

Review Article

Localization Techniques in WSN: A Review

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Abstract: Wireless Sensor Network (WSN) is a kind of wireless network, which is composed of groups of very small devices known as 'Sensor Nodes'. It is one of the fastest evolving fields. Applications of WSN comprise of search, disaster relief, remote environmental monitoring, target tracking etc. In all such applications, data gathered by the network is not useful, without location information. As nodes location is required to report the origin of event, about which the data is gathered. Node localization is highly important, for large sensor networks where users desire, to know about the exact location of the nodes to know the event location. This paper reviews different localization techniques, used for nodes location discovery in WSN and presents their parametric comparison in tabular form. This comparison is useful for better understanding of existing techniques and for the development of other novel technique.

Keywords: Wireless Sensor Network (WSN), approaches, sensor nodes

INTRODUCTION

A WSN is a collection of nodes organized into a cooperative network [1]. Each node is capable of processing with the help of one or more microcontrollers, CPUs or DSP chips, contains multiple types of memory (program, data and flash memories), have a RF transceiver (usually with a single omnidirectional antenna), and have a power source (e.g., batteries and solar cells). The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. Such nodes are called sensor nodes. Each sensor node is capable of only a limited amount of processing. But when coordinated with the information from a large number of other nodes, they have the ability to measure a given physical environment in great detail. Thus, a sensor network can be described as a collection of sensor nodes which coordinate to perform some specific action. Various novel applications are emerging in WSNs such as: habitat monitoring, smart building failure detection and reporting, and target tracking. One common feature shared by all of these critical applications is the vitality of sensor location. The core function of a WSN is to detect and report events which can be meaningfully assimilated and responded to only if the accurate location of the event is known. A straightforward solution is to equip each sensor with a GPS receiver that can accurately provide the sensors with their exact location. This, however, is not a feasible solution from an economic perspective since sensors are often deployed in very large numbers and manual

configuration is too cumbersome and hence not feasible. Therefore, localization in sensor networks is very challenging. Over the years, many protocols have been devised to enable the location discovery process in WSNs to be autonomous and able to function independently of GPS and other manual techniques. This paper gives an overview of various localization techniques. The rest of the paper is organized as follows: Section II gives the classification of Localization Techniques. In section III various Localization Techniques have been compared and section IV gives the conclusion.

CLASSIFICATION OF LOCALIZATION TECHNIQUES

In sensor networks, nodes are deployed into an unplanned infrastructure where there is no *a priori* knowledge of location. The problem of estimating spatial-coordinates of the node is referred to as localization. An immediate solution which comes to mind, is GPS or the Global Positioning System. However, there are some strong factors against the usage of GPS. For one, GPS can work only outdoors. Secondly, GPS receivers are expensive and not suitable in the construction of small cheap sensor nodes. A third factor is that it cannot work in the presence of any obstruction like dense foliage etc. Thus, sensor nodes would need to have other means of establishing their positions and organizing themselves into a coordinate system without relying on an existing infrastructure.

Localization algorithms can be classified into following categories.

- 1) Centralized vs. distributed
- 2) Anchor based vs. Anchor less
- 3) Range based vs. Range free

1. Centralized Localization:

In certain networks where a centralized information architecture already exists, such as road traffic monitoring and control, environmental monitoring, health monitoring, and precision agriculture monitoring networks, the measurement data of all the nodes in the network are collected in a central processor unit. In such a network, it is convenient to use a centralized localization scheme.

Centralized localization is basically migration of inter-node ranging and connectivity data to a sufficiently powerful central base station and then the migration of resulting locations back to respective nodes. The advantage of centralized algorithms are that it eliminates the problem of computation in each node, at the same time the limitations lie in the communication cost of moving data back to the base station.

Distributed Localization:

In the process of Distributed localization each node independently determines its location with only limited communication with one hop or multi hops neighbor nodes. It has the characteristics of small traffic, equal calculation burden of each node, little storage requirements and good scalability. However due to lack of global information location accuracy is susceptible to number of beacon nodes and the distribution of nodes.

