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MARKOV-BASED DEPLOYMENT APPROACH TO IMPROVE WSN COVERAGE

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ABSTRACT

A "wireless sensor network (WSN)" represents a gathering of limited number of sensors that are closely deployed in a recognizing area. The efficiency of any WSNs is heavily depending on the coverage delivered by the deployed sensors.

In this paper, a developed "deployment approach" is suggested to improve the WSN coverage, connectivity and reliability. This approach is based on the "Markov process". The distances between sensor node and its neighboring sensors are calculated, and then converted to the probabilities that create the transition matrix. Depending on this transition matrix the distance and toward movement for each sensor are estimated in each iteration.

The Simulation results were compared with the GSO results. Our results show that this deployment approach can provide high coverage and good reliability.

1. INTRODUCTION

In the latest years, many researchers focus on the "wireless sensor networks (WSNs)"constructions and applications. WSNs have potential applications in different vital areas. Wireless Sensor networks represent systems that encompass of certain numbers of wirelessly linked sensors that are spatially deployed in a certain region. Sensors can be deployed in large numbers due to its accepted cost and small size [1].

One of the key challenges facing the WSNs applications is how to determine the physical locations of the deployed sensor nodes. This problem represents an active research topic in the recent years. The supreme solution for such problem is to provide the sensor nodes by "Global Positioning System (GPS)". GPS is costly, power consuming and restricted for outdoor applications. To find the optimum sensors location, a set of nonlinear equations must be solved to reach the best prospect purpose in some cases. The effectiveness in this approach is how to investigate the sensors deployment by searching for the optimal or the near optimal solution [2].

2. RELATED WORK

Wen-Hwa Liao et al., presented in 2011 sensors deployment system based on "Glowworm Swarm Optimization (GSO)" to improve the nodes coverage after a process of random deployment. Each node was considered as "individual glowworms emitting". A "luminant substance" called "luciferin" and the strength of the "luciferin" is relies on the distance between the sensor node and its neighboring sensors. A sensor node is appealed towards the lower intensity of "luciferin". The sensing field coverage was maximized when the sensor nodes must move towards the lower sensor density area [3].

Guo, et al., proposed in 2012 a technique with goal coverage based on lattice scan. They divided the area into lattices. Then the best lattice was selected as a position to the next sensor. This method used smallest number of nodes to attain the coverage goal and get enhanced positions for the deployed sensor nodes [1].

Yourim Yoon, et al., proposed in 2013 an effective "genetic algorithm" using a "novel normalization method". A "Monte Carlo method" was assumed in designing an effective assessment function. They showed that their computation time can be reduced without losing the quality of the solution. They selected a small number from random samples and steadily increase the number for the succeeding generations [4].

Alduraibi et al., They proposed in 2016 three optimization models for determining the node density that varies in the objective. The first opts to achieve a desired level of detection fidelity while minimizing the number of deployed sensors. The second model considers the scenario with a constrained node count and determines the position of the available nodes such that the coverage is maximized. In the third model, they strive to minimize the number of deployed nodes when the desired fidelity is not uniform and some locations require higher coverage than others. The proposed optimization formulations are generic in nature and can be applied to any sensor coverage model [5].

3. **WSN APPLICATIONS**

WSN can be used to sense the object movement, sound, and temperature. It can be used to collect information about the system and transmit it to the Base station (BS). In military applications, WSNs can be used to observe and control the front line. Figure (1) presents a view of some WSN architecture [6].

