

ENERGY EFFICIENT COVERAGE AND DETECTION IN WSN'S USING A DESIGNED MODEL

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Abstract. There is a need of paramount design for the consideration of the trade-off between lifetime and reliability of the system in WSN's. The random sleep scheme is to be adopted to prolong the lifetime of the system where co-ordination of its neighbouring nodes is to be taken in account. An accurate model, the border effects have been investigated. Hence it improves the performance accuracy and quality analysis. Thus, designed model is very much flexible to capture the interaction among the essential parameters of the system. Therefore, our model provides beneficial directions, steps and guidelines for maximum/optimal sensor network deployment where lifetime and reliability requirements are achieved as desired. The correctness and effectiveness of our analysis are confirmed by additional simulated results. This is a real significant development in WSNs.

1. Introduction

WSNs have applications in environment monitoring, target detection, localization, surveillance etc. Generally, sensor nodes are deployed in remote and hostile environment for a long time. In this process, there is a limitation of battery power. It is very difficult to recharge and replace the battery power of all sensor nodes. The researchers intend to design an effective model to extend system lifetime monitoring the reliability of the system in WSNs.

The researchers like Shih, E etc have observed that the energy resources are conserved by scheduling sensor nodes to alternate between sleep and active mode. In this case, node density is high up to 20 nodes/m³[9,6,7]. The performances of network coverage and detection and thus related steps are disrupted due to dynamic management of duty cycles of node. Thus, the problems of WSNs are mentioned below:

- I. To minimize the number of nodes that remain active in dynamic management;
- II. And during this step, the satisfied quality of service (QOS) for point of applications is to be achieved.

Xing et al.[8] have proposed some techniques to resolve the above-mentioned problems. In these techniques, there is a need of co-ordination among nodes when location or directional information are exchanged. These are obtained by GPS (Global Positioning

System) and the directional antenna technology. During this process, much energy is consumed and the cost of tiny sensor is very high. In addition to these demerits, coordination among nodes requires more energy. It is hoped that scheduling algorithms may work/ function without geographical information.

The border effects in WSNs is a matter of investigation. There is less chance to cover the point near the border of deployment area than the points in central area. The border effects may be ignored if the ratio of the node's sensing range to the range of the deployment area is sufficiently small. Liu et al.[4] has proposed a model to evaluate the number of nodes needed to obtain the coverage ratio considering the border effect[1,4]. It is applicable only to determine the number of active nodes. In this model, the total number of nodes cannot be derived if dynamic management of nodes duty cycle is considered. However, Yen et al.[9] has formulated a design for the expected R-coverage when border effects and uncoordinated node scheduling scheme are taken in consideration. Liu et al.[4] have considered the border effects but the border area like coverage and detection are not predicted accurately in these cases also.

In view of above-mentioned observations and demerits of previous studies in this paper, a designed has been proposed/ constructed for energy-efficient coverage as well as detection quality when the border effects are considered. The random deployment strategy has following properties:

- I. Easy to handle
- II. And inexpensive for sensor networks.

Hence, this deployment is to be considered. The random sleep scheme is considered for individual nodes[5]. Here, nodes sleep and wake up at random and their behaviours are independent to each other. The advantages of this scheme are mentioned below:

- I. Simple to implementation
- II. And without bringing about control overhead.

During this scheme, deployment and sleep scheme are selected randomly, therefore there is a need to study this problem/ issue in perspective of probability.

The main achievements of this study are given below:

- I. This designed model on WSNs should indicate guidelines for the sake of optimal sensor network deployment because it is sufficiently flexible to capture the interaction among the parameters like sensor node numbers, random sleep ratio, etc.
- II. This design / model is in the position of determining the sleep ratio of required coverage and detection quality as desired by the investigator.
- III. The sufficient attention has been paid to the QOS (quality of service) which is affecting the border area. The QOS is upgraded to a higher level if the applications in border require sufficiently high degree of accuracy. The number of nodes which are required in deployment are calculated analytically in our designed WSNs.

The rest of the papers is organized as follows:

2. Network Designed / Models and considered assumptions

Suppose n sensor nodes are uniformly and independently distributed in elliptical area. A having semi-major and semi-minor axes $a > 0$ and $b > 0$ respectively. Assume that sensor's sensing range is an elliptical area centred at this sensor having semi-major and semi-minor axes a' and b' respectively such that $0 < a' < a$ and $0 < b' < b$. All sensor nodes are to have the same sensing elliptical semi-major and semi-minor axes. Each sensor is to be deployed at different location.

