Compensation of the Antenna Polarization Misalignment in the RSSI Estimation

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Abstract: The diffusion of wireless sensor networks has allowed the development of a plethora of indoor localization algorithms based on these technologies. Also if several radio signal features have been exploited in order to estimate the position, the Received Signal Strength (RSS) is probably the most used. RSS depends, in addition to the distance, also on multipath transmission, barriers and non-idealities of antenna. Differences between ideal and real omnidirectional transmission patterns or polarization angle misalignment can strongly affect the RSS value impairing the following localization algorithm.

In this paper, an algorithm to compensate the dependence of the RSS on the angle among the antennas is proposed and tested. The experimental results prove the goodness of the approach and the possibility of using this algorithm to minimize the dependence of RSS from the tilting angle among the nodes of a localization sensor network.

1 INTRODUCTION

In recent years, the study of localization problems have gained both commercial and academic interest. Indeed, the direct use of a navigation system is today a daily experience using smartphones, tablets and car navigation systems.

Localize an object or a person means to link them to a point on a map. In order to perform this connection the distances of the object from reference points have to be known. The localization algorithms can be distinguished in outdoor and indoor localization if the localized object or person is mapped outside or inside a building respectively (Franceschini et al., 2009, Curran et al., 2011).

The outdoor localizations are generally based on satellite technologies: the most famous is probably the Global Positioning System (GPS) (Hofmann-Wellenhof et al., 1993) developed by the United States Department of Defense, but also other countries have developed similar technologies. For example, European Union has recently started to realize its own positioning system called GALILEO again based on satellite signals (Hein et al., 2000). Unfortunately the satellite technologies are limited to free space, since satellite signals cannot generally cross building walls. However, beside the satellite technologies, in the last years, thanks to the increasing spread of smartphones, diverse applications based on mobile phone signals have become accessible.

Indoor localization is generally based on radio wireless technologies, even if localization system based on Infrared and Ultrasound technologies have been also developed (Randell et al., 2001).

However, also if different radio signal features or technologies can be used, and different environments can be taken into consideration, triangulation methods are almost the only way to estimate the object position. In particular, the triangulation algorithms can be classified in lateration and angulation algorithms (Hightower et al. 2001). Lateration algorithms use the distances among the object and at least three non-collinear reference anchors to evaluate the relative position. On the other hand, angulation algorithms use three angle measurements performed on two anchors at a known distance to obtain an estimation of the relative position of the object. The angles have to be measured in respect to the same reference, for example the magnetic North. Generally, angulation algorithms need more complex hardware than

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lateration ones to measure the angle of seeing between anchors and nodes, for example an array of antennas. Lateration algorithms, instead, need simpler hardware to evaluate the distance among the nodes, since it can be based on propagation time and/or signal strength. In particular, Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Received Signal Strength (RSS) are well known signal parameters used in indoor localization (Liu et al., 2007, Patwari et al., 2005). Among these, methods based on the RSS value have gained growing interest, since RSS is probably the most accessible transmission parameter that can be used to estimate the distance between two nodes. Furthermore, to measure the RSS, the more recent RF transceivers have an integrated module that estimates the RSS, the Received Signal Strength Indication (RSSI). ZigBee protocol 802.15.4-2012 uses RSSI as indication data standardizing also the RSSI measurement (IEEE 802.15.4f™-2012). Moreover, its large use is also justified by the simple equation that connect RSSI with distance (Aamodt, 2011):

$$RSSI = -10 \cdot n \cdot \log_{10} d + A \qquad (1)$$

Where n is the signal propagation constant, d is the distance between sender and receiver and A is the RSSI at a distance of one meter. n and A are two parameters that depend on the medium and also by the angle between the antennas. The easy use of RSSI value in indoor environment is traded off with several error factors as multipath, presence of barriers between source and receiving antenna, angle among the antennas.

Even if omnidiretional antennas are used, little changing of angle between the antennas could give large variation of the RSSI value and then larger error on the measurement of the distance. These variations are produced by the not ideality of the omnidiretional antennas and by the misalignment of polarization angle.

Previous works have shown the importance of these problems in the power transmission. In particular, Wadhwa et al. (Wadhwa et al., 2009) have deeply investigated how the polarization misalignment reduces the power transmission of a wireless sensor network and they propose an algorithm to estimate the relative antenna orientation and find the low power transmission path. Whereas, Huang (Huang, 2009) has shown that it is possible to improve the localization performance also in presence of antenna polarization losses with a better estimation of the parameter n and A of equation 1.

