Antenna Radiation Pattern Influence on the Localization Accuracy in Wireless Sensor Networks

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Abstract—**Localization or position determination is one of the most common applications for the wireless sensor networks. Many investigations have been made during the last decade, most of the effort being concentrated in the direction of improving the accuracy of the positioning results by using complex filtering and correction algorithms, and other techniques such as radio maps or directive antennas for the reference nodes. The most common sources of errors include reflections on nearby objects, radio frequency noise, and variable characteristics of the communication channel. In the vast majority of cases, several assumptions have been made in order to simplify the computing algorithms or the complexity of nodes, and finally their cost. The omnidirectional radiation pattern of the node antennas is such an assumption. In this paper we investigate theoretically and validate by measurements the influence of the radiation pattern on the localization accuracy of a wireless sensor node network. By taking into consideration the orientation of nodes, which could be provided by a local digital compass on each node, we demonstrate that the position accuracy could be improved with a minimum of resources. All measurements were made in radio emissions controlled environment - a semi-anechoic chamber, without affecting the generality of the proposed solution.**

Index Terms—**wireless sensor node, radiation pattern, positioning accuracy, error correction, received signal strength indicator**

I. INTRODUCTION

Determining the location of nodes is one key application of Wireless Sensor Networks (WSN), for both civil and military use. The accuracy of such systems has been extensively studied in recent years, the main sources of errors being identified and analyzed in open space test-beds and in controlled or even isolated environments. Most of the problems are generated by the propagation medium, especially by the interferences with other devices operating in the same frequency spectrum band. A significant contribution to reduced localization accuracy has the propagation channel fading, as the received signal strength fluctuates due to multipath propagation, the presence of obstacles and shadowing, reflections and scattering [1].

Specially designed antennas, filtering algorithms and other techniques have been developed and proposed in order to increase the localization accuracy [2-5]. More complex solutions include pattern recognition techniques and are also

an alternative [3].

Some of the correction techniques may be implemented in nodes, while the others have to be at the control computer level. As the sensor nodes are essentially battery powered, the lifetime of a node being crucial in all practical cases, complex algorithms in nodes are not the best solution. Also, adding electronics components such as GPS receivers is impossible. Every piece of hardware or software added to a sensor node reduces its working period, and hence the need to be carefully evaluated from this perspective.

Generally, even every node has an omnidirectional antenna, but the measurements on the radiation pattern indicate the radiation pattern is far from a circular form. Even so, in almost all cases presented in the literature, the nodes are assumed to have an ideal omnidirectional radiation pattern [6-18].

Previous works dealing with the subject propose some solutions to correct this by modifying the node PCB layout or even by using multiple or directional antennas [4, 12]. Based on this observation, we made a series of measurements in order to evaluate the real influence of the radiation pattern characteristics on distance determination.

Instead of trying to correct the radiation pattern, we propose a way to take into account the real measured values in all future determinations and correct the ranging values considering the previously measured values.

II. LOCATION DETERMINATION

The first step for determining the location of a node is to find the distances between the respective node, assumed to be mobile, and some other nodes, assumed to be fixed. This is the so-called ranging phase. There are two methods for measuring the distance, based on the received signal strength or on the propagation time measurement. Measuring the received signal strength RSSI (Received Signal Strength Indicator) is one of the most commonly used methods.

The formula of the RSSI includes factors like: the propagation constant or propagation exponent, and the received signal at a distance of 1 meter:

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

where:

n = propagation constant or propagation exponent and depends on the propagation environment;
d = distance between the sender and the receiver;

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A = received signal at a distance of 1 meter between the nodes.

Most applications require 2D location of objects, while 3D information may be useful in some special cases. Trilateration may be used to determine the position of a mobile node if the distances to other three fixed nodes, considered as reference nodes, are known (Fig. 1).
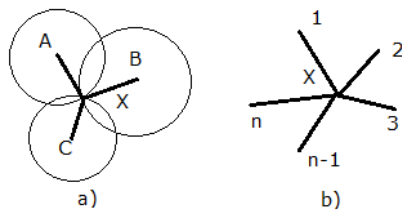

Figure 1. Distance range based localization a) Trilateration and b) Multipateration

Multilateration implies more references nodes and may reduce the mobile node position uncertainty, depending on the accuracy of the distances measurement.

