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LOCALIZATION TECHNIQUES IN WIRELESS SENSOR NETWORKS

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Abstract. The drawback of wired networks is that if we want to communicate on it wired communication has to be established. Actually, wired communication limits our mobility. In wireless networks there is no need for wires, we can connect our devices to the network. Since wireless network applications have been deployed widely, wireless sensor networks have become an important research area.

The development of wireless technology enabled us to use cheap and small sized sensors in short range communications. A sensor network consists of several nodes that are low in cost and have a battery with low capacity. Localization in wireless sensor networks is a vital issue, i.e. determining the position of a given device in the network. Location information of mobile nodes is a demand in many wireless systems.

Localization involves determining the location of the sensor node based on other sensor nodes with known locations. The node can calculate its distance and/or angle between itself and the reference points. In the 2D space, if a node knows its distance from three reference points, its position can also be determined. One more reference point is needed in the 3D space to determine the current position of the target device. The paper deals with various techniques of localization used in wireless sensor networks.

Keywords: wireless sensor network, localization, anchors, mobile nodes

1. Introduction

Distributed sensor networks have already been applied for years, but wireless sensor networks [1] have recently been focused on. The rapid development of wireless sensor networks opened the door to create low-cost, low-power and multifunctional sensor devices that are integrated with sensing, processing, and communication capabilities.

Estimating the location of a sensor is a critical task in sensor networks. There exist several location estimation techniques used in sensor networks. In the sensor network there are two types of nodes:

- nodes that know their location (they are fixed nodes and are often called anchor nodes),
- and some other nodes (called mobile sensor nodes) having the ability to estimate their location using information about their position (i.e. coordinates of a node, properties of a signal such as signal strength [2], time difference of arrival, etc.) received from the fix nodes.

After performing such measurements for different nodes, the sensor node has to combine all this information for estimating its location. The location estimation algorithm has two main requirements:

- the sensor nodes should avoid complex and time consuming computations, which would deplete their energy supply rapidly,
- the computations should take into consideration the error in the measurements, which can be significant.

Several approaches use computationally demanding methods, such as convex optimization [3], systems of complex equations [4], minimum mean square error (MMSE) methods, and Kalman filters. In these approaches, the measurement model is not adequately analyzed and the error is assumed to be small, which is not the case in most real applications of sensor networks.

Other algorithms estimate the location of a node using the Received Signal Strength Indicator method, which is the most realistic model for sensor network communication [5].

Many localization techniques used in sensor networks can be applied in a variety of wireless networks with which a wireless node can estimate its distance or its relative location to a reference point. In the past few years, several algorithms for solving the localization problem have been proposed.

2. Basis of localization

A sensor node (often called mote) is practically a device in the wireless network that is capable of data processing, information gathering and establishing communication with the other nodes in the network.

Wireless localization techniques [6] are used to give the positions of the mobile nodes considering the known location information. In 2D and 3D space reference points are needed to determine the position of a mobile device.

Using reference points, the angle and distance of a device can be calculated from the reference points. Observing the well-known scenarios it is a widely used technique that a mobile device computes its own location according to the position information of fix devices. These fix devices are also called anchors (see Figure 1).

Many applications of sensor networks require knowledge of physical sensor positions. Location information can be used not only to minimize the communication but also to improve the performance of wireless networks and provide new types of services.

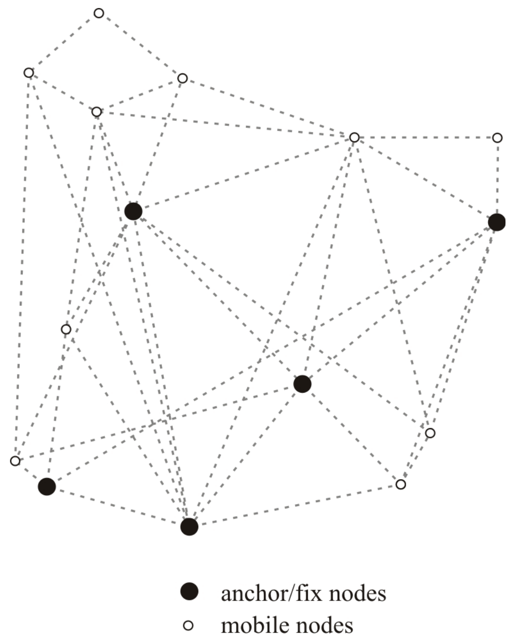

Figure 1. Nodes in a self-organizing wireless sensor network

The positioning algorithm must be distributed and localized in order to scale well for large sensor networks. Often, price, size and the precision of the localization are the main factors when choosing the position determining technique. The wireless solution generates a number of problems in connection with localization:

- a number of measurements have to be done for determining the position of a mobile node,
- choice of the localization technique depends on the given environmental conditions,
- wireless sensors are cheap devices but have limited computation capabilities,
- localization techniques need implementation with minimal hardware investment considering the given measurement possibilities,
- in many cases sensor networks should be designed for using them in multi-hop networks.