Instead of reducing the effects of the polarization losses in the RSSI estimation, in this paper, we estimate the tilting angle between a static anchor antenna and a moving antenna by means of an accelerometer and then we use it to correct the measured RSSI value. In this way, improving the accuracy on the RSSI measurements it is possible to improve also the accuracy on the anchor to mobile node distance measurements (see equation 1), thus enhancing the localization algorithms based on lateration of RSSI signals.

The remainder of this paper is organized as follows: in section 2 the algorithm of compensation is presented. In section 3 the experimental set-up and the results are shown. Finally, section 4 concludes the paper.

2 RSSI LOSS COMPENSATION

The transmitted power between a transmit and receive antenna depends also on the polarization direction and spatial orientation. In particular, misalignment polarization angle between antennas is a well-known power loss factor that, for linearly polarized antenna, can be easily estimated. Indeed, knowing the relative misalignment angle between the antennas (ϕ), the polarization mismatch loss can be evaluate using the following equation (Kishk, 2009) :

$$RSSI\_LOSS = 20\log(\cos\phi)[dBm] \qquad (2)$$

Therefore, the real RSSI, i.e. the RSSI that should be measured without misalignment error can be estimated using the following relation:

$$RSSI_E = RSSI_M + RSSI\_LOSS \qquad (3)$$

where $RSSI_E$ is the effective RSSI and $RSSI_M$ is the measured RSSI. It is also important to point out that the RSSI_LOSS value is always negative.

In order to estimate the polarization angle between two antennas an inclinometer can be used. In presence of movements where the acceleration is much lesser than gravity acceleration, accelerometer can be used as an inclinometer sensor (Luczak et al., 2006). Inclinometer sensors based on accelerometers use the known direction of the gravity acceleration and the direction of the current gravity acceleration in its local reference system to estimate the tilting angle. Using this sensor it is possible to evaluate the tilting angle respect the vertical axis.

Figure 1 shows a schematic representation of the accelerometer, the three axis are highlighted by the reference system.

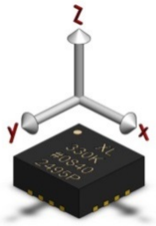

Figure 1: In figure a tri-axial accelerometer is shown.

Placing an inclinometer on a mobile antenna is possible to estimate the orientation of the antenna respect to the vertical, thus evaluating the angle between the vertical axis and the antenna axis. Furthermore, knowing also the anchor antenna orientation respect to the vertical it is possible to estimate the relative orientation of the antennas.

3 EXPERIMENTAL RESULTS

In order to verify the algorithm, two commercial wireless sensor nodes Z1 Zolertia are used (Zolertia Z1). Each node is equipped with an external omnidirectional pigtail antenna (see figure 2). In this configuration, one wireless node is used as an anchor node, while, the other wireless node is used as a moving node.

Several measurements of the RSSI have been performed at different distances and several tilting angles. During the measurements the mobile node is firmly bound to the head of a tripod that can be easily tilted in each direction (see Figure 3). At the same time the anchor node continuously acquires the data packets sent from the mobile node. The data packet has a payload composed by the three axial components of the acceleration. The RSSI value is measured by the anchor node according to CC2420 specification (CC2420). Each measurement is performed tilting continuously several times the mobile node around two perpendicular directions as figure 3 shows. Finally, acceleration and RSSI values are sent to PC in order to perform the following compensation algorithm.

The effective RSSI value is calculated using the equation 2, but limiting the maximum loss value to $RSSI_A - RSSI_M$ in order to take into consideration the non ideality of the system, i.e. the transmitted power between two orthogonal linearly polarized antennas is not zero. For each distance three repetitions are performed.

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

Figure 3: The figure shows the mote firmly bound on the head of the tripod. The two arrows show the two orthogonal rotations performed during the measurements.

In order to evaluate the goodness of the compensation, the standard deviation of the raw and corrected RSSI are compared. Moreover, the improving of the RSSI estimation is evaluated by means of the following standard deviation ratio:

$$\Sigma = \frac{\sigma(RSSI_M)}{\sigma(RSSI_E)} \tag{3}$$

Greater ratio means a better precision of the measurements. Table 1 shows, for each distance, the mean and standard deviation of the measured and corrected RSSI. In particular, the parameter Σ shows that using the compensation algorithm it is possible to increase the precision of the RSSI estimation i.e. to reduce the standard deviation of the measurements.

Table 1: In this table the mean values and standard deviation of the RSSI for several distances measurements are reported. $RSSI_M$ is the measured $RSSI$ value, $RSSI_E$ is the effective $RSSI$. $\mu(\cdot)$ is the mean and $\sigma(\cdot)$ is the standard deviation. For each distance, the standard deviations among the different measurement repetitions are also reported.

