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Localization in Wireless Ad-hoc Sensor Networks using Multilateration with RSSI for Logistic Applications

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Abstract

A multilateration algorithm is presented in this work in order to realize a precise localization of the sensor nodes in wireless sensor networks in logistic applications. RSSI (Received Signal Strength Indicator) is used for distance measurements between sensor nodes. The developed algorithm is simulated and afterwards implemented in a real sensor network for food transportation logistic. The test results show that the multilateration algorithm with RSSI reaches the requirements of logistic applications.

Keywords: Localization; Wireless Sensor Networks; Multilateration; RSSI; Logistic applications

1. Introduction

When transporting perishable or sensitive freight, wireless sensor networks (WSN) can be used to monitor the environmental parameters in the container online[1]. WSN are appropriate to solve such logistic tasks due to their low energy consumption and simple applicability. The localization of the sensor nodes in WSN enables the assignment of sensor values, e.g. temperature and humidity, to their measuring points.

Many studies about localization in WSN with different devices and algorithms were carried out[2,3,4]. The simplest method for a two dimensional localization is trilateration using distance measurements 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 in this work. Firstly, the relationship between RSSI und distances is determined empirically. After optimizing the number of anchors in the WSN through a simulation with Matlab the localization algorithm is implemented in a WSN practically and the test results are shown in this paper.

2. Localization algorithms and distance measurement approaches

Lateration and angulation are the two main localization algorithms. Lateration uses distances between the sensor nodes while the angulation determines the position based on angles[5]. Compared with angulation using specific

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antennas to determine the angles the lateration algorithm is easier to apply due to the simple distance measurements. However, the distance measurements bring usually large errors, especially using RSSI (see Section 3.2, Fig. 2a). Thus a multilateration localization algorithm with more anchors is used to reduce the influence of the distance errors on localization results. The following three approaches of distance measurement are often discussed. **RSSI** (**R**eceived **S**ignal **S**trength **I**ndication): Due to the deterministic damping of the radio signal the receiver can calculated its distance from the transmitter using RSSI (see Section 3). **ToA** (**T**ime **o**f **A**rrival) and **TDoA** (**T**ime **D**ifference **o**f **A**rrival): Both approaches consider the propagation time of a signal between transmitter and receiver and usually need additional hardware and require higher energy consumption than RSSI. Since the WSN for long time food transportation has extreme limited energy supply with batteries, the RSSI approach is chosen for such a logistic application.

3. RSSI and distance

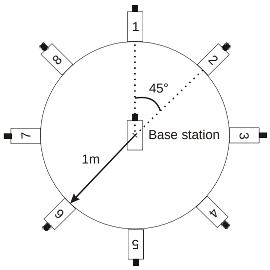
The relationship between RSSI and distance can be determined according to the following formula based on Friis transmission equation[6]:

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

where the initial signal strength A describes the absolute value of RSSI with 1 m distance to the transmitting unit. The signal propagation coefficient n shows the damping of the signal. Both parameters must be determined empirically. In the following sections the determination approach and the experimental results will be given.

3.1. Initial signal strength A

Since the antenna on a conventional sensor node is anisotropic, the parameter A cannot be identical in all directions. In this work 100 A values from each of the eight different directions (Fig.1a) are measured. The absolute RSSI mean value of 49 dBm is calculated and used as A in equation (1) (see Fig.1b).



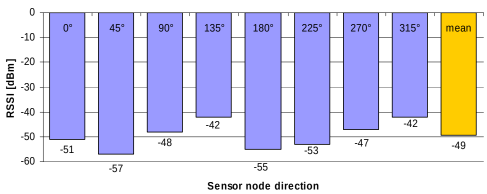


Fig. 1. (a) Placement of sensor nodes to determine *A*; (b) RSSI values in different directions.

3.2. Propagation coefficient n

To determine n, RSSI values within 10 m are measured with a step size of 1 m and compared with theoretical curves according to equation (1), whereby n is varied from 1 to 4 (Fig. 2a). 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 (RMSE) between theoretical and measured RSSI values is calculated and compared with each other (Fig. 2b). Due to the minimal RMSE $n = 2.25$ is chosen as the adequate damping factor. Fig. 2a shows the typical great errors of distance measurements with RSSI. Particularly for distances larger than 7 m the RSSI values become instable and deviate far from the theoretical curve. To reduce the practical localization error, the multilateration algorithm is used and the measurement range is restricted to 6 m diameter. This limitation still meets the requirements of a twenty-foot container (one twenty-foot equivalent unit, abbr. TEU)[7].

