 0. If the mean is nonzero value, the distribution is not symmetric and both the distribution methods do not give the same result.It is an added proof from [16] for the Half-Normal distribution to have absolute value with the Stein's method of density approach. It is given that, a random variable X with values in [0, ∞] has the Half-Normal distribution μ if and only if E [f´(x)] = E [x f(x)] –f(0)$\frac{\sqrt{2}}{\sqrt{\pi}}$ for all functions f: [0,∞]→ R, which are absolutely continuous on every compact sub-interval of [0, ∞] such that E |f´ (y)| < ∞.

For the sensor deployment, 2D Half-Normal Distribution has to be adopted. The probability density function is given as [17],

fX, Y(x, y) = 2[$\pi\sigma_1\sigma_2\sqrt{(1-\rho^2)}]^{-1}$ * [exp { -$(\frac{x}{\sigma_1})^2 + \left(\frac{y}{\sigma_2}\right)^2 / 2(1-\rho^2)\}]$ cosh $[\frac{\rho x y}{(1-\rho^2)\sigma_1\sigma_2}]$ 0<x, 0<y (2)

The X and Y each have Half- Normal distribution in two dimensions with variance (1- ρ^2), where ρ is the correlation between X and Y. The definition of correlation is $\rho_{X,Y} = \frac{Cov[X,Y]}{\sigma_1\sigma_2}$,when we consider X and Y are independent, ρ = 0.

We assume the same standard deviation along x and y dimensions for sensor node deployment $\sigma_1 = \sigma_2 = \sigma$, so the PDF is fX, Y(x, y) = 2[$\pi\sigma^2]^{-1}$ * [exp { $\frac{-(x^2+y^2)}{\sigma^2}$ /2}] (2.a)

Any WSN is deployed with an intended requirement, without which the proposal is incomplete. Here we aim to alleviate the problem of intrusion detection with the appropriate node deployment. The following section discusses the theoretical proof for the furtherance of intrusion detection with the Half-Normal distributed WSN.

Terminologies:

Few terminologies used in this paper are listed below:

R - Region of Interest (R and RoI are interchangeably used in this paper)

N - Total number of sensors in R

S - Starting position of Intruder

d - Intruder moving distance

D - Max distance permitted to travel before reaching the target region inside the R

r - Sensing range of a sensor
A - Intrusion detection area
Pd - Probability of the intruder to be detected by at least one sensor node in R

System model and Assumptions:
Sensing model: For simplicity we consider Deterministic Boolean sensing model for better network coverage. [18] Let R is the Region of Interest (RoI), r is the sensor's sensing range, and N is the total number of sensors. The probability of the intruder to be detected by any sensor is p= $\frac{\pi r^2}{R}$, so the undetected by any sensor probability is 1 - p; the probability for the intruder not to be sensed by any of the N sensors is Pn= (1 - p)N. Thus the probability of the intruder to be detected by at least one sensor node among N nodes is
Pd = 1 - (1 – p)N (3)
Detection model: Here we consider only single sensing model, the intruder is detected by any single sensor. The multiple sensing model has also been proposed in many researches [5], where the single sensing detection model has been believed as a special case of multiple sensing model. When there is atleast one sensor present in the region, it is sufficient to detect the event and communicate to the sink; and when further movement is detected by few more neighboring sensors, the event is reported to the sink. With the help of the localization prediction algorithm (APIT), the movement direction is assumed, the reported events are compared and in turn the server is alerted. When multiple sensing model is used, the uncertainty reduction is more [19] but the sink has to wait to get the m-sensors' reports and then it takes action, which is time and energy consuming and data fusion is also has to be dealt each time.
We assume the straight line motion of the intruder and single intruder detection, where the intruder can be a person, animal or vehicle. The movement detecting nodes are employed in the RoI [20] which are cost effective. The assumption includes that the nodes use multi-hop communication to the smart sinks which does the data processing and all the nodes identify their neighbors with full network coverage. While including the cluster based sensor nodes, single-hop link to the dynamic cluster head has been considered.

