Classification of Node Localization Techniques in Wireless Sensor Networks

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***A*bstract—Due to their wide applications, wireless sensor networks have attracted global research in medical care, smart homes, and environmental monitoring. These applications often expect knowledge of the exact location of nodes. Localization in sensor networks hence became an important problem. We have studied various methods in order to judiciously design a specific location solution. Given the specific characteristics of sensor networks, this solution should not be oversized; otherwise it increases the cost in terms of energy and computation which would make it impracticable. In this paper, the closest methods to our problem are studied and compared.**

Keywords-wireless sensor networks; localization; location nodes; multilateration.

I. INTRODUCTION

Recent advances in micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics have enabled the emergence and evolution of wireless sensor networks (WSNs). Nowadays, WSNs have attracted worldwide research and industrial interest, because they can be applied in various areas such as environmental monitoring, smart home, hospital surveillance, etc.

A WSN is a collection of sensor nodes, which are densely deployed in physical environment and organized into a cooperative network. Each sensor node has typically several parts (Sensors, Processor, Transceiver, Memory, and Battery). A sensor node is usually a tiny electronic device equipped with a battery for an energy source. It has physical sensors for detecting environment conditions such as temperature, sound, vibration, etc. A wireless transceiver is fitted for two way communications with other sensors [1]. In these large sensor network systems, we need nodes to be able to locate themselves in various environments. The sensed and gathered data would be meaningless without knowledge of location node in some particular applications. This problem, to which we refer to, is known as sensor localization.

We define the problem of localization as estimating the position or spatial coordinates of wireless sensor nodes. Node localization is one of challenging and fundamental issues in WSN research because sensor nodes are usually randomly deployed in harsh fields or scattered using some special device [2]. Simple solution for this problem is using of Global Positioning System (GPS) [3], but WSN constraints make the use of GPS an expensive solution in terms of cost, size, and power consumption. Furthermore, GPS cannot be used indoors or in circumstances where satellite signals are not available like dense forests. Also, because of large number of sensor nodes employed in a network, manual configuration into each node in order to get information location during deployment phase is neither practical. Many works have proposed solutions to this problem and a large number of algorithms are proposed in previous works to deal with sensor localization. In this work, our goal is to provide an overview about these localization techniques and to discuss about the characteristics of each one.

The remainder of the paper is organized as follows. In Section II, we introduce the process of localization in WSN. In Section III, we show the techniques proposed in literature that can be used by a node to compute its position, and how all the estimated information of distances and positions can be manipulated in order to allow most or all of the nodes of a WSN to estimate their positions. In Section IV, summary of these localization techniques are given. Section V concludes the paper where the future challenges and directions to improve localization in WSN are described.

II. LOCALIZATION IN WSN

The location information of each sensor node in the network is critical for many applications. This is because users normally need to know not only what happens, but also where interested events happen [1]. For example, in hospital surveillance, the knowledge of where the patient is can help the doctors arrive at the right place as quickly as possible in urgent case [4]. On the other hand, the position parameters of sensor nodes are assumed to be available in many operations for network management, such as routing where a number of geographical algorithms have been proposed [5] and [6], topology control that uses location information to adjust network connectivity for energy saving [7] [8], and security maintenance where location information can be used to prevent malicious attacks [9]. So, the design of efficient techniques for nodes' location has become necessary.

In classical localization technique, nodes in the network are split into two classes: normal nodes (which are the majority) and anchor nodes helping the others to calculate their location. Techniques that rely on such anchors are called anchor-based localization (as opposed to anchor-free localization). Generally, the localization approaches can be

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classified into main categories: range-based methods (Fine-grained) and range-free methods (Coarse-grained). They differ in the information used for localization. Range-based methods use range measurements, while range-free techniques only use the content of the messages.

The range-based localization principle is to accurately measure the range information (the distance or the angle) between two nodes on a network. Several technologies allow this measure, we have: the Received Signal Strength Indicator (RSSI) [10], the Time of arrival (TOA) [11], Time Difference of Arrival (TDOA) [12] or Angle of Arrival (AOA) [13]. After this measurement, the position can then be obtained simply by triangulation or trilateration approaches. The range-based location has two major drawbacks. The first is related to the additional hardware required for the measurement. These hardware measurements consume more energy and increase the cost of the solution. Second, the accuracy of the measurements can vary several parameters related to the network environment: the humidity, electromagnetic noise, etc.

In contrast, the range-free location avoids these two great disadvantages. Generally, these range-free localization techniques don’t rely on distance/angle estimates. They just use connectivity information between nodes. Here, the connectivity information of a node N can be its hop counts to other nodes. The connectivity is used as an indication of how close this node N to other nodes. Since no ranging information is needed, the range-free scheme can be implemented on low-cost wireless sensor networks. Another advantage of range-free scheme is its robustness; the connectivity information between nodes is not easily affected by the environment.

Another classification is based on the manner the localization is organized. We distinguish:

Centralized localization algorithm runs on a base station and it requires it to gain the measurement data from all the participating nodes. Base station determines the location of each node by the collected measurement data and transporting them into network. The distributed localization algorithm is such that all the computations are done by the sensor nodes themselves and the nodes communicate amongst themselves with one-hop or multi-hops neighbor nodes to get their positions in the network [14].

