# Distance Uncertainties of Nodes in Wireless Sensor Networks using Multilateration Algorithm

Mare Srbinovska[1], Cvetan Gavrovski[2] and Vladimir Dimcev[3]

***Abstract* – A multilateration algorithm is presented in this work in order to realize a precise localization of the sensor nodes in wireless sensor networks. Received Signal Strength Indicator (RSSI) is used for distance measurements between sensor nodes. The developed algorithm is implemented in a real sensor network. The test results show that determination of the distances of sensor nodes using this algorithm reaches the intended requirements.**

***Keywords* – Multilateration algorithm, Localization, Wireless sensor networks, RSSI.**

## I. INTRODUCTION

Wireless sensor networks (WSNs) have been used in a wide range of applications. They usually consist of a large number of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate in short distances. Their structure and characteristics depend on their electronic, mechanical and communication limitations but also on the requirements of the specific application for example for monitoring the environment, water, air, soil, etc [9]. The position of sensor nodes is usually not pre-determined, although the application can provide some guidelines and insights that can lead to the construction of an optimal design that satisfies application requirements and meets wireless network limitations.

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

The problem of estimating spatial – coordinates of the node is referred as localization [5-7]. The main 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. Many studies about localization in WSN with different devices and algorithms are analyzed. The simplest method for a two dimensional localization is trilateration using distance measurement from an unknown sensor node to three non-linear anchors with known positions. To reduce the influence of distance errors on localization accuracy a multilateration algorithm with more than three anchors is used.

The distances between the sensor nodes can be determined by measuring time of arrival (ToA), time difference of arrival (TDoA) or received signal strength indicator (RSSI).

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## II. LOCALIZATION ALGORITHMS

### A. *Lateration and angulation*

In many applications, sensors have to know their geographical locations. 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. 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. Lateration and angulation are the two main localization algorithms [8]. Lateration uses distances between the sensor nodes while the angulation determines the position based on angles. Compared with angulation using specific antennas to determine the angles the lateration algorithm is easier to apply due to the simple distance measurements.

Trilateration is a method of determining the relative positions of objects using the geometry of triangles, so to accurately and uniquely determine the relative location of a point on a 2D plane a minimum of 3 reference points are needed (fig.1).

Multilateration localization algorithm with more anchors is used to reduce the influence of the distance errors on localization results.

The process of localization by solving for the mathematical intersection of multiple hyperbolas based on the RSSI, ToA, TDoA is based on the multilateration algorithm (Fig.1). 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.

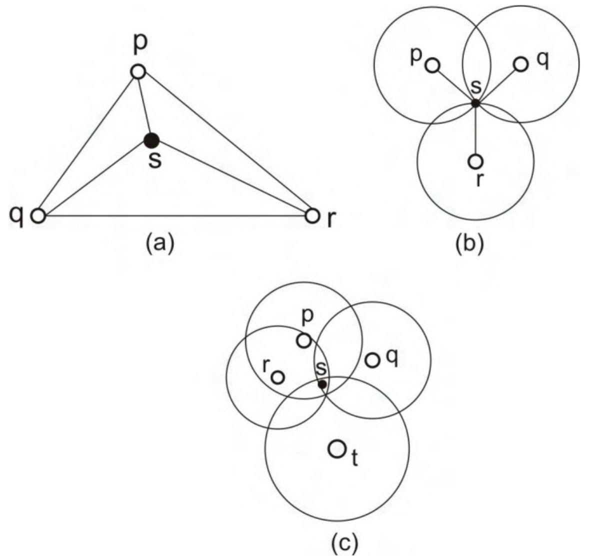


Fig. 1: (a) Triangulation (b)Trilateration (c) Multilateration

*B. Received Signal Strength Indicator (RSSI)*

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.

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).

