

Localization in Open Fields by using RSSI on IEEE 802.15.4

Paolo Barsocchi¹, Antonio Blasco Bonito¹, Stefano Chessa^{1,2}

¹ *ISTI - CNR, via Moruzzi 1, I-56124 Pisa {Paolo.Barsocchi,Bonito}@isti.cnr.it*

² *Dipartimento di Informatica, University of Pisa, Largo Pontecorvo 3, Pisa, Italy {ste@di.unipi.it}*

Abstract- Localization of mobile, wireless devices is a problem of great practical interest as it can be used to support wireless sensor networks and pervasive computing applications. The simplest methodology to provide localization information is based on the RSSI obtained from the communications of wireless devices. We consider RSSI on IEEE 802.15.4 radios and we present the results of a measurement campaign which show that the classic model (log-normal) used to model signal strength is not accurate enough. We thus propose a two-ray propagation model that better describe the path loss attenuation, not only for unobstructed outdoor environment but also for an environment with the presence of low-position obstacles.

I. Introduction

Localization of mobile, wireless devices is a problem of great practical interest, whose applications range from localization of data sensed by wireless sensor networks (WSNs) [1] to the support of context aware applications in pervasive computing [8].

There are a number of techniques to achieve localization of wireless devices. The most immediate solution is to use a GPS receiver. However such solution is often not applicable in many applications due to GPS receivers cost, power consumption and size requirements. It may also fail to work in environments where the GPS signals is not available (e.g., indoor or if obstacles prevent reception). A cheaper (and in some cases more feasible) alternative is to approximate the real coordinate of the mobile device according to some localization algorithm where only a few *wireless anchors nodes* have GPS receivers and the mobile device uses radio-based communication protocols and connectivity information to derive its approximate position. Localization algorithms can be classified according their usage of ranging techniques to measure relative distance/position from anchor nodes. These techniques include:

- Received Signal Strength Indicator (RSSI) : the mobile device estimates its distance from a signal source on the basis of measured received power, known transmit power and a propagation power loss model;
- Time Difference of Arrival (TDoA) : the mobile device measures the difference of arrival times of two simultaneously sent messages. The two messages use different communication mediums so they have different propagation times (radio and ultrasound are commonly used [9]). This technique may suffer from non line of sight effects and requires special hardware.
- Angle of Arrival (AoA) : the devices uses antenna arrays to measure the angle of arrival of received messages. This method only provides bearing information but can nevertheless be used to help in localizing nodes. The drawback of this technique is that it requires costly, large and power demanding antennas.

Clearly the localization methodology based on RSSI is the most flexible since it does not require special hardware and can be implemented via software on many existing wireless devices.

In this paper consider localization of wireless devices based on RSSI and IEEE 802.15.4 radio [10]. This because this standard for wireless communications had been designed to implement wireless networks of sensors and actuators, and it is expected to provide support to future WSNs and pervasive computing applications. More specifically we present the outdoor rural measurement campaign conduct by using MicaZ wireless sensor nodes which use an IEEE 802.15.4 radio. Our RSSI measurements have shown that the classic model (log-normal) used for the localization purposes, is not accurate enough. We propose a model based on wireless sensor measurement (two-ray propagation model) that better describe the path loss attenuation, not only for unobstructed outdoor environment but also for an environment with the presence of low-position obstacles.

^o This paper has been supported in part under the framework of the EU FP6 RinGrid project (contract n. 31891) and Intermedia (contract n. 38419)

II. Background

We detail the differences between three propagation models for predicting the power level at the receiver, namely the two-ray propagation model (hereafter referred to as 2RM), its double regression approximation and the log-normal propagation model.

A. Exact and approximated models

Previous studies conducted over GSM radios (900 MHz) found that path loss characteristics in LOS (line of sight) environment are dominated by interferences between the direct path and the ground-reflected path, as suggested in the 2RM model (Figure 1). This model is characterised by a *break point* that separates the different properties of propagation in regions near and far from the transmitter. Before the break point (in the near region) the mean attenuation is close to the free-space path loss $1/d^2$ while after that point (in the far regions) it decreases as $1/d^4$.

