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Analysis of Node Failure on Coverage in Presence of Shadowing and Fading in Wireless Sensor Networks

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Abstract

Network Coverage in a wireless sensor network (WSN) depicts the extent of area covered by sensors. Coverage is also considered a factor responsible for Quality of service. Coverage can get affected due to multiple reasons such as low energy, limited number of nodes and node failure. Node failure happens due to various reasons such as noise and low battery power. In this paper we analyze the effect of failure of nodes on network coverage in wireless sensor networks in the presence of shadowing with edge effects and Rician fading. We find the node failure has a greater impact on fading environment than the shadowing environment with the number of nodes increasing at a rapid rate to give good coverage.

Keywords: Node failure, sensing model, network coverage, coverage degree, shadowing, edge effects, Rician Fading, wireless sensor networks

INTRODUCTION

Wireless sensor networks (WSN) consist of a number of nodes which are energy constrained positioned for monitoring events of interest in the environment. Sensor nodes collect data and transmit the data collected to a common repository node called a sink [1]. WSN have a variety of applications such as monitoring and vigilance and continue to inspire tremendous research interest in the recent years.

There are a number of nodes in a sensor network and how well each of them cover a given area is referred to as sensing coverage. Each of the nodes have a limited sensing range. An event is detected if it lies within range of at least one sensor of the sensor network.

A lot of research is going on in the area of coverage of sensor networks. The sensors can sense acoustic, radio signals and detect the target based on the signals. Katti et.al.[2] studies coverage for underwater WSN in shadowed environment based on electro magnetic waves. Tsai [3] examines the sensing coverage for wireless sensor networks in shadowed environment. Liu, et.al.[4] observes the impact of edge effect with shadowing on sensing coverage in WSN. Hossain [5] studies the effect of node failure on coverage of a WSN. The sensor nodes are susceptible to failure due to low energy levels and have an impact on the coverage of the sensor network. This paper investigates the impact of node failure on sensing coverage of a WSN in the presence of shadowing and edge effects and Rician fading environment.

SENSING MODEL

The sensing area is taken as a circle with radius R with N sensor nodes distributed in this area.

A. Shadowing Effect on Sensing Coverages

As the signals suffer different shadowing loss it makes the sensing radius of a node non uniform. R refers to average sensing radius. A sensor is deployed from a target at a distance r. The received sensing signal power can be expressed as [3]

$$P_r(r) = P_t - L(d_0) - 10\beta log_{10}\left({}^{r}/_{d_0}\right) + \gamma \qquad (1)$$

r refers to the distance between the sensor node and the target; $L(d_0)$(in decibel units) is the average propagation loss at a reference distance d_0; β denotes the signal power decay factor. The parameter γ represents the shadowing in the propagation path which is a Gaussian random variable with mean m(r)= P_t− $L(d_0)$− 10βlog10 (r/d_0) and variance σ^2. P_{det} is the probability that the target is detected by a specific node. In [3], P_{det} in shadowed environments is given as: $P_{det=}$

$$\int_0^{R_{max}} Q\left(\frac{10\beta log_{10}(r/R)}{\sigma}\right) \times \frac{2\pi r}{A} dr \qquad (2)$$

where A refers to sensing area and Q refers to Q function.

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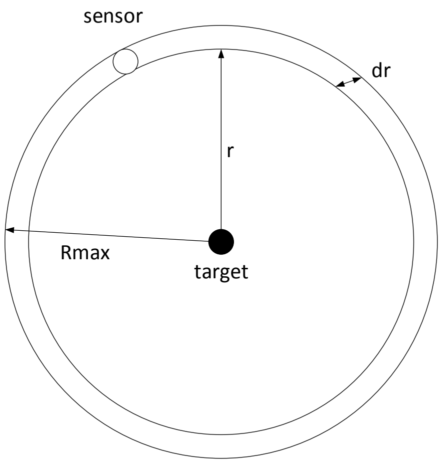

Figure 1: Sensing Model [1]

B. Edge Effect on Sensing Coverage

Contemplate a target location close to the edge of the area as shown in figure 1. The probability that a sensor node senses this target is smaller than the probability of the sensor sensing any target that is away from the edge of the area. We assume that the sensor cannot be deployed outside the sensing area. Therefore the result for detection probability obtained in (2) is marginally overestimated resulting in coverage also being marginally overestimated. This phenomenon is known as edge effect [2].