- Received Signal Strength Indicator (RSSI) [3] techniques measure the power of the signal at the receiver. 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 the case where there is a direct path between a transmitter and receiver. The receiver signal power, $P_R$ is related to distance, d, by the inverse square law.

$$P_R \propto d^{-2}$$

However this is an ideal case for a point source. In the real world the signal often decays at a faster or slower rate

$$P_R \propto d^{-n}$$

Where n is the loss exponent. An excepted form of the relation between distance and receive power simplified for the case of a one meter reference distance is:

$$RSSI\ [dBm] = -(10 \cdot n \cdot log_{10}(d) + A) \tag{1}$$

where d denotes the transmitter-to-receiver distance, n is the propagation path-loss exponent, 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.

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;
- Superposition of electro-magnetic fields;
- 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.

- Time based methods (ToA,TDoA) record the time-of-arrival (ToA) or time difference-of-arrival (TDoA). The propagation time can be directly translated into distance, based on the known signal propagation speed. These methods can be applied to many different signals, such as RF, acoustic, infrared and ultrasound.

- Angle -of -Arrival (AoA) systems estimate the angle at which signals are received and use simple geometric relationships to calculate node positions.

*C. Multilateration*

Multilateration [4] is one of the most popular techniques for positioning applied in wireless sensor networks.

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

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

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

For system of linear equation, a solution can be computed that minimizes the mean square error, the solution is the pair $(x_u, y_u)$ that minimizes $\|\mathrm{Ax} - \mathrm{b}\|_2$, where b is the right-hand side from equation (2). Minimizing this expression is equivalent to minimizing the mean square error. As a function of x, its gradient has to be set to zero:

$$A^T Ax = A^T b \tag{3}$$

Equation (3) has a unique solution under certain conditions

*D. Propagation coefficient n*

To determine n, RSSI values within 30m are measured and compared with theoretical curves according to equation 1 whereby n is varied from 1 to 4 (figure 2). 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 [1], [2] is calculated and compared with each other. Due to the minimal root mean square error n=2.25 is chosen as the adequate damping factor. Figure 3 shows the typical errors of distance measurements with RSSI.

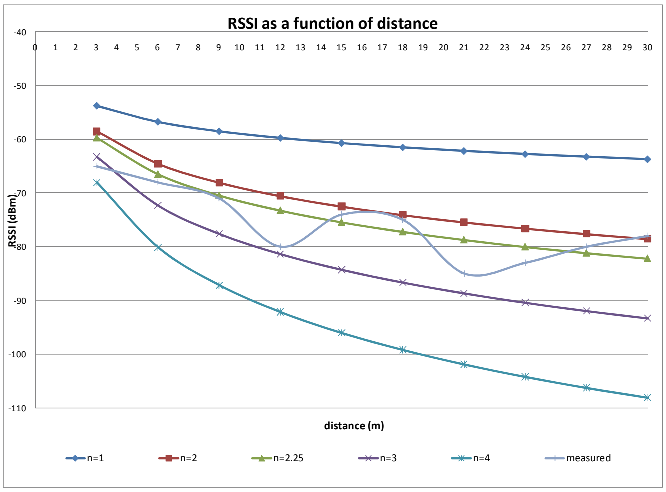


Fig. 2. Measured vs. calculated RSSI with different n

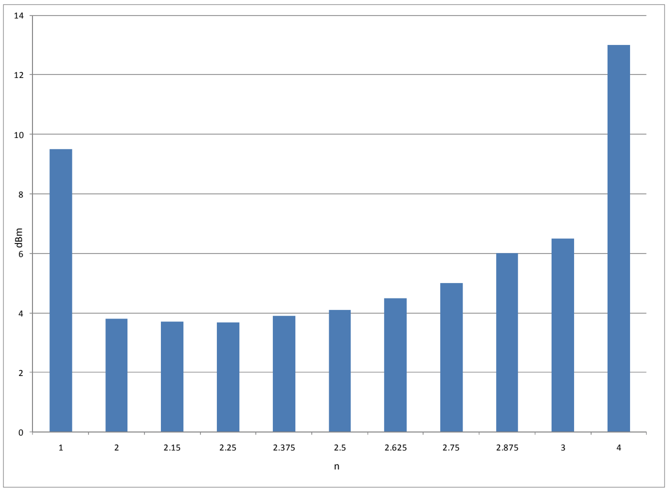


Fig. 3. Root mean square error between theoretical and measured RSSI with different n

## III. Implementation and Results

The localization algorithm is implemented in a real sensor network which consists of 6 sensor nodes. For the experimental setup a 2.4GHz 802.15.4 Zigbee development kit belonging to the Silicon Laboratories network, is used. The board is shown in Fig. 4.