A point event E within A is detected if it is found inside of at least one active sensor node's sensing range. A point's neighbouring area N is defined as a region that any sensor node covers this point if the sensor node is located within the region. If border effects are not considered then for each point in A , $N_A = \pi a' b'$. If the point E coincides with centre of elliptical area then figure 1. Is considered otherwise figure 2 which is illustrated below:

Figure 1: Illustration of central area, border area and neighboring area with $A = \pi A$

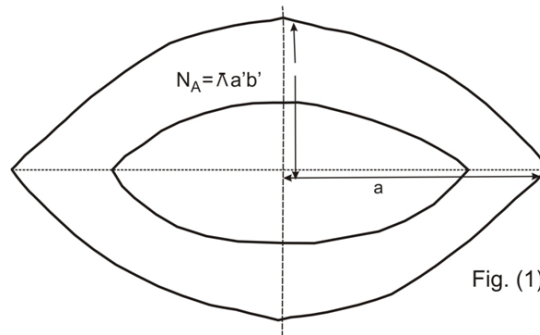
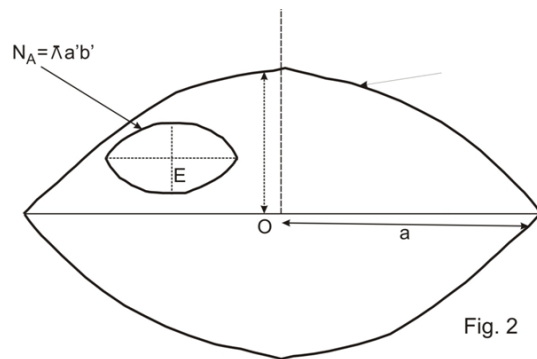


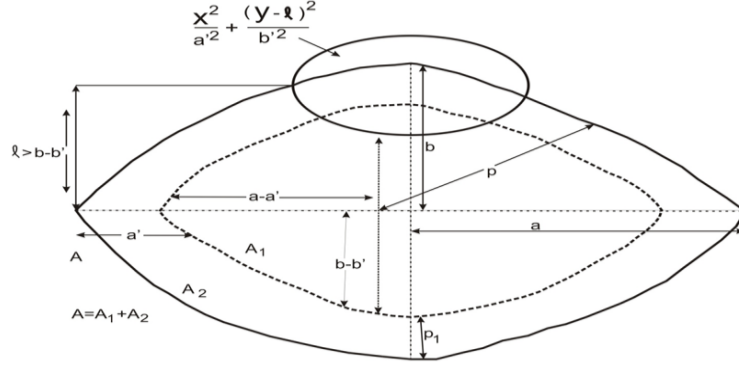
Figure 2: Illustration of central area, border area and neighboring area with $A = \pi AB$



If the border effects are taken into accounts the area A is divided into two parts A_1 and A_2 in the figure 3 to analyse the problem.

The central area A_1 that is concentric with A , has semi-major and semi-minor axes $a-a' > 0$ and $b-b' > 0$ respectively. For any point in A_1 , its neighbour area is $N_{A_1} = \pi a' b'$. For an arbitrary point in border area A_2 , only shadowed part is to be considered for probability of being deployed with sensor nodes. Thus $N_p < \pi a' b'$.

Figure 3



In our study. All sensors have the same sensing period T and sleep ratio α with $0 < \alpha < 1$. It defines the percentage of time when the sensor is in sleep state.

3. Analysis of WSNS Coverage

In this study, nodes are deployed with a uniform distribution. Let $\phi = \frac{N}{\pi ab} < 1$. ϕ is the probability which is fallen by a sensor node on a point's neighbouring area.

The number of nodes within N is to help a binomial distribution $B\left(n, \frac{N}{\pi ab}\right) = B(n, \phi)$.

The probability is obtained by the expression

$$P^\alpha = \sum_{k=1}^n n_{C_k} \left(\frac{N}{\pi ab}\right)^k \left(1 - \frac{N}{\pi ab}\right)^{n-k} = \left(\frac{N}{\pi ab} + 1 - \frac{N}{\pi ab}\right)^n = 1^n = 1 \quad (1)$$

P is the probability that the arbitrary point is covered by at least one node.