III. TEST SETUP AND RANGE MEASUREMENTS

We used for range measurements a setup made of a fixed control node and a mobile node, the mobile node being at a constant distance from the fixed control node and rotating 360 degrees on its own axis.
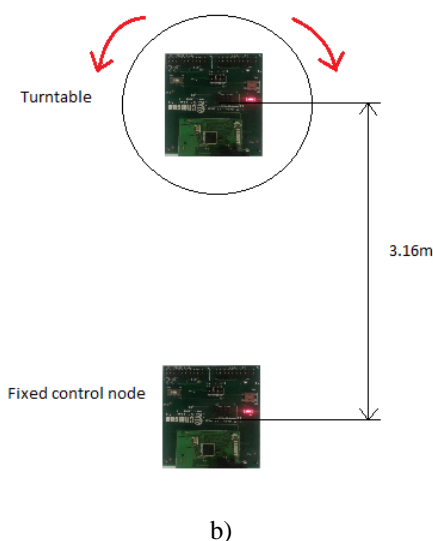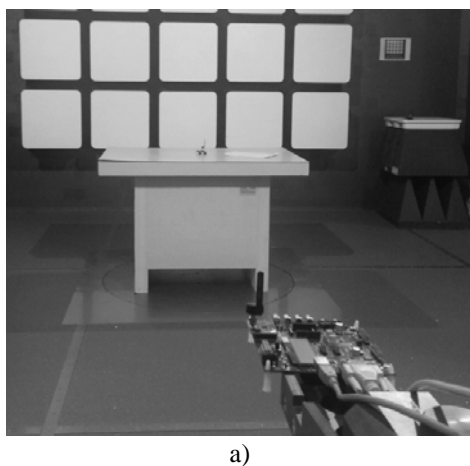

a)

b)

Figure 2. The test setup in the anechoic chamber with the mobile node on the turntable and the fixed control node on the mast

The nodes are equipped with CC2431 from Texas Instruments and placed into an isolated environment made of a 3m test distance semi-anechoic chamber. The mobile node on the turntable has been maintained at a fixed distance of about 3 meters from the fixed node and rotated 360 degrees on a horizontal plane, at about 0.8 meters above the ground.
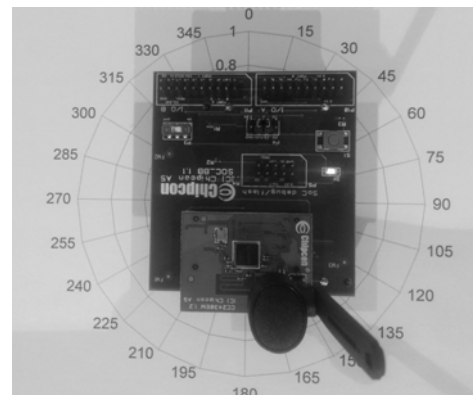

Figure 3. One of the mobile sensor nodes used for radiation patterns measurements

The RSSI signal calculated at the fixed node has been recorded for each 15 degrees of turntable rotation (Fig. 4).

Figure 4. The RSSI pattern for one node (black) and the theoretical RSSI calculated from the distance between nodes

The calculated distances from the determined RSSI values are graphically represented in Fig. 5:

Figure 5. The real calculated distance from the RSSI measurements (black) and the real distance (grey)

As one may observe in Fig. 6, the differences between the real distance and the calculated ones based on the measured RSSI are, for some angles, affected by considerable errors.