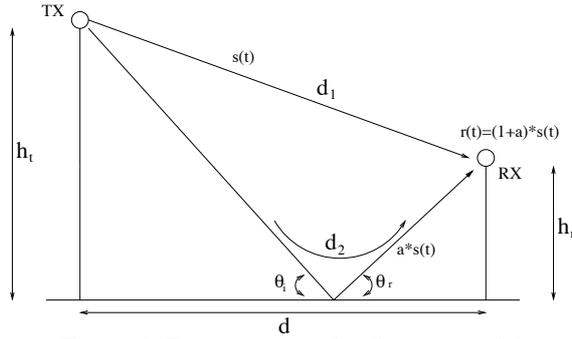


Figure 1. Two-ray ground reflection model

With the help of Figure 1, the path length difference of the two components can be computed as

$$\Delta d = d_2 - d_1 = \sqrt{d^2 + (h_t + h_r)^2} - \sqrt{d^2 + (h_t - h_r)^2} \quad (1)$$

When the distance d between transmitter and receiver is much greater than their distance from the ground, the ground reflection coefficient can be approximated with -1 [2], and the channel gain G becomes

$$G|_{dB}(d_1, d_2) = 20 \log\left(\frac{\lambda}{4\pi}\right) + 20 \log\left(\left|\frac{1}{d_1} - \frac{e^{j\theta_\Delta}}{d_2}\right|\right) \quad (2)$$

A good approximation of this behaviour is the double regression model suggested by [3], where 2RM is approximated by two slopes meeting at the break point b . The *two-ray CMU Monarch model* used in ns-2 [4] (in fact a double regression model) adopts the double regression model, with the break point set to

$$\frac{4\pi h_t h_r}{\lambda} \quad (3)$$

The double regression model approximates 2RM with a piecewise-linear function having two slopes of -20 and -40 dB/dec; however, the higher the frequency, the less this approximation is accurate.

In Figure 2 2RM and its double regression approximation are superimposed for two different signal frequencies. For a GSM frequency of 900 MHz, compatible with those considered in [3], the maximum error is 14 dB, which is the distance between the deepest dip and the -20dB/dec segment; the dip occurs at a distance of 6m, and the path loss there is the same as at 32m. In the case of wireless sensor network (WSN) at 2.4GHz, the maximum error is 24dB; the dip occurs at a distance of 16m, and the path loss there is the same as at 150m. These numbers indicate that the approximation error is more significant at WSN frequency than at GSM frequency. Moreover, the higher the frequency, the higher the number of dips, which are not modelled by the piecewise-linear double regression model.

B. Log-normal propagation model

Another popular statistical propagation model used to estimate the distance between the nodes [11] is the log-normal propagation model described as

$$\bar{P}_r[dB] = P_0[dB] - 10\alpha \cdot \text{Log}(d / d_0) \quad (4)$$

where $\bar{P}_r[dB]$ is the mean power, σ_{dB}^2 is the variance of the shadowing, $P_0[dB]$ is the received power in dB at a reference distance d_0 , d is the distance between transmitter and receiver, and α is the path-loss exponent. The path loss exponent measures the rate at which the received signal strength decreases with distance, it depends on the specific propagation environment but is generally within 2 and 4.

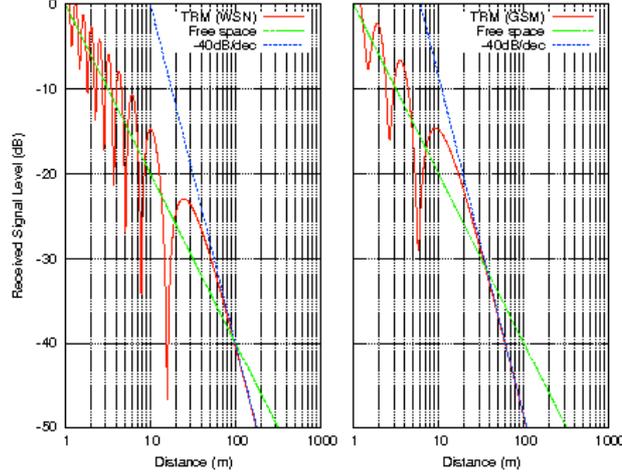


Figure 2. Comparison between 2RM at WSN and GSM frequencies for $h_t = h_r = 1\text{m}$.

