Tunable Transmission Power to Improve 2D RSSI Based Localization Algorithm

D. Polese, L. Pazzini, A. Minotti, L. Maiolo and A. Pecora
IMM-CNR, Via del Fosso del Cavaliere 100, 00133 Roma, Italy

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Abstract: Radio frequency wireless technology is surely one of the most used technologies in indoor localization. RF-signals have been utilized in several ways to estimate the distances among the anchor nodes and the mobile nodes and, probably the methods based on the measure of the Received Signal Strength (RSS) are the most explored ones. RSS depends on the transmission medium and environment and this affects also the distance measurement performances. To mitigate the external influences, transmission parameters, as for example the transmission channel and transmission power, can be tuned. To this purpose, in this work the influence of the power transmission on the localization algorithm performance is investigated. In particular a method to select the power transmission that allows the best localization performance is presented. The results show that the localization performance depend on the transmission power. Moreover, a method to establish the best power transmission for the specific environment is presented and tested.

1 INTRODUCTION

Nowadays, localization of objects or humans in indoor environment is gaining growing interest. It is used in a huge number of applications, from the indoor navigation to the logistic, up to the environmental monitoring (Fu et al., 2009, Mainwaring et al. 2002, Vicentini et al. 2014, García-Hernández et al. 2007). These kinds of applications are generally based on radio frequency (RF) wireless technologies, even if examples of applications based on infrared and ultrasound technologies have been also developed (Randell and Muller, 2001). The RF technologies have the main advantages of a wider range of use compared to other technologies, and moreover, a direct line of sight between anchors nodes and mobile node is not required.

Although many algorithms for the evaluation of the mobile nodes position have been introduced, they can be roughly classified in angulation and lateration algorithms. The former uses the angle of arrival of the signals measured from the anchor respect to the same reference (typically the magnetic North) while the latter uses the distances from the anchor nodes. Due to simpler hardware that is required to evaluate the distance, the lateration algorithms are largely the most utilized. Whichever positioning algorithm is implemented, several methods can be used to estimate the anchor to mobile node distances: Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Received Signal Strength (RSS). Among them, mainly due to its simplicity of implementation, the measurement of the RSS has been extensively investigated.

The principal advantage of the measurements of the RSS to estimate the distances between two antennas is due to the integration of this measurement in the more recent RF transceivers. Indeed, the measurement of RSS is defined and sometimes mandatory required and standardized by the last communication protocols (IEEE 802.11-2012, IEEE 802.15.4f-2012). Moreover, another reason relies in the simple relation that connects Received Signal Strength Indicator (RSSI) and distance:

$$\mathrm{RSSI} = -10 \cdot \eta \cdot \log_{10} \mathrm{d} + \mathrm{A} \quad (1)$$

where η is the signal propagation constant, d is the distance between sender and receiver and A is the RSSI at a distance of one meter. The two parameters η and A depend on the medium and on environmental factors. Therefore, several error factors can affect the RSSI estimation as multipath, presence of barriers between source and receiving antennas, angle among them, environmental electromagnetic interferences and interferences of

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other transmitting systems.

In order to limit these problems some transmission parameters can be modified or some misbehavior can be compensated (Polese et al., 2014, Wu et al. 2012). For example the transmission frequency and power are two easily accessible and tunable parameters that could improve the localization performance.

In transmission systems, the choice of the transmission frequency depends on the analysis of the quality of the transmission channel. A largely used parameter to estimate the better transmission frequencies in presence of noise and/or interference is the Signal to Interference plus Noise Ratio (SINR) (Jeske and Ashwin, 2004, Shin et al, 2007). An estimation of this parameter allows to choose the best working frequency. On the other hand, the transmission power is generally chosen considering only the power consumption or the maximum transmission distance. However, more often, transmission power and frequency are not selected with any regards to the goodness of the distance measurements.

In this paper, we take into consideration the effect of the power transmission on the correct distance estimation. In particular, a method to estimate the best power transmission will be presented and a classical lateration algorithm will be used to compare the localization performances adopting different transmission powers to show the goodness of the method.

The remainder of this paper is organized as follows: in section 2 the method for the estimation of the best transmission power is presented. In section 3 the localization algorithm is explained. In section 4 the experimental set-up is described. In section 5 the results are shown and finally, section 6 concludes the paper.

2 HOW TO ESTIMATE THE BEST POWER TRANSMISSION

The signal between the transmitting and the receiving antenna can follow different paths in addition to the direct line of sight. Thus, the power of the signal detected by an antenna is a weighted sum of the power of the signals coming from the different directions. In indoor application, the two parts, the power carried by the reflected signals and the direct signal, can be comparable. This effect, in addition to the limit of detection of the transceivers can produce different profiles of power decay inside the close environment that are highlighted by η.

