

An Adaptive Indoor Positioning Algorithm for ZigBee WSN

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ABSTRACT: The areas of positioning and tracking through Wireless Sensor Network (WSN) have received considerable attention recently driven by the requirement to obtain high positioning accuracy with minimum cost possible. A wide range of proposed approaches regarding the positioning area have emerged, however most of them suffer from either requiring an extra sensor, high power consumption, inaccessible indoors, or offer high positioning error. This paper presents a research and development of an adaptive positioning system for ZigBee WSN based on the Received Signal Strength (RSS) system. The proposed system is an efficient positioning system in both indoors and outdoors, where it offers reasonable positioning accuracy (0.1 – 0.6) meters, and achieves low power consumption. The proposed system has been validated through a number of real experiments using XBee modules.

Keywords: Positioning, Wireless Sensor Network (WSN), Zigbee, Localization

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1. Introduction

Wireless Sensor Network (WSN) has become a vital research area due to their wide ranging applications in military, safety, industrial and environment [1, 2, 3]. A WSN is a collection of sensor nodes organized into a cooperative network. Sensor nodes are small in size, low in cost, and have short communication range. Researchers have focused on diverse aspects of WSN, such as hardware design, routing protocols, data aggregation, and positioning. Positioning and tracking systems play significant role in a various number of applications including safety, monitoring, and controlling. Researchers have focused on two aspects when designing a WSN localization system: first, localization accuracy, and second, power consumption.

In spite of WSNs were not designed for the purpose of the positioning task, it is possible to determine the position of a mobile target with reasonable accuracy using the radio frequency. The Received Signal Strength (RSS) values obtained from any received packet can be used to estimate the distance between the transmitter and the receiver nodes, and therefore triangulate the position of a target node. WSN-based positioning systems can be categorized into range-based and range-free. The former requires attaching an extra sensor (GPS receiver, ultrasonic, or infrared) to each reference node in order to position the mobile target node, whereas the later locates the mobile target with no requirement for distance information. Range-free systems are more suitable for low cost and low- power sensor networks, but they offer low localization accuracy, whereas range-based systems offer efficient localization accuracy.

RSS positioning system may be categorized into two different schemes; the triangulation and fingerprinting. The former estimates the location of target node based on triangulating the RSS values from reference nodes (with previous knowledge about reference node locations). The later requires the collection of RSS values at several positions to form a database of location fingerprints.

In this paper, unlike the existing systems which mainly focus on simulation, an adaptive positioning approach is proposed practically based on RSS function. In which the location of target node is estimated through triangulating the RSS values obtained from reference nodes. Moreover, a positioning factor is computed before starting the tracking process in order to enhance the positioning accuracy. The proposed system in this paper consists of two phases: the initialization phase, and the positioning phase.

In this paper, the following terms are used:

- **Reference node:** the node with a predetermined position.
- **Target node:** the node with unknown position, the position of this node is estimated using one of the positioning methods.
- **Positioning method:** the way used to estimate the position of the target node.

The rest of this paper is organized as follows: Section 2 briefly discusses the related existing systems. In Section 3, the adaptive positioning system is presented. Section 4 discusses the implementation of the proposed system and then in Section 5, the system is evaluated through real experiments. Finally, Section 6 draws conclusions and presents suggestions for future works.

2. Related Works

A wide range of WSN-based positioning and tracking systems have been researched and addressed in [4, 5]. In this section, the most relevant and foremost approaches are discussed.

RSS system have been researched and addressed in a wide number of research papers. The system proposed in [6] includes a distributed hybrid algorithm based on divide and conquer. In [7], authors presented a localization system for tracking the location of mobile robots. The system implemented in [8] includes experimental results of the deployment of a WSN for inventory and positioning of mobile assets in an indoor building, whereas the authors of [9] proposed an integrated real system based on WSN for patient monitoring, localization and tracking.

In [10], authors presented a hybrid localization system based on RSS and inertial systems. Authors of [11] proposed a procedure and modeling of location estimation for object tracking in WSN using RSS system. In [12] authors proposed an online tracking system for ZigBee WSN using RSS system. Authors of [13] proposed autonomous mobile robot localization based on multisensor fusion method. An efficient indoor localization system is proposed in [14] based on the RSS system. A distributed positioning system is proposed in [15]; real experiments were conducted to obtain the localization accuracy.

A wide range of RSS techniques have been proposed and implemented recently, however they lack to one or more of the following issues:

- Low localization accuracy.
- High power consumption.
- Complicated initialization phase.