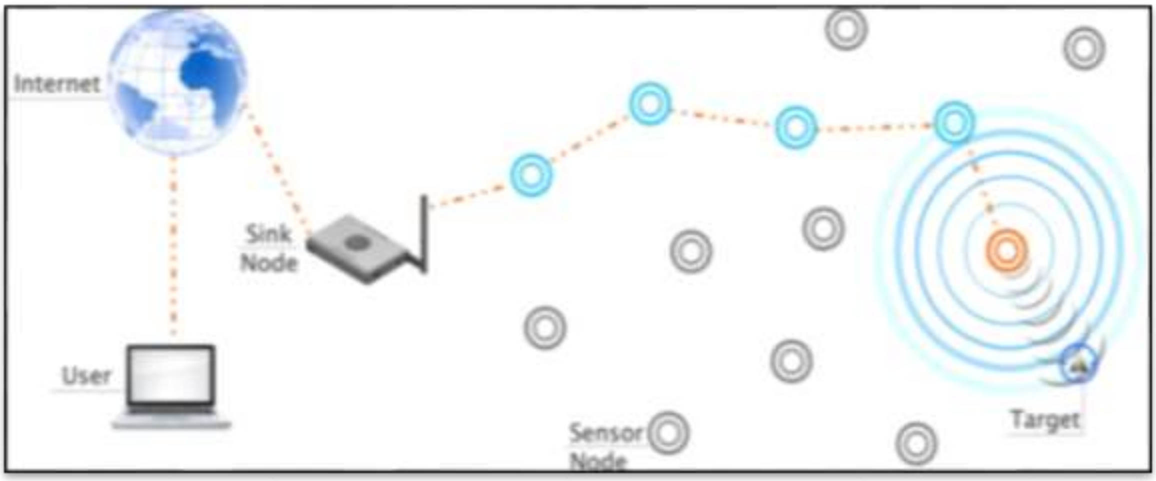


Figure (1): WSN architecture sample [6].

4. SENSORS DEPLOYMENT

The deployment approaches in WSN was divided into two groups as "sparse" and "dense deployments". In the given field of interest the "sparse deployment" can be used with little number of nodes deployed while the "dense deployment" can be used in high number of deployed sensors [7]. The "dense deployment" technique was used in the case of every event wanted to be noticed or there are multiple sensors are deployed to cover the same area. The sparse deployment is suitable to achieve maximum sensing area with minimum number of sensors. The sensor nodes are either static or mobile so they can change their positions with time [2].

Sensors are deployed in certain field either by locating them in "predetermined places" or randomly deployed. "Random sensors deployments" approach is one type of the "dense deployments". WSNs with mobile sensors are normally initiated with a "random deployment" and by their mobility change their locations to the best suitable location [1] [2].

4.1 STATIC DEPLOYMENT

In "static deployment", sensors are static and their locations must be selected due to certain "optimization strategy". Sensors locations will stay fixed and not changed during the operation of the network. "Static deployment" strategy can be achieved by deterministic steps and random deployments. This approach (the "deterministic deployment") starts by surveying the area of interests and continuing with the deployment process [2].

4.2 DYNAMIC DEPLOYMENT

One important application of a "dynamic deployment" was used in robots. Mobility helps in attending the sensing goal by letting the sensor move towards a maximum sensing performance. In "random deployment" most of the nodes are tossed in the first step, then a special utilization and reformation estimations to select the next movement [8]. Many developed algorithms were built such as "virtual force oriented particles algorithm"[9],"simulated annealing algorithm"[10], "particle swarm optimization algorithm" [11] and "simulated annealing genetic algorithm" [3].

5. SENSING AREA

The essential aim of any WSN is to have maximum sensing area (maximum coverage area). Coverage or sensing in WSN represents the backbone issue due to its relation with the energy consumption, network reconfiguration and connectivity. A basic problem is how to achieve maximum effective sensing area by deploying the sensors in an optimal manner. A good sensing area is that area in which every point in the area will covered and monitored by at least one sensor [12].

