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A Review of Localization Techniques for Wireless Sensor Networks

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ABSTRACT

One problem in wireless sensor network technology is localization problem. In the most applications, the data collected by the network without location information isn't useful. Location information has an important role in both networking and application domains of wireless sensor network. This paper surveys the localization algorithms and proposes a different taxonomy based on key features. In additional, it introduces the important factors to validate the performance of localization techniques.
KEY WORDS: *wireless sensor networks, localization algorithm, learning, range, anchor.*

1. INTRODUCTION

Wireless sensor network (WSN) has a wide range of applications, including target tracking, vehicle tracking, event detection, people monitoring, forest fire detecting [1], routing and, etc. In all of these applications collected data are not usable without knowing about the location of an event which is the location of the sensor. Localization is an essential issue in the WSN technology. Localization problem refers to the process of estimating and computing the positions of sensor nodes [2]. The importance of this fact led researchers to seek a solution for localization problem. One easy way is manual configuration but this is impractical in large scale or when sensors are deployed in inaccessible areas such as volcanoes or when sensors are mobile. Another way is to add global positioning system (GPS) to each sensor. GPS has affected by heavy trees and buildings because it requires line-of-sight between the receiver and satellites. So, it has low accuracy due to poor signal reception. In additional, using GPS in large scale is not cost efficient. Therefore, several localization algorithms introduced to solve localization problem. This literature categorizes localization techniques in a proposed taxonomy with new viewpoints and new aims. The rest of this paper is organized as follows. Section 2 discusses related work. Section 3 describes the process of nodes localization and signal modality. It also investigates measurement techniques, absolute and relative location for nodes. Section 4 introduces taxonomy for localization algorithms. The aim of section 5 is clarifying some of the most important evaluation factors. Section 6 sets out the open issues for localization techniques. In section 7, the paper is concluded.

2. Related work

WSN localization is an active area of research with several surveys [3], [4], [5], [6], [7] on this topic. But there are some important techniques which are not discussed in them. In other hand, this paper categorizes localization techniques in a new proposed taxonomy. This taxonomy helps to distinguish different schemes based on key features and also helps to understand the operation of varies localization algorithms. In another view, it is usable for who wants to implement a new localization algorithm. Then, the paper also introduces key factors to evaluate localization algorithms. It is usable to validate a new algorithm or compare existence algorithms in order to find the best for an especial application.

3. Localization process

A localization algorithm localizes sensor nodes based on input data. If there is any anchor available in the network, the most common inputs are the location of anchors. Other inputs are connectivity information for range free techniques, distance or angle between nodes for range based techniques that calculated based on signal modality. Generally, the output of localization algorithm for anchor based techniques is absolute coordinate and for anchor free methods is relative coordinate. Each step will be discussed in the next parts of the paper (Fig. 1).

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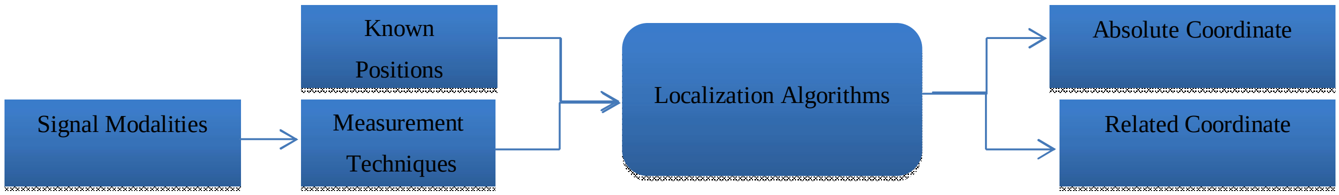

Fig.1. Process of a localization algorithm.

3.1 Signal modality

Signal modality has high effect on the accuracy of location estimation. Choosing a sufficient signal type depends on the various factors such as node hardware, the application and environment. Using additional hardware is not proper in terms of cost and energy. Different environment has various effects on the performance of location determination. For example, in humidity air, acoustic performs better than radio signal, because, moisture absorbs and reflect high frequency radio, when it has little effect on the vibration sound. Furthermore, different applications make different constrains to choose a signal type. For instance, in military applications, nodes should localize in the silent manner, so radio frequency with silent property is a good choice. Acoustics also used in many localization approaches like Ultra in cricket approach [8] and audible in beamforming [9]. One other signal type is infrared (IR) signal which is not usable for outdoors because of high attenuation and also its difficulty to read when sunlight is available. All sensors have onboard radio hardware. Frequency, phase, strength of RF is used for location estimation in many applications [10].