2. Anchor Based:

Anchor-based algorithms operate on an ad-hoc network of sensor nodes where a small percentage of the nodes (*anchors*) are aware of their positions either through manual configuration or using GPS. Anchor nodes broadcast their locations information to their neighbors. The goal is to estimate the positions of as many unknown nodes as possible using anchor node information. Anchor-based algorithms usually produce an absolute location system where absolute node position is known, for example, latitude, longitude, and altitude. However, the accuracy of the estimated position is highly affected by the number of anchor nodes and their distribution in the sensor field [2].

Anchor Free:

Anchor-free algorithms do not make any assumptions regarding node positions. In this case, instead of computing absolute node positions, the algorithm estimates relative positioning, in which the coordinate system is established by a reference group of nodes. In some cases knowing the relative positions of

the nodes compared to each other is enough, for example, location aided routing [3].

Moreover, a relative coordinate system can be transformed to an absolute coordinate system if the coordinates of three separate non-colinear nodes are known in case of 2D (or four in case of 3D). Anchor-free schemes have the disadvantage that when the reference node moves, positions have to be recomputed for nodes that have not moved. This is considered a minor problem in sensor networks where sensor nodes are usually assumed to be stationary.

3. Range Based:

Range Based methods depend upon distance or angle between nodes to obtain unknown node's location. In the first stage, a node merely estimates its distance to other nodes in its vicinity using one or more features of the received signal. In the second stage, a node uses all the distance estimates to compute its actual location. The method employed in stage two to compute the actual location depends on the signal feature used in stage one, such as:

- a. Received Signal Strength Indicator (RSSI) :This category of distance related measurement techniques estimates the distance between neighboring sensors from the received signal strength measurements [4]-[8].These techniques are based on a standard feature found in most wireless devices, a received signal strength indicator(RSSI) .They are attractive because they require no additional hardware , and are unlikely to significantly impact local power consumption ,sensor size and thus cost.

In free space, the received signal strength at a receiver is given by Friis equation [9]

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \dots\dots\dots 3.1$$

Where P_t is the transmitted power, $P_r(d)$ is the received power at a distance d from the transmitter, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, L is a system loss factor not related to propagation and λ is the wavelength of the transmitter signal.

In a real environment, the propagation of an electromagnetic signal is affected by reflection, diffraction and scattering. Moreover the environment will change depending on particular application(e.g., indoor versus outdoor).It is very difficult ,if possible to obtain the received signal strength using analytical methods .However measurements have shown that at any value of d ,the received signal strength $P_r(d)$, at a particular location is random and distributed log-normally about the mean distance-dependent value is ,

$$P_r(d)[dBm] = P_o(d_0)[dBm] - 10n_p \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \dots\dots\dots 3.2$$

Where $P_o(d_0)[dBm]$ is a reference power in dB mill watts at a close-in reference distance d_0 from the transmitter, n_p is the path loss exponent which indicates the rate at which the received signal strength decreases with distance and the value of n_p depends on the specific propagation environment, X_σ is a zero mean Gaussian distributed random variable with standard deviation σ and it accounts for the random effect of shadowing.

- b. Time of Arrival: This method -called also “time of flight”-, exploits the relationship between the beacon-node distance and the transmission time that a signal has to travel between sender and beacon. If the velocity of the signal is known and assuming that the sender and receptor know the time when a transmission starts, then the time of arrival of the signal is an indicative of the beacon-node distance and this distance can be computed using the propagation time by either the beacon or the node [10].

The two main disadvantages of this method are: it is necessary to have a synchronized sender and receiver. Depending on the transmission medium that is used, a high clock resolution is required to produce results of acceptable accuracy. For example, for acoustic waves, this requirement is modest (about microseconds) but for radio, a very high resolution is necessary (about nanoseconds).

- c. Time Difference of Arrival (TDoA): There is a category of the localization algorithms utilizing TDoA measurements of the transmitter’s signal at a number of receivers with known location information to estimate the location of the transmitter. Fig.1 shows a TDoA localization scenario with a group of four receivers at locations r_1, r_2, r_3, r_4 and a transmitter at r_t . The TDoA between a pair of receivers i and j

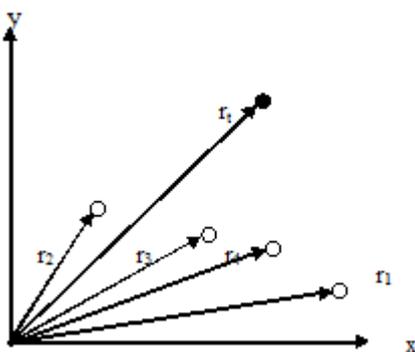


Fig.1: Localization using Time difference of arrival measurements

is given by:

$$\Delta t_{ij} \triangleq t_i - t_j = \frac{1}{c} (\|r_i - r_t\| - \|r_j - r_t\|), \quad i \neq j \dots\dots 3.3$$

where t_i and t_j are the time when the signal is received at receivers i and j respectively, c is the propagation speed of the signal and $\|\cdot\|$ denotes the euclidean norm.

