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AN IMPROVED LOCATION ESTIMATION ALGORITHM IN AN AD HOC SENSOR NETWORK FOR INDOOR ENVIRONMENTS

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ABSTRACT

Wireless Sensor Networks (WSNs) present one of the most representative and vibrant examples of networked embedded systems. A lot of WSNs applications require the determination of the node's location [1]. In this paper, we propose the possible improvement of localization estimation of unknown wireless sensor nodes (unknowns or mobile nodes) through feeding the network with the additional information about the a priori known distances between mobile nodes. We prove experimentally on the real testbed that our method can enhance the accuracy of location estimation.

For the localization of unknowns, we have used prepositioned anchor nodes (beacons). The proposed scheme is based on the Symmetric Double-Sided Two-Way Ranging method (SDS-TWR) [2]. The WSN was implemented using ZEBRA2411 modules from senTec Elektronik GmbH, based on the chip set ZRP1 developed by Freescale Semiconductor.

Index Terms— Localization, ToF, WSN, Sensors, Testbed, Experimental, ZEBRA

1. INTRODUCTION

1.1. Motivation

Nowadays, more and more attention is paid to a growing number of applications using wireless communication and to the WSNs as the part of it. Advances in technology have made it possible to build WSNs using inexpensive and small - comparable in size to the €1 coin - nodes consisting of a low power processor, a modest amount of memory, a wireless network transceiver and a sensor board. A plenty of novel applications in the scope of indoor environment are emerging: building monitoring, smart building failure detection, failure reporting, and target tracking as well. In these applications it is necessary to accurately orient the nodes in a short period of time and with less computation because of the power limitation. The popular GPS solution for localization is unanimously considered as not realistic since WSN nodes are supposed to operate at low-complexity and low-power consumptions.

Localization is still a new and exciting field, with new algorithms, hardware, and applications being developed. It is hard to say what techniques and hardware will be prevalent in the end [3].

Among the plethora of possible localization schemes, we only focus on those based on radio signal strength measurements and time-of-arrival estimation, since they do not require extra circuitry that would result in higher cost and energy consumption.

1.2. Aim

In the light of the above motivation, two key aspects can be mentioned. These are the development of new and efficient localization algorithms specifically tailored to GPS–less environments, their validation via simulation and experimentation, and the performance analysis of today commercially available WSN chips for location estimation in realistic GPS-less environments [4].

Our aim in this paper is to introduce an improved algorithm of location estimation as well as its real implementation on commercially available sensor nodes and performance analysis. The measurement campaign is performed in a typical GPS-less environment represented by a dynamic indoor scenario.

1.3. Paper Organization

The rest of this paper is organized as follows. In section 2, we present our experimental testbed used for performance analysis, as well as description of the used hardware. Section 3 describes our proposed improvement method of mobile nodes localization. Section 4 presents experimental results and their analysis. Finally, Section 5 concludes this paper.

Fig. 1. Office room at the University of Erfurt.

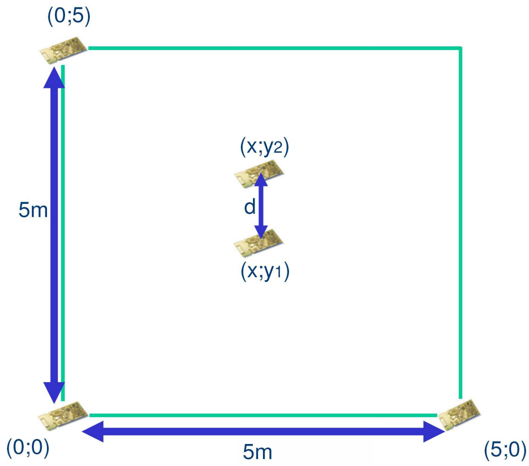

Fig. 2. Scheme of the testbed.

2. LOCALIZATION SYSTEM

2.1. Network Description

For the localization of unknown wireless sensor nodes we have used beacons with known coordinates: [0;0], [0;5] and [5;0]. The proposed scheme is based on the SDS-TWR method and uses Time-of-Flight measurements[2].

In Fig. 1, we have reported a photo of the office room where the WSN was deployed during the experiments. This room placed at the Erfurt University of Applied Sciences is equipped with standard furniture including chairs, bookshelves, desks and has two windows. This deployed WSN is composed of the following main elements:

- Three anchor nodes that were placed in the corners of the office room.
- Some unknown nodes, i.e., nodes that need to localize themselves by relying on GPS-less distributed localization techniques. The number of these mobile nodes may be different: It may range from one node (the simple localization) to several or even tens of nodes, which can localize themselves more precisely using the addition information about the distances to each other as described in Section 3.
- There was also a sniffer node, which was connected via an RS232 serial interface to a host computer and gave the information about the measured time-of-flights between nodes. In addition, all the further calculations are made by the host.