To perform a better estimation, the sensibility (D'Amico and Di Natale, 2001) of the RSSI on the distance should be maximized inside the working area. Practically, a greater sensibility allows to detect smaller variation of the antennas distance.

The sensibility can be easily calculated using equation 1:

$$\mathrm{S} = \frac{\partial \mathrm{RSSI}}{\partial \mathrm{d}} = -\frac{10}{\ln 10} \cdot \eta \cdot \frac{1}{\mathrm{d}} \tag{2}$$

and it is maximized for the power transmission that maximizes η.

However, even if each anchor independently performs the RSSI measurements and, in this way, also the estimation of the distance from the mobile node, the localization algorithm uses the whole set of distances to evaluate the position of the mobile node, so, the performances of the localization algorithm could be invalidate by the less efficient antenna. To take into account the behavior of the whole system and to estimate the best transmission power, a single parameter that considers the magnitude of the η and its variability among the different anchors has been chosen:

$$\mathrm{N} = \frac{\mu\left(\eta_i \cdot (\mathrm{A}_i - \mathrm{RSSI}_{\min})\right)}{\sigma^2\left(\eta_i \cdot (\mathrm{A}_i - \mathrm{RSSI}_{\min})\right)} \tag{3}$$

where $\mu(\cdot)$ represents the mean operation among the anchors, η_i and A_i are the signal propagation constants of the ith anchor, whereas, $\sigma(\cdot)$ represents the standard deviation operation among the anchors and finally, $RSSI_{min}$ is the minimum RSSI detectable by the transceiver. The transmission power used by the mobile node to communicate on the network that maximizes N should also improve the performance of the localization algorithm.

3 LOCALIZATION ALGORITHM

To investigate the influence of the transmission power on the localization performance a classical localization algorithm based on lateration is used to compare the localization performances as function of the mobile node transmission power.

Localization algorithm uses an optimization procedure to seek the coordinates that minimize the error between the distance measured using a signal characteristic, in our case the RSSI (R_i), and the Euclidian distances calculated with the estimated mobile node coordinates (D_i) (Zanca et al. 2008):

$$E_d = \min_x \sum_{i \in Anchors} w(i)(D_i - R_i)^2 \qquad (4)$$

It is important to note that the coordinates of the anchor nodes are known. In this case the weight *w(i)* are chosen quantized inversely proportional to the distance experimentally measured through the equation 1, i.e. each weight is taken in the set $\left\{\frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16}, \frac{1}{32}\right\}$ as they are ordered by distances R_i. In this way, each weight contributes exactly the half of the previous and the double of the next one in the Equation 4. The result of this approach is that nearer anchors contribute more in the position estimation.

4 EXPERIMENTA SET-UP

A standard office room, furnished with classical furniture as desks, cabinets and work bench is arranged with a wireless sensor network composed of 5 nodes. Inside the working space several testing points, at well-known position, have been installed. In figure 1 a schematic representation of the room is shown, it is important to note the mobile node placed on a tripod and the anchor nodes placed on the room walls.

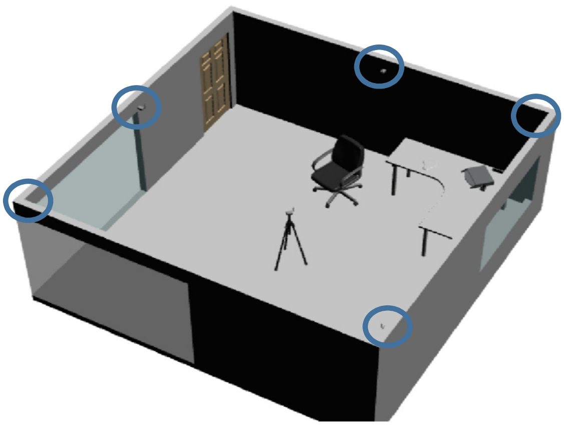

Figure 1: Schematic representation of the test room arrangement. It is possible to note the mobile node on a tripod and the anchors node attached on the walls highlighted by the circles.

The network is composed of commercial wireless sensor nodes Z1 Zolertia (Zolertia, 2013) equipped with an external pigtail antenna (see figure 2). In this experiment, only one mote acts as a mobile node, whereas the others are used as anchor nodes. The anchor nodes are disposed along the walls.

