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Simple and Effective Online Rssi Calibration Method in Wireless Sensor Networks Wsns

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Abstract: The Received Signal Strength Indicator (RSSI) of a radio channel provides a feasible way of estimating distance between sensor nodes. It is preferred to use this distance measurement technique because the sensor nodes do not require any additional hardware but only a radio transceiver. Both medium characteristics and node hardware consistency influences RSS measurement results. The calibration method proposed in this paper considers both these error generating factors. It is proposed an online calibration method that based on the known distance between anchor nodes adjusts the distance measurement equation by introducing a calibration factor. How the measurements are influenced by different number of iterations is also analyzed in this paper. It is proven that for an indoor WSN scenario the error is reduced between 60% and 96% after the online calibration method is applied.

Keywords: Wireless Sensor Network; Localization; Radion Signal Strentgth Indicator (RSSI) ; Radio iregularity

1. INTRODUCTION

In many wireless sensor network applications it is important to know the exact location of sensor nodes. For example, in applications like fire surveillance, precision agriculture water quality monitoring, sensing data without knowing the sensor location is meaningless (Patwari, *et al.,* 2003). When enabled with the ability to know their position, sensor nodes can support a rich set of geographically aware protocols (Akyildiz, 2002).

Sensor network localization uses inter-sensor measurements to estimate the location of sensor nodes knowing only the exact location of few nodes called anchors. Inter-sensor measurements techniques can be broadly grouped as follows: received signal strength (RSS) measurements, angle of arrival (AOA) measurements, propagation time based measurements. Received signal strength indicator (RSSI) has become a standard future in most wireless devices because RSS based localization techniques (Bahl, *et al.,* 2000, Bergamo, *et al.,* 2002, Niculescu, *et al.,* 2003) require no additional hardware and are unlikely to significantly impact local power consumptions, sensor size and thus the cost (Mao, *et al.,* 2007).

There has been a lack of comprehensive characterization of fundamental factors contributing to RSSI variability from the radio irregularity constraint of RSSI localization algorithms (Fang, *et al.,* 2010). Existing distance-estimation based techniques rely on a log-normal radio propagation model (Rappaport, 2001) to estimate inter-sensor distances from RSS measurements. The path loss exponent (PLE) is a key parameter in the log-normal model which characterizes the transmission media and accurate knowledge of this factor is required in order to obtain an accurate estimate from RSS measurements.

In a real WSN scenario a calibration method is needed to reduce the localization errors induced by RSS. These localization errors are induced by the transmission media properties and hardware device characteristics (Fang, *et al.,* 2010). The transmission media properties contain the media type, the background noise and some other environmental factors, such as the temperature, humidity, weather conditions and obstacles within the transmission media. The hardware device characteristics include the wireless communication part (the node transmitting power, receiver sensitivity) and antenna (antenna directivity and antenna gains). It is concluded in (Fang, *et al.,* 2010) that RSS can work well about the localization variability performance for specially instrumented scenarios, such an ideal open, outdoor environment, after strict selection of sensor nodes and calibration.

It is proposed in this paper an online calibration method and it is proven throughout experiments that RSSI can be used for indoor ranging measurements without a strict selection of sensor nodes or sophisticated approximation algorithms. Also how the number of iterations used for RSSI measurements influences the results is discussed. The rest of the paper is organized as follows. In section II it is presented related work for RSSI localization in WSN. Section III describes the scenario and hardware used in this paper for experiments. The ranging measurements values obtained before the calibration are also presented. The calibration method technique introduced in this paper it is presented in section IV together with the ranging measurement results obtained after the calibration. Conclusions and future work proposal are discussed in section V.

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2. LITERATURE REVIEW

Many researchers are carrying out extensive work to analyze and improve the RSSI-based localization in WSNs. (Rencheng, *et al.,* 2010 - Benkic, *et al.,* 2008). In (Rencheng, *et al.,* 2010) the results of two RSSI-based localization algorithms (Trilateration and Maximum Likelihood Estimation) in WSNs are presented. They chose an error model for the simulations based on the idea that, although the antennas of same performance parameters are used, the different antennas often show some differences in real experiments. So it can be stated that it is not sufficient to consider only the error induced by the medium when it comes to RSS measurements but also the error induced by the hardware equipment.