IV. PROPOSED PROCEDURE

Few techniques are mandatory for a completely functioning WSN. The foremost thing to be implemented is the localization, which is defined as identifying the location of both the network nodes and the intruders. Since the network nodes communicate to each other, the distance based localization has been used. Some of the distributed nodes are considered to be beacon nodes which know their location through GPS or manual configuration related to the RoI. The beacon nodes (min 3) calculate the distance to the non-localized node within the communication range with the Received Signal Strength Indicator (RSSI) value. With the known three distances, the trilateration localization has been used to find the location of nodes. The localized nodes act as reference nodes to localize other nodes in the network.
The intruder detection is done by the movement detecting nodes but the movement prediction has also to be carried out for the approximate direction of intruder movement. So the distance-free Approximate Point in Triangulation (APIT) method of localization has been adopted to predict the intruder movement.
Clustering or grouping set of nodes with their head nodes communicating to sink and other head nodes has been adopted for the enhancement of the proposed approach. A centralized version of Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [21] is used here which enhances the lifetime of the nodes and reduces the energy consumption.
The random node deployment in any outdoor region suffers with the natural factors like wind and soil erosions that move the nodes to one direction. If the deployment is manually done, the issue can be solved easily. But if the region is not accessible by human, the nodes are thrown from airplane. To make the network function properly, node deployment optimization (redeployment)[22] is being done with any third party involvement including robots and actuators. This is cost effective and can be used in any unmanned region.
With these techniques, the procedure for the proposed sensor deployment has been simulated with the network simulator 2 and with Java – tinyOS tool. The procedure for the half-normal distribution based sensor node deployment is given below which is self-explanatory and used for the simulation purpose. Flow chart for the same is followed in the figure 2.