Let us consider the random sleep scheme. The probability of a point event E covered by at least one active sensor is given by

$$\begin{aligned} P^\alpha &= \sum_{k=0}^n n_{C_k} \left(\frac{\alpha N}{\pi ab}\right)^k \left(1 - \frac{\alpha N}{\pi ab}\right)^{n-k} \\ &= 1 - \left(\frac{\alpha N}{\pi ab} + 1 - \frac{N}{\pi ab}\right)^n = 1 - \left(1 - \frac{N}{\pi ab}(1-\alpha)\right)^n = 1 - \left(1 - (1-\alpha)\frac{N}{\pi ab}\right)^n \\ \therefore P^\alpha &= 1 - \left(1 - (1-\alpha)\frac{N}{\pi ab}\right)^n \end{aligned} \quad (2)$$

For every point in A_1 , the probability that a sensor node falls on its neighbouring area is equal to

$$\phi_A = \frac{\pi a' b'}{\pi a b} = \frac{a' b'}{a b}.$$

By formula (2), the probability of being covered is also obtained as $1 - \left[1 - (1-\alpha) \frac{a' b'}{a b}\right]^n$.

Thus, the expected coverage ratio of the area A_1 is given by

$$\begin{aligned} P_{A_1} &= 1 - \left(1 - (1-\alpha) \phi_{A_1}\right)^n \\ &= 1 - \left[1 - (1-\alpha) \frac{a' b'}{a b}\right]^n \end{aligned} \quad (3)$$

As shown in figure (1), for a particular point, its neighbouring area is actually the overlapped area of ellipse at the point i.e., $\frac{x^2}{a'^2} + \frac{y^2}{b'^2} = 1$ and the area of ellipse $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$

The central area A_1 , which and A are ellipses centred at the same point, has an ellipse of semi-major axis and semi-minor $a - a'$, $b - b'$ respectively. Obviously, the neighbouring of every point in A_1 is the same and its value is $\pi a' b'$. For any point in A_2 , its neighbouring area is inverse proportion to its distance away from the central point of A and is less than $\pi a' b'$.

In fig (3), there is a point (x_1, y_1) and l is the distance between this location and the centre of ellipse A and $l > b - b'$. The point of intersection of $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$ and $\frac{x^2}{a'^2} + \frac{y^2}{b'^2} = 1$ for $x=0$ is given by

$$\begin{aligned} (y - l)^2 &= b'^2, y^2 = b^2 \\ y^2 - (y - l)^2 &= b^2 - b'^2 \\ 2yl - l^2 &= b^2 - b'^2 \\ y &= \frac{b^2 - b'^2 + l^2}{2l} \\ R &\left(0, \frac{b^2 - b'^2 + l^2}{2l}\right) \end{aligned}$$

The value of point's neighbouring area $N(x_1, y_1)_{\text{area}}$

= area of shadowed region

$$\begin{aligned} &= 2 \left[\int_{l-b'}^{(b^2-b'^2+l^2)/2l} a' \sqrt{1 - \frac{(y-l)^2}{b'^2}} dy + \int_{\frac{b^2-b'^2+l^2}{2l}}^b a \sqrt{1 - \frac{y^2}{b^2}} dy \right] \\ &= 2 \left[\frac{a'}{b'} \int_{l-b'}^{(b^2-b'^2+l^2)/2l} \sqrt{b'^2 - (y-l)^2} dy + \frac{a}{b} \int_{\frac{b^2-b'^2+l^2}{2l}}^b \sqrt{b^2 - y^2} dy \right] \end{aligned}$$