6. GSO APPROACH

There are many approaches were suggested and implemented to achieve certain coverage connectivity and reliability. Wen-Hwa, et al., for example suggested in 2011 a sensor deployment

System based on "glowworm swarm optimization" to improve the coverage after an "initial random deployment" of the sensors. They considered each sensor node as "individual glowworms emitting a luminant" body called "luciferin" and the strength of the "luciferin" is depending on the space isolating the sensor node with its neighboring. A sensor node can be appealed to its adjacent with lower strength of "luciferin". When the sensor tends to move towards the area having lesser sensor concentration then the sensing coverage area will be maximized. Their simulation results showed that "GSO-based sensor deployment approach" can deliver great coverage with restricted number of the sensor movements [3]. They concluded the following GSO results:

When 50 sensors were deployed in a center of 100 X 100m area with sensing range of 5m & communication range of 10m, they found a coverage percentage of about 35.4 %. When 100 sensors were deployed at the same area and same sensing and communication ranges, they found coverage of 64.6 %. While when they used 200 sensors with the same area, same sensing and communication ranges satisfied coverage of 92.2 %. This method was failed to achieve connectivity and /or reliability with less numbers of sensors deployed randomly in such area.

7. MARKOV MODELS

A "Markov chain" represents one aspect of the "mathematical models". It has certain random occurrence depending on time in a specific style that the future state depends only on the current state. The applied “time” can be described as discrete or continuous. In some mathematical applications, such phenomenon which depends on time and only the present activity will affects the next activity was called a "dynamical system". For any time t, the upcoming path $(A(x), x \geq t)$ can be entirely stated by the current state $A(t)$, without any need to the past states. In most applications they dealt with random variables rather than the deterministic values.

Markov chains represent a very important modelling tool that can be applied for the situations in which the trials do not happen according to an "independent and identically distributed" mechanism. Markovian property means that any stochastic process $\{x_t\}$ must have the following property:

$P\{x_{t1}= j\backslash x_0= k_0, x_1 =k_1, . . . , x_{t-1}=k_{t-1}, x_t=i\} = p\{x_{t+1}=j\backslash x_t=i\}$, for $t = 0, 1, . . .$ and every sequence $i, j, k_0, k_1, . . . , k_{t-1}$. Markovian property means that "the conditional probability of any upcoming event /(any preceding events and the current state $X_t= i$), is independent of the historical events and depends only on the current state" [14].

Markov chain can be generally defined as follows: for a "set of states, $S = \{s_1, s_2,...,s_n\}$". The movement will be initiated in any one of these states and goes sequentially from state to state. Each change is titled as a step. If the chain is found in certain state s_i, then it can go to state s_j at its next step with certain probability equal to p_{ij}. This probability value will depends on states i and j only.

The transition probability represented by (p_{ij}) means the probability of going from state i to state j on the upcoming step. The transition matrix collects all the transition probabilities from state to state [2].

8. **TRANSTION MATRIX**

The transition probabilities are commonly expressed as an M x M matrix called the transition probability matrix (or transition matrix), P. The transition probability matrix P and its characteristics are given as follows [13]:

$$\mathbf{P} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{bmatrix}$$

$$\sum_{j=1}^{m} Pij = 1 \;\; for\ I = 1\ , 2\ ,....,m \qquad (1)$$

Based on the Chapman-Kolmogorov equation, the probability of the system moving from State i to State j after n periods (n transitions), that is, the n-step transition probability matrix, $P^{(n)}$, can be obtained by multiplying the matrix P by itself n time. Thus:

$$P^{(n)} = P^n \qquad (2)$$

Let the initial state vector, Q^0 , be the probability that the Markov chain is in State i at time 0. Then, the state vector, Q^n, which is the probability that the chain is in State j after n transitions, can be expressed as:

$$Q^n = Q^0 P^{(n)} \qquad (3)$$

Where Q^0=[q1 ,q2 ,…,qm]; and qi = probability of being in State i at Time 0.