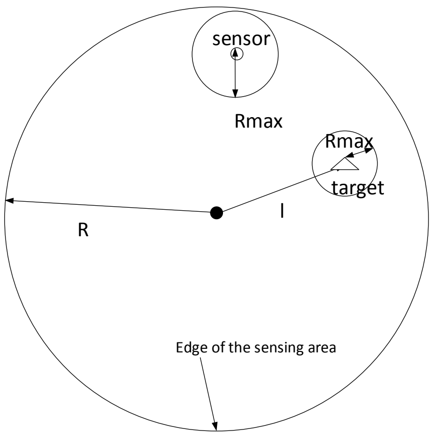

Figure 2: Edge effect on sensing coverage [3]

In the above figure the edge effect needs to be considered as the target is near the edge of the area. A node is deployed at a distance r to the target location with probability $2\pi r \times dr/A$

$$r \in \left[0, R-l\right) \; and \; 2r\left(\pi - \cos^{-1}\frac{R^2-r^2-l^2}{2lr}\right) \times dr/A \qquad (3)$$

[3]

$r \in [R-l, r_{max}]$

Where dr refers to a small difference in distance. The probability that the sensor sensed the target becomes

$$P_{det} = \int_0^{R-l} Q\left(\frac{10\beta log_{10}(r/\bar{r})}{\sigma}\right) \times \frac{2\pi r}{A} dr + \int_{R-l}^{r_{max}} Q\left(\frac{10\beta log_{10}(r/\bar{r})}{\sigma}\right) \times \frac{2r\left(\pi - \cos^{-1}\frac{R^2-r^2-l^2}{2lr}\right)}{A} dr \qquad (3)$$

$$P'_{det} = P_{det} - \int_{R-l}^{r_{max}} Q\left(\frac{10\beta log_{10}(r/\bar{r})}{\sigma}\right) \times \frac{2r\left(\pi - \cos^{-1}\frac{R^2-r^2-l^2}{2lr}\right)}{A} dr \qquad (4)$$

[3]

C. Effect of Node Failure on Sensing Coverage

The probability that a sensor can detect any event in the presence of node failure is given by P_{det} (1– Pf). P_{det} refers to the detection probability and is $\pi r^2/A$, where r is the sensing radius of a node and Pf is the probability of failure of a node. The probability that a sensor cannot detect the event is given by (1– P_{det} (1– Pf)). N is taken as the number of active nodes. Thus the coverage probability is given by [5]

$$P_c = 1 - \left(1 - P_{\det}\left(1 - P_f\right)\right)^N \qquad (5)$$

In case node failure is zero i.e. Pf = 0, the coverage probability becomes

$$P_c = 1 - (1-p)^N \qquad (6)$$

Equation (6) can be estimated as

$$P_c = 1 - exp(-Np) \quad for\; p \ll 1 \qquad (7)$$

D. Effect of Node Failure on Sensing Coverage in the Presence of Shadowing and Edge Effect

Network coverage in presence of shadowing and node failure is presented in [5]. Network coverage for shadowing with edge effect is presented in [4]. We study the effect of node failure probability in presence of shadowing with edge effect on network coverage.

Coverage probability for shadow fading model with edge effects is given by

$$P_c = 1 - \left(1 - \int_0^{R-l} Q\left(\frac{10\beta log_{10}(r/\overline{r})}{\sigma}\right) \times \frac{2\pi r}{A} dr + \int_{R-l}^{r_{max}} Q\left(\frac{10\beta log_{10}(r/\overline{r})}{\sigma}\right) \times \frac{2r\left(\pi - \cos^{-1}\frac{R^2 - r^2 - l^2}{2lr}\right)}{A} dr * (1 - P_f)\right)^N \quad (8)$$