$$\begin{aligned}
&= 2 \left[\frac{a'}{b'} \left\{ \frac{b^2 - b'^2 + l^2}{4l} \sqrt{b'^2 - \frac{(b^2 - b'^2 + l^2)^2}{4l^2}} + \frac{b'^2}{2} \sin^{-1} \left(\frac{b^2 - b'^2 + l^2}{2b'l} \right) + \sqrt{b'^2 - (y-l)^2} + \right. \right. \\
&\left. \left. \frac{b'^2}{2} \left(\frac{\pi}{2} \right) \right\} + \frac{a}{b} \left\{ 0 + \frac{b^2}{2} \left(\frac{\pi}{2} \right) \left(\frac{b^2 - b'^2 + l^2}{4l} \right) \sqrt{b^2 - \frac{(b^2 - b'^2 + l^2)^2}{4l^2}} - \frac{b^2}{2} \sin^{-1} \left(\frac{b^2 - b'^2 + l^2}{2bl} \right) \right\} \right] \\
&= \frac{\pi}{2} (a'b' + ab) + \frac{a'}{b'} \left(\frac{b^2 - b'^2 - l^2}{2l} \right) \sqrt{b^2 - \frac{(b^2 - b'^2 - l^2)^2}{4l^2}} + a'b' \sin^{-1} \left(\frac{b^2 - b'^2 - l^2}{2b'l} \right) - \\
&\frac{a}{b} \left(\frac{b^2 - b'^2 + l^2}{2l} \right) \sqrt{b^2 - \frac{(b^2 - b'^2 + l^2)^2}{4l^2}} - ab \sin^{-1} \left(\frac{b^2 - b'^2 + l^2}{2bl} \right) \quad (4)
\end{aligned}$$

Then the average neighbouring area of all point in A_2 is

$$\overline{N_{A_2}} = \iint N_{l \in A_2} \cdot l_\sigma / \pi(ab - (a - a')(b - b')) \quad (5)$$

Thus, the average coverage ratio of A_3 is

$$P_{A_2}^* = 1 - [1 - (1 - \alpha)\overline{\phi_{A_2}}] = 1 - [1 - (1 - \alpha)\overline{N_{A_2}}/\pi ab]^n \quad (6)$$

Also, the average coverage ratio of whole area A can be calculated when all the deployed sensors are active. On the basis of this value, the following observation may be taken in account:

1. The disruption of QoS under random sleep scheme;
2. The quantitative quality difference between the central area A_1 and border area A_2 .

The average neighbouring area of all point n A is obtained by

$$\begin{aligned}
\overline{N_{A_2}} &= [\pi(a - a')(b - b')\pi a'b' + \overline{N_{A_2}}\{\pi ab - \pi(a - a')(b - b')\}]/\pi ab \\
&= [\pi a'b'(a - a')(b - b') + \overline{N_{A_2}}\{ab - (a - a')(b - b')\}]/ab \quad (7)
\end{aligned}$$

Thus, by formulae (1) to (7), the average coverage ratio A without accepting the sleep scheme is given by

$$\overline{P_A} = 1 - (1 - \phi)^n = 1 - (1 - \overline{N_A}/\pi ab)^n \quad (8)$$

Our investigation is concerned with 1-coverage only. This can be extended to k-coverage also.

4. Analysis of Point Event Detection

Let us propose a mathematical model to study the probability of detection delay in case of pint event. For random sleep scheme, the point in area A are well-covered but all pint events cannot be detected at a time. Thus, an arbitrary point is t be considered in area A. This is covered by at least ne node in A.

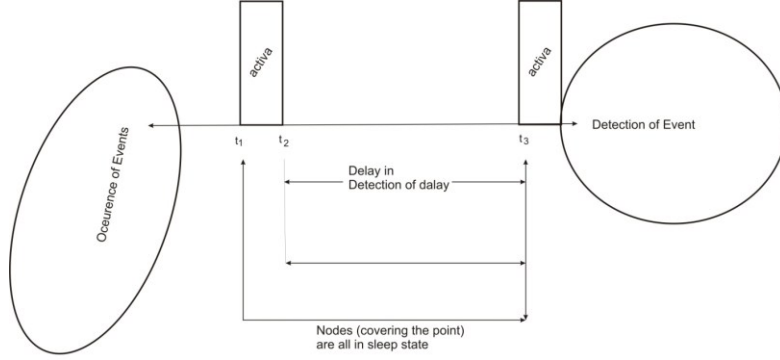


Fig. 4

Figure 4: Illustration of Point event detection delay

In figure4, WCST (worst case sleep time) is the period from t_1 to t_3 . During this period, all nodes in side this point's neighbouring area are in sleep state but an event occurs during this time period. In figure (4), the event is occurring at time t_2 . Thus, a delay in detection, denoted by t_d , is determined by

$$t_d = t_3 - t_2$$

This occurs due to detection of the event when at least one node wakes up at time t_3 .

The delay time can be decrease by following ways:

1. Increasing the number of nodes deployed in the area,
2. Decreasing the sleep ratio of each node.

For the requirement of decreasing the delay time, following steps are to be taken into account:

1. The selection of sleep ratio;
2. The detection quality of point events in central area A_1 ;
3. To analyze the detection delay probability of point events in area A_2

Due to above mentioned facts, a high degree of accuracy of detection can be achieved in the complete region A .

