DEPLOYMENT OF A WIRELESS SENSOR NETWORK IN A VINEYARD

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Abstract: A complete analysis for the deployment of a wireless sensor network in a vineyard is presented in this paper. First, due to the lack of propagation models for peer to peer networks in plantations, propagation experiments have been carried out to determine the propagation equations. This model was then used for planning and deploying an actual wireless sensor network. Afterwards, some sensor data are presented and finally, some general conclusions are extracted from the experiments and presented in the paper.

1 INTRODUCTION

The use of wireless sensor networks is nowadays in an exponential growing. Initially, these wireless networks were oriented for indoor use, like home automation and industrial control (Egan, 2005) or medical applications (Timmons and Scanlon, 2004). But many other applications that were not considered at the beginnings are nowadays coming to light: outdoor networks and, especially, sensor/actuator networks in rural areas, forests and plantations. The research results provided by this work consider this later environment.

A wireless sensor network is intended to be deployed in a vineyard, and the maximum distance between installed nodes is necessary to be previously estimated. Thus, some propagation studies have been conducted in order to analyse the behaviour of such specific radio channel at the frequency band assigned to these wireless networks: 2.4 GHz. Propagation studies in rural environments and plantations have to take into account the presence of vegetation in the propagation channel. Although there are several research works related to propagation at such condition (LaGrone and Chapman, 1961), (Richter, Caldeirinha, Al-Nuaimi, Seville, Rogers and Savage, 2005) and also an International Telecommunication Union - Radiocommunication Sector recommendation [ITU-R](2007), most of them are focused in classical master-slave (or base station to mobile terminal) configuration, where the base has a prominent height over the coverage area.

However, the proposed sensor application is intended to be deployed in terms of peer to peer collaborative networks where both, the transmitter and the receiver are at similar heights. And there is a lack in the scientific knowledge for such configuration (Hashemi, 2008).

Some previous work related to the deployment of a wireless sensor network (WSN) in a forest has been checked. Nükhet and Haldun (2009) showed the importance of these WSN in the forest fire propagation analysis, but a radio propagation study appears to be needed in order to optimize the deployment of these WSN. Hefeeda and Bagheri (2007) deployed a WSN in order to analyse the forest fire propagation, but no study was done regarding the radio propagation conditions in these wooded environments.

The principal aim of this paper is to provide a model to estimate the propagation behaviour in vegetation environments, and to present the results obtained in an actual wireless network deployment in a vineyard, installed using this model.

Firstly, a propagation analysis is built, in order to compute the maximum distances between nodes. Then, the environment where the WSN were deployed is presented and after that, the main elements of the WSN are showed. The following section indicates the way the network has been installed. Results regarding sensor data and network

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behaviour are presented in the fifth section. Finally, some conclusions are presented to close this paper.

2 PROPAGATION MODELLING

Before installing the wireless sensor network, it is necessary to study the maximum distance between consecutive nodes. There are some propagation studies in rural environments at 2.4 GHz. Cuiñas, Gay-Fernandez, Alejos and Sanchez (2010) presented a study on the propagation in mature forest at 2.4 GHz. Furthermore, Gay-Fernandez, Garcia, Cuiñas, Alejos, Sanchez, and Miranda-Sierra (2010) showed the main parameters to take into account when deploying a wireless sensor network. Thus, since wireless sensor nodes were going to be deployed at a mean height of 3 meters over the ground, and the vineyard grew up to 2 m, the propagation environment seems to be quite different from the ones presented by Cuiñas et. al. (2010).

Since the propagation analysis could not be performed in a vineyard due to the advanced status of the vineyard harvest, two measurement campaigns were deployed into grasslands and scrublands, in order to obtain a general propagation equation for the vineyard environment by extrapolating data from these two different ambiences.

2.1 Measurement Campaign

A separate transmitter and receiver configuration has been used during both measurement campaigns. Thus, large distances between transmitter and receiver could be accomplished in order to check how the signal strength attenuation with distance is.

The transmitter equipment consisted of a signal generator Rohde-Schwarz SMR, which fed an omnidirectional wide band antenna, Electrometrics EM-6865. A portable spectrum analyser Rohde-Schwarz FSH-6 is used at the receiver system with an omnidirectional antenna, similar to the transmitter end.

The data was collected around two different radials at each environment. Each radial consists of 25 points and 150 meters at the grassland environment, and 16 points and 32 meters at the scrubland one. The number of power samples gathered at grass and scrub lands is 301 and 3010 respectively.