In this paper the RSS system is considered, which is considered as range-based systems, in spite of RSS systems do not necessitate adding extra sensor device and it is based on the content of the packet received from reference nodes.

3. System Architecture

The proposed system in this paper aims to increase the positioning efficiency in terms of positioning accuracy and power consumption. The proposed system is based on the RSS approach, in which the signal strength values are converted into distances in order to triangulate the target node's position. Figure 1 summarizes the positioning system proposed in this paper.

The proposed positioning system is divided into two main phases: the initialization phase, and positioning phase. In the

initialization phase, the location of reference nodes are determined and saved to a common database, and the positioning factor $F_{i,j}$ is estimated between each pair of reference nodes (eg. between reference nodes i and j) as implemented in Equation 1. The positioning factor is estimated between the reference nodes before starting the positioning algorithm, whereas in the positioning phase, the position of target node is estimated through applying a triangulation system through using the RSS values and a positioning factor. Figure 2 presents the initialization phase of the positioning system.

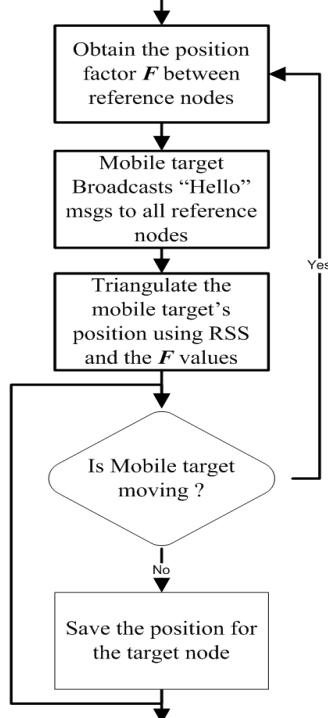


Figure 1. The flowchart for the proposed positioning system

$$f_{i,j} = \frac{d}{rss} \quad (1)$$

where $f_{i,j}$ is the poisoning factor between reference nodes i and j . d is the distance between reference nodes i and j , and rss is the RSS value between reference nodes i and j .

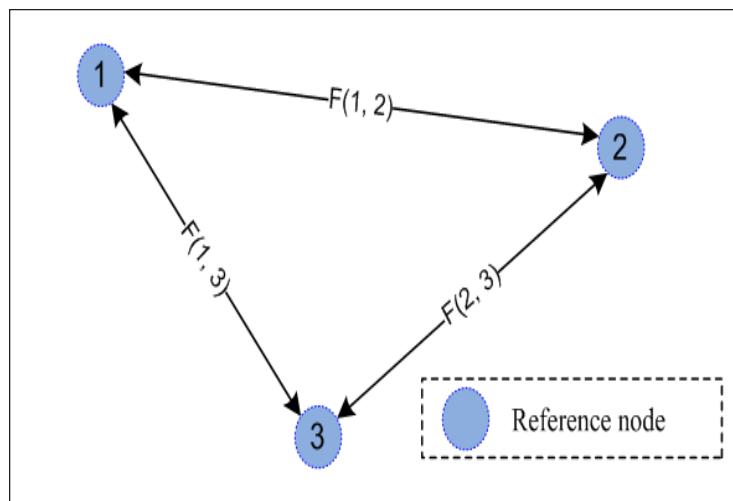


Figure 2. Computing the positioning factor in the tracking area

Through the positioning phase, an average factor is estimated based on Equation 2. The target node sends “Position” message to all reference nodes in its range. Each reference node replies to the target node with a “Reply” packet, and then the target node obtains the *RSS* values from each packet received from reference nodes. The target node afterwards computes the final distance value *fd* between the reference and target nodes through applying Equation 3. The positioning phase is presented in Figure 3.

$$pf = \frac{\sum_{n=1}^{l=1} f}{n} \quad (2)$$

$$fd = rss \times pf \quad (3)$$

where the *pf* is the average positioning factor in a given area, and *n* is the total number of obtained positioning factors from the previous stage.

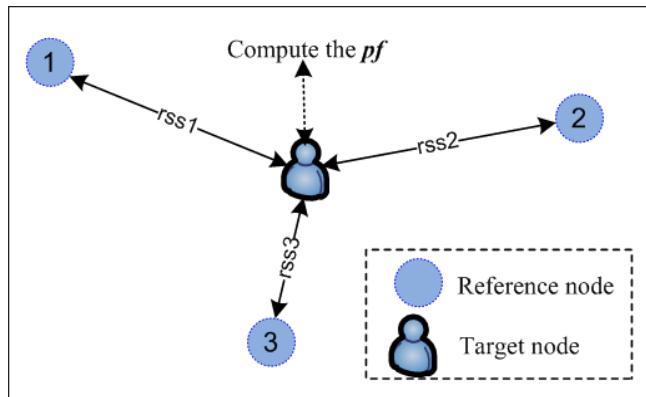


Figure 3. Positioning phase

4. System Implementation

In this section, the experimental test-bed including the ZigBee protocol, reference, and target nodes design are discussed. Our experiment test-bed (5 * 6 meters) consists of 3 reference nodes and one mobile target node.