III. Experimental setup

Since the literature provides little concrete information on the propagation of radio waves in rural environments, we conducted a long-running experiments with commercially-available hardware (based on IEEE 802.15.4 radios) to determine the effects of the distance between nodes and the effect of grass on wireless sensor communications. This section reviews the field layout and the hardware and software used in our experiments.

A. Field layout

We performed our outdoor rural measurement campaign using two MicaZ nodes [5] in an open field. The nodes had been placed 1 meter high and we performed the RSSI measurements in two different environments: the first without obstacles and the second in the presence of low-position obstacles (grass). The first environment was a wide uncultivated field with an unobstructed line of sight, far from buildings, cell phone antennas and power lines. In the second environment the grass height was about 0.7 metres.

B. Hardware and software

For the field test had been conducted over the MicaZ platform [5]. The MicaZ models is equipped with an IEEE 802.15.4 radio operating in the 2.4 GHz band and offering a 250 Kbps bandwidth. MicaZ offers the possibility of using an on-board antenna which makes sensors more manageable and self-contained with respect to an external whip antenna. Sensors are powered by a pair of standard AA batteries. Battery size usually determines the size of the sensor, so existing hardware is roughly a few cubic centimetres in size. The MicaZ platform supports the TinyOs operating system [6]. TinyOS is simple, lightweight, and event-based. It is written in nesC [7] and it can be considered a de-facto standard as it is widely used to implement wireless sensor network applications.

IV. Results

This section presents the results of the measurements of the RSSI as a function of the distance between a transmitter and a receiver (two MicaZ nodes) in the first field layout (subsection V.A) and we propose a new propagation model accordingly. Then we present the results obtained in the second field layout, with the presence of low-position obstacles (subsection V.B). In particular, we report the effects of the grass height in the newly proposed propagation model.

A. Propagation model without obstacles

Figure 3 shows the measured values superimposed over the *two-ray CMU Monarch model* and on the proposed 2RM. As we can see from this figure the log-normal propagation model widely used to estimate the receiver power presents some limits. Due to the receiver and the transmitter height from the ground, the break point appears at 100 meters therefore in this case (the transmission range is about 60 meters) the log-normal and the double regression models are coincident. In our case, 2RM predicts a dip at 16m: at this distance the received power, with vertical polarisation and an estimated relative permittivity ϵ_r of 5, is the same as the power received at about 150m; the error with respect to the double regression model is about 24dB at that point. This means that the connection is lost at very short distances (in the order of 15 meters) because the transmission range of the nodes is 60m corresponding to -35 dB of received signal level (receive signal threshold).

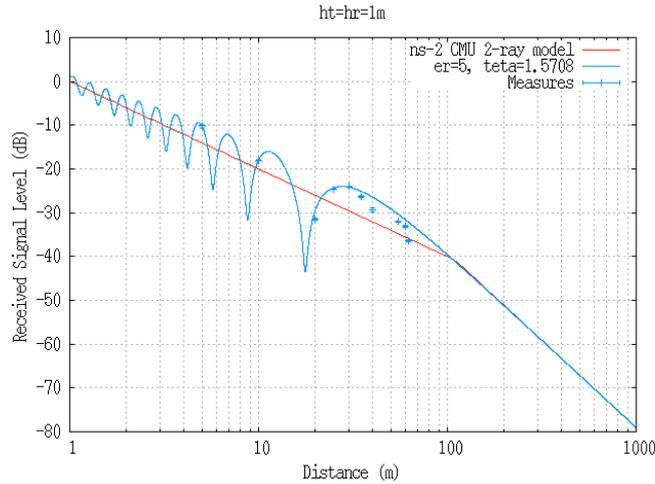


Figure 3. Measured signal level, double regression model and 2RM.