Light is also usable for some approaches like spotlight method [11]. Here, the drawback is, line of sight required, a powerful light source and special hardware for source also is needed.

3.2 Measurement techniques

Each sensor node in the network transmits a signal. This signal will be processed on the receiver nodes in order to measure the ranges or in order to count the hops. Existence techniques can categorize in two categories. Range based and Range free, which are described below.

Range based algorithms: Range estimation methods measure the distance or angle between two neighbor nodes. The famous methods of this group are Time-Of-Arrival (TOA), Time Difference of Arrival (TDOA)[12], Angle of Arrival (AOA)[13], or the Received Signal Strength Indication (RSSI)[14]. These methods use analyzing the phase or time difference to find the measurement. Extra hardware requirement, costly, complexity, noise sensitivity and additional energy consumption are the most important drawbacks of these methods.

Range-free algorithms: In order to be independent of hardware and ranging error, researchers developed Range-free techniques. They are also cost effective. They use only connectivity information and hop counts between nodes to estimate the location of nodes. These methods are adequate to many applications.

3.3 Localization algorithms

In the third step, the localization algorithm is executed. The output of this algorithm is in form of absolute or relative location.

3.4 Absolute localization

Most of the anchor based groups have absolute coordinate output. The absolute location of nodes defines by position-aware nodes. In some cases, the absolute locations obtain from relative locations by using linear transmission and some references. The absolute result is easy to understand and use.

3.5 Relative location

Mostly, outputs of anchor-free algorithms are relative coordinates. Relative location is the relationship of distance and angle between network nodes. This is proper for some applications. The relative coordinate of nodes defines by manual configuration or references. It can also transform to the absolute localization.

4. LOCALIZATION ALGORITHMS

Based on the inputs data, a localization algorithm estimates the location of nodes in the network area. Inputs can be range estimation with or without the location of beacons or access points. In the continuous, available algorithms are classified in taxonomy (Fig. 2).

They are categorized into two main groups based on learning criteria: Learning based and Non- Learning based approaches, which are described below.

4.1 non-learning based localization algorithms

Most of the localization algorithms are non-learning based. These groups classified into anchor based and anchor free classes. They will be expanded in continuous.

4.1.1 non-learning anchor based localization algorithms

Anchor refers to the nodes which are aware of their positions because of adding GPS or manual configuration (aka beacon, landmark and merit). Anchor nodes are used in some algorithms to estimate the location of other nodes which don't know their positions. Using anchors help to have better accuracy. In anchor based schemes the accuracy of location depends on the number of anchors and their distribution in the network. Several of these algorithms suffer from scalability and wide flooding. Anchor based algorithms can be deployed in the fixed, mobile or hybrid networks.

Fixed networks contain of static sensor nodes and they are used to localize non-aware nodes. Hybrid Networks consist of static nodes and mobile beacon acts as a static one (broadcasting its accurate position) and represents many virtual static beacons. The goal of these schemes is to localize static nodes. Mobility makes WSNs more flexible and enables more possible applications. However, makes additional challenges.

Latency is the first issue in mobile wireless sensor networks (MWSN)s. Another problem is Doppler shift. This problem happens when transmitter moves relative to the receiver. It causes frequency shift and makes error in measurement. The shift in frequency is related to the speed and position of both transmitter and receiver nodes. In addition to above, there is another challenge available in localization techniques with line of sight (LOS) requirement. It is possible that a sensor moves from a position with good LOS to a position with bad LOS. So, it's required to ensure LOS availability for mobile nodes. Localization algorithms in a wireless sensor network can be implemented in centralized, locally centralized and distributed manner.

Centralized implementation: In these approaches, all the information (for example, connectivity and pair wise distance measurement) about the entire network is sent to a central unit to analysis, and then computed positions are transported back into the network. Sending all information to the unit sink causes single point of view and bottle neck problem.so it is more accessible for small scale area networks. It is simple and easy to implement. Because of existence of global information, it is more accurate than other implementations.

Locally centralized implementation: In these techniques two or three central units are available. It is proposed as a solution to solve high communication overhead and scalability problem of centralized approaches.

Distributed implementation: In these algorithms, all the relevant computation is done on the sensor nodes themselves. So It is harder to implement but computational efficient and more flexible for large scale networks.

All algorithms in the non-learning category use Euclidean properties to localize the sensor nodes. The most important are Triangulation, Trilateration, Multilateration and Proximity based.