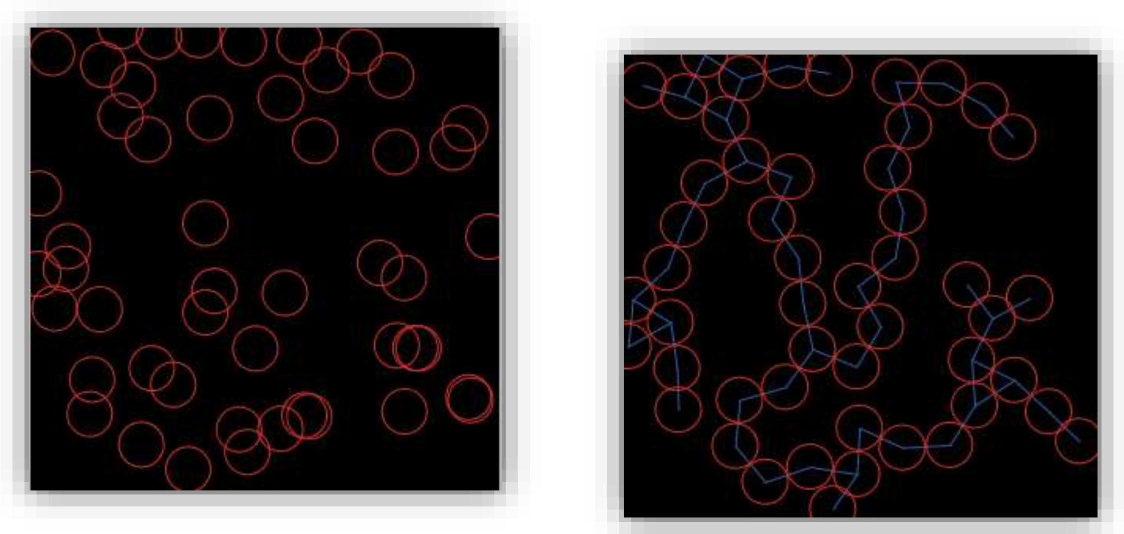
9. **SUGGESTION DEPLOYMENT APPROACH**

Markov approach is utilized in this study as a new approach to find the best possible sensors deployment. The following network conditions are suggested:

The area of interest is of (100 x 100m), numbers of the available sensors are (50, 100 and 200), and the sensors are initially deployed in a random manner. Net Logo is suggested to be used as a simulation tool to create, implement and evaluate each model in this study.

Case 1:

50 sensors are deployed randomly in a 100x 100m area as shown in figure 2-a. A suitable developed markov algorithm is used to change these sensors positions in sequential steps to reach the best possible state shown in figure 2-a.The initial transition matrix of (10) sensors is shown in figure 3-a. The transition probability is calculated with respect to certain developed criterion, and after 9 iterations the transition matrix becomes as figure 3-b.



a: initial random deployment

b: final deployment

FIGURE 2 : initial and final deployment of 50 sensors

$$\begin{pmatrix}
0 & 0.159 & 0.076 & 0.18 & 0.129 & 0.094 & 0.044 & 0.105 & 0.057 & 0.156 \\
0.163 & 0 & 0.162 & 0.099 & 0.034 & 0.112 & 0.188 & 0.093 & 0.115 & 0.035 \\
0.074 & 0.152 & 0 & 0.13 & 0.121 & 0.141 & 0.051 & 0.143 & 0.055 & 0.134 \\
0.149 & 0.079 & 0.111 & 0 & 0.071 & 0.148 & 0.15 & 0.137 & 0.102 & 0.052 \\
0.159 & 0.04 & 0.154 & 0.106 & 0 & 0.118 & 0.186 & 0.099 & 0.098 & 0.038 \\
0.094 & 0.109 & 0.146 & 0.18 & 0.096 & 0 & 0.136 & 0.019 & 0.091 & 0.127 \\
0.038 & 0.161 & 0.047 & 0.16 & 0.133 & 0.119 & 0 & 0.127 & 0.063 & 0.152 \\
0.11 & 0.095 & 0.155 & 0.173 & 0.084 & 0.02 & 0.151 & 0 & 0.096 & 0.116 \\
0.072 & 0.142 & 0.072 & 0.158 & 0.101 & 0.116 & 0.092 & 0.116 & 0 & 0.13 \\
0.167 & 0.036 & 0.149 & 0.067 & 0.033 & 0.135 & 0.185 & 0.118 & 0.109 & 0
\end{pmatrix}$$