These effects are important for simulation studies targeted to either routing performance or application performance in WSNs, but are also important for the localization purpose. A transmission range reduction may be consequent to one or more different effects, such as a less sensitive receiver, a non-direct antenna orientation, a mismatch between transmitting and receiving antenna polarisation, or scattering due to obstacles very close to the transceivers. Since this can happen for both the transmitter and the receiver, one can get signal strength variations in excess of 20dB due to the horizontal radiation pattern alone. Consider however that the vertical radiation pattern would increase these numbers. As a consequence, the connection can be lost even at distance less than 15 meters in correspondence to the RSSI dips. Generally, any reduction in the transmission range makes the effect of the dip appear and break the connectivity. Furthermore, rural environment simulations for WSN should consider transceivers whose performance is generally less than the declared one, which is generally variable to keep the changing orientation into account, and that may show a dip in the transmission range at about 15m for transceivers at 1m height from the ground. Typical values for the ground relative permittivity ϵ_r are 4, 15, 25, while polarisation of the radio wave may change significantly due to reflection or scattering process [2].

B. A. Propagation model with obstacles

The proposed 2RM does not consider obstacles between the transmission point and reception point. In an actual rural propagation environment, many obstacles such as grass, trees, and wooden poles cause shadowing and reflection for the propagation paths, reducing the received levels. Here we present the

results obtained in a rural LOS environment with the presence of low-position obstacles such as grass.

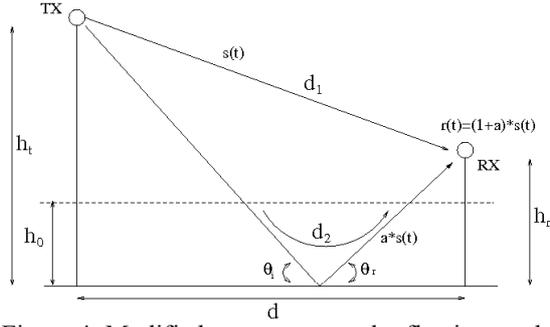


Figure 4. Modified two-ray ground reflection model

The grass height was about 0.7 metres, therefore with respect to the previous result the receive power decreases dramatically. In this case the transmission range is about 20 meters, according with the previous receive signal threshold (-35 dB). We observe that in this field layout the grass now becomes the new reflection area of the radio waves. Clearly the direct wave is not affected by the presence of grass and reaches the receiver without interferences. On the other hand, the reflected waves are reflected over the ideal plane formed by the surface of the grass (which is 0.7 meters high). Thus the reflection area is raised at the level of the grass and the effective transmitter and receiver antennas heights become lower. Therefore the propagation distance for the reflected wave is shorter, as in the formula below, than when the wave is reflected by the field (Fig. 4). Helping with Figure 4, the path length difference can be expressed by

$$\Delta d = d_2 - d_1 = \sqrt{d^2 + ((h_t - h_0) + (h_r - h_0))^2} - \sqrt{d^2 + ((h_t - h_0) - (h_r - h_0))^2} \quad (5)$$

Figure 5 shows the path loss characteristics by using, as path length difference, the equation (5), and shows the path loss to be larger, after the break point, than in the 2RM. This is because break point b moves toward the transmission node due to the effect of h_0

$$b = \frac{4\pi(h_t - h_0)(h_r - h_0)}{\lambda} \quad (6)$$

In this case the log-normal propagation model is not coincident with the double regression model because the break point is less that the transmission range.

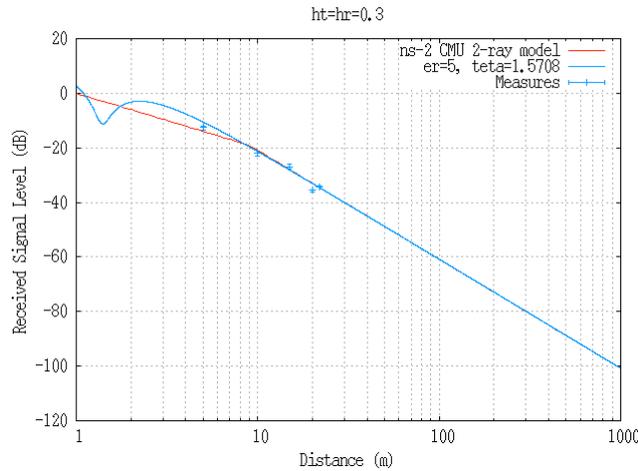


Figure 5. Measured signal level, double regression model and 2RM.