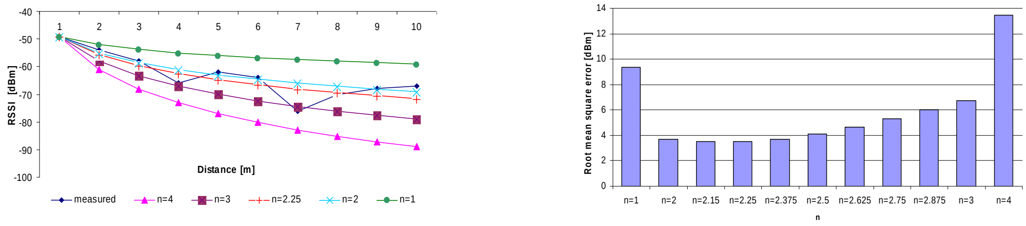


Fig. 2. (a) Measured vs. calculated RSSI with different n; (b) Root mean square error between theoretical and measured RSSI with different n

4. Optimization of anchor number

Theoretically, more anchors bring higher location accuracy. However, too many anchors cause high energy consumption and calculation complexity. The number of anchors is optimized through a simulation with Matlab. 121 test points are uniformly distributed in a circuit with 6 m diameter which is determined in Section 3. N_A anchors are uniformly distributed on the circuit. Errors are added on the distances from the N_A anchors to each test point. The errors are chosen randomly from interval [-1.0, +2.0] m according to the experimental measurement results in Section 3 (Fig. 2a). The localization algorithm was simulated with different number of anchors (N_A = 3, 4, 6, 8, 10, 20, 50). The position errors are shown in Fig. 3. The correction quality of multilateration stagnates when more than eight anchors are used. To keep low complexity and energy consumption, six is chosen as the optimal number of anchors.

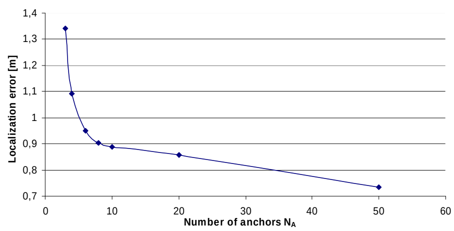


Fig. 3. Simulation results of localization error with N_A = 3, 4, 6, 8, 10, 20, 50

5. Implementation and test

The localization algorithm is implemented in a real sensor network which consists of Tmote Sky sensor nodes. Four and six anchors are used for localization in this test, separately, since the multilateration with four anchors is the simplest one and with six anchors is the optimized one according to the simulation results in Section 4. The distribution of anchors and test nodes is shown in Fig. 4. Node 1 is the origin of the circuit and the node index 2 to 8 is assigned depending on how far the test nodes are away from the origin.

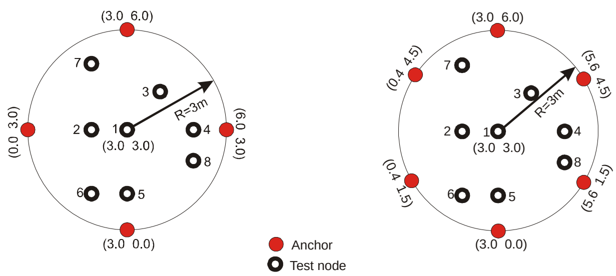


Fig. 4. Placement of the anchors and test nodes (a) with 4 anchors; (b) with 6 anchors

Most of the localization errors are smaller than 1.8 m except node 8 with four anchors (Fig. 5a). The localization accuracy decreases, when the test nodes depart further from the origin, because the distance measurement errors from the different anchors are difficult to compensate. The calculation time of the localization is also determined. Fig. 5b shows that the calculation time depends linearly on the number of used anchors N_A. The relationship can be described by the equation (2). With the short calculation time the communication in the WSN is not disturbed by the additional localization overhead.

$$t[ms] = 7 \cdot N_A - 2 \tag{2}$$

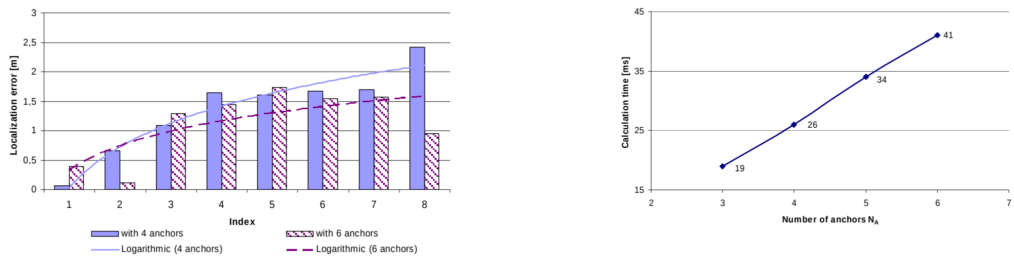


Fig. 5. (a) Localization errors of eight test nodes with four and six anchors; (b) Localization calculation time with different number of anchors

6. Conclusion

The multilateration localization algorithm in WSN was represented. The RSSI was used to determine the distances between sensor nodes. The relationship between RSSI and distance as well as the optimal number of the necessary anchors was determined through practical experiments and simulation. Finally, the localization algorithm was implemented in a sensor network. The test results showed that the measurement range, the localization accuracy and the calculation time can reach the requirements of logistic applications.

Acknowledgements

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