Radio-Electric Validation of an Electronic Cowbell Based on ZigBee Technology

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Abstract

The tracking of cows in large, extensive farms, as well as the possibility of checking on some veterinary data in real time, could open new business horizons for meat producers. A proposal for an electronic cowbell is presented, in order to provide an inexpensive technical solution for the exploitation of such free-running cattle. The idea is based on ZigBee technology, which a rapidly developing technology. Different rural environments have been analyzed from propagation measurements, and an estimate of the number of network nodes (or "motes") and the cost of the system is presented.

Keywords: Radio propagation; farming; attenuation measurement; tracking; vegetation; cowbell; ZigB

1. Introduction

Our modern, developed society is more and more devoted to ecologic products. Although beef meat arrived in many homes only after the generalization of intensive farming, where cows are fattened up almost statically, nowadays cows grown in extensive farms are a must. As the cows can move freely along large areas, the result is that the meat's fatty content is reduced, and its quality and flavor obviously becomes better.

However, the control of the location – and even some veterinary parameters, such as the body temperature – of the cows can be a problem in such extensive farms. This letter is intended to propose a solution to this problem, allowing the cattle to move freely but maintaining control of the safety and health of the cattle at any moment. The idea is the use of ZigBee [1] networks to provide both features: some motes [sensor nodes] of the network could be installed on trees or bushes, at fixed locations, and other motes would be placed on the cow's collars. The static motes would provide the location of the moving motes by means of triangulation algorithms. The dynamic motes (or the motes on the cows) would be equipped with temperature sensors to obtain veterinary data, and some other environmental sensors, in order to gather the living conditions of the cows.

These dynamic motes would act as electronic cowbells, because they would provide information on the status and location of the cows. In an initial stage, the electronic cowbell could be worn by the cow that leads the herd, extending the usage of the device to all the animals in successive phases. The static motes would also provide connectivity to the farmer, getting the information on the location and well-being of the cows. The data could be read by a laptop, or even a PDA device.

The success of such a system is closely related to a good wireless network design, which has to take into account the presence of vegetation in the propagation channel. The propagation aspects in peer-to-peer configurations are a key topic. There have been several research works related to propagation under such conditions [2, 3], and even a recommendation of the International Telecommunication Union – Radiocommunication Sector (ITU-R) [4]. However, most of these were focused on the classical master-slave (or base-station-to-mobile-terminal) configuration, where the base antenna was installed at 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 there is no predominant location. Although there have been some similar studies in other frequency bands [5], there is a lack of scientific knowledge for such configurations [6].

In this paper, an extensive 2.4 GHz propagation study is presented, based on six large measurement campaigns in the same number of scenarios. The attenuation factor is calculated for each environment. Based on these parameters, the range of coverage and a simple estimation of the number of motes per

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hectare are then explained. These values are needed to design wireless networks to locate cows freely moving across different environments.

2. Measurement Campaigns

Large measurement campaigns have been carried out to test the viability of the outdoor tracking system. These campaigns were developed in different kinds of forested environments, formed both by evergreen and deciduous trees, as well as in grasslands and scrublands. The aims of such campaigns were to define the maximum distance between motes that allowed their connectivity, as a function of the different vegetation in the forest spaces.

The effect of these different environments on the radio-link quality was analyzed by means of Equation (1), where p_0 is the reference power at 1 m from the transmitter, d is the distance in meters between the transmitter and receiver, and n is the factor that determines the power decay rate with the distance:

$$p = p_0 d^{-n} . \tag{1}$$

Knowledge of these parameters is necessary for planning the deployment of the ZigBee network in the required environment.

2.1 Measurement Setup

The measurements were developed using a narrowband scheme. A separate transmitter and receiver were used during the campaign, allowing large distances between both ends.

The transmitter segment consisted of a signal generator (Rohde-Schwarz SMR) connected to an omnidirectional wideband antenna (Electrometrics EM-6865). This transmitter was capable of generating pure tones at the frequency under test: 2.4 GHz. The transmitter power was fixed at 19 dBm at the signal generator's output. Due to the rural locations, far from electric supply points, the complete system was powered by an electric generator running on fuel. This allowed measurement sessions of up to seven hours with a highly stable electricity supply.