VI. Conclusions

We have presented the results of a measurement campaign conducted to evaluate the RSSI on IEEE 802.15.4 radios. We have shown that the classic model (log-normal) used to model signal strength is

not accurate enough and we have thus proposed a two-ray propagation model that better describe the path loss attenuation, not only for unobstructed outdoor environment but also for an environment with the presence of low-position obstacles. Table 1 shows the error localization position using the classical log-normal model and the proposed 2RM. Future works include the analysis of RSSI in indoor environments in presence of walls and complex obstacles.

Without obstacles		
Real distance [m]	Error position with log-normal model	Error position with 2RM
5	2	-
10	2	-
20	15	1
25	8	-
30	15	-
35	15	5
40	10	10
55	18	5
60	15	5
65	2	18
Low-position obstacles		
Real distance [m]	Error position with log-normal model	Error position with 2RM
5	1	1
10	2	-
15	8	1
20	40	5
22	28	-

Table 1. Comparison between the error position localization by using log-normal and the proposed model with the presence of low-position obstacles and not.

References

- [1] P. Baronti, P. Pillai, V. Chook, S. Chessa, A. Gotta, and Y. F. Hu, „Wireless sensor networks: a survey on the state of the art and the 802.15.4 and zigbee standards,” *Computer Communications*, 30:1655-1695, 2007
- [2] T. S. Rappaport, *Wireless Communications*, Prentice-Hall, 2th ed. Upper Saddle River, New Jersey 2002.
- [3] E. Green and M. Hata, “Microcellular propagation measurements in a urban environment,” *in proc. PIMRC*, pp. 324 – 328, Sept. 1991.
- [4] J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, and J. Jetcheva, “A performance comparison of multi-hop wireless ad hoc network routing protocols,” *in Mobile Computing and Networking*, pp. 85–97, 1998.
- [5] Crossbow Technology Inc. <http://www.xbow.com>.
- [6] J. Hill, R. Szweczyk, A. Woo, S. Hollar, D. E. Culler, and K. S. J. Pister. “System Architecture Directions for Networked Sensors”, In *Proceedings of the 9th International Conference on Architectural Support for Programming Languages and Operating Systems (ASPLOS-IX)*, pp. 93-104, Cambridge, MA, USA, November 2000.
- [7] D. Gay, P. Levis, R. von Behren, M. Welsh, E. Brewer, and D. Culler, “The nesC Language: A Holistic Approach to Networked Embedded Systems”, *Proc. ACM SIGPLAN Conference on Programming Language Design and Implementation (PLDI 2003)*, pp. 1-11, San Diego, CA, USA, June 2003.
- [8] K. Cheverst, N. Davies, K. Mitchell, A. Friday, and C. Efstathiou, Developing a context-aware electronic tourist guide: some issues and experiences, *SIGCHI conference on Human Factors in Computing Systems*, 17–24, 2000
- [9] L. Girod and D. Estrin, “Robust Range Estimation Using Acoustic and Multimodal Sensing”, *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001)*, pp. 1312- 1320, Maui, HI, USA, October-November 2001
- [10] Institute of Electrical and Electronics Engineers, Inc., “*IEEE Std. 802.15.4-2003 Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (LR-WPANs)*”, New York, IEEE Press. October 1, 2003.
- [11] N. Patwari, I. Hero, A.O., M. Perkins, N. Correal, and R. O’Dea, “Relative location estimation in wireless sensor networks,” *IEEE Transactions on Signal Processing*, vol. 51, no. 8, pp. 2137–2148, 2003.