CONNECTIVITY IN A SENSOR NETWORK

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ABSTRACT

In this paper, the issue of full connection probability and network efficiency using a minimum number of nodes in wireless sensor networks is addressed. The network characteristics were investigated through a number of simulations in Matlab. Using various input parameters two realistic scenarios were approximated: a football pitch, a building. It was also examined the impact of different parameters on the full connection probability (sensors scattering model, path loss model, Tx / Rx powers and observer placement). It was discovered that the environment itself, defined by its radio propagation properties, has the greatest impact on the full connection probability.

1. INTRODUCTION

There are many applications of wireless technology, with the aim to satisfy the desire of modern users to be able to communicate anytime and anywhere.

Wireless sensor networks are a particular kind of ad hoc networks, in which nodes are smart sensors. They exchange information on the environment in order to provide a global view of the monitored region. This information is made accessible to the external user through one or more gateway nodes. Sensors exchange data with their neighboring nodes periodically, in order to improve data collection and detect unusual situations.

The features of a sensor network are listed below:

1. Homogeneous network - sensor networks are composed of the same kind of sensors.
2. Stationary network - nodes composing a WSN (Wireless Sensor Network) are generally stationary, or at most slowly moving.
3. Dispersed network - generally, nodes composing a WSN are spread over a large region, so that single hop communication between nodes is not possible.
4. Large network size - typically, the number of nodes composing a WSN is from a few tens to thousands [1].

The function of the nodes is to monitor physical or environmental conditions, such as vibration, temperature, pressure, sound, motion and pollutants, at different locations. There is no pre-programmed network topology. The nodes self-organize their networks.

In the background of wireless sensor network is often mentioned data flow processing. Sensor networks produce multiple data streams of observations from their sensors. Data are coming all the time (on-line) and there is no assuming on the data sequence. Generally they are of unlimited size.

The wireless radio propagation environment presents limitations to the performance of radio communications systems. The signal between the transmitter (Tx) and the receiver (Rx) is subject to propagation phenomena, and obstacles generate attenuation of the signal power. Path loss and shadow fading, the main causes of such signal variations, are described. The path loss is the loss range of the power radiated by the Tx. The shadow fading (or shadowing), on the contrary, is caused by the presence of physical obstacles between Tx and Rx, such as buildings or parts of them that obstruct the propagation of electromagnetic waves attenuating the signal.

Nodes in wireless sensor networks exchange information through transceivers. The nodes Tx and Rx establish a radio connection only if the power of the signal received by Rx is higher than the sensitivity threshold. We can assert that $P_r \geq \beta$, where P_r is the power of the received signal and β is the sensitivity threshold. The value of β depends on both the communication data rate and the wireless transceiver features. The higher the data rate is, the higher β will be. If P_t is the power transmitted by the node u and P_r is the power received by the node v, it can be written that [1]:

$$P_r = \frac{P_t}{PL(u,v)}, \quad (1)$$

where $PL(u, v)$ is the path loss and it is assumed:

$$\frac{P_t}{PL(u,v)} \geq \beta \quad (2).$$

The study of the path loss and the shadowing are two of the main questions in wireless network design. They are consequences of phenomena such as reflection, scattering, and diffraction.

Log-normal shadowing

This model takes into consideration practical measurements showing the fact that the average value of the signal between Tx and Rx is very different from the predicted one. The measurements have shown that the value of path loss at any distance d is random and log-normally distributed [3]. This model of path loss can thus be described by the formula:

$$PL(d)\,[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10\gamma \log\left(\frac{d}{d_0}\right) + X_\sigma, \quad (3)$$

where X_σ is the zero-mean Gaussian distributed random variable with standard deviation σ, all expressed in dB, γ is path loss exponent. The log-normal distribution describes the random shadowing effects, occurring over a large number of measurement locations, which have the same distance between the Tx and Rx but different physical obstacles in the middle [3]. Therefore, it is possible to refer to this model as Log-normal shadowing, which means that the measured signal values in dB, between Tx and Rx at a specific distance d, follow the Gaussian distribution [1].