By the help of Fig (2) and above analysis, the conditional probability, denoted by $P_{S/C}$, of a point that is not covered by any active node even it could be covered, is calculated by

$$P_{S/C} = \frac{\sum_{k=1}^n n_{C_k} (\alpha - \phi)^k (1 - \phi)^{n-k}}{1 - (1 - \phi)^n} = \frac{(\alpha \phi + (1 - \phi))^n - (1 - \phi)^n}{1 - (1 - \phi)^n} = \frac{(1 - (1 - \alpha) \phi)^n}{1 - (1 - \phi)^n} \quad (9)$$

Now the probability of a given point event which is uncovered for at least m slots is

$$P_{td}(td \geq m) = P_{S/C} - \frac{\sum_{i=1}^m \{ \sum_{k=1}^n \alpha^{ik} (1 - \alpha^k) n_{C_k} \phi^k (1 - \phi)^{n-k} \}}{1 - (1 - \phi)^n}$$

$$\begin{aligned}
&= P_{S/C} - \frac{\sum_{i=1}^m \{ \sum_{k=1}^n n_{C_k} \alpha^{ik} \phi^k (1-\phi)^{n-k} - \sum_{k=1}^n n_{C_k} \alpha^k \alpha^{ik} \phi^k (1-\phi)^{n-k} \}}{1-(1-\phi)^n} \\
&= P_{S/C} - \frac{\sum_{i=1}^m \{ (\alpha^i \phi + (1-\phi))^n - (1-\phi)^n - (\alpha \alpha^i \phi + 1 + \phi)^n + (1-\phi)^n \}}{1-(1-\phi)^n} \\
&= P_{S/C} - \frac{\sum_{i=1}^m \{ (1-\phi(1-\alpha^i))^n - (1-\phi(1-\alpha^{i+1}))^n \}}{1-(1-\phi)^n} \tag{10}
\end{aligned}$$

By previous section of this research paper, ϕ_A and $\overline{\phi_A}$ may be calculated. The detection delay of point event can be calculated analytically if the node number n and sleep ratio α are known in advance. Equivalently, if other parameters are known then the number of sensors to be deployed can be evaluated.

5. Simulation Results

In this section, there is a need of comparison between analytic results and simulation results. In the simulation, locations of nodes are conforming to uniform random distribution over an elliptical area A with semi-major and semi-minor axes a and b respectively. The area A is divided into many small grids with size 0.1×0.1 . The node's sensing ranges are set as $a' = 10, b' = 10$.

Let us consider the following table to determine ab :

Sl. No.	$a' = b' = 10$	$\frac{a'b'}{ab}$	Ab	The period T (in second)	Time slot (in second)
1	10	1	100	10	1
2	10	0.5	200	15	1
3	10	0.2	500	20	1
4	10	0.1	1000	25	1

In the first set of experiments $\frac{a'b'}{ab} = 1$ and the number of nodes n is varied from 1 to 10 with an increment of 1. At first, the simulation results of coverage ratio (denoted be SC-A) of whole area A is to be obtained when deployed nodes are all active. After this, the random sleep scheme has been adopted. The coverage ratio of both central area A_1 and border area A_2 are to be measured under different combinations of $n(1,2,3,\dots, 10, 11,\dots, 15)$ and $\alpha (0.2, 0.4, 0.6)$ denoted by SC- A_1 -0.2, SC- A_1 -0.4, SC- A_1 -0.6, SC- A_2 -0.2, SC- A_2 -0.4, SC- A_2 -0.6 respectively. The coverage ratio can be estimated as follows:

The simulation coverage ratio for a single time slot is calculated by estimating the proportion of the number of grids to the total number of grids in the area:

Simulation coverage for a single time slot

$$= \frac{\text{The number of grids}}{\text{The total number of grids in the area}}$$

1000 time slots are considered for each deployment. 100 deployments are generated for every combination of parameters. Then, average simulation results are obtained. It is shown in fig 5(1). The analytical results AC-A: AC- A₁-0.2, AC- A₁-0.4, AC- A₁-0.6 are compared with SC- A₁-0.2, SC- A₁-0.4, SC- A₁-0.6 respectively. It is found that both curves match almost everywhere.