Distance [m]	1	2	4	6
μ($RSSI_M$)[dBm]	2.5931 ± 0.0918	-3.9685 ± 0.9025	-10.3634 ± 0.2591	-13.9524 ± 0.2384
σ($RSSI_M$)[dBm]	5.8428 ± 0.3043	7.0881 ± 0.1037	5.3859 ± 0.3793	4.8319 ± 0.5009
μ($RSSI_E$)[dBm]	6.4558 ± 0.1994	-0.0826 ± 0.9147	-5.9072 ± 0.6053	-10.0582 ± 0.1136
σ($RSSI_E$)[dBm]	4.5586 ± 0.4693	5.4023 ± 0.2295	5.2761 ± 0.2435	4.1028 ± 0.6833
Σ	1.2817	1.3121	1.0208	1.1777

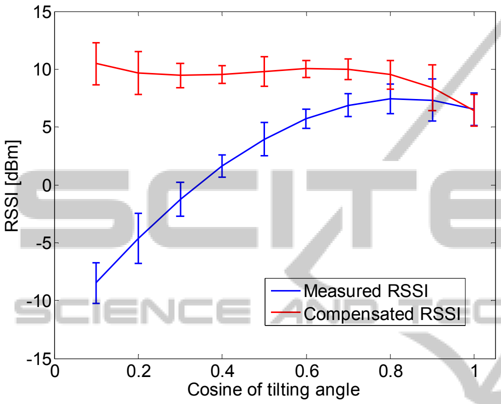

Figure 4: In the figure the mean profile of the measured RSSI is compared with the mean profile of the compensated RSSI during several tilting. The measured RSSI changes with the cosine of the tilting angle whereas the compensated RSSI is almost unchanged.

Figure 4 shows an example of a RSSI measurement when the mobile node is tilted several times. The measured RSSI changes with the cosine tilting angle whereas the compensated RSSI is almost unchanged, this means that the algorithm is able to reduce the losses due to the antenna misalignment error.

Figure 5 shows another evidence of better evaluation of the RSSI using the proposed algorithm. In this figure, the accuracy of the estimated RSSI value is evaluated sketching the differences among the RSSI.
measured when the polarization effect is negligible $(\cos(\phi) < 0.99)$, thereafter called RSSI aligned ($RSSI_A$), and the mean value of the corrected and
raw RSSI. $RSSI_A$ can be considered the correct RSSI value, since it is the RSSI value measured when the antennas are aligned. The average values of the RSSI corrected and raw are performed on the whole set of the acquired values during the measurement. In particular, the RSSI is evaluated in an almost continuous range of angle values between approximately 0 to π rad.

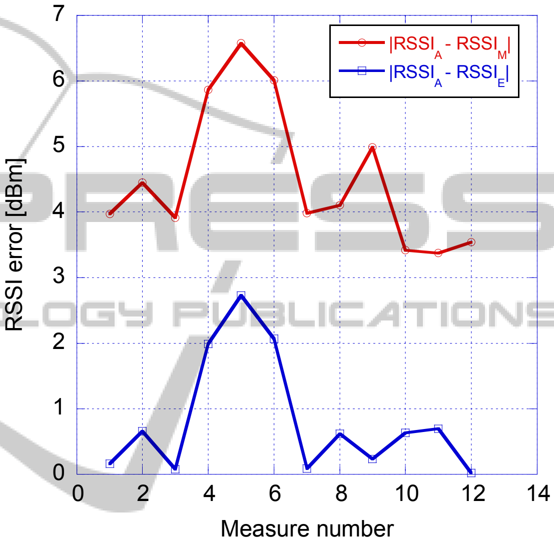

Figure 5: Absolute difference between the RSSI measured with zero angle of tilting and the mean value of the RSSI measured and corrected for all the rotations. Correcting the RSSI it is possible to reduce the mean error in the RSSI evaluation of almost 2 times.

Values near to zero of the previous difference $(RSSI_A - RSSI_E)$ mean that the compensation algorithm is able to correctly counterbalance the power loss effect depending on the antenna misalignment. It is worth of noting that this difference is always lesser than the difference with the raw values ($RSSI_A - RSSI_M$). Moreover, for the most part of the measurements this difference is lesser than one dBm whereas uncorrected difference is always greater than three dBm. These results suggest that this algorithm can potentially minimize the antenna misalignment errors.

4 CONCLUSIONS

In conclusion, a simple algorithm to reduce the effect of the tilting angle between antennas has been shown. A common accelerometer utilized as tilting sensor is exploited to estimate the RSSI loss that is used to correct the measured RSSI. In this way, the proposed algorithm can evaluate the misalignment angle between two antennas in order to compensate the transmission losses.

The algorithm has been tested using two commercial Wireless Sensor Nodes and the results have shown that it is able to reduce the dependence on the tilting angle of the RSSI at least by a factor 2.

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