During the experiment, the mobile mote has been put in six different testing points and the RSSI values of the mobile node signal is measured by the different anchor nodes. The gateway node collects 100 RSSI values for each one of the 8 transmission power levels available on the CC2420 transceiver. The RSSI values are measured by the anchor node according to transceiver specifications. The whole set of RSSI data is sent to the PC through a USB connection.

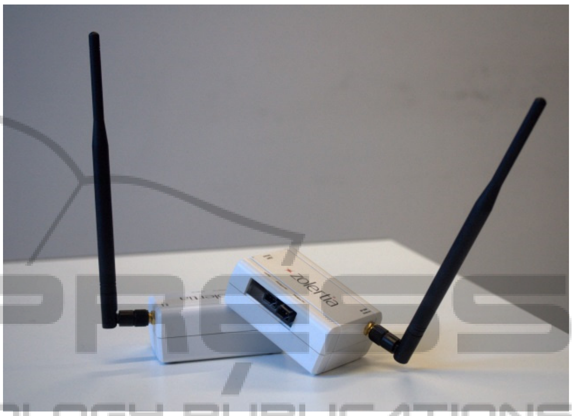

Figure 2: The two wireless sensor nodes equipped with external pigtail antenna.

5 RESULTS

5.1 Calibration

Equation 1 connects distance and RSSI measurements using two parameters that have to be evaluated in the working environment, namely A and η.

The parameter A is easily estimated using its definition i.e. the received power when the antennas are placed at 1 meter of distance. Therefore, to estimate the diverse A parameters the mean values of 100 RSSI packets measured placing the mobile node at 1 m of distance from each anchor are used.

To estimate η the mobile node is placed at different known positions and 100 RSSI packets are measured by the anchor nodes for each position. Using the equation 1, the value of η that best fits the experimental data is implemented in the following localization algorithm. The fitting has been performed in MATLAB environment.

5.2 Test Points

The mobile node is placed in six different positions inside the working area. For each position and for each power level the RSSI is measured by the anchor

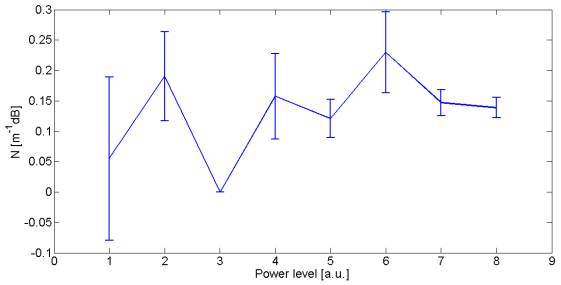

Figure 3: Variation of the parameter N for different power levels.

nodes and stored. Five of the six data sets are used to estimate the parameter η and the sixth position is used to validate the result. This kind of approach is called Leave One Out Cross Validation (LOO-CV) and it has the main advantage of allowing an estimation of the prediction error when the dataset is not very large (Hastie, 2009).

Figure 3 shows the values of the parameter N for the different eight power levels provided by the CC2420 transceiver. Since for each power level six possible calibration subsets can be used, the standard deviation showed in figure 3 takes into account the variation of the parameter N along the subsets. Finally, it is important to note that the maximum of the parameter N is obtained for the 6th power level.

5.3 Position Estimation

Following a LOO-CV approach, the position of each testing point is evaluated using the previously described localization algorithm adopting the parameters A and η estimated during the calibration procedure. Figure 4 shows the points classified using the algorithm when the transmission power is changed. The circles show an area of 0.5 m around the correct testing point where the algorithm should classify the point. It is possible to note that the performance of positioning changes accordingly with the chosen transmission power.

To evaluate the different performances of positioning as function of the transmission power, the mean error between the estimated position and the real position is reported. In the figure 5, the mean error and its standard deviation calculated on the 100 measurements performed for each position, are shown. It is possible to observe that the positioning error has different behaviors depending on the test positions. In particular, position 2 and 5, that are in opposite corners of the testing area, have a better positioning performance with an error around 0.5 m or even less for position 2. However, the figure shows that for each position there is a power transmission that minimizes the mean error.

