Localization Techniques in Wireless Sensor Networks using Measurement of Received Signal Strength Indicator

M. Srbinovska, V. Dimcev, C. Gavrovski and Z. Kokolanski

Abstract—**The presented paper describes different localization techniques in wireless sensor networks (WSN) and corresponding localization algorithms. Correct location is required for many WSN applications, but it is often too expensive to include GPS adapters in each sensor node. Instead of requiring every node to have GPS installed, all localization methods assume only a few nodes equipped with GPS hardware which know their positions without communicating with other nodes. The sensors with unknown location information and their coordinates will be estimated by the sensor network localization algorithms. The main goal of localization procedures is to deduce, as accurately as possible, the location of a node from the partial information obtained from a set of nodes, which already know their location.**

Measurement of the received signal strength indicator (RSSI) parameter is used for distance determination between sensor nodes. The developed algorithm is implemented in a real sensor network.

Index Terms—**Wireless sensor networks, Localization, Sensor nodes**

I. INTRODUCTION

Wireless networking has become a very popular research topic, over the last decade. Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power and multi-functional sensors that are small in size and communicate in short distances. Cheap, smart sensors, networked through wireless links and deployed in large numbers, provide enormous opportunities for environmental monitoring, medical treatment, agriculture, military affairs but also in households and traffic pollution areas [1]. Beside these, WSN are also used in some dangerous working environment like mines and nuclear power stations in order to monitor their safety status.

The progress of both sensing and information technology is making the physical world measurement data more available

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and cheap in terms of acquisition, processing, storage and retrieval. Intelligent sensors, which are possibly arranged in wired or wireless networks, can acquire raw data from the environment for long periods of time and those data can be safely stored [2,3].

In sensor networks, nodes are deployed into an unplanned infrastructure where there is no a priori knowledge of location. The problem of estimating spatial – coordinates of the node is referred as localization. The main practical objective is to locate each node as accurately as possible with a certain amount of error about the distances between a subset of nodes in wireless sensor networks. To identify the coordinates of sensor nodes (also called unknown nodes) requires measuring a distance e.g., measuring time of arrival (ToA) or time difference of arrival (TdoA) [4]. Difficulties concerning time measurement result from synchronization of involved devices as well as the high mathematical effort to calculate the position. The measurement of the received signal strength (RSS) offers a possibility to determine distance with minimal effort.

Perhaps the simplest method of providing localization is to equip every sensor node with a GPS receiver. However, a GPS receiver is expensive in terms of money, size and energy. Another alternative is hand-placing each sensor and manually recording its position. This is unpractical and error prone approach unsuitable for large sensor networks and many of the proposed WSN applications [5].

Most of the existing works focus on increasing the accuracy in position estimation by using different mathematical techniques such as triangulation, multilateration, multidimensional scaling, etc.

The rest of the paper is organized as follows. In section II measurement techniques in WSN localization are discussed; these include distance related measurements. In section III radio signal measurements are explained, received signal strength (RSS) – based distance measurements, time of arrival (ToA) and time difference of arrival (TDoA).

Section IV discusses different radio signal propagation models for wireless communications that predict signal strength loss with distance – path loss; include free space propagation model, two-ray ground model and log – distance model. Experimental and measurement results are given in Section V. Finally a summary is provided in Section VI.

II. LOCALIZATION TECHNIQUES

The goal of the location estimation methods is to calculate the position (coordinates) of sensor nodes in wireless sensor networks. Localization in WSN is a complex problem that can be solved in different ways [6].

Some localization techniques allow to estimate nodes position using information transmitted by a set of nodes that are aware of their own locations (GPS for example). It can be distinguished two classes of methods depending from the nodes hardware capabilities:

- Connectivity based methods that use only connectivity information to locate the entire sensor network;
- Distance based methods that use inter-sensor distance or angle measurements to determine location of the nodes.