Three different heights were analysed for the transmitting and receiving antennas: 0.9, 1.2 and 1.6 meters. Both antennas were placed at the same height in our analysis, in order to simulate the best conditions for a peer to peer propagation.

2.2 Propagation Model

903 power samples per frequency were collected at each one of the 50 points under measure at the grassland environment. The power samples per frequency at each point were 9030 at the scrubland environment, because there was a high time-variance of the received power.

The objective of the data processing is the analysis of the results by means of a regression to know how the power decays with distance. The attenuation of the received power seems to fit a linear equation of the form $P=P_0-n\cdot 10\cdot\log_{10}(d)$, where d is the distance between transmitter and receiver in meters, P_0 is the received power, in dBm, at 1 meter from the transmitter, P is received power, in dBm too, at a distance d from the transmitter and n is a factor that shows the rhythm of the power decay with distance.

When the previously explained regression fitting is applied to the collected samples, data from Table I and II are obtained for grassland and scrubland respectively. These tables show the attenuation factors "n_1" and "n_2", obtained for the first and second regression section respectively; the mean error produced with this estimation; and the cut-off point of the two regressions. Rows with a dash in "n_2" and "Cut-off point" columns indicate that in these cases a single regression seems to fit the data better.

Table 1: Grassland regression data.

H(m)	n_1	n_2	Error[dB]	Point[m]
0.90	1.75	4.13	1.47	22
1.20	2.07	3.55	1.20	37
1.60	2.04	3.61	1.70	85

Figures 1 and 2 show the equation fitting results at both environments. All the power values that are shown in the figures have been normalized to a transmission power of 0 dBm, in order to easily use with another transmitting power value.

Table 2: Scrubland regression data.

H(m)	n_1	n_2	Error[dB]	Point[m]
0.90	2.63	4.63	2.61	13
1.20	2.20	5.18	1.23	13
1.60	1.88	5.58	1.60	13

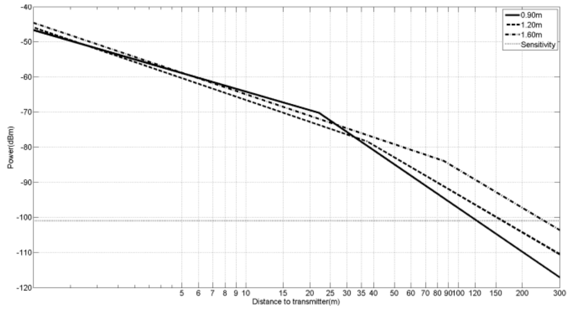

Figure 1: Propagation equations in grasslands.

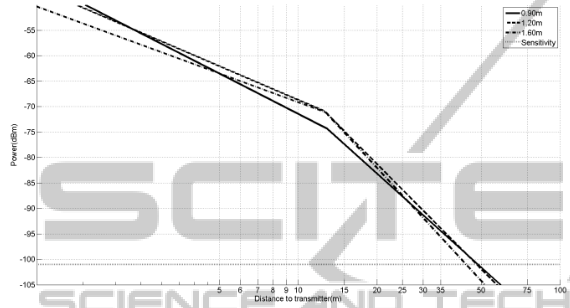

Figure 2: Propagation equations in scrublands.

2.3 Estimated Distance between Nodes

According to the eko node datasheet, the transmission power of these wireless nodes is +3 dBm and their sensitivity is -101 dBm. Thus, taking into account data from tables I and II and these power values, an estimation of the maximum distance between nodes could be done for both environments.

As indicated, figures 1 and 2 show the regression lines obtained for both environments with the aid of data from Tables I and II. Furthermore, these figures show a dotted line at -101 dBm which provides the maximum range coverage at the point it crosses with the regression lines. Table 3 shows the maximum distances between nodes for each environment and antenna height. These data have been extracted from Figures 1 and 2. Thus, when deploying the wireless sensor network, nodes should be deployed with a maximum distance of 250 m if there is line of sight (LoS) between them and at a maximum of 48 meters if there are scrubs or trees between them.

Table 3: Maximum distances between nodes.

H(m)	Grassland	Scrubland
0.90	123 m	48 m
1.20	162 m	48 m
160	254 m	44 m

The antenna heights considered for grasslands and scrublands campaign could represent the vineyard situation. There, the antennas would be higher over the ground, but the distance to the canopies would be similar at these measurements.

3 ENVIRONMENT

The selected environment to deploy this wireless sensor network is a vineyard located in a mountain side from Ribadavia, in Ourense, Spain. This vineyard is property of the winery company “Vitivinícola del Ribeiro”, a SME founded on the appellation region “Ribeiro”, in Galicia.