The deployment of the anchor nodes as well as two mobile nodes is shown in Fig. 2.

The office used for the experiment represents the dynamic measurement environment where people may come into and go out of the room during the normal operation of the network, thus modifying the characteristics of the actual radio propagation channel.

2.2. Sensor Nodes

To get the full picture of deployed testbed, in this subsection we will describe the sensor nodes that were used in our research work.

The WSN is implemented using ZEBRA2411 modules from senTec Elektronik GmbH, based on the chip set ZRP1 developed by Freescale Semiconductor[5]. This module works in the 2.4GHz ISM frequency band and allows wireless communication over a distance of more than 1000m (line of sight).

ZEBRA contains a microcontroller, the High Frequency (HF) circuitry and a chip antenna with low noise amplifier (LNA) and power amplifier (PA) stages. An integrated Freescale HCS08 MCU serves as the base band controller. The used integrated timer/counter operates as well as the MCU with the 8MHz frequency. A protocol SMAC (Simple Media Access Control) has been used for communication between nodes, which were programmed using the Metrowerks CodeWarrior development environment from Freescale. Additionally, the ZEBRA modules (Fig. 3) can be connected to a host computer and communicate with it over a simple RS232 connection.

3. PROPOSED ALGORITHM

To improve the robustness of location estimation of an unknown node we used to place more unknowns nearby to the wanted one with the known distances to each other.

The mobile nodes, for which the positions have to be found, have a priori known distances to each other defined at the beginning of the experiment. Each node

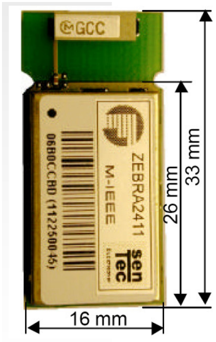

Fig. 3. ZEBRA2411.

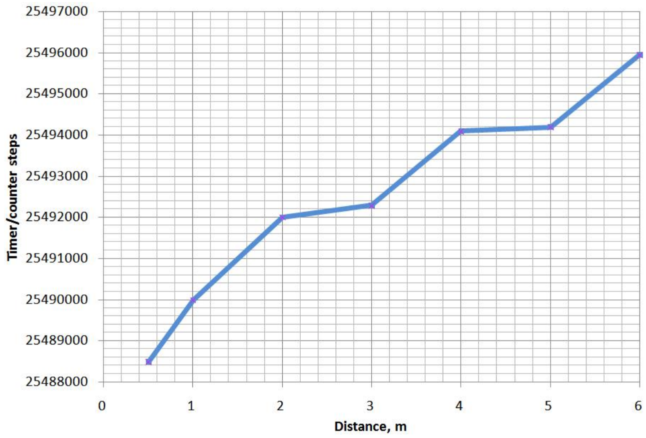

Fig. 4. Average values of the measured time-of-flight as the basic characteristic for distance measurement.

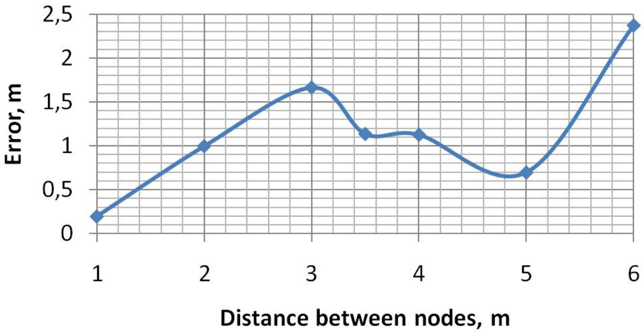

Fig. 5. Average distance error.

estimates its distance to the given anchors separately and calculates its coordinates. After the localization of each node we can refine the results using this additional information about the distances between unknowns. In such a way, we have more information about the node being searched and can calculate its position more accurately.

As a practical application example of this idea could be the known distances between nodes attached to the object being monitored or tracked. If we speak about tracking of a human body and attach three unknowns to his arm (wrist, elbow and shoulder), we can a priori measure the distances between wrist and elbow, elbow and shoulder. These paramenters stay constantly during the whole tracking time and can be used to refine the localization.

To prove the efficiency of the idea mention above we show in this paper the test results for the WSN with three anchor nodes and only two unknowns (Fig. 2). During the experiments the ToF measurement technique has been used. It is also possible to apply this algorithm to all the other localization schemes.