Distance based methods require additional equipment but with this method it can be reached much better resolution than in case of connectivity based ones. The proximity information between nodes often helps to determine their geometric relationship. The distance between them or angle of a singular triangle can be easily estimated.
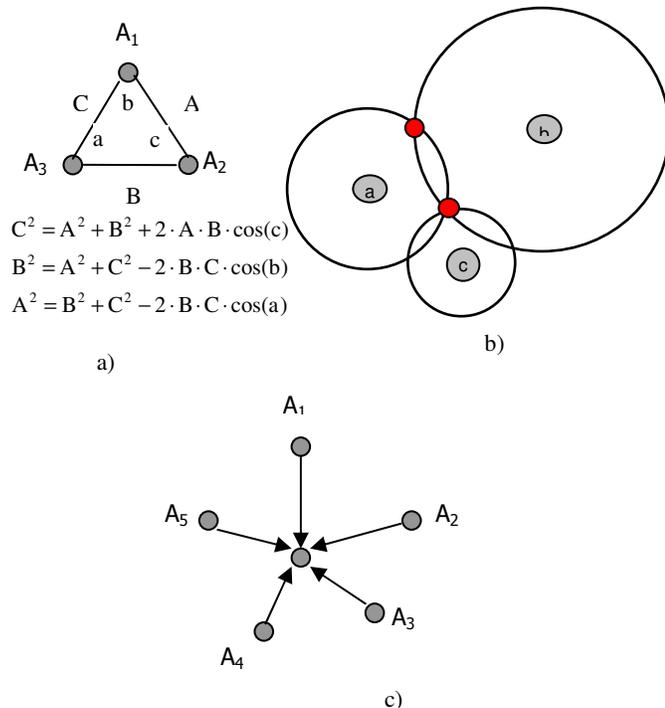
When the distances between an object and a number of nodes are measured, it is also required to find the actual position of nodes by combining the distance measurements. The most used methods for the distance measurements from three or more nodes are: triangulation, simple trilateration and multilateration.

Triangulation is a method for finding the position of a node, when the angles are measured by Angle of Arrival technique. An example of such a procedure is shown in Figure 1.a. The object X measures its angles with respect to the beacons A1, A2 and A3. The measured angles form three straight lines along the directions XA1, XA2 and XA3. The intersection between the three lines defines the location of the node X. The accuracy of this technique is heavily dependent upon the accuracy of the employed angle measurement technique

Simple trilateration is used when we have an accurate estimate of distances between a node and at least three beacon nodes. This simple method finds the intersection of three circles centered at beacons as the position of the node. The scenario is shown in Figure 1.b.

Multilateration is accepted as the most appropriate way to determine the location of a sensor node based on locations of beacons. An example is shown in Figure 1.c, where the nodes A1, A2, A3, and A4 are beacons, with known estimates of their locations, while the node X estimates its location using a multilateration procedure. The procedure attempts to estimate the position of a node by minimizing the error and discrepancies between the measured values.

The characteristics of wireless communication are partially determined by the distance between sender and receiver, and if these characteristics can be measured at the receiver they can serve as an estimator of distance. The most important characteristics are Time of Arrival (ToA), Time Difference of Arrival (TdoA), and Received Signal Strength Indicator (RSSI).

$$C^2 = A^2 + B^2 + 2 \cdot A \cdot B \cdot \cos(c)$$
$$B^2 = A^2 + C^2 - 2 \cdot B \cdot C \cdot \cos(b)$$
$$A^2 = B^2 + C^2 - 2 \cdot B \cdot C \cdot \cos(a)$$

Fig. 1. Localization Basics a) Triangulation b) Trilateration c) Multilateration.

III. RADIO SIGNAL MEASUREMENTS

Time of Arrival (ToA) uses the relationship between distance and transmission time when the propagation speed is known. If the sender and the receiver know the time when the transmission starts the time of signal propagation can be used to estimate the distance. To provide acceptable accuracy a very high accurately synchronized clocks are required for sender and receiver. To overcome the need for explicit synchronization, the roundtrip time is often utilized. Roundtrip propagation time measurements measure the difference between the time when a signal is sent by a sensor and the time when the signal returned by a second sensor is received at the original sensor. But, this method is affected by the internal delay required for handling the signal in a second sensor [7].

Another technique that is used to overcome the need of explicit synchronization is time difference of arrival (TDoA) method, which utilizes implicit synchronization by directly providing the start of transmission information to the receiver. It is possible if two transmission mediums of different propagation speeds are used. For example the sender can send and ultrasound and radio signal simultaneously. When the receiver gets the radio signal it can start measuring the time until arrival of the ultrasound transmission, safely ignoring the propagation time of the radio communication [7]. The main disadvantage of this technique is the need of two types of senders and receivers on each node.