The receiver end was constructed around a portable spectrum analyzer (Rohde-Schwarz FSH-6), which was fed by a similar omnidirectional antenna. Once each tone frequency was caught, the spectrum analyzer was configured in a zero-span mode, in order to record the time series of the received power. The power supply of the analyzer was its internal batteries, allowing up to six hours of operation. This analyzer was connected to a portable laptop, to record the data collected.

The antenna heights during the campaigns were fixed at 1.5 m, which represented a typical peer-to-peer link scenario.

2.2 Measurement Procedure

The data were collected along different radials for each environment. The transmitter was placed at a fixed location within each forest, and the radials used to place the receiver were traced from this transmission point. The receiver was moved to different points situated on, or near, the radial lines. The reception points were selected using a tree as a reference in the wooded environments, and using predefined distances in the grass and scrub lands. Each radial was defined with a minimum size of 20 different points. In addition, up to 300 received power samples were recorded at each measurement point.

3. Measurement Environments

Up to six different environments were analyzed in these campaigns, all of them located near the campus of the University of Vigo. There were four kinds of forests, composed of pines, eucalyptus, and oak trees. This last environment was analyzed in two different situations: with leaves, and without leaves. Furthermore, the study included the analysis of propagation in grasslands and scrublands.

The first environment was a pine forest, mainly composed of *Pinus pinaster* trees. This pine usually reaches a height of from 20 to 35 m. The trees' canopies were irregular, open, and were present only on the top of the tree trunk. The radio propagation path was under the influence of the tree trunks, but not under the influence of their canopies.

The eucalyptus forest was basically composed of *Eucaliptus globulus*. This tree usually has a height from 30 to 55 m. The tree canopies were present only on the top of the tree trunk, so the radio propagation path was affected as in the pine forest.

The third and fourth environments were basically composed of young oak trees, from the species *Quercus robur*. They were analyzed in two different seasons: summer (trees with leaves) and winter (trees without leaves). The oak trees were from 3 to 10 m high. They presented canopies with a ball-like shape, which occupied 50% of the total height. The leaves had sizes of from 7 to 14 cm. The radio propagation path was under the influence of both the tree trunks and the canopies.

Table 1 shows the estimated tree densities for each of the forests studied.

Table 1. The tree densities for the forests studied.

Forest	Trees per Hectare
Pine	110
Eucaliptus	150
Oak tree (with leaves)	205
Oak tree (no leaves)	205

Grasslands and scrublands were the last two environments that were studied. The first was basically composed of low-height grass (lower than 25 cm), and the second was composed of scrub with a height of 1.5 m.

4. Results

More than 500,000 samples were gathered during these six measurement campaigns. This large amount of data required processing to be analyzed. This section describes the processing procedures, as well as the main results obtained for each situation.

4.1 Data Processing and Regression Fitting

Data processing was done following Equation (1). As is shown in Figure 1, a linear decay seemed to be adequate to fit the data in logarithmic units. The parameters P_0 and n of Equation (1) were estimated for each scenario, and they are summarized in Table 2.

4.2 Distance Between Adjacent Motes

The principal aim of this study was to determine the maximum distances between motes that could be reached in each environment. This distance was calculated from the required signal-to-noise ratio (SNR) and the noise power necessary to get a predefined bit-error rate (BER) or packet-error rate (PER).

As the bandwidth of a ZigBee channel is 5 MHz, we measured the noise power in a 5 MHz empty channel at 2.4 GHz. The FSH-6 spectrum analyzer [7] provided a value of -89 dBm. The measurement was made by means of the FSH channel power function, which integrated the noise-power values within our bandwidth to form the total power.

The average frame length for IEEE 802.15.4 is 22 bytes. If a packet-error rate of 2% is desired, a bit-error rate of less than 1.14×10^{-4} would be needed. The required signal-to-noise ratio would then be approximately 0 dB [8].

Based on these two parameters, range-coverage distances could be estimated for each environment. Table 3 contains the maximum and recommended distances between motes in different environments computed from the measurements, taking into account the maximum and typical transmitted powers and the sensitivity of the motes as indicated in the ZigBee standard [8], with 0 dBi-gain antennas. Although the maximum distance between motes in the oak-tree scenario changed depending on whether or not there were leaves, the recommended spacing appeared to be the same for both cases. This effect seemed to be caused by the different attenuation parameters, which was lower in the environment without leaves.