Each board features a silicon laboratories C8051F121 microcontroller and a Chipcon CC2420 2.4 GHz 802.15.4 transceiver [10]. Support components include a USB interface, JTAG programming interface. The data transfer rate goes up to 250kBps, the radiation power is 1mW (low power mode) or 40mW (high power mode).

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.

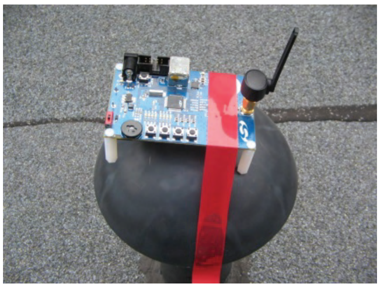

Fig. 4 Sensor node

In order to estimate the RSS-to-distance curve a set of sensor nodes has been positioned as in Fig.5. 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.

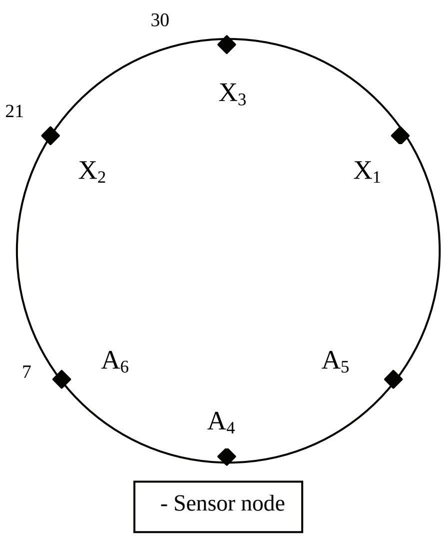


Fig. 5. Position of the sensor nodes in free space

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 [12]. 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.

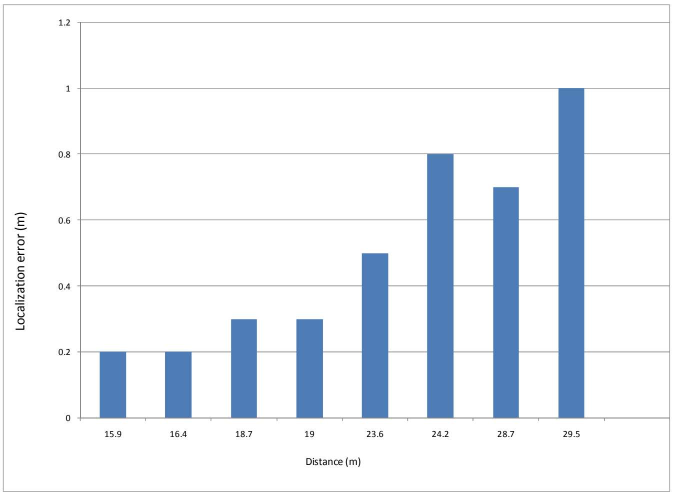


Fig. 6 Distance uncertainties of the sensor nodes

The uncertainties [11] for the distances of the sensor nodes are shown in figure 6. The positions of the nodes are given in figure 5. The localization error is increasing, when the receiving nodes depart from the transmitter. The largest distance between nodes is 30 meters, for this distance the uncertainty is 1m. This inaccuracy 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.

## IV. Conclusion

Wireless sensor networks are widely applicable to many practical applications including environmental monitoring, military applications, etc. in which sensors may need to know their geographical locations. The multilateration localization algorithm in wireless sensor network was explained. The relationship between RSSI and distance was determined through practical experiments. Distance uncertainties of the sensor nodes through experimental measurements were presented.

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