Localization algorithms used in large-scale ad-hoc sensor networks should meet some requirements. These algorithms should be

- self-organizing,
- tolerant to node failures,
- energy and computation efficient (little consumption and low-computational steps).

The most important and user-oriented factors are the accuracy and the precision of the given positioning algorithm.

2. Types of localization

Localization can be classified in many aspects (Fig. 2). Localization techniques can be divided into two categories based on the communication between nodes:

- centralized localization techniques,
- and decentralized localization techniques.

Centralized localization techniques involve data transfer to a central node in order to compute the location for each node. Communication with centralized computing is expensive, and sending data serially by time within the network introduces latency, and it consumes energy and network bandwidth as well.

Decentralized or distributed localization techniques depend on each sensor node being able to determine its location with only limited communication with nearby nodes. Distributed localization techniques do not require centralized computation.

Distributed localization techniques involve two kinds of techniques such as [7]:

- range-based,
- and range-free localization techniques.

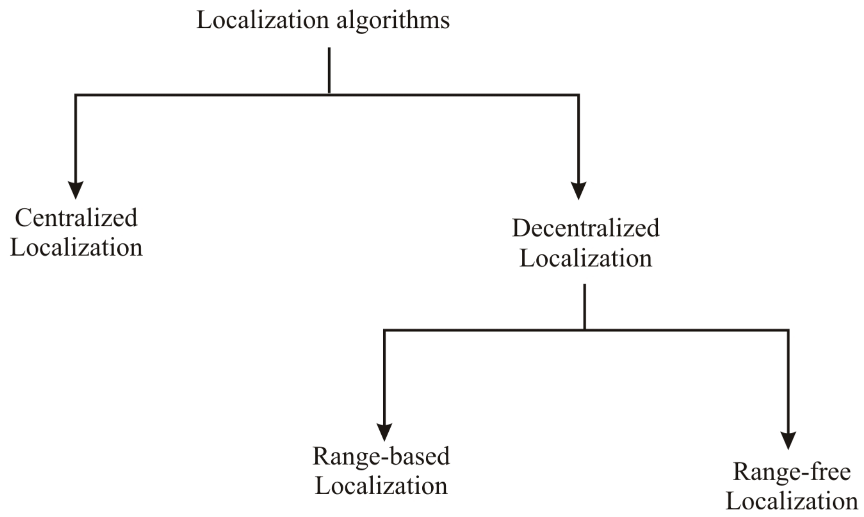

Figure 2. Types of localization

Range-free methods calculate the distance between two nodes in a number of hops and do not take into consideration any coordinate system. In range-free algorithms [7] nodes can estimate their position according to the known localization information of the neighbouring nodes. In this case, it is assumed that not all the nodes have distance, angle or other metric information. Position of the target node can be calculated as the 'centroid' of the surrounding fix nodes or it can be derived from geometric relations.

Range-based methods estimate distance and direction of two nodes from a measurement (i.e. angle of arrival measurements, distance related measurements and received signal strength measurement). Range-based algorithms make distance estimations between the fix and mobile nodes. The positions of a group of nodes in the wireless network are known by means of simple distance measurement. The target nodes try to estimate their position relative to the fix nodes.

3. Localization methods

There are several advanced localization algorithms based on machine learning and data fusion techniques.

3.1. Weighted centroid method

The idea of the centroid method (Fig. 3) is that the position of the target device is calculated by the known positions of the anchor nodes in the transmission range. Although this algorithm is very simple, efficient, easy to implement and needs low computational operations, it produces a lower level of precision. It is widely used in such dense sensor networks – there are fix nodes having known positions – that contains overlapping ranges. The known positions can be weighted, so the unknown position can be calculated as follows:

$$\tilde{x} = \frac{\sum_{i=1}^{N} \omega_i x_i}{\sum_{i=1}^{N} \omega_i} , \tag{3.1}$$

where N is the number of anchors in the transmission zone, x_i is the position and ω_i is the weight of the *i-th* fix node. An adequately selected weighting method can result in more precise information about the position of the given node.

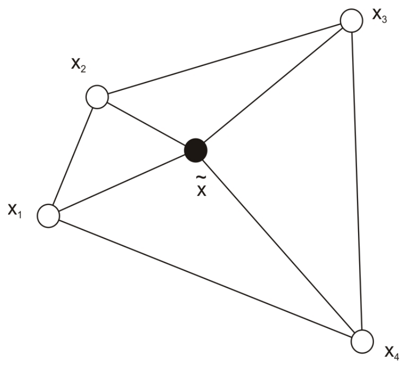

Figure 3. Centroid method

In practice, mobile nodes broadcast messages that are received by the fix nodes in the transmission range. This message sending and receiving mechanism helps the nodes to establish connection between themselves.