Another singular result was the difference in the maximum range coverage between the grassland and the scrubland

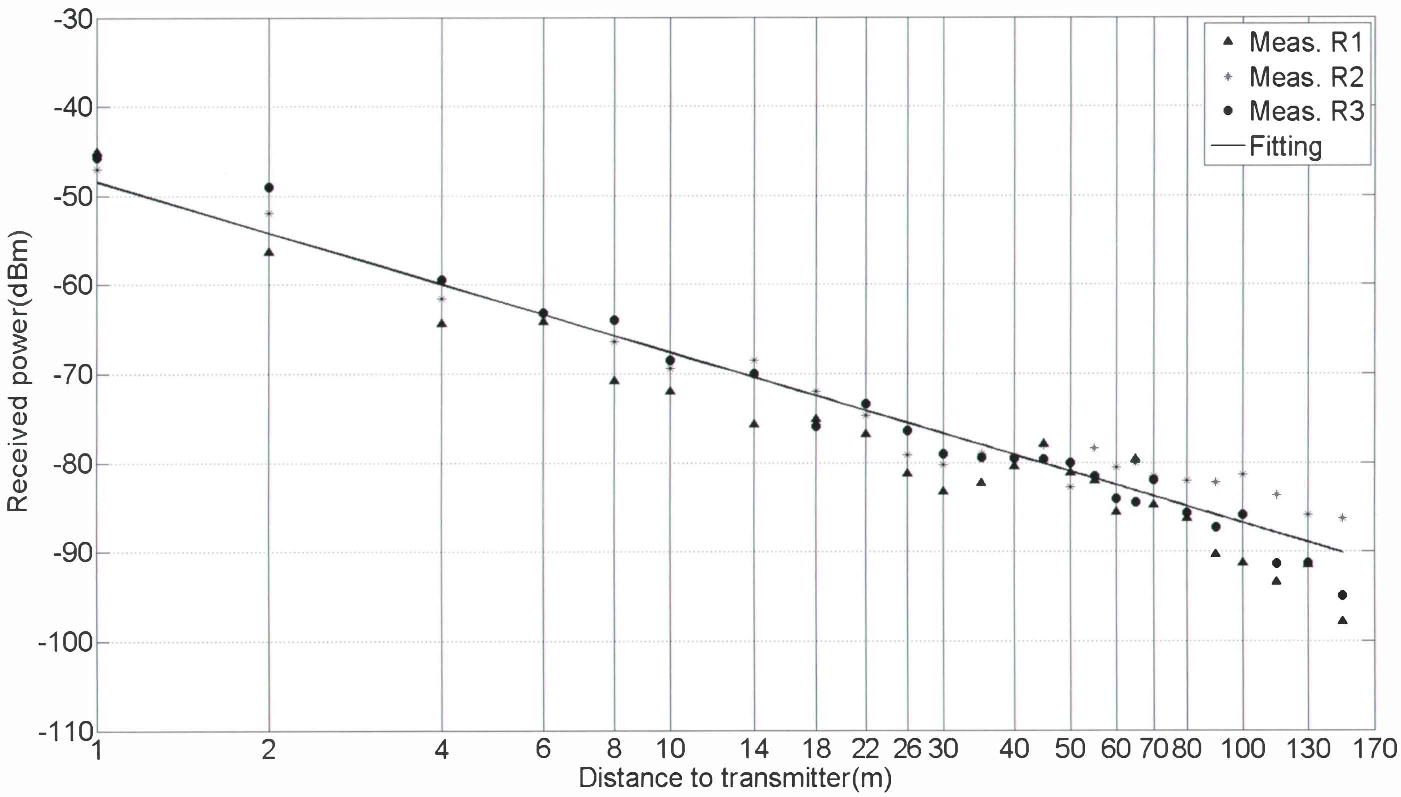

Figure 1. An example of the measured received power, and regression fitting along the three radials, for the grassland scenario at 2.4 GHz.

Table 2. P_0 and the exponent, n, for the rate of decay at 2.4 GHz.

Forest	P_0 (dBm)		n	
Pine	–44.4		2.55	
Eucalyptus	–48.7		2.06	
Oak tree (with leaves)	–42.2		2.75	
Oak tree (no leaves)	–50.7		2.15	
Grassland	–48.5		1.92	
Scrubland	$d < 16$ m	$d > 16$ m	$d < 16$ m	$d > 16$ m
	–49.3	–1.42	2.14	6.12

Table 3. The distances between motes.