a: Initial Transition Matrix

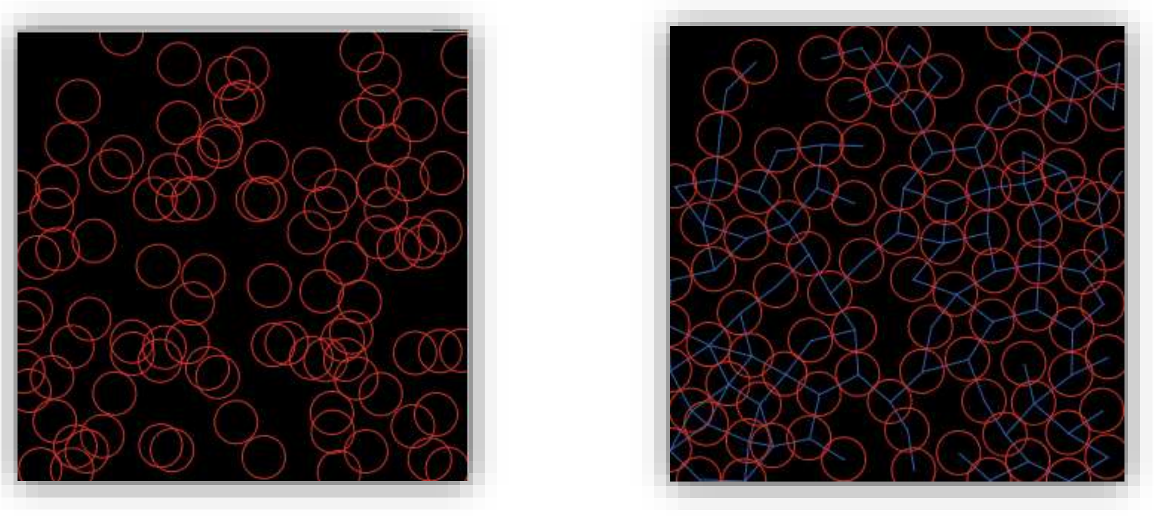
0	0.137	0.093	0.288	0.047	0.097	0.13	0.066	0.047	0.094
0.099	0	0.154	0.156	0.065	0.101	0.187	0.074	0.129	0.034
0.07	0.158	0	0.223	0.097	0.139	0.035	0.119	0.035	0.123
0.113	0.084	0.117	0	0.1	0.134	0.134	0.116	0.117	0.086
0.049	0.092	0.134	0.263	0	0.096	0.177	0.049	0.092	0.049
0.07	0.101	0.135	0.247	0.068	0	0.155	0.034	0.1	0.089
0.079	0.156	0.029	0.207	0.104	0.129	0	0.118	0.05	0.127
0.06	0.092	0.145	0.268	0.043	0.043	0.177	0	0.103	0.07
0.042	0.157	0.042	0.265	0.08	0.123	0.074	0.101	0	0.116
0.084	0.043	0.148	0.196	0.043	0.111	0.189	0.069	0.118	0

b: Final transition Matrix

Figure 3: sample of the transition matrix for the 10 sensors

Case 2:

100 sensors are deployed randomly in a 100x 100m area as shown in figure (4).