According to the connection metric, the weights can be calculated as follows:

$$\omega_i(t) = \frac{n_{received}^{(i)}(t)}{n_{sent}^{(i)}(t)} \quad , \tag{3.2}$$

where t is the duration of transmission of the broadcast messages, $n_{received}(t)$ and $n_{sent}(t)$ are the number of received and sent messages during t. Only those nodes will be considered that reached a given ratio – usually over 90 %.

3.2. Bounding box method

The bounding box method (Fig. 4) is a simple and low computational localization technique. The accuracy of this technique is limited, but it is simple, fast to implement and to run on sensor nodes.

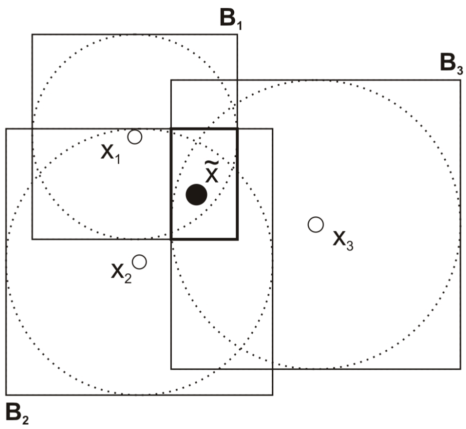

Figure 4. Bounding box method

The main concept is that boxes are created around the transmission range of the nodes, and the target device is located in the intersection of these boxes. The distance between the target device and the *i-th* fix node can be estimated by the side length of the *i-th* bounding box. The result of the position estimation is the intersecting box or its centre:

$$\tilde{x} \in \left\{ \bigcap_i B_i \right\}, \tag{3.3}$$

where B_i is the box created around the x_i-th node, and the side length of the box is twice the transmission range.

3.3. Point in Triangle method

The Point in Triangle method (Fig. 5) is a range-free localization scheme. In this approach the target device sends a beacon message that is received by the fix nodes. After that, the anchor nodes create communication triangles, i.e. they form all the possible subsets of three nodes.

$$\begin{aligned} \tilde{x} &\in T_1 = \{x_1, x_2, x_3\} \\ \tilde{x} &\in T_2 = \{x_1, x_2, x_4\} \\ \tilde{x} &\in T_3 = \{x_1, x_3, x_4\} \\ \tilde{x} &\in T_4 = \{x_2, x_3, x_4\} \end{aligned}, \tag{3.4}$$

where T_i is the *i-th* subset that forms the *i-th* triangle. In each triangle the so-called *PiT* test decides whether the target device is in the current area or not.

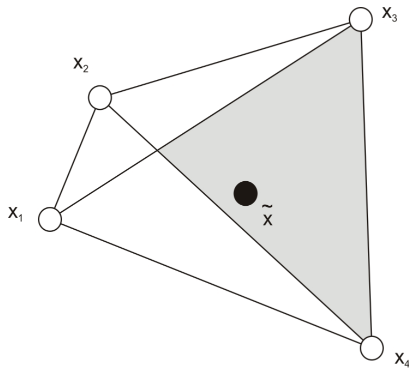

Figure 5. Point in Triangle based localization

Finally, the intersection of these areas will produce the position of the target:

$$T_{target} = \bigcap_{i=1}^{4} T_i \; . \tag{3.5}$$

The main disadvantage of this method is the great number of computational steps, as the PiT test must be done for all the triangles to examine whether the current area includes the target device or not.

Actually the PiT test is based on geometry: for a given triangle the mobile node is outside the triangle if the gradient of the distance estimated to each vertex of the triangle is positive, i.e. the mobile node moves farther away from the points.

Conclusions

In wireless communication the localization of mobile devices is a major problem. Location-based applications are very close to our daily life; it is a process to compute the locations of wireless devices and relies on the geometric relationship of network nodes.

As outlined in the paper, the positioning method should not increase the cost and complexity of a sensor because an application may require a great number of sensors. Communication and collaboration between nodes should be minimized for achieving energy saving. Most wireless sensor networks have a limited computation ability, so the main goal is to implement and run simple distance estimation functions. The estimation must be very close to the real position. If the position estimated is close to the average value, then estimation is said to have great precision. When the position estimated is almost the same as the real position, the degree of accuracy is very high. Absolute precision can never be achieved, although a well-chosen estimator can improve the accuracy.

Precision and costs may contradict each other, but these are important factors in location-based services. Extra hardware may be required to achieve higher localization accuracy using the existing localization algorithms that generate higher cost.

Fusion of techniques can improve localization precision and reduce the variance of the position estimation that may minimize communication and the computation overhead of the sensors.

As regards further work, software development is planned to simulate localization techniques presented in the paper for comparing them in several aspects such as speed, time of running, performance and maintainability. The simulation is expected to provide useful results for providing solution to performance and energy optimization in the localization process. After drawing conclusions from these results an algorithm is planned to be recommended which is optimized for performace, as well as to give correction factors for the localisation methods described in the paper.

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