In (Wu, *et al.,* 2008) the effects on time domain and frequency domain on RSSI signals are studied. It is stated that multipath fading and the change in environment plays the greatest role in affecting RSSI signals. Even though the experiments were conducted under attempts to maintain a steady and unchanging environment, it is still unsuccessful in finding out the regularity of RSSI signals and repeatability. Because of this a calibration method is needed where for each sensor node different parameters are used to reduce to a minimum value the RSSI measurement error.

It is concluded in (Kumar, *et al.,* 2009) that the estimated error in distance measurements for RSSI based localization in WSN's is almost uniform under ideal conditions. In this case, using sophisticated approximation algorithm, efficient localization can be achieved through RSSI measurements. However, in a real case scenario RSSI proves not to be a good indicator of distance measurement (Benkic, *et al.,* 2008). Problems like how to interpret the RSSI values, tolerances between -4,+4, -8 and +8 dBm which are quite high deviation for distance measurements made the authors in (Benkic, *et al.,* 2008) conclude that RSSI is a bad estimator for distance measurements. In (Fang, *et al.,* 2010) the authors sustain that the main drawback of using RSSI is its instability and interference susceptibleness noticed in real environments. It is proven through simulations and experiments that RSSI measurement errors are also induced by hardware device characteristics besides transmission media properties. They propose a calibration method for RSSI measurements and it is concluded that RSSI can work well about the localization variability performance for specially instrumented scenarios, such an ideal open, outdoor environment, after strict selection of sensor nodes and calibration. The results show that RSSI calibration measurements can be successfully applied to localization in sensor networks. For the selection process the transmitted power level for each node is measured and only the ones which have the value closest to 0 dBm are selected. By doing this the error introduced by the hardware equipment is reduced. However, as it is shown in (Wu, *et al.,* 2008) the path loss exponent can't be considered constant for all the nodes so this also needs to be taken into account if the error distance measurements need to be reduced further.

In this paper it is not proposed a strict selection of sensor nodes neither an ideal scenario. The online calibration method proposed here will make possible the use of all the sensor nodes without an a priori selection. Also the online calibration method takes into account the error which appears because of the path loss exponent variation for different regions of the network. By doing this both types of errors which affect the RSSI ranking measurements are considered and it will be shown throughout experiments that the online calibration method reduces the RSSI ranging measurements errors by up to 96%. It will be also studied how choosing different number of iterations affects the ranging measurement results.

In (Di, *et al.,* 2010) the authors show that the lower bound of the expected localization error for a network is a function of the anchor density and the variance of anchor-to-sensor distance measurements. It can be stated that the lower bound of the expected localization error will be improved by reducing the anchor-to-sensor distance measurements errors with the help of the online RSSI calibration method presented in this paper. In the next chapter it is described the hardware kit used for the RSSI measurements. Also the scenario used for experiments it is presented together with the RSSI ranging measurements results.

3. MATERIAL AND METHODS

Experimetanl Setup and Ranging Measurement Results

The Jennic JN-514x series IEEE 802.15.4 transceiver **(Fig. 1),** including ZigBee PRO is an ultra low power, low cost wireless microcontroller operating in the 2.4GHz ISM band (Zheng 2010). It uses direct sequence spread spectrum (DSSS) with each symbol mapped to a 32-chip PN sequence. Each 32-chip sequence represents a data symbol and therefore the chip rate (RC) is 32 times the symbol rate (of 62.5kSps), and the symbol duration (1/symbol rate=16μs). A built-in 'ranging engine' based on RT-ToF calculates the propagation time of a RF signal between two nodes. Anisotropy is a common and non-negligible phenomenon in wireless networks caused by different factors such as, antenna type, antenna gain, and environment dependant path loss (Rappaport, 2002). In the age of compact devices, a light weight, small-sized and inexpensive antenna plays an important role to

overcome the realistic concerns of external mounted antennas. There are many situations in which small size is important (particular in hand-held equipment). There are two different variants of Jennic's wireless modules: modules with an integrated antenna and modules with an external antenna. Experimental results discussed in this paper are based on the Jennic wireless modules with an integrated antenna. The JN-514x modules with integrated antenna are based on a folded-monopole, Omni-directional characteristic (IEEE 802.15.4, 2010). In order to optimize the received power, static and approximately aligned configuration is considered between nodes.



