Enhancing Network Coverage Using Sensing Models in Wireless Sensor Network

J Vidhya¹, P Prasanna², M Margarat³, S Jayalakshmy⁴

¹,³,⁴ Associate Professor, Department of Electronics and Communication Engineering, IFET College of Engineering, Villupuram.
² UG Scholar, Department of Electronics and Communication and Engineering, IFET College of Engineering, Villupuram.

¹ vidhyaja@gmail.com, ² prasana4599@gmail.com, ³ margarat.rosy@gmail.com, ⁴ saijal2805@gmail.com

Abstract. WSN is a wireless network made of wireless sensors that is used to monitor the system, environmental or physical conditions. Network coverage is a critical Quality of Service parameter in the design of WSN. The sensing model used to design the network decides the coverage. In this paper, the effects on sensing coverage by multi-path fading and shadowing effects have been studied. A model for calculating coverage probability has been derived for an environment in presence of shadowing effect combined with multi-path fading. Deployment scheme directly influences the performance of the WSN. A multiple deployment scheme is proposed for shadowed and non-shadowed environments using Rayleigh and shadow fading. For the same value of sensing coverage, a significant depreciation in the required number of nodes is shown.

1. Introduction

Number of sensor nodes connected wireless forms a network to supervise and sense the desired environment is called Wireless Sensor Network. For deployment in non-ideal environments, these low cost nodes are linked wireless to supervise the environment. The applications fields are environment monitoring and protection, defense and surveillance and healthcare. The important issues in WSN are cost, network coverage, power efficiency and node deployment. [1-3]. One of the important issue in WSN is Network Coverage. Coverage is a measure of quality of supervising targets by the network of sensors [4-6]. Different applications need different degrees of coverage [7-9]. The deployment strategy can either be deterministic or random. It is determined by the area to be supervised and the importance of the application. It determines the cost, time, number of sensor nodes required to achieve a maximum coverage range that is covered by the budget. The node deployment strategy strongly effects the sensing coverage [10-12].

Deterministic node deployment is used for an environment which is controlled and human friendly. Generally, it assumes uniform sensing radius in all the directions [13]. But in practical sensor network, the sensor radius is determined by the environmental factors and quality of the sensing device which produces an imprecise data [6]. Besides path loss, there is a power loss because of the environmental factors causing variations in the Received Signal Strength (RSS) [14, 15]. Deviation of the signal due to reflection is multi-path fading and shadowing is the disruption in the propagation path. They both have a negative effect on the sensing coverage quality. So, it is logical to address the both together in sensing coverage problems. The remaining part is ordered as follows. In Sect. 2, an introduction to the sensing model is described. In Sect. 3 a non-shadowed environment is briefed. In Sect. 4, sensing in a shadowed environment is discussed. In Sect. 5 Rayleigh fading and in Sect. 6, multiple deployment strategies are discussed. In Sect. 7 the analysis of results are deliberated and conclusions are shown in Sect. 8.
2. Sensing Model

Deterministic category contains Boolean or Disk sensing model whilst probabilistic category contains Elfes and shadow-fading model [15].

2.1 Shadow-fading sensing model

This model takes dependency factors like obstacles (foliage’s, buildings, etc.) into account. So that the sensing radius varies in all the direction. This model is identical to the shadowing effect.

\[ P_{\text{det}}(x) = Q \left( \frac{10\eta \log_{10}(x/\tau)}{\sigma} \right) \]

2.2 Elfes sensing model (ESM)

According to ESM, the probability for an event detected by a node at distance x is,

\[ p(x) = \begin{cases} 
1, & x \leq R_1 \\
p, & R_{\text{max}}>x>R_1 \\
0, & x \geq R_{\text{max}}
\end{cases} \]

where the physical properties of the sensor are modified by the parameters \( \lambda \) and \( \gamma \). The maximum radius of the sensor is \( R_{\text{max}} \). The uncertainty in sensor detection starts from \( R_1 \). This model becomes boolean when \( R_1=R_{\text{max}} \).

\[ p(x) = \begin{cases} 
\exp(-\lambda x), & x \geq 0 \\
0, & x \geq R_{\text{max}}
\end{cases} \]

2.3 Boolean sensing model

If the event occurs within the sensing range then it is assumed detected, else not. It ignores the environmental characteristics (obstacles). The radius of sensing is constant in all directions. The detection probability for an area A is,

\[ P_{\text{det}} = \frac{\pi R_s^2}{A} \]

where, \( R_s \) is the node’s maximum radius. The detection probability \( P_C \) of target by at least one sensor can be shown as

\[ P_C = 1 - \exp \left( -\frac{N_{\text{sen}} R_s^2}{A} \right) \]

