Localization System using RSSI Measurement of Wireless Sensor Network based on Zigbee Standard

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Abstract – **Localization in wireless sensor networks gets more and more important, because many applications need to locate the source of incoming measurement as precise as possible. In this paper the localization system estimates the distance between sensor nodes by measuring the RSSI (received signal strength indicator) at an appropriate number of sensor nodes.**

Keywords – **Localization system, RSSI, node**

I. Introduction

The increasing miniaturization of electronic components and advances in modern communication technologies lead to the development of extreme small, cheap, and smart sensor nodes. These nodes consist of sensors, actuators, a low power processor, small memory and a communication module.

Wireless sensor networks can monitor large areas and be applied in a variety of fields, such as monitoring the environment, air, water and soil. Sensor networks can also offer sensing data for different applications, that adapt to the user's circumstances in a ubiquitous computing environment. If they are appropriately designed, sensor nodes can work autonomously to measure temperature, humidity, pressure, and so on. In the future, sensors will be cheaper and deployed everywhere, thus, user-location-dependent services and sensor locations will become more important. Although GPS (global positioning system) is a popular location estimation system, it does not work indoors because it uses signals from GPS satellites. Using sensor networks instead of GPS makes indoor localization possible.

There are various techniques of how sensor nodes can learn their location automatically, either fully autonomically by relying on means of the wireless sensor networks itself or by using some assistance from external infrastructure.

As a result of the stochastic distribution of all nodes in the deployment phase, a determination of the node's position is required. Determing the position of sensor nodes in wireless sensor nodes represents a real challenge. To identify the exact 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).

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Difficulties concerning time measurement results 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.

In wireless sensor networks, it is important to keep energy consumption low, so IEEE 802.11 for wireless LANs, which was designed for high-power devices such as PCs, is not suitable for wireless sensor networks. Many protocols that cut off wireless devices in order to reduce energy consumption have been proposed, but a standard has not been defined, so sensors are not subject to standardization and a protocol has not been disseminated. IEEE 802.15.4 for low-rate wireless personal area networks has appeared recently. This standard is expected to be suitable for wireless sensor networks and is being offered in some products on the market. However, most past studies on localization systems carried out the performance evaluation on systems based on 802.11 for wireless LANs, and there has been insufficient investigation of using Zigbee or IEEE 802.15.4. Accordingly, in this study, we implemented a positional estimation technique using RSSI in a sensor network in accordance with the Zigbee standard and evaluated its position-estimation ability.

The reminder of this paper is organized as follows: section II gives an overview of the IEEE 802.15.4 standard. III, IV section discusses the theoretical background and practical realization of measuring the RSSI in Zigbee devices. Section V describes the mathematical basics of the model. Our experimental results we present in section VI followed by the conclusion which closes this paper.

II. Overview of the IEEE 802.15.4

The 802.15.4 is a part of the IEEE family of standards for physical and link-layers for wireless personal area networks (WPANs). The WPAN working group focuses on short range wireless links, in contrast to local area and metropolitan area coverage explored in WLAN and WMAN working groups, respectively. The focal area of the IEEE 802.15.4 is that of low data rate WPANs, with low complexity and stringent power consumption requirements.

The ZigBee alliance provides instructions only for the upper layers (i.e., from the third to the seventh layer) of the ISO/OSI stack. At the first layers levels of the ISO/OSI stack (physical, PHY, and medium access control, MAC), the ZigBee technology is based on the IEEE 802.15.4 standard and guarantees (theoretically) a transmission data rate equal to 250 kpbs in a wireless communication link. Three transmission bands (Fig.1) are allowed by the ZigBee standard: (i) 2.4GHz, (ii) 868 MHz, and (iii) 916 MHz. While the first transmission band is available worldwide, the second and third are available only in Europe and USA, respectively.

The IEEE 802.15.4 supports two PHY options. The 868/915MHz PHY known as low-band uses binary phase shift keying (BPSK) modulation whereas the 2.4GHz PHY (high-band) uses offset quadrature phase shift keying (OQPSK) modulation. Both modulation modes offer extremely good bit error rate (BER) performance at low Signal-to-Noise Ratios (SNR). The IEEE 802.15.4 physical layer offers a total of 27 channels, one in the 868MHz band, ten in the 915MHz band, and, finally, 16 in the 2.4GHz band.