Fig. 1. Jennic Kit - JN-514x series

For the RSSI ranging measurements an indoor scenario is considered as depicted in Figure 2. The indoor experiments were performed in an office of 4m by 8 m with a floor to ceiling height of 3m. Two sensor nodes were placed in line of sight and the distance between them was varied from 1m to 6m with a resolution of 1m. In the Jennic kit only the RSSI look up table and path los exponent can be changed. There is no access to modify other parameters which are used in the ranging measurement equation. The purpose of the calibration method presented in this paper is to make possible the use of the hardware without any priori set up. Because of this, for the experiments carried out the path los exponent and RSSI look up table are not changed. The values for these are the ones recommended and provided by Jennic. The RSSI ranging option was used to measure the distance between the sensor nodes. The indoor scenario is depicted in Figure 2. The number of iterations used was changed between 20, 100, 150, and 255 for each distance measurement. 255 iterations is the maximum that can be chosen because of the registry hardware limitations which is on 8 bits register. How the number of iterations influences the RSSI results is also studied in this paper. For each set of iterations 10 sets of measurements are made. The experiments are repeated several times with different sensor nodes in order to validate the results.



Fig. 2 Example of a figure caption. (figure caption)

In **(Table I)** the average ranging measured values obtained for the above described scenario are presented (together with the nes obtained after the calibration fucntion which is decribed in section IV). It can be noticed that for each set of iterations different results are obtained. It was expected to obtain the smallest error for the measured distance when the number of iterations is maximum (255) but this is contradicted by the obtained results. How the number of iterations inlfuences the hardware equipement for the RSSI measurements needs to be further studied but it was proven throughout experiments that this has a big influence for the obtained results. The measured values for the distance between 1m and 5m are depicted in **(Fig. 3 to Fig. 7)**.

Table 1 Indoor Ranging Measured values

RSSI Indoor Measurements			
No. of Iterations	*Average of 10 measurements (m)*		*Real distance(m)*
	Before Calibration	*After Calibration*	
20	3.66	1.98	1
100	1.84	1.05	
150	1.69	0.88	
255	2.67	1.05	
20	4.51	2.59	2
100	4.1	2.20	
150	4.78	2.66	
255	4.9	2.97	
20	3.66	2.95	3
100	4.83	2.99	
150	7.91	4.18	
255	5.17	3.09	
20	6.95	3.87	4
100	8.72	4.60	
150	8.74	4.63	
255	7.67		
20	7.89	4.97	5
100	9.13	6.01	
150	8.45	6.46	
255	9.4	5.72	