Forest	Distance (m)	
	Maximum	Recommended (±5 dB)
Pine	40	25
Eucaliptus	90	52
Oak tree (with leaves)	50	35
Oak tree (no leaves)	60	35
Grassland	135	75
Scrubland	27	23

Table 4. The number of static motes needed.

Forest	Number of Motes per Hectare	
	Minimum	Recommended
Pine	6.7	16.7
Eucaliptus	1.5	4.1
Oak tree (with leaves)	4.4	8.7
Oak tree (no leaves)	3.1	8.7
Grassland	0.7	2.0
Scrubland	14.4	19.8

Table 5. An estimate of the cost per hectare (€).

Forest	Minimum Cost per Hectare	
	Year 2010	Year 2012
Pine	35	17.5
Eucaliptus	7.6	3.8
Oak tree (with leaves)	22.8	11.4
Oak tree (no leaves)	16	8
Grassland	3.6	1.8
Scrubland	75.2	37.6

environments. As shown in Table 3, the distance between adjacent motes seemed to be five times higher in grassland than in scrubland. This effect could have been caused by the high elevation of the undergrowth in the scrubland environment.

4.3 Precision of the Location

According to [9], three types of devices have been defined for this analysis: the coordinator, routers, and motes. The coordinator acts as a gateway between the ZigBee network and a PC. The routers or reference nodes are located at known positions. They have a double mission: routing messages from the network to the coordinator, and acting as reference nodes in the location algorithm. The motes or blind nodes could be called cowbells. They initiate the location algorithm, and also have the ability to sense external data such as humidity, temperature, etc.

The location algorithm was tested by using a Texas Instruments CC2430/31 kit [10, 11], which implements a standard triangle-computation algorithm. This algorithm was improved in order to take into account the height of the static motes. The original two-dimensional algorithm thus became a three-dimensional algorithm. The technique employed to locate the cows was based on that described in [12]. We reached a location precision of around 5 m, which would seem to be enough to find a cow within a forest. However, there was no doubt that the location precision depended on the spacing of the motes and their distribution.

With regard to the separation between motes, the larger the distance between the motes, the lower will be the accuracy of the location. We there have a tradeoff between the precision of the location and the number of motes needed to cover an area. The maximum number of motes (the sum of static and dynamic motes) should be less than 65536, which seems to be enough for this purpose.

Regarding the distribution of the motes, for instance, a suboptimal algorithm for deploying a wireless-sensor network was given in [13]. This kind of algorithm would appear to be very useful in grassland and scrubland environments. Nevertheless, in a forest, the motes should be placed on the trees, and the location of a tree can't be chosen.

4.4 Viability of the Proposal

The number of static motes per unit area could be estimated from the data in Table 3. These estimations are presented in Table 4, to cover one hectare of land. The computations were obtained by estimating the motes needed to cover an area of 1000 hectares, and then the mean per hectare is presented. This procedure was applied because a minimum of four motes is necessary to ensure the performance of the location algorithm, and this value could be determinant in short-range surfaces.

Currently, the cost of ZigBee motes is dramatically decreasing. A minimum total cost of 35 € per hectare can therefore be estimated for the recommended pine-forest situation. In two years, this cost is expected to be reduced by more than 50%, so the cost when installing such system could be under 18 € for each hectare. Table 5 contains the estimated cost for each situation, assuming the recommended number of motes was applied. This amount seems to be affordable by farmers if they think that perhaps the increase in the price of the meat could be around 25%, which is an estimate of the difference between meat from cattle living in stables and that from cows that are freely running.

5. Conclusion

A proposal to use ZigBee technology to help farmers in extensive cow farm situations has been presented. The idea is the use of an electronic cowbell: this means having a node on each cow within a forest to provide tracking of the location, and health parameters.

The propagation conditions were tested by means of a large measurement campaign within different rural environments. Evaluations of the ranges and required numbers of motes per unit area have also been presented. The translation from the number of motes per area unit into the effective cost was estimated. The final cost seemed to be affordable, compared to the benefits of meat from free-running cows.

6. Acknowledgements

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