This terrain is located in an exclusive area just in front of the “Castrelo de Miño” reservoir. The proximity of such amount of water causes high humidity in the surrounding terrains, and because of this, and the high mean temperature, the risk of suffering a plague in the vineyard rise up to values extremely high. These are the main reasons for which this environment has been selected for this pilot experience.

4 EQUIPMENT

The Crossbow Eko pro series kit was the selected equipment for the wireless sensor network (WSN) deployment. This kit is a wireless agricultural and environmental sensing system for precision agriculture, microclimate studies and environmental research. Figure 4 depicts the main components of this WSN kit.

Figure 3: Eko pro series kit.

The Eko system can be enhanced with various sensors such as soil moisture, ambient humidity and temperature, leaf wetness, soil water content and solar radiation. All of them are going to be used in the deployment under analysis.

The main components of the WSN are showed in figure 3. There are the eko nodes, an Eko base station, and several sensors plugged into each eko node. The following sections describe each item in detail and the way they are interconnected.

4.1 Wireless Sensor Nodes

The eko nodes (Figure 3 in yellow) are a fully integrated, outdoor, solar-powered wireless sensing device that allows users to deploy a multi-point monitoring solution that provides real-time data from their environment. These nodes are capable of an outdoor range up to 2 miles depending on the environment and node hardware configuration chosen.

Each eko node can accommodate up to 4 different sensors.These nodes integrate a Memsic's IRIS processor radio board and antenna, powered by rechargeable batteries and a solar cell.

Six of these nodes were deployed in this test, each one with four different sensors plugged in.

4.2 Sensors

Crossbow (2009) contains the main features of the sensors installed in this pilot. The number of each kind of sensor in the WSN has been fixed according to the requirements of the vineyard owner.

4.3 Gateway and Base Station

The eko base station (Figure 3 in black and grey) consists of three components: the eko base radio, the eko gateway and the eko view application.

The eko gateway is an embedded sensor network gateway device. It provides an Ethernet connection where a PC can be connected to view or copy all the WSN collected data.

The eko base radio is a fully integrated packaged that provides the connection between the nodes, sensors and Gateway. The base radio integrates another IRIS processor/radio board, antenna and USB interface board. This interface is used for data transfer between the base radio and the gateway. The eko view application has not been used for this pilot, since data cannot be visualized at the gateway location.

4.4 WSN Architecture

Sensor data gathered with the aid of the WSN is going to be locally stored in a PC. Both the computer and the gateway are going to be installed in a hut to get power supply for the equipment during the pilot duration. The location of this hut is represented as a red circle in Figure 6.

The data stored in the local PC should be transmitted to a remote server at the University of Vigo. Thus, all the sensor data could be available in real time outside the vineyard.

To achieve this data transmission, a GPRS modem is needed, since there is no line of sight between the hut location and the winery building.

Figure 4 depicts the main schema of the whole system.

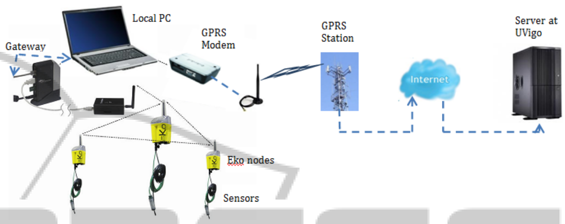

Figure 4: System Architecture.

Figure 5 shows the transmission system, composed by the eko base station and a TC-65 GPRS modem from Siemens. This modem is connected to the laptop by a RS232-serial interface.

5 NETWORK DEPLOYMENT

5.1 Nodes Location

Up to 6 eko nodes have been deployed inside the Vitivinícola's vineyard. Each one with four different sensors plugged in.

The distribution of the nodes along the vineyard has been done so each one was located in a different variety of grape, according to the vineyards owner. Thus, the correspondence between node location and varietal is shown in table 4. This table depicts also the estimated distances to the base station.

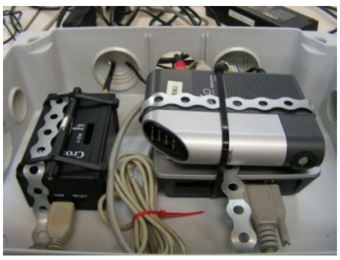

Figure 5: Transmission System.

According to the recommendations of the vineyard's owner, all the eko nodes are able to measure ambient temperature and humidity, and the same parameters for the soil. Furthermore, the leaf wetness appears to be quite important, so this sensor has been connected to each node too. Solar radiation and soil water content sensors seem to provide less important data, so they have been equally distributed within the WSN.

Table 4: Node location and environment.