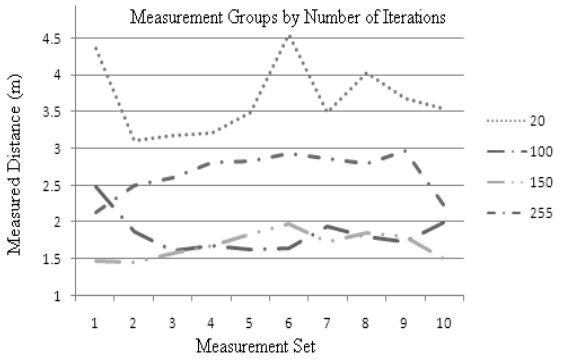


Fig. 3 Ranging measurements for 1m distance

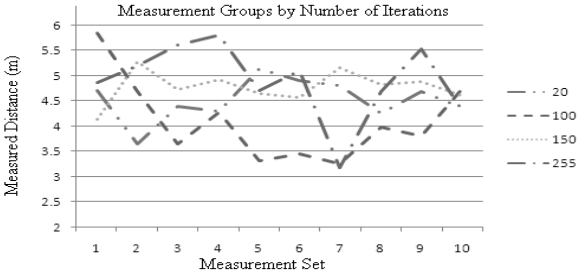


Fig. 4 Ranging measurements for 2m distance

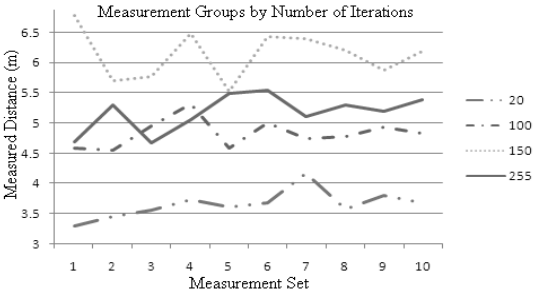


Fig. 5 Ranging measurements for 3m distance

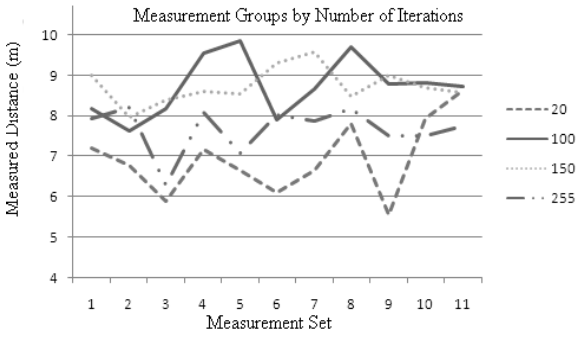


Fig. 6 Ranging measurements for 4m distance

From these measurements it can be cocnluded that the values obtained for different group of iterations follows a different trend for every case. For the 1m scenario the best results are obtained when 150 iterations are used, 100 iterations for 2m, 20 iterations for 3m, 20 iterations for 4m, and 20 iterations for 5m. By chosing a small number of iterations will lead to less power consumption and less time needed for ranging measurements and thus localization

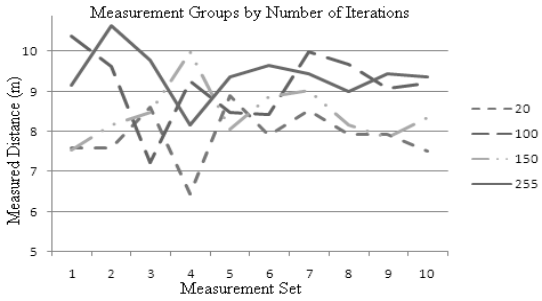


Fig. 7 Ranging measurements for 5m distance

In the next section it is expalined how the distance between two sensor nodes is calculated based on the RSSI factor. The online calibration method it is described and the results obtained after the calibration are presented.

Calibration Method Technique

Jennic kit uses Eq. 1 for measuring the distance between two sensor nodes based on the RSSI factor. In this equation the following terms are explained:

- d = the distance between two sensor nodes (m)
- RSSI = Received Signal Strength Indicator (dB)
- Ptx = nominal transmit power level of the anchor (dBm)

$$d = 0.02x10^{(108-RSSI+P_{TX})/20} \quad (1)$$

It can be noticed that the measured distance can be repsresented through Eq. 2 (distance calibration equation), where:

- d_m = measured distance
- d = real distance
- ε = error induced by both hardware iregularity and medium (referinta de mai devreme) = calibration factor

$$d_m = 0.02x10^{(108-RSSI+P_{TX}+\varepsilon)/20} \quad (2)$$

Based on Eq. 1 and Eq. 2 it can be stated that the calibration factor will have the following equation:

$$\varepsilon = 20\log\frac{d}{0.02} - 108 + RSSI \quad (3)$$

Table 2 Calibration Factor Values

RSSI Indoor Measurements		
No. of Iterations	*Calibration Factor*	*Real distance(m)*
20	-10.825	1
100	-4.445	
150	-2.57	
255	-6.58	
20	-5.15	2
100	-4	
150	-6.53	

RSSI Indoor Measurements		
No. of Iterations	*Calibration Factor*	*Real distance(m)*
255	-3.9	
20	-1.8547	3
100	-3.66	
150	-5.93	
255	-3.819	
20	-2.845	4
100	-6.11	
150	-5.74	
255	-3.915	
20	-4.3	5
100	-5.1694	
150	-5.13	
255	-5.43	

If the distance between two anchor nodes is considered as known and also the tramsmited power level by each anchor (set to 0 dBm as it is specified in Jennic documentation) then the calibration factor can be calculated using Eq. 3. Based on the distance measured values presented in Table I and Eq.3 the results obtained for ε are presented in Table 2. These values are then used for a new set of measurements were Eq. 2 is used to calculate the distance instead of Eq. 1.

The measured values (average of 10 measurements) obtained for the distance after the calibration are presented in **(Table 2).** It can be observed that after the calibration method the measured distance improved significally by up to 96%. The ranging measurements obtained for each set of iterations are presented in **(Fig. 8 to Fig. 12)**.