By applying \([1-x]^n = e^{-nx}\) as \( n \) is very large, (5) can be rewritten as

\[ P_C = 1 - (1 - P_d)^N \]

3. Non-Shadowed Environment

Fig. 1 sensing for non-shadowed. (a) Sensing a target distant from the perimeter. (b) Sensing a target nearby the perimeter.
The sensor radius i.e., $R_{\text{max}}$, is constant in all directions for a non-shadowed environment. It forms a disk-shaped sensing range. As depicted in Fig. 1(a), if the location of the target is far distant from the sensor, it cannot be sensed as the distance between is smaller than $R_{\text{max}}$. The detection probability for the target by a specific sensor is

$$P_{\text{det}} = \frac{\pi R_{\text{max}}^2}{A}$$  \hspace{1cm} (7)

The probability that a network not detecting the target is

$$P_{\text{NS}} = 1 - (1 - P_{\text{det}})^N$$  \hspace{1cm} (8)

The sensing coverage as the probability for being undetected is identical in the desired region is

$$C = 1 - P_{\text{NS}}$$  \hspace{1cm} (9)

The edge effect has been ignored in (9) due to the small ratio compared to the entire sensing region. As depicted in Fig. 1(b), the probability that a sensor is detects the target from a location nearby the edge is lower than the values obtained from (7).

4. Shadowed Region

For shadowed region, the radius of the sensor is not uniform due to various amount of loss due to shadowing and diverse propagation paths.

The average sensing radius $R_i$ can be calculated for an environment using

$$R_i = R_{\text{max}} \times 10^{[t_{\text{min}}(d_o) - L_i(d_o)]/10\beta}$$  \hspace{1cm} (10)

$$P_{\text{det}} = \int_0^{R_{\text{max}}} P_{\text{det}}(r) \times \frac{2\pi r}{A} \, dr$$  \hspace{1cm} (11)

$$P_{\text{det}} = \int_0^{R_{\text{max}}} \left[ Q \left( \frac{10\beta \log_\sigma (\overline{R}/r)}{\sigma} \right) \times \frac{2\pi r}{A} \right] \, dr$$  \hspace{1cm} (12)

$$P_{\text{NS}} = \exp \left[ \int_0^{R_{\text{max}}} 2\pi A r \left[ Q \left( \frac{10\beta \log_\sigma (\overline{R}/r)}{\sigma} \right) - 1 \right] \, dr \right]$$  \hspace{1cm} (13)

5. Rayleigh Fading

Rayleigh fading is the fading caused by the multi-path reception of the received signal due to scattering by objects in the environment before it is received. Both the shadow and Rayleigh fading may occur in a channel. As the signal power received from different directions may differ as they suffer from multi-path and shadow fading. $R_{\text{max}}$ is the maximum and $R$ is the average sensor radius $r$ is assumed as continuous and $dr$ approaches zero, and detection probability for the target in the region $2\pi r \, dr$ of area $A$ can be derived as follows

$$P_d = \frac{1}{A} \left[ \int_{r=0}^{R_{\text{max}}} Q \left( \frac{10\beta \log_\sigma (\overline{R}/r) - \sqrt{2}}{\sigma} \right) \times 2\pi r \, dr \right]$$  \hspace{1cm} (14)

According to (6), the probability of coverage $P_C$ can be shown as

$$P_C = 1 - \exp \left( - \frac{N}{A} \left[ \int_{r=0}^{R_{\text{max}}} Q \left( \frac{10\beta \log_\sigma (\overline{R}/r) - \sqrt{2}}{\sigma} \right) \times 2\pi r \, dr \right] \right)$$  \hspace{1cm} (15)

This equation can be used in determining the number of nodes for required for the desired region and also to predict the coverage for the area.

6. Multiple Deployment

The coverage can be improved by dividing the entire area to be monitored or sensed into multiple sub-regions. And the uniformity of the nodes deployed in the region can be improved by deploying equal amount of nodes in each partition. Some number of sensors can be saved if same coverage is required. The partition of the whole sensing area as $M^2$ sub-regions is assumed, where the partition factor is $M$. Then the area of the each sub-region is $A/M^2$ as square and the uniform amount
of nodes randomly deployed in each partition is \( \frac{N}{M^2} \). The probability of the target being undetected by the sensor network in a non-shadowed region is

\[
P_{NS} = \left(1 - \frac{\pi M^2 R_{max}^2}{A}\right)^{\frac{N}{M^2}}
\]

(16)

Following this, according to (9), the entire region coverage \( C \) can be determined.