4.1 ZigBee Protocol

ZigBee is low power consumption, low cost and low data rate wireless communication standard designed to be deployed in home automation and remote control applications. ZigBee protocol offers three main roles; coordinator, router and end-device. Only one coordinator is required for each ZigBee network, since it starts a network formation. ZigBee router is an optional network component where it participates in multi-hop routing of messages. Finally, ZigBee end-device is utilized for low power operation and it's not allowed to participate in routing of messages. In our real experiments, router nodes play the role of reference nodes, whereas the coordinator plays the role of target node. A ZigBee network with three main roles is depicted in Figure 4.

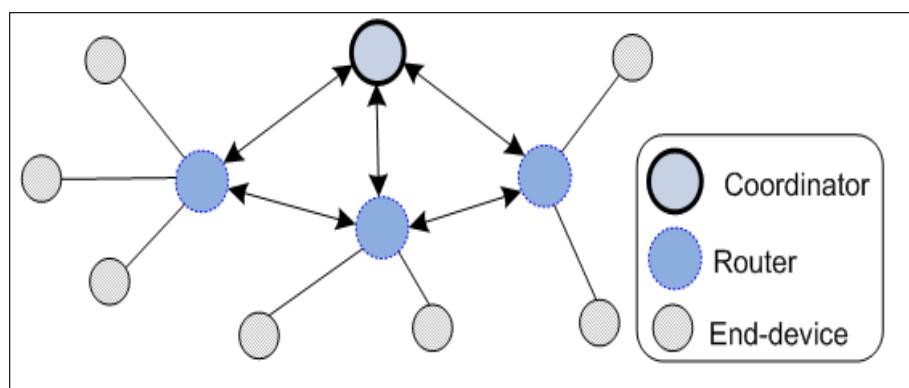


Figure 4. ZigBee network standard with three roles

4.2 Reference Node Model

In the experiment test-bed, XBee Series 2 module was used for both the reference and target nodes as depicted in Figure 5. The reference node consists of one XBee module and 2 AAA batteries, as shown in Figure 6. In the initialization phase, each reference node has to exchange “Hello” messages between each other, in order to determine the positioning factor value. In the positioning phase, reference nodes will exchange messages with the target node to obtain the RSS values.



Figure 5. XBee series 2 module

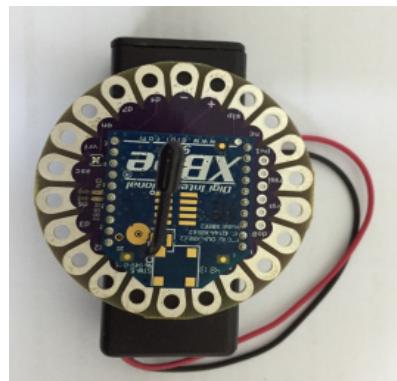


Figure 6. Reference node model

4.3 Target Node Model

The target node design is the same as the reference node model, however additional sensor is added (accelerometer sensor) in order to detect the movement of the target node. Therefore, the target node does not have to continuously exchanging messages with reference nodes while it is not moving. However, as soon as the target node has moved, then it starts exchanging packets with reference nodes in order to determine the new location of the target node. Target node model is presented in Figure 7.

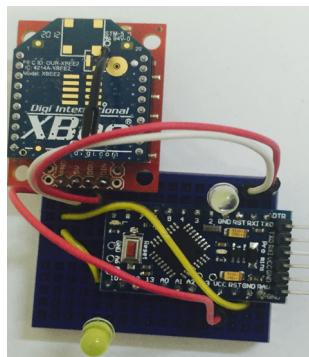


Figure 7. Target Node Model

5. System Evaluation

In order to verify the validity of the proposed positioning system discussed in this paper, two poisoning systems were implemented and tested: First, the regular poisoning system based on triangulation RSS values. Second, the poisoning system proposed in this paper. The poisoning system was evaluated through measuring the positioning error and the total number of transmitted packets.