Figure 6 summarizes the results of figure 4 showing the Root Mean Square Error Cross Validation (RMSECV) for the different transmission powers. The profile of the RMSECV shows that the

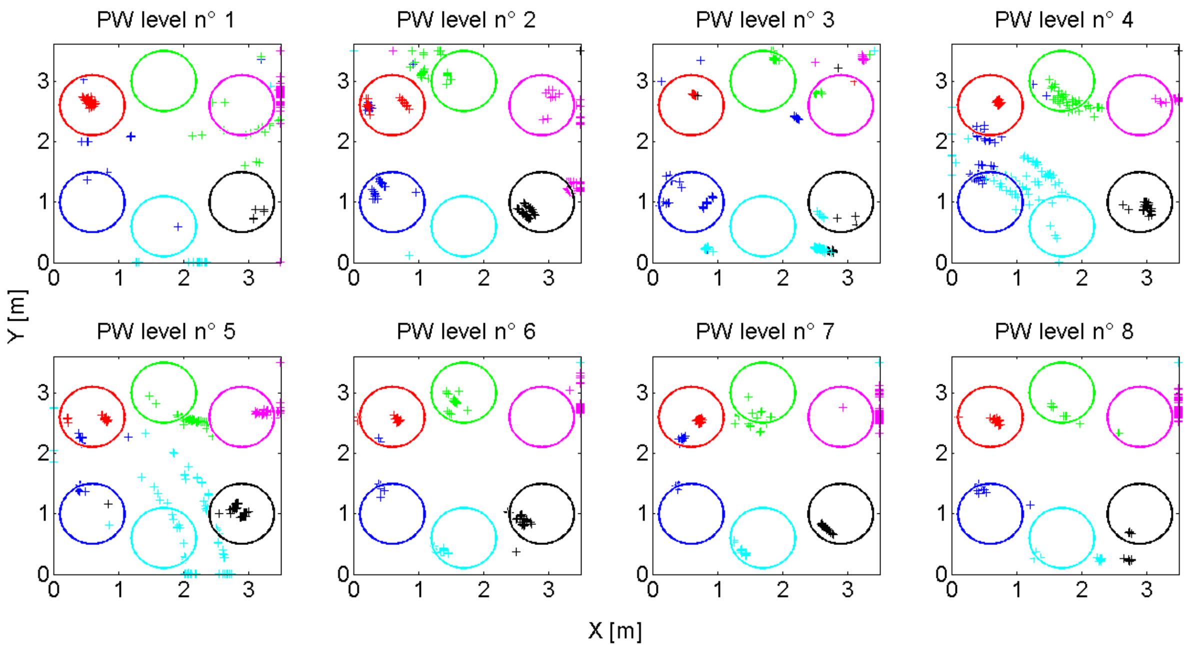

Figure 4: In the figure the point estimated using the different transmission powers are shown.

transmission power PW level 6 provides the better positioning results with a RMSECV error less than 0.5 m.

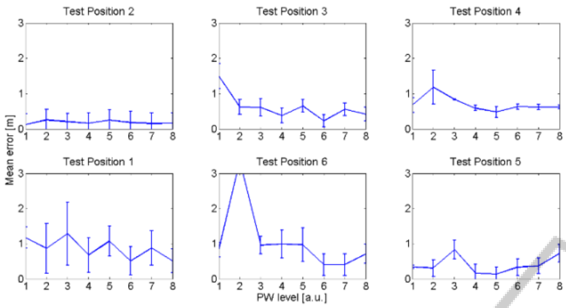

Figure 5: Mean positioning error and its standard deviation calculated on 100 measurement performed for each position are shown as function of the different power levels.

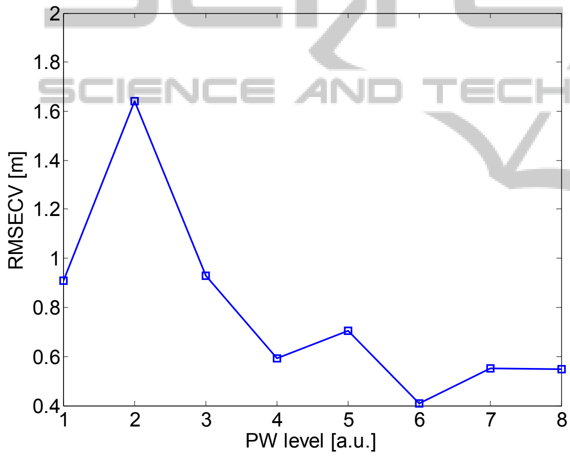

Figure 6: RMSECV for the different power levels.

Comparing the results of figure 6 with the results of figure 3 it is possible to note that the parameter N was maximized by the 6^{th} power level, as expected.

6 CONCLUSIONS

In this work the possibility to improve the indoor localization by selecting the most suitable transmission power has been investigated. In particular, a simple calibration method that takes into account also the best transmission power related to the specific indoor environment has been presented. The final results have shown that the mean error in the localization decreases almost three times respect to the worst power selection.

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