7. Simulation and Results

7.1 Sensing models

The numerical results were shown in this section to show effects of the sensing models on coverage. The figure 2 shows the Coverage Probability \( (P_c) \) VS number of nodes (N) for the probabilistic models i.e., BSM, ESM and Shadow Fading Sensing Model (SFSM). \( P_c \) for BSM has the greatest coverage, but it does not take shadow effects into account. The study shows that the BSM achieves the best coverage. Due to the uncertainty in detection the ESM coverage probability \( P_c \) degrades. From existing literatures, BSM is better than the probabilistic models. But it is not practical due to the unavailability of non-ideal environments and irregularities in the sensor. \( P_c \) ESM degrades due to the detection uncertainty. Elfes Sensing Model (ESM) is similar to the BSM. Also, it does not enclose the shadowed area. The sensing model for the area to be enclosed should be selected based on the requirements and nature of the coverage area. Shadow Fading Sensing Model (SFSM) takes shadowing effects into account. So, SFSM for designing the sensing model for the WSN is considered. To improve this model, further multi-path effects are added to the Shadow Fading Sensing Model.

7.2 Shadow fading & Rayleigh fading

Using equation (18), the sensing model with shadow fading and Rayleigh fading which includes the multi-path effects is simulated and shown in the figure 3. The degree of multi-path effect is represented using \( \Omega \) in decibel (Ohm) in the simulation. Figure 3 shows the simulation of graphs for \( \Omega = 0 \), \( \Omega = 1 \), \( \Omega = 2 \) and \( \Omega = 3 \). As the degree of multi-path effect increases, the Probability of Coverage \( (P_c) \) decreases. The coverage range is high when the multi-path effect is null. To further increase the sensing coverage, we simulate the Rayleigh fading and Shadow fading model in multiple deployment environments and analyses its sensing coverage for various levels of multi-path effects and multiple partitions using equation (17).
To further increase the coverage, we simulate the Rayleigh fading and Shadow fading model in multiple deployment environments and analyses its sensing coverage for various levels of multi-path effects and multiple partitions. Figure 4 shows the multiple deployment scheme for the shadow fading and Rayleigh fading Scheme. The graphs are deployed for different multiple deployments and multi-path effects. The probability of sensing coverage for the proposed model with $\Omega=0\text{dB}$ and $\sigma=0\text{dB}$ produces an output identical to as the Shadow-Rayleigh fading effect are absent. As the $\sigma$ (standard deviation) for the Shadow/Rayleigh faded environment increases, depreciation in the average sensing radius occurs. This signifies the degradation of the network coverage. Every cell in the network is evaluated using the same network topology. When shadow and Rayleigh fading are introduced into the environment, there is a deterioration in the coverage about 30%. To increase the coverage to an acceptable range, for example $C=0.99$, the number of nodes required doubles then the minimum number of required nodes as $N=2000$. The number of nodes to achieve the coverage $C=0.90$ is $N=1500$ for $\sigma = \sigma_1=6\text{ dB}$.
The standard deviation for Shadow fading is $\sigma$ and for Rayleigh fading is denoted by $\sigma_1$. To increase coverage, a greater number of nodes is required. In figure 4(a), on comparing the graphs for $M=1$, $5$ and $10$, it is observed that there is an increase in $M=5$ and $M=10$ while correlated to $M=1$. In figure 4a, 4b,4c,4d, the improvement in the coverage is better observable for $M=15$ as compared to the graphs of other partition factors in all the graphs. The uniform distribution proposed by this method improves the coverage for the shadow-Rayleigh environment. For $M=15$, it is better noticeable because each partition is better compared to coverage per node to improve coverage. For $M=15$, the coverage is 0.90 in figure 4(d) than for the same number of nodes in fig 4(c), the coverage is 0.98. This is due to the increase in the Rayleigh fading constant (Omega as denoted in figure 4). As the Rayleigh fading constant increases, the coverage greatly decreases.

| S. NO | PARAMETER                          | VALUE                          |
|-------|------------------------------------|--------------------------------|
| 1     | Maximum sensing radius, $R_{\text{max}}$ | 20m                           |
| 2     | Path loss exponent, $\eta$         | 4                              |
| 3     | Area, $A$                          | $1000000 \text{ m}^2$          |
| 4     | Number of nodes, $N$               | 0 to 2500 nodes                |
| 5     | Standard deviation, $\sigma$      | 6dB                            |
| 6     | Rayleigh fading constant, $\mu$    | 0 dB, 2dB, 4dB, 5dB            |
| 7     | Multiple Deployment, $M$           | $M=1$, $M=5$, $M=10$, $M=15$   |