Node	Grape variety	Distance to BS (m)
1	Godello	165
2	Albariño	345
3	Treixadura	80
4	Treixadura	200
5	Loureira	295
6	Godello	105

5.2 Network Behaviour

Table 5 shows the final network configuration and behaviour according to Figure 6 and the data gathered during December 2010. The second column presents the following node in the path towards the base station. These nodes are usually called "father" node. The third column indicates the distance between one node and its father. The last column shows the received signal strength indicator (RSSI) in dBm between a node and its father. These values depict that almost all the radio links between one node and its father are strong. The only one with some problems is the link between nodes 3 and 6. This link seems to have very low signal strength probably because there is a small terrain elevation between these nodes.

Table 5: Network configuration and behaviour.

Node	Father	Distance (m)	RSSI (dBm)
1	3	88.5	-77.5<P<-74.5
2	1	80	-77.5<P<-74.5
3	6	110	-86.5<P<-83.5
4	Base	156	-77.5<P<-74.5
5	4	150	-77.5<P<-74.5
6	Base	40	-77.5<P<-74.5

Figure 6: Nodes distribution.

The nodes distribution is shown in Figure 6, where eko nodes are represented as yellow circles, the base station location is shown with a red circle, and the Vitivinícola del Ribeiro central building is represented with a red square.

6 RESULTS

Figures 7 to 10 present different data gathered by the sensors of the eko nodes.

For instance, Figure 7 shows the evolution of the ambient and soil temperature, in ºC, during December, 2010. According to this data, the mean ambient temperature was 6.28ºC with a standard deviation of 4.67ºC, while the soil mean temperature was 7.26ºC with a standard deviation of only 2.63ºC.

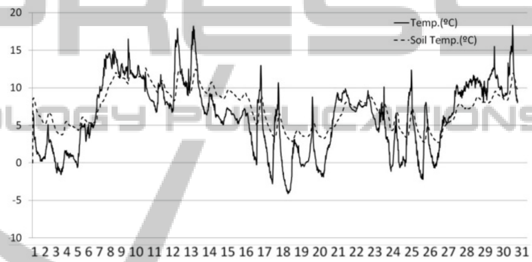

Figure 7: Ambient and soil temperature (ºC) Node 2.

Figure 8 represents the ambient humidity of node 7 during the same month. These data reveals that the mean ambient humidity is around 90% with a standard deviation of 10%.

Figure 8: Ambient Humidity (%) Node 7.

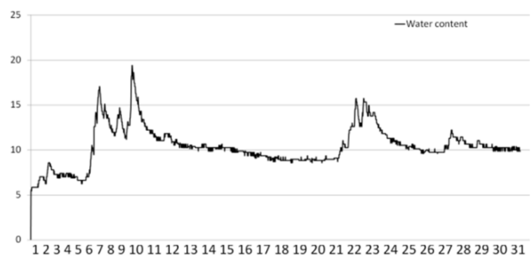

Figure 9: Soil Water Content (%) Node 7.

Figure 9 depicts the soil water content present at the node 7 location. Peaks at day 7 and 10 indicate they were rainy days, followed by a 12 days period almost without rain.

Other sensor data shows, for example, solar radiation, in Watts per square meter, present at each node location. (Figure 10).

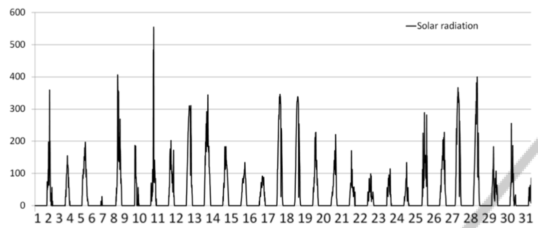

Figure 10: Solar radiation (W/m^2) Node 7.

7 CONCLUSIONS

A complete measurement campaign was developed to model the propagation channel of the links among elements of a wireless sensor network. This propagation model has been used for planning an actual installation in a vineyard close to Ribadavia, in Galicia. The Eko technology, from Memsic, has been selected for this deployment. Up to 6 eko nodes were set up into the vineyard, to cover an area of approximately 6 km2.

Four different sensors have been plugged into each eko node, to collect different ambient and soil parameters, like humidity, temperature, solar radiation, water content, etc.

With the aid of these sensor data, vineyard owners could, for instance, predict the appearance of a plague in their terrains or optimize the terrain irrigation. Furthermore, the time between sulphate applications in the vineyard could be extended. This last improvement may allow farmers to save a lot of money in material and labour, and reduce the amount of chemical products applied to the vineyard.

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