We analyse the effect of node failure on network coverage in the presence of shadowing with edge effect for coverage degree (d) one. For coverage degree, d ≥2 the coverage probability with node failure [4] in presence of shadowing and edge effects can be expressed as

$$P_c = 1 - \left(1 - \int_0^{R-l} Q\left(\frac{10\beta log_{10}\left(\frac{r}{\overline{\overline{r}}}\right)}{\sigma}\right) \times \frac{2\pi r}{A} dr + \int_{R-l}^{r_{max}} Q\left(\frac{10\beta log_{10}\left(\frac{r}{\overline{\overline{r}}}\right)}{\sigma}\right) \times \frac{2r\left(\pi - \cos^{-1}\frac{R^2 - r^2 - l^2}{2lr}\right)}{A} dr * (1 - P_f)\right)^N - N$$
$$* \int_0^{R-l} Q\left(\frac{10\beta log_{10}(r/\overline{r})}{\sigma}\right) \times \frac{2\pi r}{A} dr + \int_{R-l}^{r_{max}} Q\left(\frac{10\beta log_{10}(r/\overline{r})}{\sigma}\right) \times \frac{2r\left(\pi - \cos^{-1}\frac{R^2 - r^2 - l^2}{2lr}\right)}{A} dr$$
$$* (1 - P_f)\left[\left(1 - \int_0^{R-l} Q\left(\frac{10\beta log_{10}\left(\frac{r}{\overline{\overline{r}}}\right)}{\sigma}\right) \times \frac{2\pi r}{A} dr + \int_{R-l}^{r_{max}} Q\left(\frac{10\beta log_{10}\left(\frac{r}{\overline{\overline{r}}}\right)}{\sigma}\right) \times \frac{2r\left(\pi - \cos^{-1}\frac{R^2 - r^2 - l^2}{2lr}\right)}{A} dr * (1 - P_f)\right)^{N-1}\right] \quad (9)$$

E. Effect of Node Failure on Sensing Coverage in presence of fading

The model considering only the shadowing effects is described by the shadowing sensing model. Rician fading refers to fading of non-specular power in the presence of a dominant, non-fluctuating multipath component described by the Rician probability distribution function [6]. Rician fading provides a close approximation of attenuation due to multipath fading in wireless channels [7].

The network coverage in presence of node failure probability for Rician fading sensing model. is given by [8] :

$$P_c = 1 - \exp\left(-\frac{N}{A}\int_0^{R_{max}} P_d(r)\, dr\right) \quad (10)$$

where

$$P_d = \frac{1}{A}\int_0^{R_{max}} P_d(r) * 2\pi r\, dr \text{ and} \quad (11)$$

$$P_d(r) = \int_0^{\infty}\int_{10\eta log_{10}\left(\frac{r}{R}\right)}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} e^{[-(x^2/2\sigma^2)]} \times \frac{y}{\sigma 1^2} e^{[-(y^2/2\sigma 1^2 + K)]I_0\left(\frac{\sqrt{2K}y}{\sigma 1}\right)} dxdy \quad (12)$$

Node failure probability for degree d =1 is given by:

$$P_c = 1 - \exp(-NP) \text{ where} \quad (13)$$

$$P = P_d(1 - P_f) \quad (14)$$

Therefore,

$$P_c = 1 - \exp(-N\frac{1}{A}\int_0^{R_{max}} (\int_0^{\infty}\int_{10\eta log_{10}\left(\frac{r}{R}\right)}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} e^{[-(x^2/2\sigma^2)]} \times \frac{y}{\sigma 1^2} e^{[-(y^2/2\sigma 1^2 + K)]I_0\left(\frac{\sqrt{2K}y}{\sigma 1}\right)} dxdy) * 2\pi r\, dr\, (1 - P_f)) \quad (15)$$

Node failure probability for degree d=2 is given by:

$$P_c = 1 - \exp(-NP) - NP(\exp(N-1)\,P) \quad (16)$$

Where

$$P = P_d(1 - P_f) \quad (17)$$

$$P_c = 1 - \exp\left(-N\left(\frac{1}{A}\int_0^{R_{max}} (\int_0^{\infty}\int_{10\eta log_{10}\left(\frac{r}{R}\right)}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} e^{[-(x^2/2\sigma^2)]} \times \frac{y}{\sigma 1^2} e^{[-(y^2/2\sigma 1^2 + K)]I_0\left(\frac{\sqrt{2K}y}{\sigma 1}\right)} dxdy) * 2\pi r\, dr\right)(1 - P_f)\right) -$$