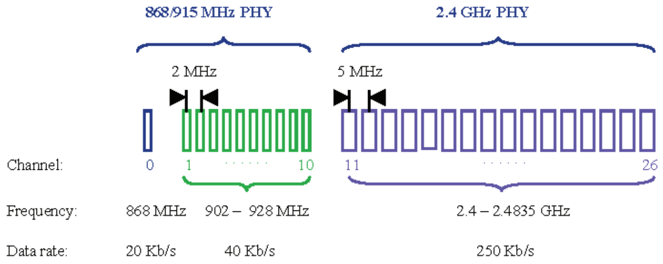

Fig.1 Bandwidth and data rate of IEEE 802.15.4

The raw bit rates on these three frequency bands are 20 kbps, 40 kbps, and 250 kbps, respectively. Unlike, for example, Bluetooth, the IEEE 802.15.4 does not use frequency hopping but is based on direct sequence spread spectrum (DSSS). In this case the measurements are made in the 2.4GHz frequency band as that is the area where inter-technology problems can be prominent and due to the fact that it is a tempting for larger scale sensor deployments.

III. LOCALIZATION ALGORITHM FOR ESTIMATION OF DISTANCE

Lots of localization algorithms require a distance to estimate the position of unknown devices. In addition to mere connectivity information, the communication between two nodes often allows to extract information about their geometric relationship. Using elementary geometry, this information can be used to derive information about node positions. When distances between entities are used, the approach is called lateration.

For lateration in a plane, the simplest case is for a node to have precise distance measurements to three noncolinear anchors. The extension to a three-dimensional space is trivial (four anchors are needed). Using distances and anchors positions, the node's position has to be at the intersection of three circles around the anchors. The problem here is that, in reality, distance measurement are never perfect and the intersection of these circles will , in general, not result in a single point. To overcome these imperfections, distance measurements form more that three anchors can be used, resulting in a multilateration problem. To use multilateration, estimates of distances to anchor nodes are required. This ranging process ideally leverages the facilities already present on a wireless node, in particular, the radio communication device. 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 Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), and Time Difference of Arrival (TdoA).

IV. RECEIVED SIGNAL STRENGTH INDICATOR

One possibility to acquire a distance is measuring the received signal strength of the incoming radio signal. The idea behind RSS is that the configured transmission power at the transmitting device (P_T) directly affects the receiving power at the receiving device (P_R). The RSSI is a very important indicator for wireless networks, since it can be used to characterize the channel status. Generally, the received signal strength gradually decreases as the receiver moves away from the transmitter. The relationship between RSS and transmitter-receiver (T-R) separation distance is described as a propagation model.

According to Friis' free space transmission equation, the detected signal strength decreases quadratically (n is usually two) with the distance to the sender.

$$P_R = P_T \cdot G_T \cdot G_R \cdot \left(\frac{\lambda}{4\pi}\right)^2 \cdot \left(\frac{1}{d}\right)^n \qquad (1)$$

P_T and P_R are the power of the transmitter and receiver, G_T and G_R are the gains of the transmitter and receiver antennas respectively. λ is the wavelength and d the distance between transmitter and receiver. The received power increases with the square of the wavelength (or decrease with the square of the frequency). This comes from the fact that an antenna with the same gain is larger at lower frequencies and therefore catches more power from the radiated field.

The path loss exponent describes the influence of the transmission medium. In free space, the path loss exponent is theoretically two, which describes the equal power distribution from an isotropic radiator on the surface of a sphere. N<2 means that the medium bundles the wave, giving a path loss smaller than in free space. An attenuating medium gives a path loss exponent n>2.

In embedded devices, the received signal strength indicator (RSSI) which is defined as ratio of the received power to the reference power. Typically, the reference power represents an absolute value of $P_{\mathrm{Ref}} = 1mW$.

$$RSSI = 10 \cdot \log \frac{P_R}{P_{\mathrm{Ref}}} \qquad [RSSI] = dBm \qquad (2)$$

An increasing received power results a rising RSSI. Thus, distance d is indirect proportional to RSSI.