- d. Angle of Arrival (AOA): This method consists of the angle obtained between a reference node and the node which wants to know its position. The AOA is typically gathered using radio-chips or microphones array, which allows a listening node to determine the angular direction of a transmitting node [11].

One can also obtain AOA data from optical communication [12]. This method is implemented by spatially separated microphones that hear a single transmitted signal. By analyzing the phase or time difference between the signal arrivals at different microphones, it is possible to discover the angle of arrival of the signal. Unfortunately, AOA's hardware tends to have a big form factor and is more expensive than the distance estimation methods, since each node must have one speaker and several microphones.

4. Range Free:

Range-free localization never tries to estimate the absolute point to point distance based on received signal strength or other features of the received communication signal like time, angle, etc. This greatly simplifies the design of hardware, making range-free methods very appealing and a cost effective alternative for localization in WSNs.

- a. Centroid: The Centroid scheme was proposed by Bulusu et al. in [13]. In Centroid based Algorithm all anchors first sends their positions to all sensor nodes within their transmission range. Each unknown node listens for a fixed time period t and collects all the beacon signals it receives from various reference points. Secondly, all unknown sensor nodes positions are calculated by a centroid determination from all n positions of the anchors in range. The centroid localization algorithm is simple but the location error is high due to the centroid formula.

It is the most basic scheme that uses anchor beacons, containing location information (X_i, Y_i) to estimate node position. After getting these beacons, the unknown node use the following centroid formula to computes its location, given as:

$$(X', Y') = \left(\frac{\sum_{i=1}^n X_i}{n}, \frac{\sum_{i=1}^n Y_i}{n} \right) \dots\dots\dots 4.1$$

Where n is the number of anchor nodes, (X_i, Y_i) are their coordinates and (X', Y') are estimated position coordinates of the anchor node.

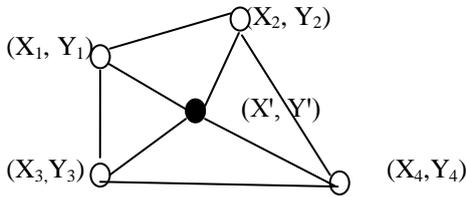


Fig. 2:Centroid Method

- b. DV-Hop Localization: DV-Hop localization is proposed by D. Niculescu and B. Nath in the Navigate project [14]. DV-Hop localization uses a mechanism that is similar to classical distance vector routing. In this work, one anchor broadcasts a beacon to be flooded throughout the network containing the anchors location with a hop-count parameter initialized to one. Each receiving node maintains the minimum counter value per anchor of all beacons it receives and ignores those beacons with higher hop-count values. Beacons are flooded outward with hop-count values incremented at every intermediate hop. Through this mechanism, all nodes in the network (including other anchors) get the shortest distance, in hops, to every anchor.

In order to convert hop count into physical distance, the system estimates the average distance per hop without range based techniques. Anchors perform this task by obtaining location and hop count information for all other anchors inside the network. The average single hop distance is then estimated by anchor i using the following formula:

$$Hopsize_i = \frac{\sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum h_j} \dots\dots\dots 4.2$$

where, (x_j, y_j) is the location of anchor j, and h_j is the distance, in hops, from anchor j to anchor i. Once calculated, anchors propagate the estimated HopSize information out to the nearby nodes.

Once a node can calculate the distance estimation to more than 3 anchors in the plane, it uses triangulation (multilateration) to estimate its location. Theoretically, if errors exist in the distance estimation, the more anchors a node can hear the more precise localization will be.