Technique which estimates the distances between neighboring nodes is the method based on a standard feature found in most wireless devices, a received signal strength indicator (RSSI). Based on the known transmit power, the effective propagation loss can be calculated. Theoretical and empirical models are used to translate this loss into a distance estimate. This method has been used mainly for RF signals.

In practical scenarios, the ideal distribution of RSSI is not applicable, because the propagation of the radio signal is interfered with a lot of influencing effects e.g:

- Reflection of objects;
- Diffraction at edges;
- Refraction by media with different propagation velocity.

The low complexity and the fast calculation recommend this localization algorithm as very popular and often used in wireless sensor networks.

IV. THE RADIO SIGNAL PROPAGATION MODELING

There are many radio propagation models [8] known for wireless communications that predict signal-strength loss with distance – path loss. There are three models widely used for wireless sensor networks.

Free space propagation model is built on the assumption that the transmitter and receiver are in the line of sight, and there are no obstacles between them.

The receiver signal power, P_R is related to distance, d, by the inverse square law:

$$P_R = C_f \frac{P_t}{d^2} \tag{1}$$

Two-Ray ground model adds reflection to the previous model. A two-ray ground model receiver receives two rays, direct communication ray and reflected ray:

$$P_R = C_f \frac{P_t}{d^4} \tag{2}$$

In the real world the signal often decays at a faster or slower rate, known as log-distance model

$$P_R \propto \frac{P_t}{d^n} \tag{3}$$

Where: n is the loss exponent, C_f is a constant that depends from the transceiver characteristics, P_t is the power of transmitter signal. An excepted form of the relation between distance and receive power simplified for the case of a one meter reference distance is:

$$RSSI\,[dBm] = 10 \cdot n \cdot \log_{10}(d) + A \tag{4}$$

where: d denotes the transmitter-to-receiver distance, A represents the RSS value measured by a receiver that is located 1m away from a transmitter, and RSS is the actual measured value at distance d. The signal propagation

coefficient n shows the damping of the signal. Both parameters must be determined empirically [9]. By measuring the RSSI at different distances the values of n and A can be determined (4). A linear least square approximation to solve n and A should be implemented.
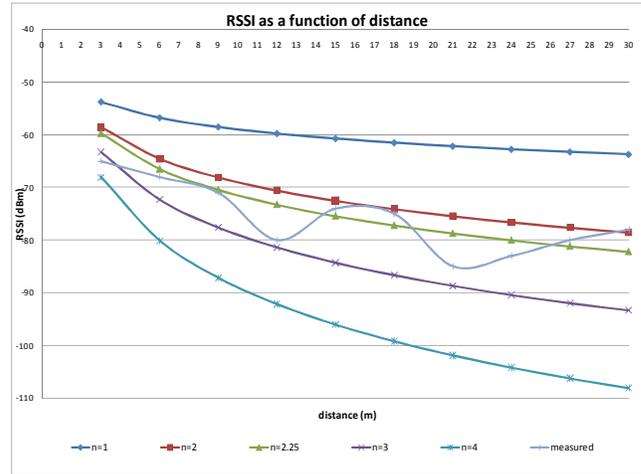

Fig.2 Measured vs calculated RSSI with different n.

To determine n, RSSI values within 30m are measured and compared with theoretical curves according to equation 4 whereby n is varied from 1 to 4 (figure 2).
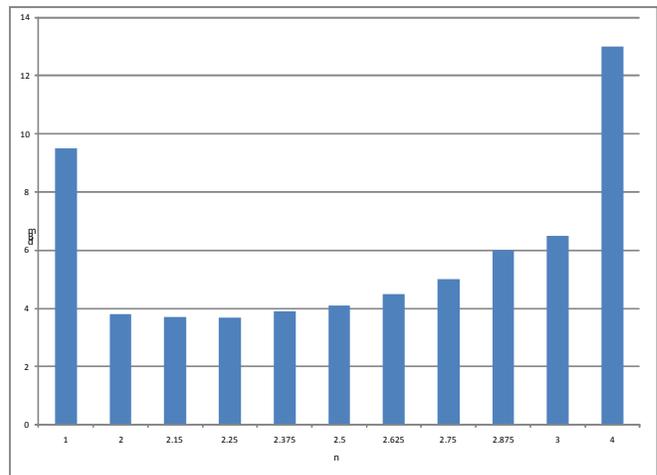

Fig. 3 Root mean square error between theoretical and measured RSSI with different n.

