LOCALIZATION ESTIMATION SYSTEM USING MEASUREMENT OF RSSI BASED ON ZIGBEE STANDARD

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The design of accurate localization algorithms in the realization of wireless sensor networks is a challenging task. Localization in wireless sensor networks is becoming 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) from an appropriate number of sensor nodes.

Keywords: Localization, RSSI, node, sensor networks

1. INTRODUCTION

Wireless sensor networks (WSNs) are a particular type of ad hoc network, in which the nodes are 'smart sensors', that is small devices (approximately the size of a coin) equipped with advanced sensing functionalities (thermal, pressure, acoustic, etc.), a small processor and a short-range wireless transceiver.

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 link and deployed in large numbers provide opportunities for monitoring and controlling homes, cities and environment. In environmental monitoring applications such as water quality monitoring and precision agriculture, the measurement data are meaningless without knowing the location from where the data are obtained.

The position of the sensor nodes is very important for several reasons:

- Measurements without a location where they were gathered are generally useless;
- Full covered sensor networks enable energy aware geographic routing;
- Self configuration and self organization are key mechanisms for robustness and can easily be supported by position information;
- In many applications the position itself is the information of interest.

Although GPS (global positioning system) is a popular location estimation system, it does not work indoors because it uses signals from satellites. This system requires line of sight to some satellites, consumes additional energy and is too expensive to get integrated on hundreds of energy constrained sensor nodes. Using sensor networks instead of GPS makes indoor localization possible. To identify the exact coordinates of sensor nodes (also called unknown nodes) requires measuring a

distance e.g., measuring of Received Signal Strength Indicator, measuring time of arrival (ToA) or time difference of arrival (TdoA).

2. IEEE 802.15.4 STANDARD

The IEEE 802.15.4 standard has been adopted by the ZigBee Alliance for wireless personal area network technology. The reference model (Fig. 1), shows the various layers of the ZigBee wireless technology architecture the relationship of the IEEE 802.15.4 standard to the ZigBee alliance MAC layer protocol model. These layers facilitate the features that make ZigBee very attractive: low cost, very low power consumption, reliable data transfer, and easy implementation. Using the IEEE 802.15.4 specifications, the alliance focuses on the design issues related to the network, security and applications layers.
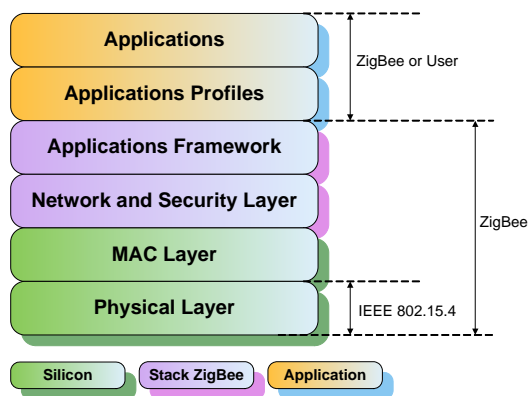

Fig.1 IEEE 802.15.4 and ZigBee reference model

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 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.

3. LOCALIZATION ALGORITHM FOR ESTIMATION OF DISTANCE

Lot 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 (Fig.2). 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.
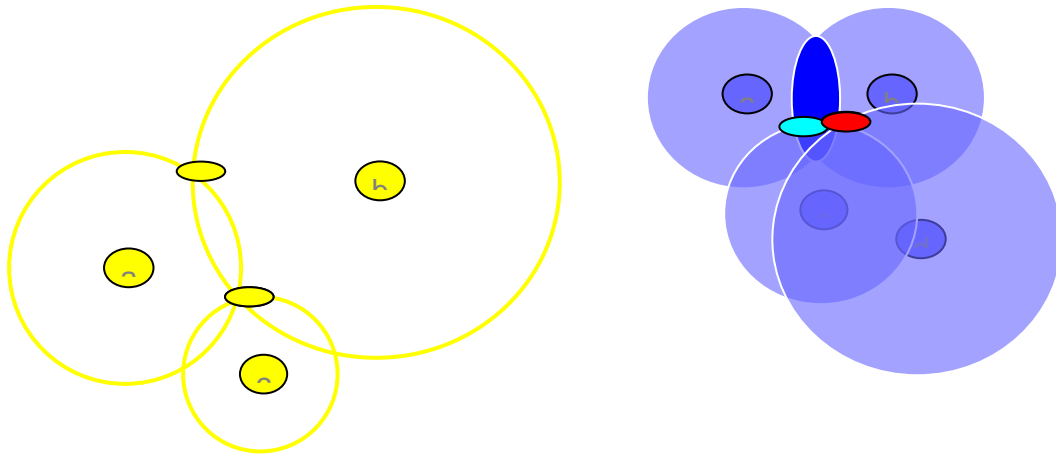
Fig. 2 Trilateration method

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).

4. RECEIVED SIGNAL STRENGTH INDICATOR (RSSI)

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

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

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). The free space equation is valid only for values of d that are relatively far from the transmitting antenna. For values of d within the so-called close-in distance d_0, the path loss can be assumed to be constant.

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.

5. MATHEMATICAL BASICS FOR THE LATERATION PROBLEM

Multilateration [4] 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 (Fig. 2), a set of three equations follows:

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

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.