For the second set of experiments, for a given node number, the detection delay probability of central area A₁ and border are A₂ under different values of sleep ratio α (0.2,0.4,0.6) and time slots ζ (1,2,3,..., 20, 21, ... 25), denoted by SD-A₁- 0.2, SD-A₁- 0.4, SD-A₁- 0.6, SD-A₂- 0.2, SD-A₂- 0.4, SD-A₂- 0.6 respectively. The node number is also selected purposely. It is remarkable to note that when ϕ deployed sensor nodes are all waking up, the whole area A is almost covered. Then, the disruption in detection quality can be studied under different values of α and the quantitative difference between central area A₁ and the border area A₂. In case of each time slot, the random sleep scheme is considered, the coverage ratio p_ζ is obtained as

$$p_\zeta = \frac{\text{Number of covered grids}}{\text{Total number of grids in this area}}$$

The long run coverage of $1-p_\zeta$ helps in estimation of $p_{S/C}$. Every grid is considered as a point event. If the detection delay is equal to 1s, 2s, 3s, ..., 20s, 21s, ..., 25s then the number of experiments are recorded respectively. The simulation results for averages over 150 runs are shown in fig5(ii).

The additional experiments for $\frac{a'b'}{ab} = 2$, $\frac{a'b'}{ab} = 1$ and $\frac{a'b'}{ab} = 0.2$ have been conducted to check the accuracy of the simulation results and theoretical results. These results are shown in fig(5), fig(6) and fig(7).

The main points of the observations from simulation are given below:

1. The analytic results are very near to the simulation results. This indicated the correctness and validity of the derivations in this research paper.
2. The QoS of central area A₁ outperforms that the border area A₂ on detection quality and coverage.
3. The coverage ratio is proportional to the number of deployed nodes i.e., the coverage ratio increases/ decreases with the increasing /decreasing number of deployed nodes.
4. If number of nodes is fixed, then the probability of detection delay is directly proportional to α I.e., the probability of detection delay increases/ decreases with the increase/decrease of α .

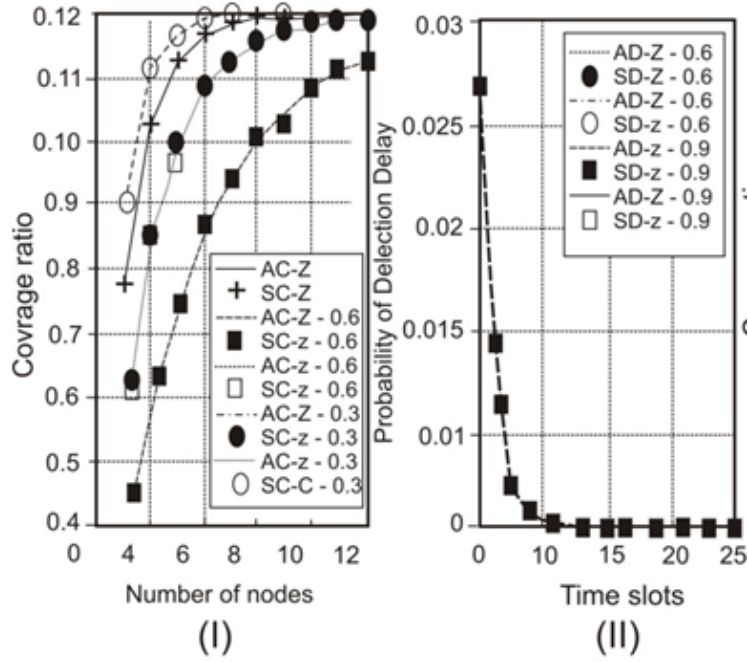


Figure 5: Comparing analytical results with simulation results $\frac{a'b'}{ab} = 2$