$$N(\frac{1}{A}\int_{0}^{R_{max}}(\int_{0}^{\infty}\int_{10\eta log_{10}(\frac{r}{R})}^{\infty}\frac{1}{\sqrt{2\pi\sigma^2}}e^{[-(x^2/2\sigma^2)]}\times\frac{y}{\sigma1^2}e^{[-(y^2/2\sigma1^2+K)]I_0\left(\frac{\sqrt{2Ky}}{\sigma1}\right)}dxdy)*2\pi r\,dr)(1-$$

$$P_f)\,(\exp(N-1)\,(\frac{1}{A}\int_{0}^{R_{max}}(\int_{0}^{\infty}\int_{10\eta log_{10}(\frac{r}{R})}^{\infty}\frac{1}{\sqrt{2\pi\sigma^2}}e^{[-(x^2/2\sigma^2)]}\times\frac{y}{\sigma1^2}e^{[-(y^2/2\sigma1^2+K)]I_0\left(\frac{\sqrt{2Ky}}{\sigma1}\right)}dxdy)*2\pi r\,dr)(1-P_f)\,)$$

RESULTS AND DISCUSSION

We show the graphical results of the effect of node failure on coverage in presence of shadowing and edge effects. A circular area is assumed of radius 100 m and a sensor is assumed to have maximum sensing range of 10 m. The plot consists of Network coverage with the number of nodes with varying shadowing parameter and degree. The shadowing parameter β is taken as 2 dB. Three different values of Pf (Node failure Probability) Pf = 0, 0.4 and 0.8 are considered for network coverage.

A. Results for Coverage in the presence of Shadowing and Edge effects

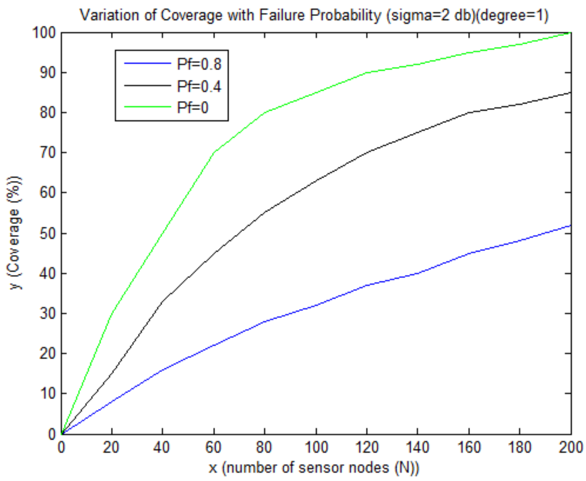

Figure 3: Coverage with Number of sensor nodes for d=1 and sigma=2 db

The Figure 3 depicts variation of coverage probability with shadowing parameter of 2 dB and degree =1. We observe in the graph the coverage probability increases with increasing number of nodes. Also, the coverage probability is maximum when node failure is zero i.e Pf=0 and keeps decreasing with increasing node failure. Coverage probability in the presence of shadowing and edge effects can be overcome by increasing the number of sensor nodes used for coverage. We observe that network coverage is about 90% for N=100 with Pf =0. This falls to around 68% for Pf=0.4 and to around 30% for Pf =0.8.Thus, the network coverage decreases by 20% for the failure of 40% nodes and by about 50% for the failure of additional 40% nodes.

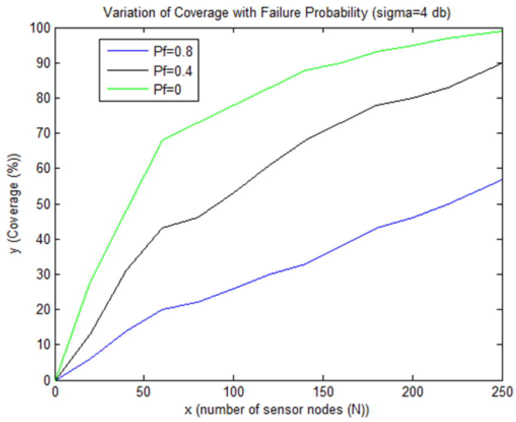

Figure 4: Coverage with no of sensor nodes sigma=4db

Fig.4 shows the network coverage with number of nodes for shadowing parameter increased at 4 db. We observe that now greater number of nodes (more than 200) are needed for achieving coverage probability of above 90%. For N=100 and Pf =0 the coverage probability is at around 80% which dropped from 90% at sigma=2 db for the same number of nodes. As Pf increases the coverage further drops. For Pf =0.4 the coverage is at 60% and further goes down to 20% for Pf =0.8. Therefore, we can say that as sigma increases the number of nodes for achieving greater network coverage also increases. Therefore, higher the shadowing greater number of nodes are required for network coverage.

