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DETERMINATION OF THE POSITIONS OF THE SENSOR NODES

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Abstract: *Localization of the nodes in wireless sensor networks is very important, because many applications need to locate the source of incoming measurement signal as precise as possible. In this paper one algorithm for location estimation of the sensor nodes is explained. The distance of the nodes is estimated by measuring the received signal strength indicator (RSSI) from an appropriate number of nodes.*
Key Words: ***wireless sensors, localization, algorithm***

1. INTRODUCTION

In recent years, there has been an increasing interest in wireless sensor networks in academic, industrial and commercial sectors. Wireless sensor networks can be used in a variety of fileds, such as for monitoring the environment, water, air, soil, etc. Sensor nodes collect the measurement data (e.g., temperature, pressure, humidity, etc.), and transmit them compressed and aggregated together with those of neighboring nodes, to the other nodes. In this way, every node in the network acquires a global view of the monitored area that can be accessed by the external user connected to the wireless sensor network through one or more gateway nodes.

They can be used in different dangerous working environments like mines or nuclear power stations in order to monitor their safety status. The integration of the local processing and storage allows sensor nodes to perform complex filtering and triggering functions, as well as to apply application specific or sensor-specific data compression algorithms [6]. The ability to communicate not only allows information and control data to be communicated across the network of nodes, but nodes to cooperate in performing more complex tasks, like statistical sampling, data aggregaton and system health and status monitoring. Increased power efficiency gives applications flexibility in resolving fundamental design tradeoff, e.g., between sampling rates and battery lifetimes.

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 error within the limits for the distances [2] 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). The measurement of the RSS offers a possibility to determine distance with minimal effort.

2. POSITION ESTIMATION ALGORITHM

In many applications, sensors have to know their geographical locations. Theoretically, Global Positioning System (GPS) can be used for a sensor to locate itself. In reality, it is not practical to use GPS in every sensor node because a sensor network consists of thousands of nodes and GPS becomes very costly.

Other solution is to initialize the coordinates of the sensor nodes during the installation. This is low cost, but unpractical option, escpecially if the network consists of hundreds or thousands of nodes. For some applications the mobility of the nodes is required, so the initial topology of the nodes becomes invalid and new algorithms for determining the positions of the unknown nodes are necessary.

To solve the problem, many localization methods have been developed, instead of requiring every node to have GPS installed, all localization methods assume only a few nodes equipped with GPS hardware. These nodes are called anchor or beacon nodes and they know their positions without communicating with other nodes.

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.

Most of the algorithms for position estimation of unknown sensor nodes require distance knowledge between the nodes. Information about the distances between the nodes or knowing the angle in a triangle can be used to determine the position of unknown nodes. When distances between two or more nodes are used, the method is called lateration, when angles between nodes are used the method is known as angulation.

Angulation method involves gathering Angle of Arrival (AoA) measurements at the sensor node from at least three sources. Then using the AoA references, simple geometric relationships and properties are applied to compute the location of sensor node.

Trilateration is a method of determining the relative positions of objects using the geometry of triangles similar to triangulation. Unlike triangulation, which uses

AoA measurements to calculate a subject's location, trilateration involves gathering a number of reference tuples of the form (x,y,d). In this tuple, d represents an estimated distance between the source providing the location reference from (x,y) and the sensor node. To accurately and uniquely determine the relative location of a point on a 2D plane using trilateration, a minimum of 3 reference points are needed (fig.1).

Multilateration (fig.1) is the process of localization by solving for the mathematical intersection of multiple hyperbolas based on the RSSI, ToA, TDoA. In multilateration when N receivers are used, it results in N-1 hyperbolas. If a large number of receivers are used, N>4, then the localization problem can be posed as an optimization problem that can be solved using, among others, a least square method.

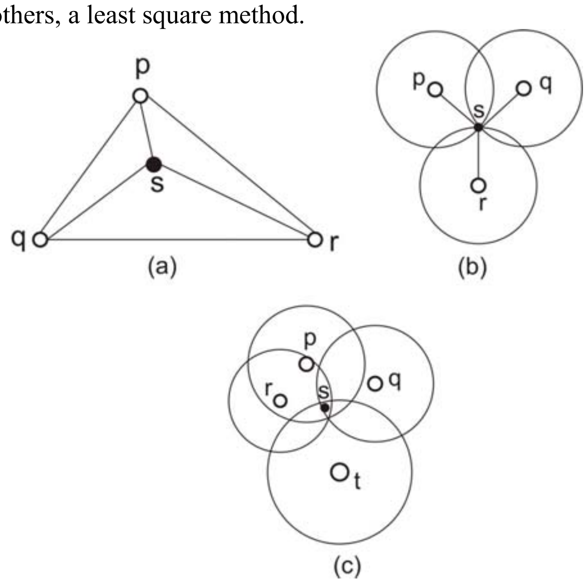

Fig. 1: *(a) Triangulation (b)Trilateration (c) Multilateration*

2. 1 Time of Arrival (ToA)

ToA exploits the relationship between distance and transmission time when the propagation speed is known. Assuming both sender and receiver know the time when a transmission starts, the time of arrival of this transmission at the receiver can be used to compute propagation time and thus, distance. Depending on the transmission medium that is used, time of arrival requires very high resolution clocks to produce results of acceptable accuracy. For sound waves, these resolution requirements are modest, they are very hard for radio wave propagation.