TABLE 1: SIMULATION PARAMETERS

8. Conclusion

In a randomly distributed WSN, the effect of shadow and Rayleigh fading on coverage have been presented and a multiple deployment scheme has been proposed for this model. To calculate coverage probability, a mathematical model has been derived. As the effects of fading are increased, the nodes required to achieve the desired coverage is also increased. Better network coverage is
provided by the proposed sensing model for a realistic sensing field as compared to other probabilistic models. Hence, it will be more useful in calculating the performance of WSN in a natural territory. It is noticed that as the standard deviation for the Shadow-Rayleigh fading increased, average radius of a sensor reduced sharply. It depreciates the coverage range of the sensor network. The multiple deployment schemes further improves the coverage probability for this realistic sensing model.

9. Future Scope
The limitation for the proposed model is that the Shadow and Rayleigh fading cannot exit in nature alone. It can be overcome by considering Rician fading with this proposed model in the future.

10. Reference
[1]. Al Karaki, J. N. and Gawanmeh, A. (2017). The optimal deployment, coverage and connectivity problems in wireless sensor networks: Revisited. IEEE Access, 5, 18051–18065.

[2]. G. Mao, B. D. O. Anderson and B. Fidan, (2007). Path loss exponent estimation for wireless sensor network localization, Computer Networks, 51(10), pp.2467–2483.

[3]. Ghosh, A. and Das, S. K. (2008). Coverage and connectivity issues in wireless sensor networks: A survey Journal of Pervasive and Mobile Computing, 4(3), pp.303–334.

[4]. Guo, X., Zhao, C., Yang, X. and Sun, C. (2011). A deterministic sensor node deployment method with target coverage and node connectivity. Lecture notes in computer Science, 7003, 201–207.

[5]. Guy, C. (2006). Wireless sensor networks. In Sixth international symposium on instrumentation and control technology: Signal analysis, measurement theory, photo-electronic technology, and artificial intelligence (Vol. 6357, p. 63571I). International Society for Optics and Photonics.

[6]. Hossain, A., Biswas P.K., and Chakrabarti S., (2008). Sensing Models and Its Impact on Network Coverage in Wireless Sensor Network, Third International Conference on Industrial and Information Systems, Kharagpur, pp.1-5.

[7]. Li, X., Wan, P., Wang, Y. and Frieder, O. (2003). Coverage problems in wireless adhoc sensor networks. IEEE Transactions for Computers, 52, 753–763.

[8]. M. Hefeeda and H. Ahmadi, (2007). A probabilistic coverage protocol for wireless sensor networks, Proceedings of the 15th IEEE International Conference on Network Protocols, pp. 41–50, Beijing, China.

[9]. Ming Liu, Jiannong Cao, Wei Lou, Li-jun Chen and Xie Li, (2005). Coverage analysis for wireless sensor networks, Lecture Notes in Computer Science pp. 711-720, Springer-Verlag Berlin Heidelberg.

[10]. Pathan, A. (2015). A comparative study between multi-path fading channels. International Journal of Engineering Development and Research, 3(6), 720–725.

[11]. Puccinelli, D., and Haenggi, M. (2006). Multi-path fading in wireless sensor networks: Measurements and interpretation. Proceedings of IWCMC, pp. 3–6.

[12]. Q. Wang, K. Xu, G. Takahara and H. Hassanein, (2006) Deployment for information oriented sensing coverage in wireless sensor networks, Proceedings of IEEE Globecom, San Francisco, CA, pp. 1-5.
[13]. Qing, W. X. and Shu-qin, Z. (2009). Research on efficient coverage problem of a node in wireless sensor networks. *Proceedings of IEEE conference on industrial mechatronics and automation* pp. 9–13.

[14]. Rai, N. and Daruwala, R.D. (2017). Effect of probabilistic sensing models in a deterministically deployed wireless sensor network. *Proceeding of the international conference TENCON*, pp. 1352–1355.

[15]. S. S. Dhillon and K. Chakrabarty, (2003). Sensor placement for effective coverage and surveillance in distributed sensor networks, *Proceedings of IEEE WCNC*, pp. 1609–1614.

[16]. Soreanu, P. and Volkovich, Z. (2009). New sensing model for wireless sensor networks. *International Journal on Advances in Networks and Services*, 2(4), pp.261–272.