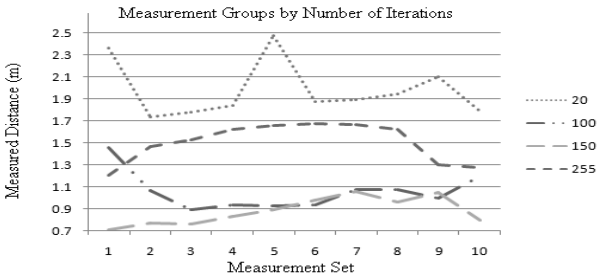


Fig. 8 Ranging measurements after calibration for 1m

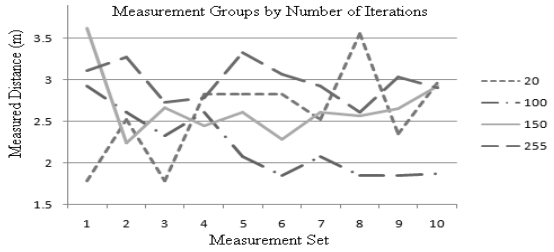


Fig. 9 Ranging measurements after calibration for 2m

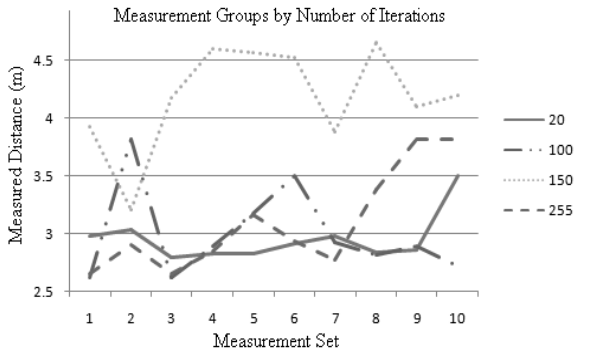


Fig. 10. Ranging measurements afer calibration for 3m

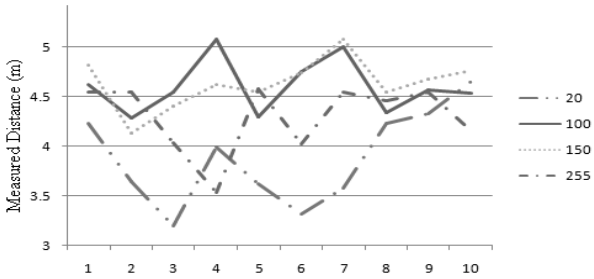


Fig. 11. Ranging measurements after calibration for 4m

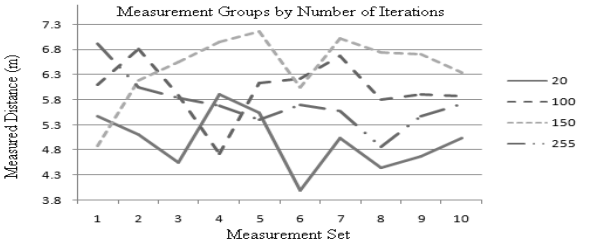


Fig. 12. Ranging measurements after calibration for 5m

In this section an online calibration technique for RSSI ranging measurements was proposed. It was proven through experiments that the error is reduced by up to 96%. It was also shown that the number of iterations chosen for the ranging measurements plays an important role but how this happens needs to be further studided. Conclusions and future work proposal are stated in the next section.

4. CONCLUSIONS AND FUTURE WORK

Ranging measurements based on RSSI technique for an indoor WSN scenario were coudcted in this paper. A calibration equatin based on the RSSI factor and known distance between anchor nodes was proposed. The calibration factor was calculated and a calibration equation was used for new ranging measurements. The results show an improvement by up to 96% for the ranging estimates when the calibration function is used. The calibration function can be used online for an indoor scenario without any a priori hardware setup or sensor nodes selection. It was also studied how different number of iterations influences the ranging measurement results. It was shown that,

instead of the expectations, the best results are not obtanined for the highest number of iterations case. Why this happens needs to be further studied.

Future work is carried out in developing a matehmatical model for the WSN scenario which, based on given limit for the ranging (localization) error, it can choose to use a specifc number of iterations. This is needed because different applications have different requirements when it comes to error localization so using less iterations for the ranging measurements can lead to less power consumption and can reduce the calculation time.

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