2. SIMULATIONS

The sensors, thrown onto the area, were scattered according to two probability distributions - uniform and Gaussian. In the first case, the sensors are supposed to be uniformly distributed inside the area, while in the second case they are supposed to follow the typical bivariate Gaussian bell shape distribution. The uniform distribution was chosen for the

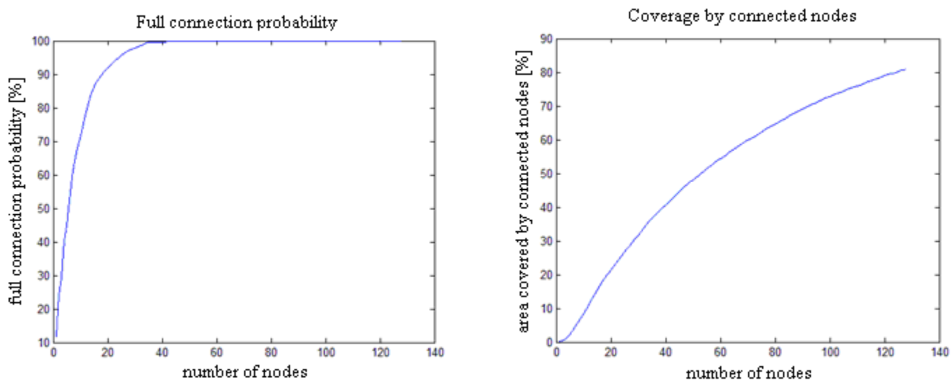
building and the tunnel, as well as in some of the outdoor simulations, and the Gaussian distribution was used in the outdoor environments.
One of the most important parameters is the sensor connectivity. It depends on two values - the transmitted power and the sensitivity. As they have the same impact on the link budget, it was decided to use them as a single parameter. In fact, increasing the transmitted power and proportionally reducing the sensor sensitivity would result in the same connectivity. The coverage area is an area around the sensor that enables collecting information on the quantity measured, and it is represented as a circular area of a certain radius. (Tab. 2.1)

Tab. 2.1 Simulation parametres for Matlab

Parameter	**Office**	**Football pitch**
Area dimensions [m]	[110 75]	[110 75]
Sensor Tx power [dBm]	-10	-10
Sensor sensitivity [dBm]	-90	-90
Path loss exponent	3.0	3.0
Path loss st. deviation [dB]	8	8
Coverage radius [m]	6	6
Sensor distribution	uniform	Gaussian

2.1. OFFICE WITH SOFT PARTITIONS

In order to run this simulation, it is necessary to set up the important variables characterizing this kind of environment. The main shadowing sources are soft and hard walls as well as people, furniture, devices, etc.
The full connection probability value increases a lot with a small number of sensors. It depends on the small path loss exponent of an office building with soft partitions. No hard divisions are able to reflect big quantities of energy. As a consequence, the approximated connectivity radius is quite high in comparison with the whole area, and just a few nodes are enough to produce a good probability of full connection.
The coverage curve is always rising and an interesting point is its shape. The first part of the curve presents a particular result. It is characterized by a positive second derivative. It is due to the fact that only the connected nodes are being considered. When the number of nodes connected to the observer is small, the coverage by connected nodes is low and the rate of the curve is slow. As the number of nodes thrown increases, the number of nodes connected to the observer rises and the full connection probability rises.
The efficiency curve is a direct consequence of the coverage curve. (Fig. 2.1)