The methods which are proposed in [15-21] are in the group of anchor based and non-learning localization algorithms. Convex position algorithm [16] is a centralized localization algorithm for fixed networks. This method is based on semi-definite programming with high computation cost. This algorithm is executed by a single centralized node. So, it is not feasible for many ad hoc applications. CBLALS method [20] is a locally centralized localization algorithm for fixed networks. It uses ultrasound and RF signals with TDOA measurement technique to localize indoor sensors. In more details, CBLALS establishes cluster on the whole network by improving tri-color method. Three-dimensional localization performs on each cluster. Then, one head beacon is chosen for each cluster, based on some rules. Finally, the local coordinate of each cluster will be transformed to global coordinate by head beacons.

In DV-hop algorithm [18], at the first step all anchors flood their location to the network via a message. The massage is propagated hop by hop and counts the hop count from anchor to node heard. Each node has a counting table and maintains the minimum number of hops that is away anchors. Anchor nodes calculate average hop-distance and send it back to the network as correction factor. When a non-anchor node gets correction factor from nearest anchor, uses it to estimate its distance to anchors. Then, node performs trilateration to estimate its location.

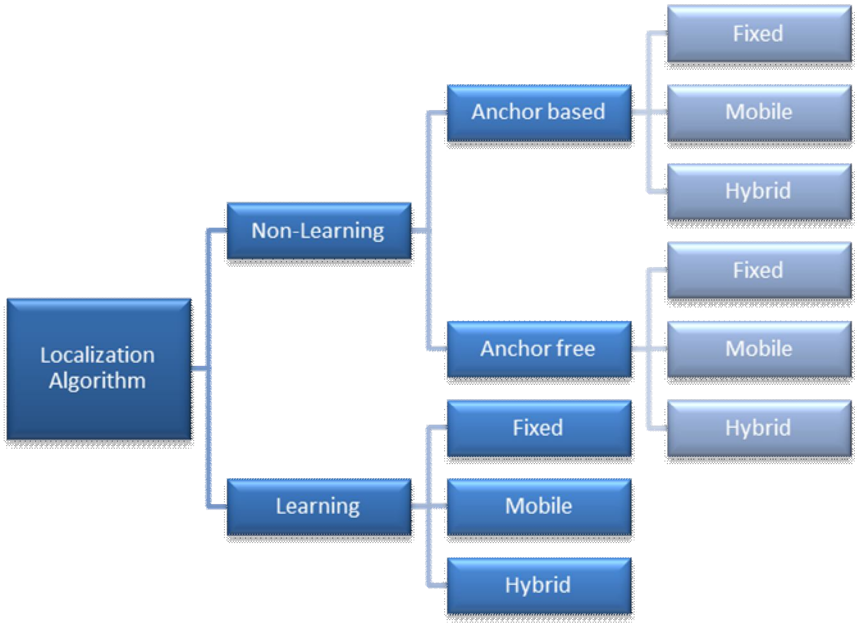

Fig.1. The proposed taxonomy for localization algorithms

The proposed algorithm given in [19] is called distributed grid-based transmitting power (DGL). In this technique, anchor nodes can change their communication range by increasing their transmitting power. Each node establishes a rectangular coordinate system and divides it into square grids.

Distributed Range-free Localization (3D-DRL) [21] is a technique for three dimensional wireless sensor networks under irregular radio propagation environment. The interested area is divided into cubic cells. Each anchor votes for each cell. Each non anchor node estimates its location by using the average of the center of gravity of cubic cells with highest votes.

4.1.2 non-learning anchor free localization algorithms

In contrast to anchor based, this category has not even one anchor node. In these schemes instead of finding the nodes' position, the algorithm finds relative positions of the nodes in the coordinate system by a reference group of nodes (anchors).

These approaches can be deployed in fixed, hybrid and mobile networks with the same properties as mentioned in the last section. There is also many localization techniques implemented based on Centralized, Locally Centralized and Distributed.

The methods which are given in [22-25] are in the group of anchor free and non-learning localization algorithms. Basically, the multi-dimensional scaling (MDS-MAP) technique uses data analysis and information visualization to display distance-like data in geometrical visualization. This algorithm computes the shortest distance between all pairs of nodes and then makes a distance matrix and applies MDS to construct relative location of nodes. If there was sufficient anchor numbers available, it can estimate absolute nodes' location by transforming relative locations. MDS requires global information and it has high communication and computation cost. IMDS-MAP approach [23] is based on MDS-Map method. It is locally centralized algorithm for large scale networks and accuracy required.