A. Procedure half-normal-
1. Begin
2. intnoofnodes,

http://dx.doi.org/10.21172/ijiet.132.10

```
3.        beaconnodes⊆noofnodes,
4.        nl[] = noofnodes – beaconnodes,
5.        refnodes,
6.        i=0,
7.        cluster;
8. double RoI;
9. while (nl  = true)
10. Call deploy_noofnodes( )        // Deploy noofnodes in half-normal distribution in RoI
11. if (GPS_value)
12.       beaconnodes _location = "GPS_value"  //related to RoI
13. else
14.       input beaconnodes_location
15. end if
16. if (3 beaconnodes in "Range") || (3 refnodes in range)
17.       call distance_calculation( ) // helps to calculate the distance to any nl node in range
18.      call localize_trilateration( )          // it will localize the node with trilateration
19.       nl[i] = refnodes; i++
20. else
21.       call Optimize_node_placement( )   // for redeployment
22. end if
23. end while loop
24. if (cluster == 1)
25.       call c-LEACH( )            // c-LEACH is for clustering after localization
26. else
27.       Goto step 29
28. end if
29.  if (node_status  = "moving")
30.       call APIT( )                      //APIT algorithm to predict movement
31.       Write to Server database
32.       Message to Sink
33. else
34.       Goto step 31
35. end if
36. end procedure
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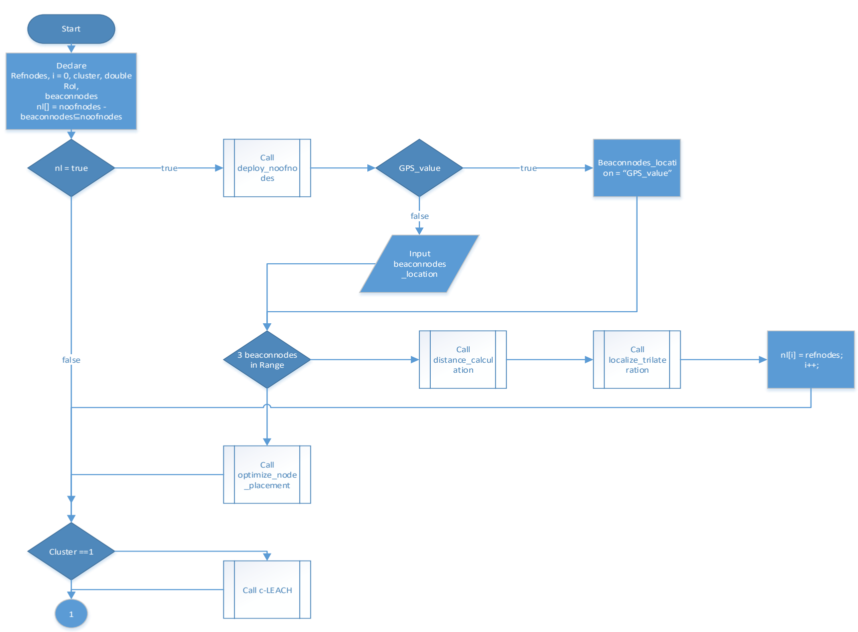

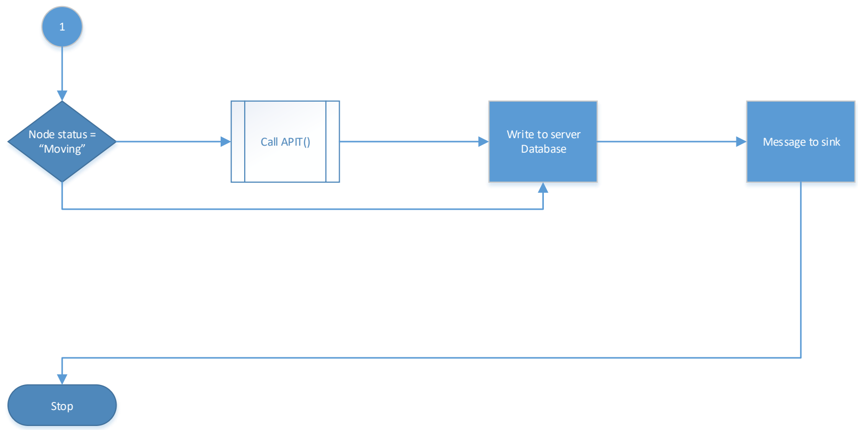

Figure 2. Flow chart of the proposed approach

V. SIMULATION

The simulation screenshots of the proposed half-normal distribution based sensor node deployment have been shown in the following pictures. Few simulation parameters are, Number of nodes:25, 50, 200, Localization: Trilateration, Simulation area:100 * 100 to 1000 * 1000, Routing protocol: AODV, Sensing radius: 10 to 20 m, Sink nodes: 3, Number of moving nodes: 2 or 3.

The figure 3a shows the deployment of 25 nodes thrown randomly with two intruders and the figure 3b shows 50 nodes where the detection is sooner in the same sized RoI. Initially after deployment, the nodes get localized (red colored nodes are localized reference nodes and blues are beacon nodes) and when the movement is detected by any of the node in the RoI, the message is communicated to the sink. The sensing range is also varied and tested for the performance with different number of sensors. Figure 4a shows the clustered node deployment with 50 nodes. The energy consumption is less in clustering compared to the non-clustered deployment. The intruder detection is implemented in Java- tiny OS simulator which has been shown in figure 4b. The APIT localization method has been used which predicts the intruder movement and the prediction error is also shown.