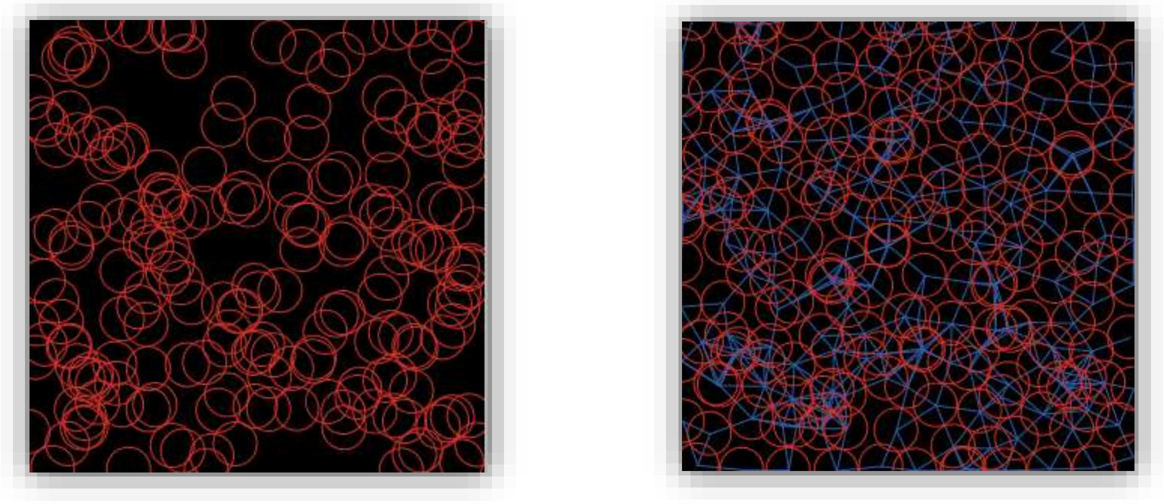
a: initial random deployment

b: final deployment

Figure 4: initial and final deployments of 100 sensors

Case3:

200 sensors are deployed randomly in a 100x 100m area as shown in figure (5).



a: initial random deployment

b: final deployment

Figure 4: initial and final deployments of 200 sensors

Table (1) summarizes the results of the above three cases. Figure (6) shows a clear comparison between this paper results and the GSO (developed by Wen-Hwa, et al.,) results. From the results it's clear that the developed approach gave a good results comparing with the GSO.

Table (1) the results of the suggested cases.

Cases	No. of Sensors	Field area	Sensing Range	Communication Range	Total coverage area
Case 1	50	100 X 100	5	10	37.8786
Case 2	100	100 X 100	5	10	74.326
Case 3	200	100 X 100	5	10	95.5595

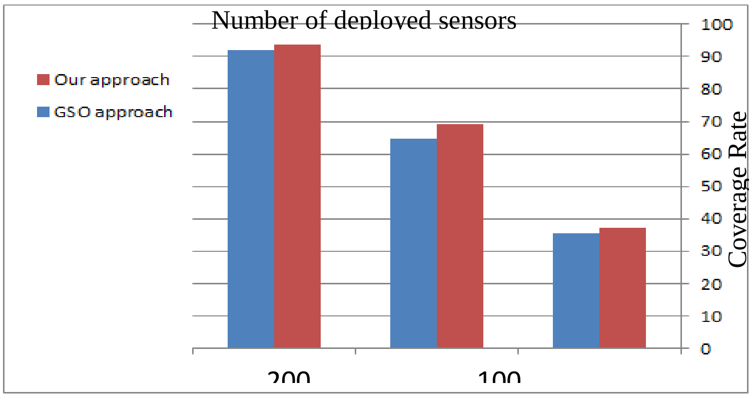


Figure 6: comparison between this paper results and the GSO approach

10. CONCLUSION

In this study, we have suggested and developed a markovian algorithm to develop the process of sensors deployment. The proposed approach is to model the sensing field, nodes positioning and the sensors communication range. The results indicate a best approach in achieving good coverage of the sensing field and connectivity of the network as compared to other methods such as GSO. This method ensures full connectivity and good system reliability. Different numbers of sensor nodes are deployed randomly and then re-change their positions in a sequential manner till reaching the final optimal location for each node. The end position for each node is ensuring good and reliable connectivity with all neighbors in addition to reduce the overlapping. A connected graph representation is also used to show the network connectivity.

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