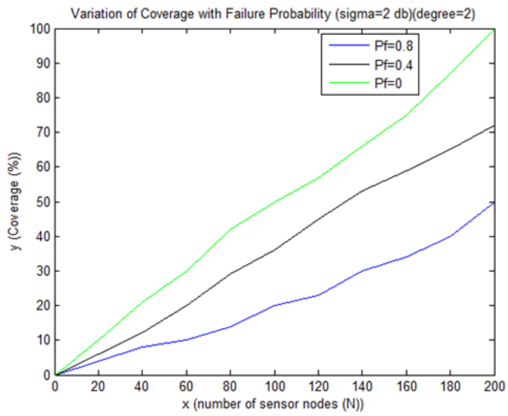

Figure 5: Coverage with no of sensor nodes sigma=2 db d=2

Fig. 5 shows the variation of network coverage with number of nodes for coverage degree, d = 2 and shadowing parameter at 2 db. The other parameters are similar as for coverage degree, d = 1. We observe that as the failure probability increases the coverage further goes down. For example at N=100 and Pf =0.4 the coverage is around 35% and further reduces to around 20% when Pf becomes 0.8. We can observe the network coverage significantly decreases with the node failure probability becoming higher. Also for the coverage becomes much less for degree=2 in comparison to degree d=1 for example, the coverage dropped from 60% for N=100 from degree =1 to 35% for N=100 for degree d=2.

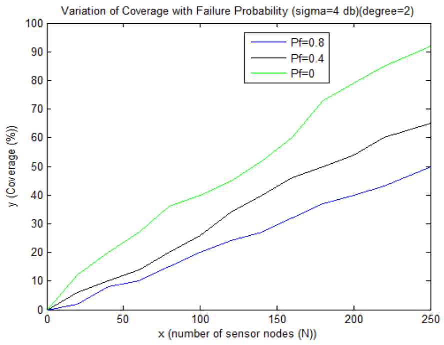

Figure 6: Coverage with no of nodes sigma=4db d=2

Fig.6 shows coverage with number of nodes with failure probability for degree d=2 and shadowing parameter at 4 db. We observe that these parameters give us the least coverage percentage and use the maximum number of nodes. For Pf =0 i.e. for no node failure the coverage probability for N=100 is around 40% which reduces to 25% for Pf =0.4 and further reduces to less than 20% for Pf =0.8. We also observe that the maximum coverage which is around 90% when Pf =0 requires 250 nodes. Although the coverage probability as found in [2] is overestimated as stated in [3] the overall effect is almost same when we consider aspect of node failure for coverage probability. Therefore, network coverage depends on shadowing and node failure and an increase in both can impact coverage adversely.

F. Results for Coverage in the presence of Rician fading

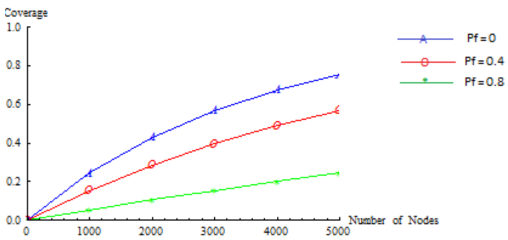

Figure 7: Coverage with No.of nodes

The above figure shows network coverage with number of nodes. Three values of *Pf* = 0, 0.4 and 0.8 are being considered for the same. We observe coverage increases with increasing number of nodes. When probability of failure is zero, *Pf* = 0, the network coverage achieves maximum value. It may also be observed from figure 7, for *N* = 5000, network coverage is about 80% when *Pf* = 0. It falls to 50% and 20% for *Pf* = 0.4 and 0.8 respectively. Thus, the coverage decrease by 30% for the failure of 40% nodes and by about 50% for the failure of another 40% nodes. Also we observe that in presence of shadowing and edge effects the number of nodes used were much less and the coverage was almost 100% for Pf=0 and at 80% for Pf=0.4 at 200 nodes whereas in case of Rician fading the number of nodes is far greater and even at Pf=0 the maximum coverage is 80% at 5000 nodes which drops to 60% for Pf=0.4 at 5000 nodes. Therefore the impact of node failure on network coverage in presence of Rician fading is much higher.