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

- Reflections of metallic objects
- Superposition of electro-magnetic fields
- Diffraction at edges
- Refraction by media with different propagation velocity

- Polarization of electro-magnetic fields

These effects degrade the quality of the determined RSSI significantly. Thus in many applications, RSSI has a very high variance and low entropy (Fig.2).

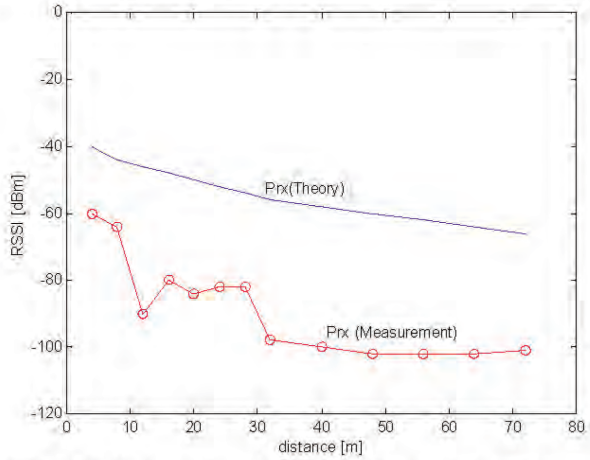

Fig.2 a)RSSI as quality identifier of the received signal power b) received signal strength of a Chipcon CC2420 sensor node

V. Mathematical basics for the lateration problem

Multilateration is one of the most popular techniques for positioning applied in WSNs and serves as a primitive building block, it is worthwhile to have a closer look at the mathematics behind it. Let assume that there are three anchors with known positions (x_i,y_i), i=1,2,3, a node at unknown position (x_u,y_u), and perfect distance values d_i, i=1,2,3. From the Pythagoras theorem, a set of three equations follows:

$$(x_i - x_u)^2 + (y_i - y_u)^2 = d_i^2 \quad i = 1,2,3 \tag{3}$$

To solve this set of equations, it is more convenient to write it as a set of linear equations in x_u and y_u.

$$2 \cdot \begin{bmatrix} x_3 - x_1 & y_3 - y_1 \\ x_3 - x_2 & y_3 - y_2 \end{bmatrix} \cdot \begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} (d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \\ (d_2^2 - d_3^3) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2) \end{bmatrix} \tag{4}$$

Where the matrix on the left side and the right hand side only consists of known constants.

The real challenge for triangulation arises when the distance measurements are not perfect but only estimates $\tilde{r}$ with an unknown error ε are known. Solve the above equation with $\tilde{r}_i = r_i + \varepsilon_i$ will in general not yield the correct values for the unknown positions (x_u,y_u).

The intuitive solution to this problem is to use more than three anchors and redundant distant measurements to account into an overdetermined system of equations, written in matrix form as

$$2 \cdot \begin{bmatrix} x_n - x_1 & y_n - y_1 \\ \vdots & \vdots \\ x_n - x_{n-1} & y_n - y_{n-1} \end{bmatrix} \cdot \begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} (d_1^2 - d_n^2) - (x_1^2 - x_n^2) - (y_1^2 - y_n^2) \\ \vdots \\ (d_{n-1}^2 - d_n^2) - (x_{n-1}^2 - x_n^2) - (y_{n-1}^2 - y_n^2) \end{bmatrix} \tag{5}$$

VI. Experimental results

In order to create an experimental setup for a ZigBee network, is used 2.4 GHz 802.15.4 development kit belonging to the Silicon Laboratories. The target board is shown on Fig.3.

The board is a powerful module to transmit data wireless. It works in the worldwide free available 2.4 GHz ISM Band. It is made to receive or transmit data conform to the standard IEEE 802.15.4. Each board features a silicon laboratories C8051F121 microcontroller and a Chipcon CC2420 2.4 GHz 802.15.4 transceiver. Support components include a USB interface, JTAG programming interface, a variety of pushbuttons and LED's and a voltage regulator. The data transfer rate goes up to 250kBps, the radiation power is 1mW (low power version) or 40mW (high power version). There exist 16 different channels with 5 MHz Bandwidth (each of them). For undisturbed transmission the module uses DSSS (direct sequence spread spectrum).