5.1 Positioning Accuracy

In this section, the localization error was estimated through adopting two positioning systems. Figure 8 shows the positioning accuracy for a several number of test points, and presents the actual and estimated positions through applying two systems. Figure 9 presents an evaluation for the proposed system in four areas (indoor, indoor complex, outdoor, and outdoor complex), in which in each environment, the average positioning error was estimated.

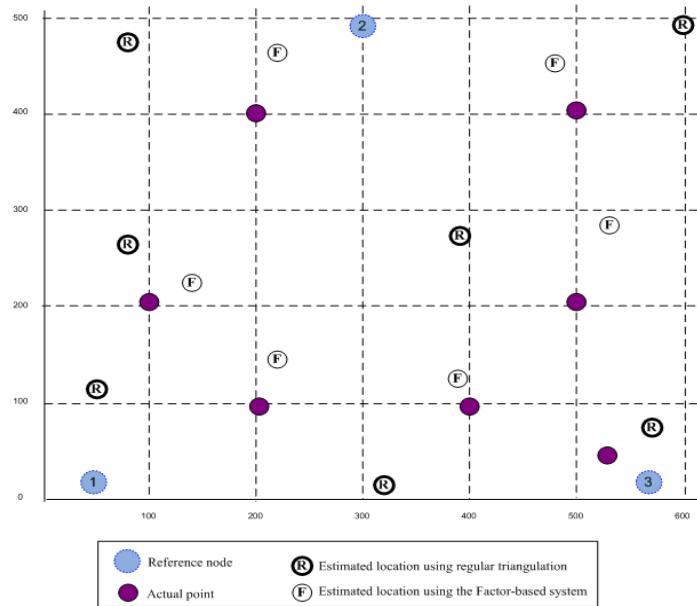


Figure 8. Estimation the positioning accuracy in two systems

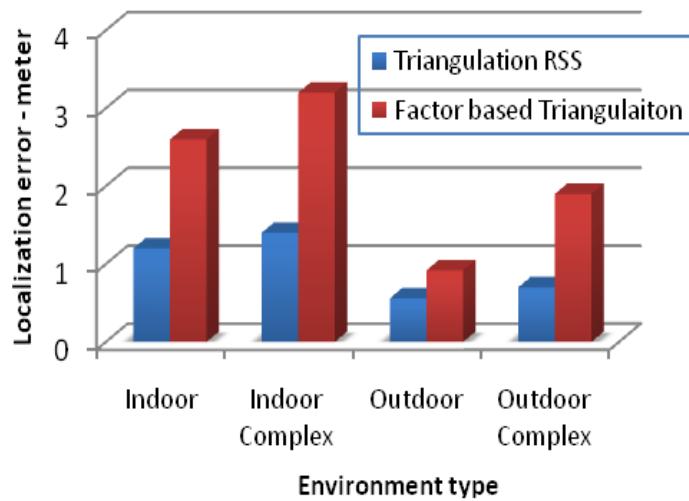


Figure 9. Estimating the energy consumption in two systems

5.2 Power Consumption

Another significant factor when using a positioning system through WSN is the power consumption. In this section, the total number of transmitted packets is evaluated in the two systems. As presented in Figure 10, the proposed system in this paper achieves low power consumption than the regular positioning system. This is because the proposed system in this paper is based on accelerometer sensor in which can detect the movement of the target node and then starting receiving packets in order to obtain the RSS values from the received packets.

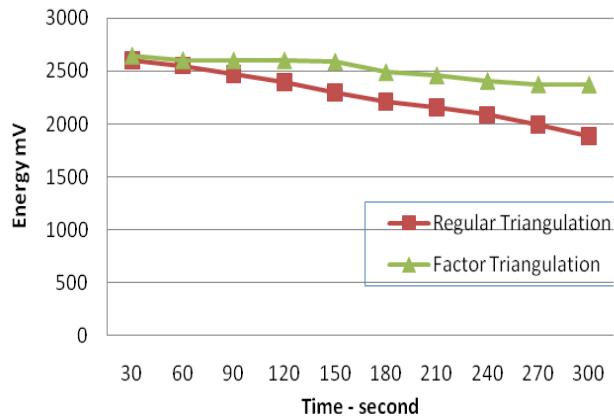


Figure 10. Estimating the energy consumption in two systems

6. Conclusion & Future Works

In this paper, an adaptive positioning system for ZigBee WSN has been designed, and experimentally tested through a number of real experiments. The new positioning system can be adapted in any environment including outdoors and indoors. It also offers low positioning error compared to the regular positioning system and achieves low power consumption due to the integration of accelerometer sensor into the target nodes. For future work, the proposed system will be tested in various numbers of indoor places.

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