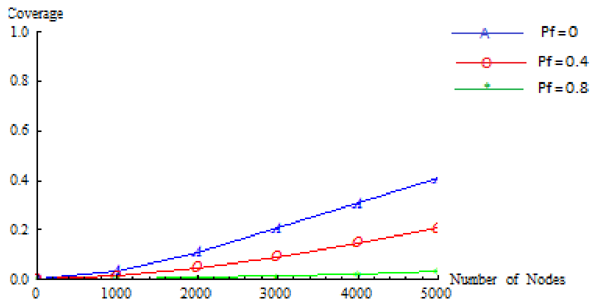

Figure 8: Coverage with No. of nodes

Fig. 8 shows the variation of network coverage for coverage degree, *d* = 2. It is observed for *N* = 5000, network coverage is 40% when *Pf* = 0. It falls to 20% and 5% for *Pf* = 0.4 and 0.8 respectively. We observe the network coverage decreases when the node failure probability becomes high. On comparing with shadowing we observe that the coverage is much less in case of Rician fading with coverage of just 20% at 5000 nodes and Pf=0.4 whereas in case of shadowing the coverage although degraded between d=1 and d=2 but settled at 70% with 200 nodes.

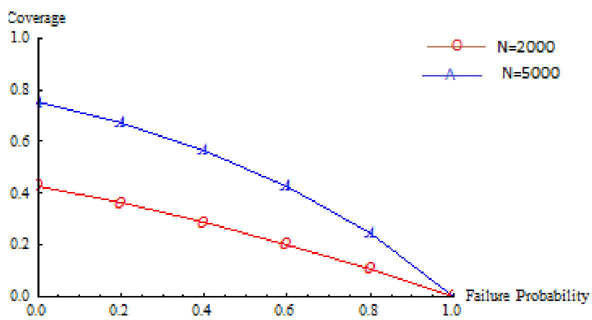

Figure 9: Coverage with Failure Probability

Fig. 9 shows the coverage (coverage degree, d =1) with probability of node failure (Pf). We observe network coverage goes down with increasing Pf and ultimately to zero for Pf =1 as all nodes become non-functional.

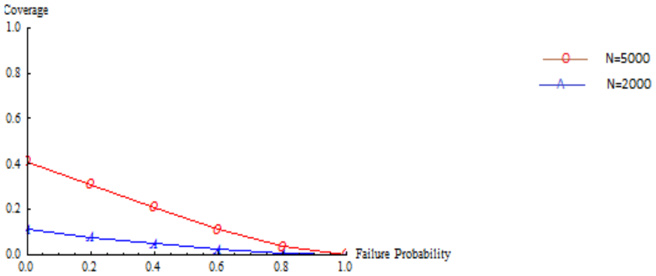

Figure 10: Coverage with Failure Probability

Fig. 10 shows coverage with failure probability for coverage degree, d = 2. We observe network coverage further decreases in comparison to degree=1 for example, for Pf=0.2 d=1 the coverage is about 70% which reduces to less than 40% for d=2. Also for less number of nodes the coverage is also very low with maximum coverage of about 10% for 2000 nodes.

CONCLUSION

In this paper, we analyze the impact of shadowing with edge effect and Rician fading on network coverage in the presence of node failure. The network coverage is reliant on sensing parameters, node failure probability and number of nodes along with the environment parameters. The decrement in network coverage in the event of node failure is greater in case of fading than shadowing requiring greater number of nodes for network coverage.

We gather the network coverage decreases due to node failure in case of shadowing as well as fading but the extent to which it decreases in fading is much more than shadowing. This indicates that node failure has a greater impact on fading than shadowing environment when network coverage is concerned. To overcome the issue of degradation of network coverage due to node failure probability, extra nodes can be deployed and target coverage considered with scheduling. This will lead to not only network lifetime maximization but also save energy.

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