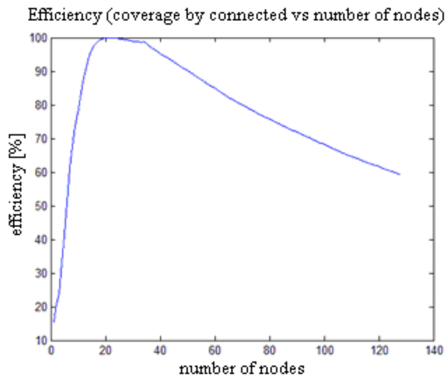


Fig. 2.1 Full connection probability, coverage and efficiency curve of the office

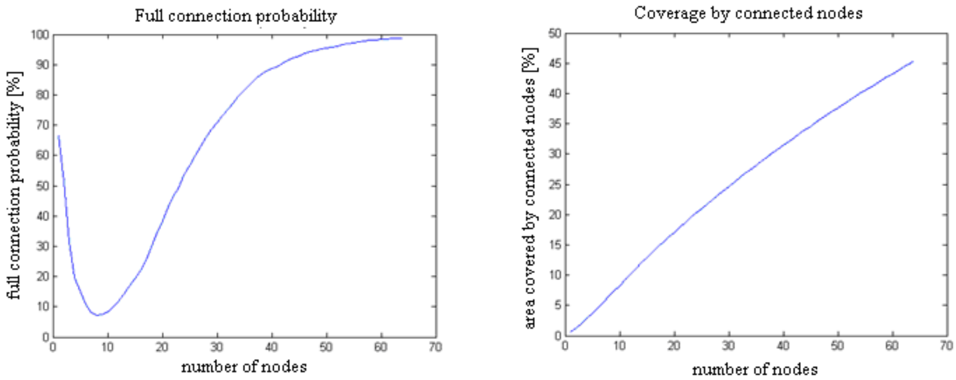
2.2. FOOTBALL PITCH

In this case, no clutter types such as buildings or foliage are considered. However, the presence of grass between transmitter and receiver must be taken into account.

For the case of perimeter observer the full connection probability curve has a negative slope with a small number of nodes because one sensor has a higher probability to be connected than several nodes have. The situation changes after dropping some extra nodes. The probability of the network to be fully connected is increasing because the average number of clusters will converge to one and the number of nodes will rise.

It can be seen that the coverage curve is almost straight line because the coverage grows slowly. It depends mostly on the small coverage radius chosen. The slope is a little less steep after a threshold around the twentieth node. After adding more nodes, the increase in area coverage gained by each additional node will be smaller.

Simulations show good results in terms of percentage of efficiency as a function of the number of nodes. The efficiency curve increases with rising number of nodes until the threshold point between the tenth and the twentieth node. After this point, no significant gain of covered area can be expected by deploying more nodes. (Fig. 2.2)



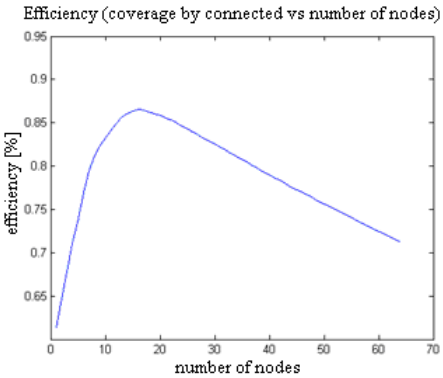


Fig. 2.2 Full connection probability, coverage and efficiency curve of the football pitch

3. CONCLUSION

We have investigated the issues of coverage and connectivity by keeping a minimum number of sensor nodes to operate in a wireless sensor network.

It can be concluded that the value of shadowing standard deviation has an important impact on the link budget. A strong influence can be noticed when comparison of two different simulations changing the model of scattering the sensors in the area. When a uniform distribution is used, the sensors are spread all over the area and a large number of clusters can be generated with a few nodes. This phenomenon can lead to a drop in the probability curve in its first part. On the other hand, using a Gaussian distribution, the sensors are concentrated around the center of the area (expected value of the Gaussian variable) and, generally, are always connected to each other.

We found out that the environment itself, defined by its radio propagation properties, has the greatest impact on the full connection probability.

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