2.2 Time Difference of Arrival (TDoA)

To overcome the need for explicit synchronization, the TDoA method utilizes implicit synchronization by directly providing the start of transmission information to the receiver. This can be done if two transmission mediums of very different propagation speeds are used – for example, radio waves propagating at the speed of light and ultrasound, with a difference in speed of about six orders of magnitude.

Hence, when a sender starts an ultrasound and a radio transmission simultaneously, the receiver can use the arrival of the radio transmission to start measuring the time until arrival of the ultrasound transmission, ignoring the propagation time of the radio communication.

The obvious disadvantage of this approach is the need for two types of senders and receivers on each node. The advantage is better accuracy compared to other approaches.

2.3 Received Signal Strength Indicator (RSSI)

Issues of interest in radio design include propagation, impairments, environment, sensitivity, antenna design, channel bandwidth and frequency of operation. Many design factors are related parametrically to the frequency band in use.

The most basic model of radio –wave propagation typically found in wireless sensor networks environments involves the direct or free space wave. In this model radio waves emanate from a point source of radio energy, travelling in all directions in a straight line, filling the entire spherical volume of space with radio energy that varies in strength with a $1/(\text{distance})^2$ rule.

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

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

where: 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 is 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.

3. BASICS OF THE LATERATION ALGORITHM

Multilateration [4] is one of the most popular techniques for positioning applied in wireless sensor networks. Three anchors with known positions (x_i,y_i), i=1,2,3, a node at unknown position (x_u,y_u), and the distance values d_i between nodes i=1,2,3 are known. From the Pythagoras theorem follows:

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

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:

$$2 \cdot \begin{bmatrix} x_3 - x_1 & y_3 - y_1 \\ x_3 - x_2 & y_3 - y_2 \end{bmatrix} \cdot \begin{bmatrix} x_u \\ y_u \end{bmatrix} =$$

$$\begin{bmatrix} \left(d_1^2 - d_3^2\right) - \left(x_1^2 - x_3^2\right) - \left(y_1^2 - y_3^2\right) \\ \left(d_2^2 - d_3^3\right) - \left(x_2^2 - x_3^2\right) - \left(y_2^2 - y_3^2\right) \end{bmatrix} \qquad (3)$$

The real challenge for triangulation arises when the distance measurements are not perfect, but only estimates $\tilde{d}$ with an unknown error ε are known. 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:

$$2\cdot\begin{bmatrix} x_n - x_1 & y_n - y_1 \\ \vdots & \vdots \\ x_n - x_{n-1} & y_n - y_{n-1} \end{bmatrix}\cdot\begin{bmatrix} x_u \\ y_u \end{bmatrix} =$$

$$\begin{bmatrix} \left(d_1^2 - d_n^2\right) - \left(x_1^2 - x_n^2\right) - \left(y_1^2 - y_n^2\right) \\ \vdots \\ \left(d_{n-1}^2 - d_n^2\right) - \left(x_{n-1}^2 - x_n^2\right) - \left(y_{n-1}^2 - y_n^2\right) \end{bmatrix} \quad (4)$$

For system of linear equation, a solution can be computed that minimizes the mean square error, the solution is the pair $\left(x_u, y_u\right)$ that minimizes $\left\|\mathrm{Ax} - \mathrm{b}\right\|_2$, where b is the right-hand side from equation (4). Minimizing this expression is equivalent to minimizing the mean square error. As a function of x, its gradient has to be set to zero:

$$A^T Ax = A^T b \quad (5)$$

Equation (5) has a unique solution under certain conditions.

4. EXPERIMENTAL RESULTS

For this experiment it is used 2.4GHz Zigbee development board from Silicon laboratories. The 2.4GHz 802.15.4/Zigbee board is consisted of 6 nodes. Each of the nodes have the following basic components:

- C8051F121 MCU Microcontoller
- Chipcon CC2420 transceiver
- Silicon laboratories CP2101 USB – UART bridge

Fig. 2 *Sensor node*

The target board is shown in Fig.2. CC2420 802.15.4 radio frequency (RF) transceiver is used to initialize wireless connection. C8051F121 microcontroller communicates with CC2420 [5] through serial peripheral interface (SPI) interface. It works in the worldwide free available 2.4 GHz industrial, scientific and medical (ISM) band. It is made to receive or transmit data conform to the standard IEEE 802.15.4. 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).