- c. APIT: [15] is an area-based range-free localization scheme. It assumes that a small number of nodes, called anchors, are equipped with high-powered transmitters and know their location, obtained via GPS or some other mechanism. Using beacons from these anchors, APIT employs a novel area-based approach to perform location estimation by isolating the environment into triangular regions between anchor nodes. A node's presence inside or outside of these triangular regions allows a node to narrow down the area in which it can potentially reside. By utilizing different combinations of anchors, the size of the estimated area in which a node resides can be reduced, to provide a good location estimate.

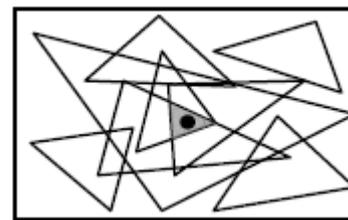


Fig 3: An Area-based APIT Algorithm Overview

The actual algorithm is as follows:

- Step 1 Receive beacon positions from hearable beacons.
- Step 2 Initialize inside-set to be empty.
- Step 3 For each triangle T_i in possible triangles formed over beacons, add T_i to inside-set if node is inside T_i . Goto Step 4 when accuracy of inside-set is sufficient.
- Step 4 Compute position estimate as the center of mass of the intersection of all triangles in inside-set.

The theoretical method used to narrow down the possible area in which a target node resides is called the *Point-In-Triangulation Test* (PIT). For three given anchors: $A(ax; ay); B(bx; by); C(cx; cy)$, the Point-In-Triangulation test determines whether a point M with an unknown position is inside triangle $\triangle ABC$ or not. APIT repeats this PIT test with different anchor combinations until all combinations are exhausted or the required accuracy is achieved. At this point, APIT calculates the center of gravity (COG) of the intersection of all of the triangles in which a node resides to determine its estimated position.

d. Amorphous Localization: The Amorphous Localization algorithm [16][17], proposed independently from DV-Hop, uses a similar algorithm for estimating position. First, like DV-Hop, each node obtains the hop distance to distributed anchors through beacon propagation.

Once anchor estimates are collected, the hop distance estimation is obtained through local averaging. Each node collects neighboring nodes' hop distance estimates and computes an average of all its neighbors' values. Half of the radio range is then deducted from

this average to compensate for error caused by low resolution.

The Amorphous Localization algorithm takes a different approach from the DV-Hop algorithm to estimate the average distance of a single hop. This work assumes that the density of the network, n_{local} , is known a priori, so that it can calculate HopSize offline in accordance with the Kleinrock and Silvester formula [18]:

$$Hopsize = r(1 + e^{-n_{local}} \cdot \int_{-1}^1 e^{\frac{-n_{local}}{\pi}(\arccos t - t\sqrt{1-t^2})} dt) \dots\dots\dots 4.3$$

Parametric Comparison

Table 1: Performance Comparison

Parameters	Centroid	DV-Hop	Amorphous	APIT
Accuracy	Fair	Good	Good	Good
Node Density	>0	>8	>8	>6
Anchor Heard	>10	>8	>8	>10
ANR	>0	>0	>0	>3
DOI	Good	Good	Fair	Good
GPS Error	Good	Good	Fair	Good
Overhead	Smallest	Largest	Large	Small

Table 1 provides an overview of performance comparison of different range free schemes, and it can be used as a design guide for applying range-free schemes in WSN systems.

A description of these parameters follows:

- Node Density (ND): Average number of nodes per node radio area.
- Anchors Heard (AH): Average number of Anchors heard by a node and used during estimation.
- Anchor to Node Range Ratio (ANR): The average distance an anchor beacon travels divided by the average distance a regular node signal travels.
- Anchor Percentage (AP): The number of anchors divided by the total number of nodes (1000~3000 nodes). This value can be derived from the three parameters described above using the formula: $AP=AH/(AH+ND*ANR^2)$.
- Degree of Irregularity (DOI): DOI is defined as an indicator of radio pattern irregularity.
- GPS Error: This parameter is defined as the maximum possible distance from the real anchor position to the GPS estimated anchor position in units of node radio range (R).

CONCLUSION

Localization in wireless sensor networks is an important issue. Great efforts have been made by many researchers and a variant of algorithm also have been proposed. In this paper, we proposed a new classification for localization techniques. In this classification, localization algorithms were classified based on different key features like Centralized, Distributed, Anchor Based, Anchor Less, Range Based and Range Free. This classification is useful for better understanding of the operations of various localization methods and working as an aiding tool for the development of a novel localization algorithm.

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