Fig. 3 Sensor node

We conducted an experiment to investigate the relationship between the measured RSSI and the distance between nodes. All of these measurements were performed in a free space at the area near the Department of metrology at AGH University in Krakow, Poland in a sunny day to minimize the interferences. The positions of these sensor nodes are shown on Fig.4.

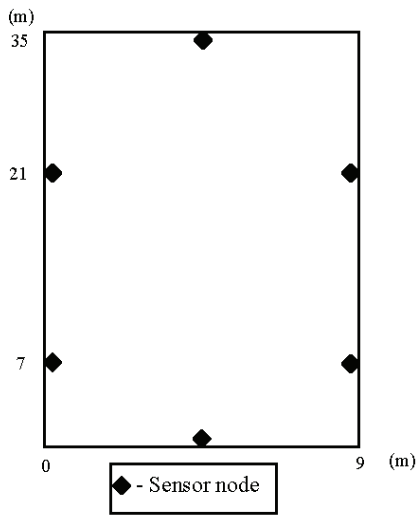

Fig.4 Positions of sensor nodes in free space

We performed ten measurements for each position and took the average as the measured RSSI value. Usually, signal strength is expressed in dBm units, which is the dB expression of power referenced to 1mW so that higher dBm value corresponds to higher power. In current sensor nodes, their radios can report the Received Signal Strength Indicator (RSSI) for each received packet in dBm units. Then, using the eq. 2 we computed the estimated distances between nodes. The relation between the estimated and measured values is shown on fig. 5. The position estimation error is 3%.

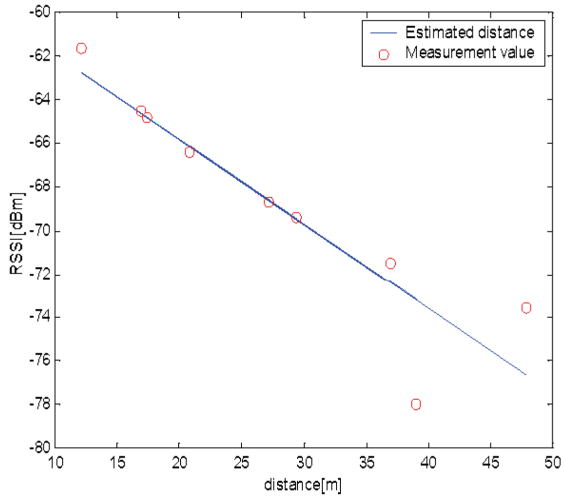

Fig. 5 Relationship between communication distance and RSSI value

The algorithm (Fig.6) for estimating the distances is entirely developed using programming language Labview. Programming an application in Labview is very different from programming in a text based languages like C or Basic. Labview uses graphical symbols (icons) to describe programming actions.

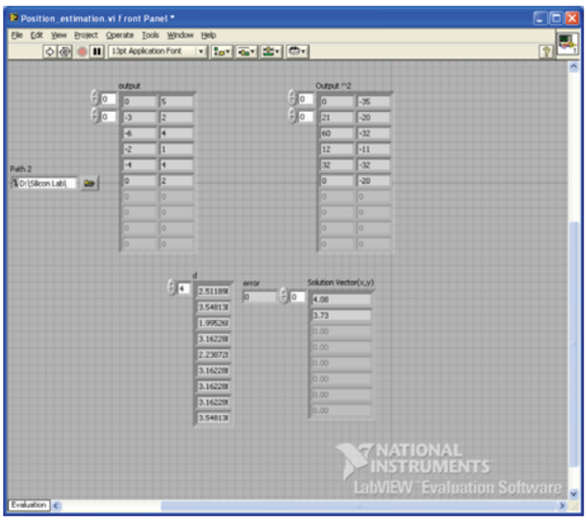

Fig. 6 Front panel of the estimated distance

We used the multilateration technique for positioning the nodes in Wireless Sensor Networks. The mathematical approach was explained in section V.

Although the positioning algorithm does not yet provide the desired results very exactly, 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.

VII. Conclusion

This paper has summarized theoretical and practical facts concerning the analysis of RSSI measurements. The algorithm for positioning the nodes and its realization is illustrated. Localization system that uses RSSI in a sensor network based on the Zigbee standard is implemented. The distance measurement accuracy of our technique through actual experimental results is evaluated. The positions of the nodes using the Labview software were estimated.

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

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