In this experiment it is proposed one method for position determination of the sensor nodes. The distance of the nodes is estimated by measuring the RSSI from all nodes, where the positions of three random nodes are fixed. The position of the unknown node is determined using the method of multilateration. All of these measurements were performed in a free space at the area near the Department of metrology at AGH University in Krakow, Poland, on a sunny day to minimize the interferences.

In order to estimate the RSS-to-distance curve a set of sensor nodes has been positioned as in Fig.3. The positions of three main nodes are known (in the figure named with A_4, A_5 and A_6), the received signal strength to this nodes are known, the location of the three nodes named with X_1, X_2 and X_3 should be determined.

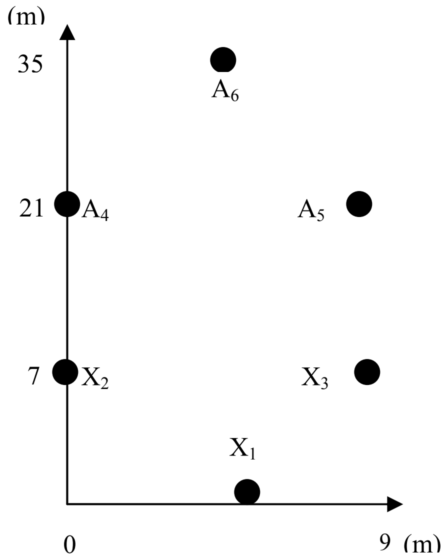

Fig.3 *Position of sensor nodes in free space*

In current sensor nodes, radios can report the RSSI for each received packet in dBm units. We performed ten measurements for each position [1], [9] and took the average value. The relationship between the RSS and the distance is shown in fig.4. As the distance increases, the RSSI decreases quadratically as the receiver moves away from the transmitter. The measurement error increases with the distance [1], [9] (fig.4).

We collected for several distances, repeated samples of RSSI values in an open field setup. Then we counted how many times each distance resulted in a given RSSI value and computed the density of this random variable. The probability density function of distances resulting in a given RSSI values is developed using the programming language LabVIEW (fig. 5). 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.

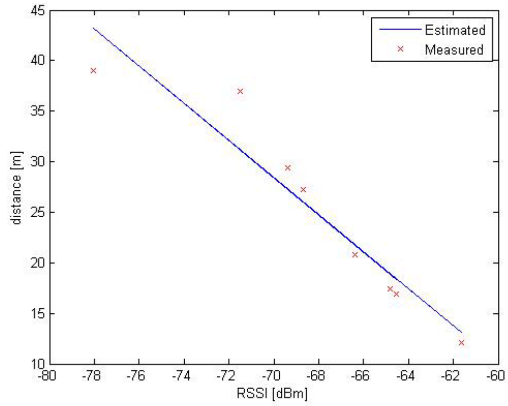

Fig.4 *Relationship between RSSI and distance*

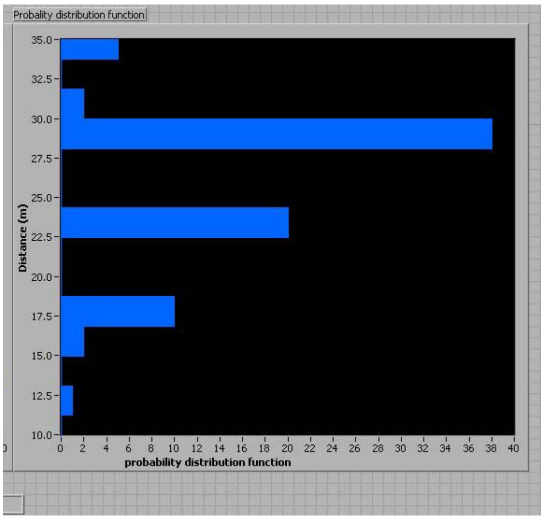

Fig. 5 *Probability density function of distances*

In general, the result of a measurement is only an approximation or estimate of the value of the measurand and thus is complete only when accompanied by a statement of the uncertainty of that estimate [8]. 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 uncertainties for the distances between the nodes are given in Table 1.

Table 1. *Distance uncertainties*

$d[m] \pm u_d[m]$
$12,3 \pm 1,2$
$16,4 \pm 0,53$
$18,7 \pm 2,9$
$23,6 \pm 0,91$
$28,7 \pm 2,0$
$29,5 \pm 0,862$
$35,6 \pm 2,75$

5. CONCLUSION

Wireless sensor networks are widely used to many practical applications including environmental monitoring, military applications, etc. in which sensors may need to know their geographical locations.

In this paper one algortihm for position estimation of sensor nodes is presented. Localization system that uses RSSI in a sensor network is implemented. Determination of the position of the sensor nodes using one approach for position estimation is presented. The distance measurement accuracy of our technique through actual experimental results is evaluated.

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