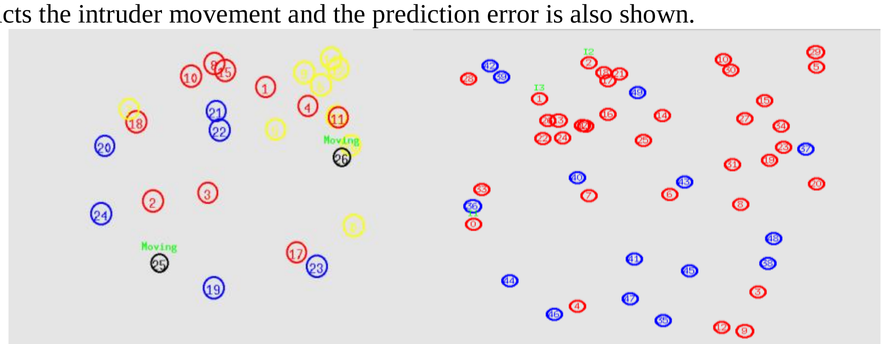

Figure 3. (a) and (b) Number of nodes 25 and 50

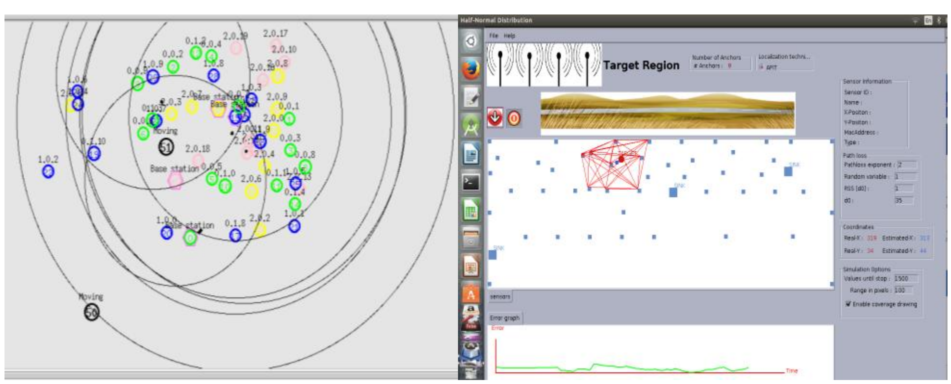

Figure 4. (a) Clustering with 50 nodes (b) APIT localization for the intruder in half-normal deployment with error graph

VI. RESULTS

The proposed half-normal distribution based sensor node deployment has been implemented with different network parameters including sensing range, number of sensors and intruder's starting position with and without cluster and the differentiated detection probability is compared with the uniform distribution as well as the clustering part of half-normal distribution.

The figure 5 shows the comparison graph for the network parameter sensing range. When the intruder starts from the boundary, the detection probability of the three deployment methods is very close to each other (Fig 5b) with the varied sensing range. But if the intruder is suddenly enters the network region in between (Fig 5a), the proposed method outperforms in detecting the intrusion, which produces closer performance to the clustered approach.

The figure 6 shows the detection probability in terms of number of sensors. The number of sensors is varied from 25 to 200 in different sized RoI. The half-normal and clustered approaches produce better differentiated detection probability than the uniform distribution, when the intruder enters in the network suddenly.

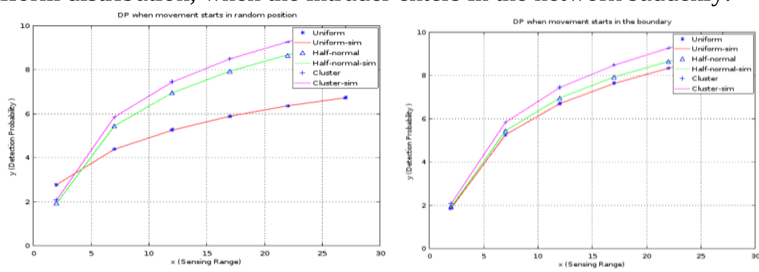

Figure 5. (a) and (b) Comparison of uniform, half-normal and cluster-based deployment of nodes in terms of sensing range

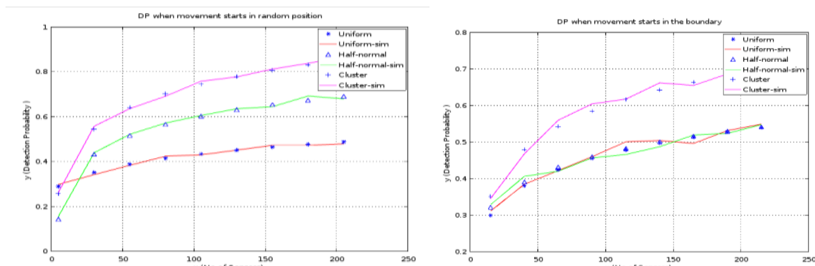

Figure 6. (a) and (b) Comparison of uniform, half-normal and cluster-based deployment of nodes in terms of number of sensors

VII. CONCLUSION

Wireless Sensor Network is a growing technology which involves many research areas in its development and application. In this paper we have chosen the deployment of sensor nodes for our research, which is application specific and plays a pivotal role in the performance of the WSN. The probabilistic Half-Normal distribution based deployment approach is discussed in this paper with its relevant application domain and simulation results for achieving better differentiated intrusion detection. The proposed deployment technique and the clustered approach provide better differentiated detection probability when compared to the uniform distribution in terms of varied number of sensor nodes and sensing range, provided the sudden entry of the intruder.

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