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

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

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

$$2 \cdot \begin{bmatrix} x_n - x_1 & y_n - y_1 \\ \vdots & \vdots \\ x_n - x_{n-1} & y_n - y_{n-1} \end{bmatrix} \cdot \begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} (d_1^2 - d_n^2) - (x_1^2 - x_n^2) - (y_1^2 - y_n^2) \\ \vdots \\ (d_{n-1}^2 - d_n^2) - (x_{n-1}^2 - x_n^2) - (y_{n-1}^2 - y_n^2) \end{bmatrix} \quad (4)$$

6. 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. Each board features a silicon laboratories C8051F121 microcontroller and a Chipcon CC2420 2.4 GHz 802.15.4 transceiver [5]. Support components include a USB interface, JTAG programming interface, a variety of pushbuttons and LED's and a voltage regulator.

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
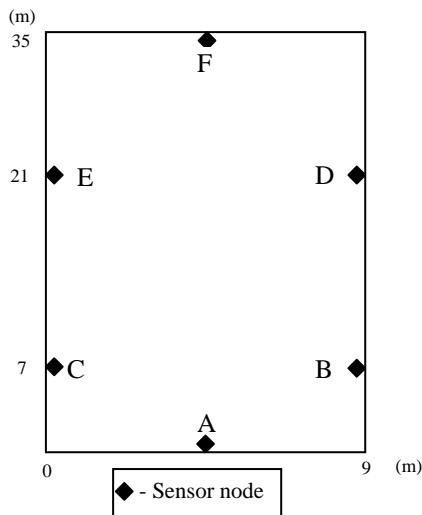
nodes are shown on Fig.4.

Fig.4 Positions of sensor nodes in free space

We performed measurements for each position and took the average as the measured RSSI value. 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. 1 we computed the estimated distances [4] between nodes. The relation between the estimated and measured values is shown on fig. 5. The position estimation error is 3%.
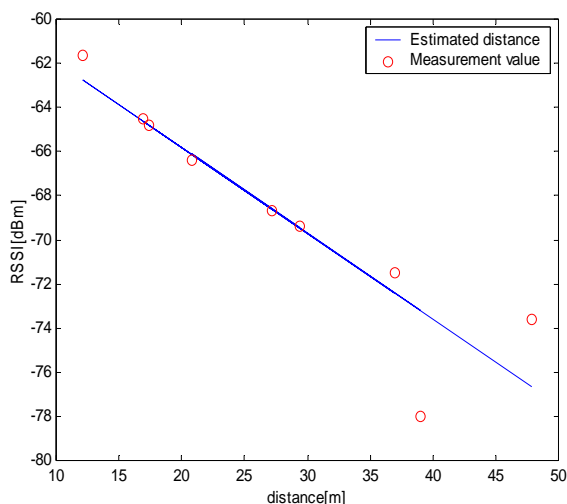

Fig. 5 Relationship between communication distance and RSSI value

The algorithm (Fig.7) based on multilateration technique for determing the position of the unknown node (A, B and C are the nodes with unknown positions), while three nodes (D, E and F) have fixed coordinates 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 (Fig.6) to describe programming actions.
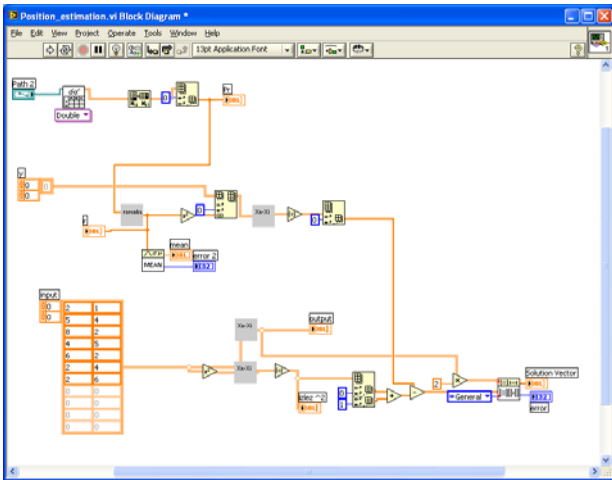

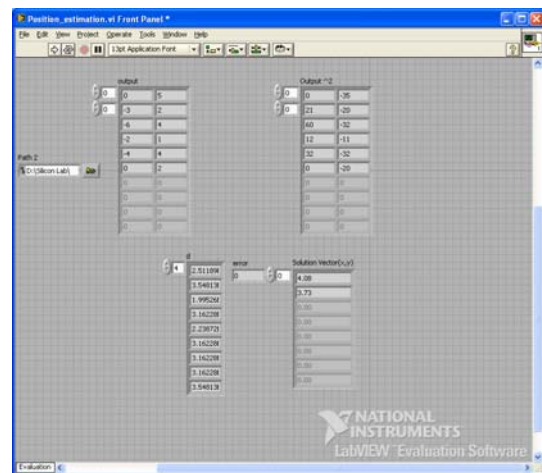Fig. 6 Block diagram of the position of the unknown node

Fig. 7 Front panel of the position of the unknown node

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.

7. 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 this 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.

8. REFERENCES

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