The majority of the RSSI values are in the area between theoretical curves n=2 and n=3, thus more n values in interval [2.0, 3.0] are researched.

The root mean square error between theoretical and measured RSSI values is calculated and compared with each other. Due to the minimal root mean square error n=2.25 is chosen as the appropriate damping coefficient.

Figure 3 shows the typical errors of distance measurements with RSSI.

V. EXPERIMENTAL RESULTS

In order to create an experimental setup for a ZigBee network, 2.4GHz 802.15.4 development kit belonging to the Silicon Laboratories is used. The board is shown in Fig. 4.

Fig. 4. Sensor node.

Each board features a silicon laboratories C8051F121 microcontroller and a Chipcon CC2420 [10] 2.4 GHz 802.15.4 transceiver. Support components include a USB interface, JTAG programming interface, a variety of pushbuttons and a voltage regulator.
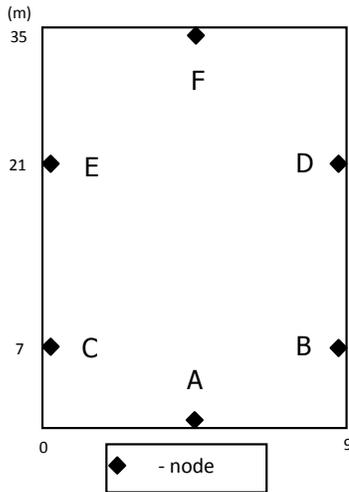

Fig.5 Positions of the nodes in free space.

It is conducted an experiment to investigate the relationship between the measured RSSI and the distance between nodes.

The locations of three main nodes are known (in the figure named with D, E and F), the received signal strength to this nodes are known, the location of the three nodes named with A, B and C should be determined (Fig.5)

Ten measurements for each position and took the average value are performed. The relationship between the received signal strength and the distance is shown in fig.6.

RSSI – based ranging methods require the knowledge of the RSS-to-distance curve as follows:

$$d = 10^{\left[\frac{RSSI-A}{10 \cdot n}\right]} \qquad (5)$$

where d denotes the transmitter-to-receiver distance, n is the propagation path-loss exponent. Due to the minimal root mean square error n=2.25 is chosen as the appropriate damping factor.
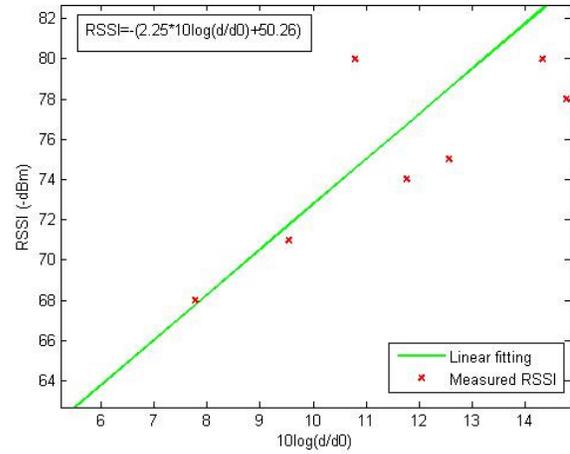
The RSS-to-distance reference curve in (5) is obtained via a least-square linear fitting from several RSS measured values. The obtained result is shown in Fig.6 along with real measurements. In Fig. 6 i) the RSS values are represented in dBm as provided by the receiver nodes, ii) the distance d in x-axis is normalized to the reference distance of 1m, and iii) the fitting parameters are A=50.26 and n=2.25. Obtained result for the path-loss exponent compared to the theoretical value (n=2) is due to the fact that receiver nodes are located very closed to huge buildings, which provides constructive reflected propagation path in addition to the direct one.

In general, the result of a measurement is only estimate of the value of the measurand and is complete only when accompanied by a statement of the uncertainty of that estimate [11].

Thus the ideal method for evaluating and expressing measurement uncertainty should be capable of readily providing an interval, in particular, one with a coverage probability or level of confidence that corresponds in a realistic way to that required.