4.2 learning based localization algorithms

In previous sub-section, we mentioned non-learning based approaches but in this section we will classify a number of localization techniques that employ the concepts from machine learning. Localization techniques based on learning approaches are interested because of having simple implementation and modest requirements. The input of learning approaches can be signal strengths or hop-count information which can obtain at no cost. Generally, machine learning based localization algorithms function in two phases: offline training phase and online localization phase.

In the first phase, the training information gathers from the network. Learning approach runs on the information and the result is a predicted model. After that, in the online localization phase, any sensor can use this model to localize itself without knowledge about other sensors. This property makes the learning based localization algorithms cost efficient, fast and low computation. However, it has its own limitation; the accuracy of algorithm depends on the number of training data which is produced by beacons. Therefore, more beacons make more accuracy and more cost for algorithm.

According to our knowledge there are only anchor based techniques in this group. And anchors are used to make training information for learning localization algorithms.

In addition of using learning concepts in fixed networks, it is also sufficient for dynamic sensors.

As mentioned before each node can determine its position individually in distributed manner. In additional, past information is useful in the learning procedures. So, such algorithms are suitable for target tracking especially where the information about target is sparse. In this case, Euclidean approaches are not useful.

Generally in hybrid case, there are several access points and some mobile nodes available. The goal is to localize mobile nodes.

The localization algorithms in this field can implement in Centralized, Locally Centralized and Distributed schemes. Most of them are based on kernel functions to solve the localization problem.

LSVM technique is [26] is a distributed algorithm based on SVM algorithm for fixed networks. Connectivity measurement is used as training data for learning machine. Connectivity information makes the algorithms to be applied for large network area.

The proposed method given in [27][28] are mobile network localization algorithms for indoors. These two algorithms are based on RSS information. They assume that direct signal from all beacons are possible for nodes. So these algorithms are not applicable for large scale networks.

5. Evaluation of localization algorithms

In the last sections, we categorize different algorithms in the proposed taxonomy in order to help researchers for designing a new localization algorithm or distinguishing the existence approaches and identifying the key efficient factors. After new algorithm implementation, or for choosing a proper existing localization approach for specific application, it is very important to validate it.

There exist a large number of factors which affect the performance of localization algorithms. But, there are not standard criteria as evaluation for localization schemes. This part tried to introduce the more important criteria to compare and validate the localization algorithms.

Accuracy: It is the most important key for location evaluation. Most of the application needs high accuracy.

Scalability: Scalability is an important factor to validate the localization algorithm. As mentioned in the last section, Centralized approaches suffer from scalability. In contrast distributed algorithms are suitable for large scale networks.

Robustness to Failure and Error: Localization algorithm should be robust against node failure and Error and noise in the input data.

Coverage: One other significant factor key is coverage. It means how much of the network can be localize with the algorithm. There is also attention on the simplicity of adding another node to the network after completing the initial localization algorithm.

Cost: The cost of localization technique refers to several items, including, computation and communication cost, number of beacon nodes or access point, processing time, energy consumption, hardware or software required by each node, etc.

There are many other factors like distribution of anchors and non-anchors, irregular node densities, border problem, geometric shape of the network, etc. It’s not able to have all factors together. The best result is trade off among criteria based on the application requirement. When a localization algorithm has excellent performance on the simulation environment, maybe it has not satisfaction performance in the real.

6. OPEN ISSUES

With several proposed localization algorithms but there are some issues that need more attention yet.

Security in the Network: Accuracy of the output of localization algorithm is really important. Some localization algorithms have high accuracy. But, after implementation they are subject to attacks. Therefore, it is important to consider the security and privacy of nodes locations. There is some work in this field like [29] but the problem is not solved adequately.

3D area: More of the proposed localization algorithms are applicable for 2D area. However, many of applications need 3D localization algorithms.

Low cost, anchor based location approach*:* Since many applications especially in industry fields are anchor based and it is avoidable to decrease number of anchors, it is required to decrease another cost of localization methods.

Large scale mobile learning approach*:* Learning concepts have been considered because of their good efficiency on the performance of localization especially for mobile networks. But more works are developed for mobile indoors. And most of the large scale localization algorithms just can work on the fixed networks.

7. Conclusions

In this paper, we proposed a new classification for localization techniques. In this classification, localization algorithms were classified based on different key features like learning, anchor existence, movement in network, etc. This classification is usable to understand the operation of varies localization methods and it is also usable for who wants to implement a new localization algorithm. In additional, some evaluation factors were introduced to validate new proposed methods or to compare different existence techniques in order to find the best one for a specific application.

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