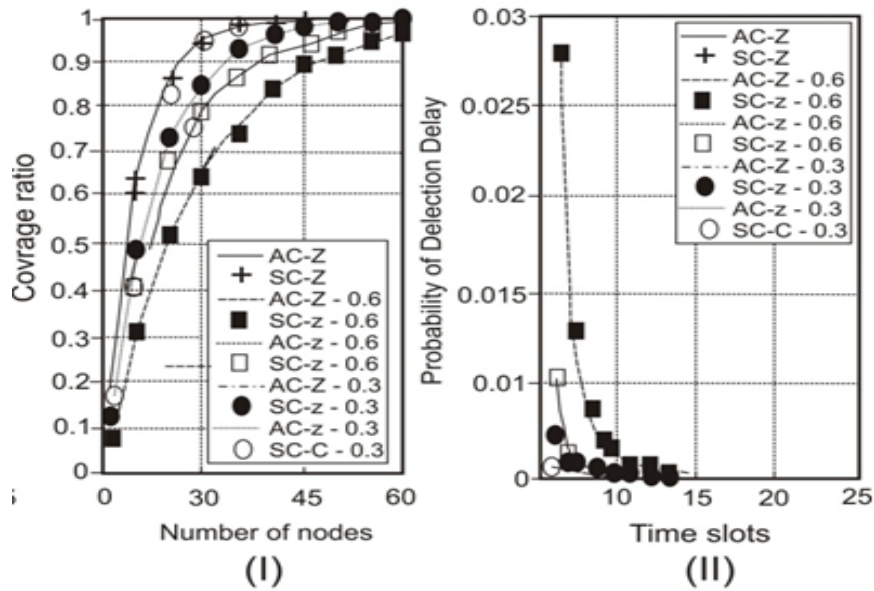


Figure 6: Comparing analytical results with simulation results $\frac{a'b'}{ab} = 1$

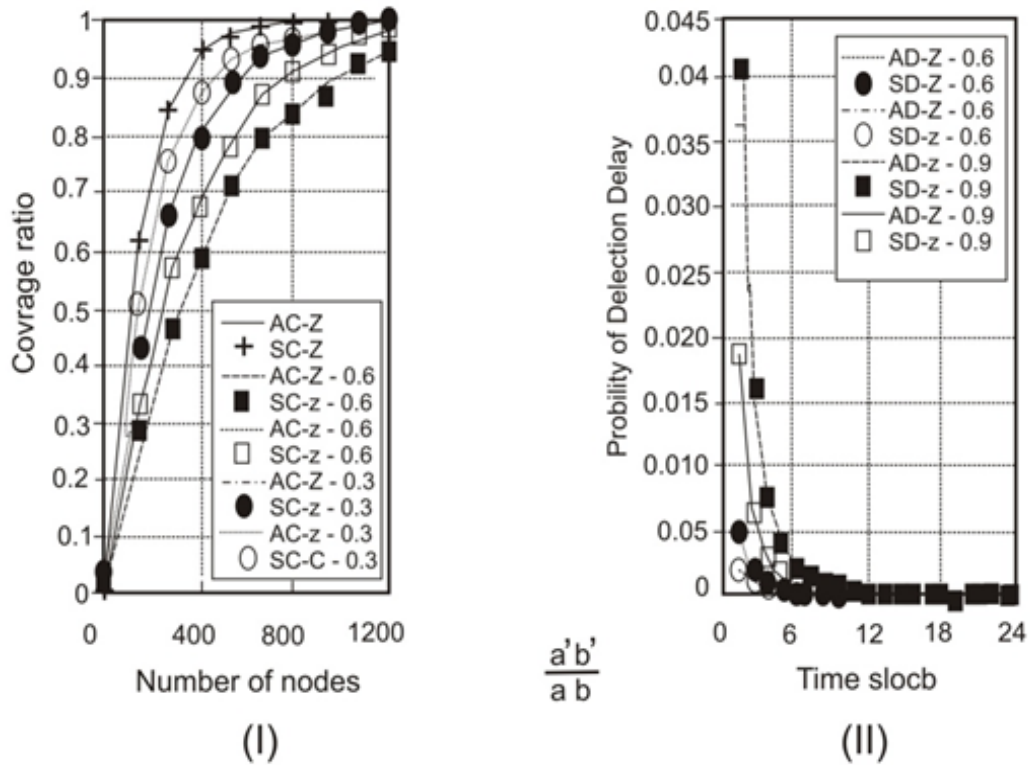


Figure 7: Comparing analytical results with simulation results $\frac{a'b'}{ab} = 0.2$

6. Conclusion

Following conclusions are derived from this research paper.

- i. A mathematical model for energy-efficient coverage and detection has been prepared.
- ii. This model reflects the effects of border.
- iii. The extensive simulation experiments verify the correctness and effectiveness of the model of this research paper.
- iv. This model shows the capability for analysing the trade-off between network lifetime and system reliability of WSNs effectively up to the mark.
- v. The optimal sensor network deployment can be achieved by this model.

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