The ToF method mentioned above was not chosen accidentally. Our earlier research on ZEBRA platform has shown that the ToF-based localization algorithm gave the best potential for accurate position estimation even without any additional hardware[6]. Because of the poor internal oscillator frequency 8 MHz we had to modify the chosen SDS-TWR algorithm and repeat it 1000 times to get realistic results with average distance measurement error of 1.2 m.

The current research process has shown several more problems. Some of them are the finite tolerance of the device crystal reference frequency and the random media access delay. The first one has been solved with the short timer calibration at the beginning of the localization task. To remove the random media access delay we have developed a simple access algorithm to avoid the unpredictable delays during the distance estimation between network nodes.

The next section introduces the received experimental results.

4. EXPERIMENTAL RESULTS

As mentioned above, we have performed all the tests using just two mobile nodes. Basically, the experiment contains three main phases: determining the basic characteristic for the distance measurement, calculating the theoretical coordinates of each node separately and refining the results using the information about distances between nodes.

4.1. Basic Characteristic

Hundreds of tests have been completed to determine the basic characteristic for the distance measurement. The candidates among many others were minimum, maximum, average of measured time-of-flight and number of timeouts. For the indoor localization the average of measured time has been chosen as a basic characteristic, since it was determined as the most stable one (Fig. 4).

Because of the multipath propagation factor, the graphic of the average measured time is not very simple. Using this graphic we can compare the current measured value with the stored one and determine the distance between nodes. The experimantal average distance error is shown in Fig. 5.

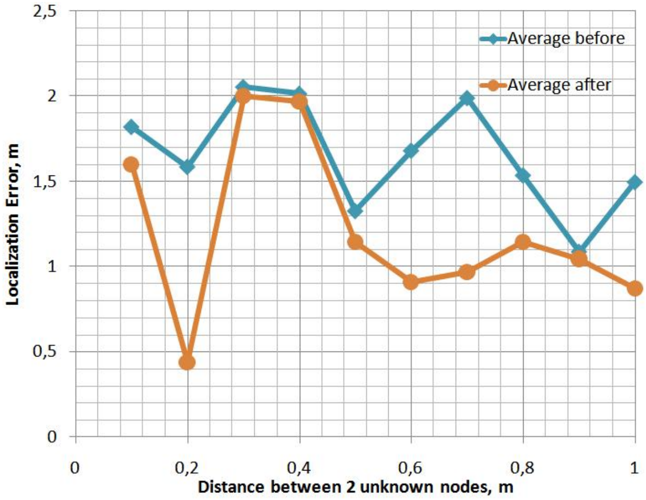

Fig. 6. Average localization error before and after refining.

4.2. Calculation of the Coordinates

After at least three distances to the anchors, for the two-dimensional case, are available, we can start the location estimation. For the computation of a node position we used the classical trilateration method. The equations (1) determine the theoretical coordinates according to our testbed topology. r_1, r_2 and r_3 are the distances to the first, second and third anchor respectively.

$$x = \frac{r_1^2 - r_2^2 + 5^2}{2 * 5^2}; y = \frac{r_1^2 - r_3^2 + 5^2}{2 * 5^2}; \qquad (1)$$

The trilateration was executed for each mobile node separately.

4.3. Improvement of Results

To improve the calculated coordinates, as mentioned in Section 3, we used the a priori measured distance between two mobile nodes. The following simple algorithm was developed. The euclidean distance between two calculated positions (s. Section 4.2) will be computed. If it differs from the real one, these positions will be drawn either together or apart along the line including both of the locations until the distance between new positions equals the real one.

In Fig. 6 the experimental results of the localization before and after refining for the distances between unknowns from 0.1 to 1 metre are shown. According to the graphic, the experiment confirms that the proposed improvement of location estimation is 1.4 times more efficient even using only two mobile nodes with a priori known distance between them.

5. CONCLUSION AND FUTURE WORK

Previous work in localization algorithms focus on individual accuracy of sensor position estimates without considering the destances between unknowns. In this paper, we proposed a novel improvement method for the sensor node localization in a highly dynamic indoor environment. The used location estimation is based on the ToF technique without the need of any additional hardware. The calculated average positioning error is about 1m, that is much better, for example, as the results received in [4] or [7] using the RSSI-based (Received Signal Strength Indicator) algorithms (the reported average positioning error over the whole observation time in [4] as well as [7] is more than 2m).

However, the proposed scheme has still very high energy costs: each localization takes more than 100000 sendings, that is about 20 seconds.

In terms of future work, we plan to increase the number of mobile nodes that have a priori known distances to each other. Ongoing and future research works concern with the analysis of the impact of the number of unknowns on the localization error. Moreover, the reducing of energy costs shall be investigated as well.

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