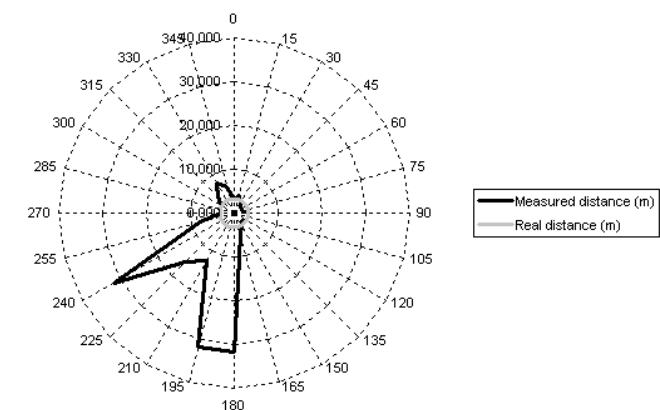| Angle	Measured	Practical	Difference	Calculated Distance	Real Distance	%err
0,00	-44	-44	0	3,162	3,162	0,00
15,00	-45	-44	-1	3,981	3,162	-25,90
30,00	-43	-44	1	2,512	3,162	20,56
45,00	-42	-44	2	1,995	3,162	36,90
60,00	-42	-44	2	1,995	3,162	36,90
75,00	-41	-44	3	1,585	3,162	49,88
90,00	-44	-44	0	3,162	3,162	0,00
105,00	-44	-44	0	3,162	3,162	0,00
120,00	-44	-44	0	3,162	3,162	0,00
135,00	-43	-44	1	2,512	3,162	20,56
150,00	-44	-44	0	3,162	3,162	0,00
165,00	-46	-44	-2	5,012	3,162	-58,49
180,00	-54	-44	-10	31,623	3,162	-900,00
195,00	-54	-44	-10	31,623	3,162	-900,00
210,00	-50	-44	-6	12,589	3,162	-298,11
225,00	-51	-44	-7	15,849	3,162	-401,19
240,00	-54	-44	-10	31,623	3,162	-900,00
255,00	-48	-44	-4	7,943	3,162	-151,19
270,00	-44	-44	0	3,162	3,162	0,00
285,00	-44	-44	0	3,162	3,162	0,00
300,00	-44	-44	0	3,162	3,162	0,00
315,00	-46	-44	-2	5,012	3,162	-58,49
330,00	-48	-44	-4	7,943	3,162	-151,19
345,00	-47	-44	-3	6,310	3,162	-99,53

Figure 6. The values of the measured RSSI, calculated distances and the differences between them and the real values (Angle is in degrees, Measured, practical and Difference are in dBm, Calculated Distance and Real Distance are in meters)

From the table in Fig. 6, we may extract the value of the $RSSI_{Correction}$ value as:

$$RSSI_{Correction} = RSSI_{Measured} - RSSI_{Practical} \qquad (2)$$

and use it in future range measurement.

Most of WSN sensor nodes have a 1/4 wavelength antenna (including the ones in our experiment), mounted on the same board as the electronics. The radiation pattern is the same as of a 1/2 wavelength dipole antenna with an omnidirectional radiation pattern. Due to the presence of the electronics on the electronics board, the radiation pattern is distorted, meaning the transmitted and received power is not the same for all board orientations. Even for identical nodes, with the same hardware components, PCB layout and antennas, the radiation patterns are not the same, differences of 5dBm to 15dBm being common, as in Fig. 7:
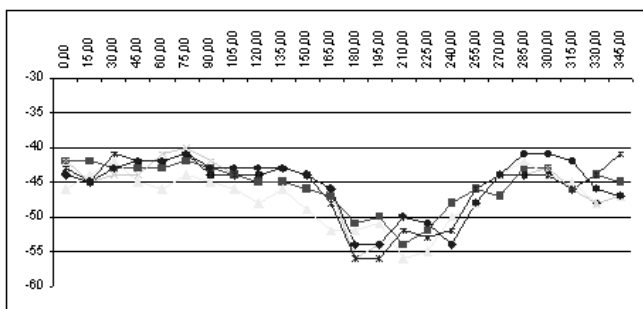

Figure 7. The RSSI values received for different six nodes, each of them being successively placed at a fixed distance from the measuring node and rotated 360 degrees

A relevant source of errors is the polarization mismatch due to misalignment of antennas. For all measurements, the sensor nodes were placed on the same horizontal plane, with their antennas kept in a vertical position. In a future investigation one may consider this as another source of errors.

IV. RADIATION PATTERN ERROR CORRECTION

As the node antenna radiation pattern is not circular, for the one-dimensional case and only for distance determination, a very simple idea is to measure the antenna characteristics and the differences between the measured values and the theoretical ones stored in a file, at the central network computing node of the WSN network. This may be done for all network nodes, in standard and repeatable technical conditions. For future measurements, the recorded errors could be used for correcting the measured RSSI values.

$$RSSI_{Corrected} = RSSI_{Measured} - RSSI_{Correction} \qquad (3)$$

$RSSI_{Corrected}$ being used for calculating the distance. An example for one node may be seen in Fig. 8. The "Correction" column contains the error information, taken the initial measurement of the node, from Fig. 6.