The measurement uncertainty u(x) [11] is defined as standard deviation of arithmetic mean $\bar{x}$:

$$u(x) = \frac{1}{\sqrt{n}} \cdot \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2} \qquad (6)$$

For the uncertainty of x_T is valid:

$$x_T = \bar{x} \pm s_{\bar{x}} \qquad (7)$$

The equation (7) is defined as interval in which the accurate value will appear with some probability, known as confidence interval.

The measurement uncertainty u_y of the unknown parameter is defined with:

$$u_y = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i}\right)^2 \cdot u(x_i)^2} \qquad (8)$$

where u_x are the uncertainties of the known parameters;

In this case, for the distance uncertainties between nodes, parameter d depends from the uncertainties of transmitted u_{P_t} and received power u_{P_R} :

$$d = \sqrt{C_f \frac{P_t}{P_R}} \qquad (9)$$

Distance uncertainty is calculated with the relation:

$$u_y = \sqrt{\left(\frac{\partial d}{\partial P_T} \cdot u_{p_T}\right)^2 + \left(\frac{\partial d}{\partial P_R} \cdot u_{P_R}\right)^2} \qquad (10)$$

The distance uncertainties of the sensor nodes are presented in Figure 7. The localization error (fig. 7) is increasing, when the receiving nodes depart from the transmitter [12]. The positions of the nodes are shown in figure 5. The largest distance between nodes is 30 meters, for this distance the uncertainty is 1m.
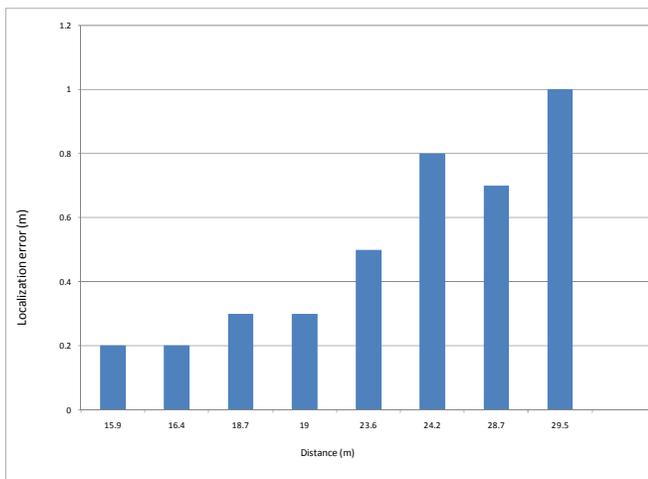

Fig. 7 Localization error.

For the largest distance of 30 meters the localization error is 3%.

This inaccuracy is due to the fact that receiver nodes are located very close to huge buildings, which provides constructive reflected propagation path in addition to the direct one. Multipath arises when more than one path is available for radio signal propagation. Metallic materials as well as dielectrics (or electrical insulators) cause reflections. When multiple signal propagation paths exist, the actual signal level received is the vector sum of all the signals incident from any direction or angle of arrival.

A main challenge with RSS ranging is that the effect of reflecting and attenuating objects in the environment can have larger effects on RSS than distance.

The presented algorithm in combination with Zigbee offers lots of advantages. The most important advantage is the simplified implementation process due to already defined fundamental functions within the provided protocol suite of Zigbee.

VI. CONCLUSIONS

Wireless sensor network localization is attracting significant research interest. WSN are widely applicable to many practical applications including environmental monitoring, military applications, etc. in which sensors may need to know their geographical locations. Accurate and low-cost localization is a critical requirement for the deployment of wireless sensor networks in a wide variety of applications. The simplicity of RSS is especially appealing for the localization in WSN because of their cost, size and power consumption.

This paper has provided a review of the measurement techniques in WSN localization and the corresponding localization algorithms. In this experimental work a RSS-based localization approach for outdoor wireless sensor networks is presented. The RSSI was used to determine the distances between the sensor nodes.

This experiment has summarized theoretical and practical investigations concerning the analysis of RSSI measurements. Localization system that uses RSSI in a sensor network based on the Zigbee standard is implemented. The distance measurement accuracy of the used technique through actual experimental results is evaluated.

In the future research, it is planned to apply measurement of RSSI using different antenna polarization. Rotation of the received antenna from vertical to horizontal will affect the receive energy from multiple signals. It is important to investigate the position of an antenna in order to decrease the scattering of the received signal.

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