Angle	Measured	Practical	Correction	Calculated Distance	Real Distance	%err
0,00	-44	-44	0	3,162	3,162	0,00
15,00	-45	-44	-1	3,162	3,162	0,00
30,00	-44	-44	1	3,981	3,162	-25,90
45,00	-42	-44	2	3,162	3,162	0,00
60,00	-42	-44	2	3,162	3,162	0,00
75,00	-41	-44	3	3,162	3,162	0,00
90,00	-44	-44	0	3,162	3,162	0,00
105,00	-45	-44	0	3,981	3,162	-25,90
120,00	-44	-44	0	3,162	3,162	0,00
135,00	-43	-44	1	3,162	3,162	0,00
150,00	-44	-44	0	3,162	3,162	0,00
165,00	-47	-44	-2	3,981	3,162	-25,90
180,00	-54	-44	-10	3,162	3,162	0,00
195,00	-55	-44	-10	3,981	3,162	-25,90
210,00	-51	-44	-6	3,981	3,162	-25,90
225,00	-53	-44	-7	5,012	3,162	-58,49
240,00	-54	-44	-10	3,162	3,162	0,00
255,00	-49	-44	-4	3,981	3,162	-25,90
270,00	-44	-44	0	3,162	3,162	0,00
285,00	-45	-44	0	3,981	3,162	-25,90
300,00	-44	-44	0	3,162	3,162	0,00
315,00	-46	-44	-2	3,162	3,162	0,00
330,00	-48	-44	-4	3,162	3,162	0,00
345,00	-47	-44	-3	3,162	3,162	0,00

Figure 8. The values of the measured RSSI, calculated distances and the differences between them and the real values (Angle is in degrees, Measured, Practical and Correction are in dBm, Calculated Distance and Real Distance are in meters)

The graphical representation of the corrected distance, based on the values in Fig. 8 may be seen bellow:
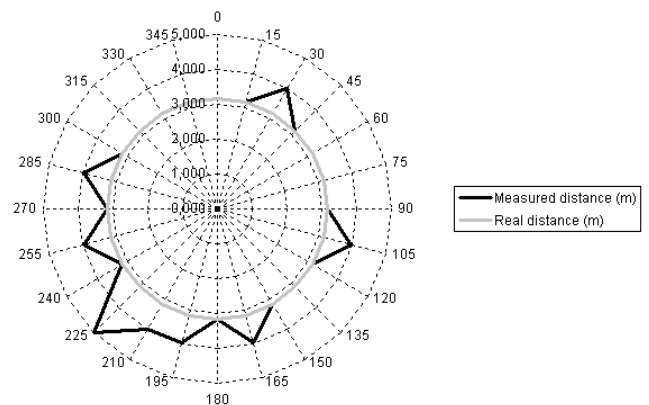

Figure 8. The real calculated distance from the RSSI measurements (black) and the real distance (grey)

Even the measurement setup was the same, the calculated distance from the RSSI level is more accurate than the uncorrected one.

In real applications, in order to make use of this error correcting information, each node has to know its relative orientation. The simplest way to do this is to integrate a compass sensor on each node, and the angle information

relative to the North-South be transmitted to the central node.

An integrated compass sensor that suits our scope is the HMC6052 from Honeywell [19]. The power consumption of the sensor and the auxiliary circuitry is around 15mA in continuous operation mode. However, the sensor may be powered only for a few milliseconds for each individual measurement, the overall WSN node autonomy being insignificantly affected. In terms of accuracy, the HMC6052 is able to deliver angle information as voltage, the microcontroller's ADC accuracy being the main limitation. It uses three digital output lines and two analog inputs for interfacing with the node's microcontroller. For a one degree resolution, sufficient for any WSN practical application, a 10 bit conversion is enough.

V. Future Work

In order to take full advantage of the method presented in this paper, it is mandatory to characterize completely the node antenna, in 3D. Even for 2D localization projects, the radiation pattern may influence the initial ranging operation, and thus affect the precision of the system if the nodes are not all of them in the same plane. Other sensors may need to be integrated on the node in order to measure the angle of inclination of the node plane relative to the ground.

VI. Conclusion

Based on observations, confirmed by extensive practical measurements, the antenna radiation pattern is not the same for all WSN network nodes, even if they are identical from the point of view of mechanical and electrical configurations. We demonstrated that the range error could be reduced if a correction factor is taken into account for every node. The characteristics of each individual node may be determined just after it was produced and before supplied to end users, the same way the antenna factor for professional antennas is measured, recorded and delivered in a so-called calibration certificate. By considering the radiation pattern irregularities, the error in the distance computed from the RSSI could be easily reduced by 15 to 95%. In order for the sensor network to make use of the correction factor of nodes, each node must be supplementary equipped with an electronic compass, thus increasing the manufacturing cost and the power consumption by a very small percent.

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