III. STATE OFART

In this section, we try to depict a not exhaustive overview of these works proposed in literature. So, five classes are planned to have an attractive description of these methods.

A.Class 1: Geometric techniques

1) Trilateration

Trilateration [15] is the most basic and intuitive method to determine the positions of the sensors. The basic principle of this algorithm is to estimate the location of the node (in 2D plane) by acquiring three beacons (anchors) with known locations and their distances from the node to be localized. The type of the signal indicator used to estimate the beacons distance is in several cases the RSSI. The evaluated of distances from anchors to the normal node are called the radiuses of these circles centered at each anchor. The intersection of these three circles is the positions of the unknown node.

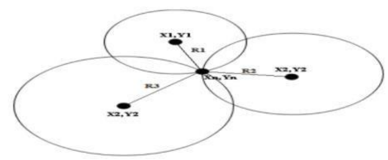

Figure 1. Trilateration localization method.

2) Multilateration

The multilateration [16] has the same principle as the trilateration, by using more than three reference points (anchors). Also, when more than three anchors are used, an over determined system of equations results. By solving this linear system, the measurements' error is minimized, thus producing better results than trilateration in the presence of inaccurate distance estimates.

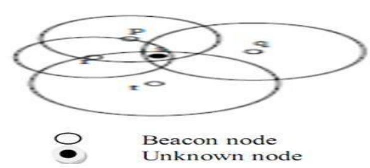

Figure 2. Local multilateration.

As it is shown in Figure 2, measuring the distances to the reference points, the unknown node can determine its position as the intersection of these circles.

3) Triangulation

In this approach [13], information about angles (using AoA) is used instead of distances. Position computation can be done remotely (Figure 3 (a)) or by the node itself (auto-localization); the latter is more common in WSN. In this last case, depicted in (Figure 3 (b)) at least three reference nodes are required. The unknown node estimates its angle to each of the three reference nodes and, based on these angles and the positions of the reference nodes (which form a triangle), computes its own position using simple trigonometrically relationships.

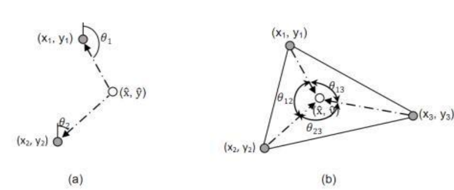

Figure 3. Illustration of triangulation method.

B. Class 2: Multidimensional techniques

1) Multidimensional Scaling(MDS)

In this class, we have multidimensional Scaling (MDS) [17], which is a technique that has taken its origins in psychometrics and psychophysics. It is used for visualizing dissimilarity data. In literature, a number of localization techniques have been reported which use MDS. These techniques are energy efficient as communication among different nodes is required only initially for obtaining the inter-node distances of the network [18].

After the calculation of the distance between all pair of nodes, Torgerson [17] tries to construct distance matrix for MDS: $D_{N,N}$=[d_{ij}].We seek the positions of points in a Euclidian space with dimension m. R^m. Let be the vector Xi = $(x_{i1}\ldots x_{im})^T$ representing the position of the point i. We can represent all the positions by a matrix $X_{N,m}= (x_1\ldots x_N)^T$. Thus, given the matrix D, the purpose of MDS is to find the matrix *X*. For the mathematical details of MDS see [17] and [19].

2) MDS-MAP(C)

Shang et al. [20] presented a centralized algorithm based on classical MDS, namely, MDS-MAP(C). This method has four stages:

- *Step 1*: Gather ranging data from the network, and form a sparse matrix R, where R_{ij} is the range between nodes i and j.
- *Step 2*: Run a standard all pairs shortest path algorithm (like Dijkstra's) on R to produce a complete matrix of inter-node distances D.
- *Step 3:* Run classical MDS on D to find estimated node positions X.
- *Step 4:* Transform the solution X into global coordinates using some number of anchor nodes.

3) MDS-MAP(P)

MDS-MAP (P) [20] is more complicated than MDS-MAP(C) because it builds for each node a local map of the small sub-network in the node's vicinity and then merges (patches) the local maps together to form a global map. More exactly, the procedure of this method is shown below [21]:

- *Step 1:* Divide a wireless sensor network into several clusters; the method of dividing the cluster is k-hop clustering.
- *Step 2:* Use traditional MDS-MAP algorithm to build the location map of each cluster which is produced in step1.
- *Step 3:* Merge (patch) the location map of each cluster together to form a global location map.

Finally, in this class, we can cite Curvilinear Component Analysis (CCA-MAP) [22], which is similar to MDS-MAP, but it is better than MDS-MAP because it is more effective and it performs very well for stationary WSNs. As a starting map, the local map of a randomly selected node is used. After that, the neighbor node whose local map shares the most nodes with the current map is selected to merge its local map into the current map.

C. Class 3: Area-Based techniques

1) Approximate Point In Triangulation(APIT)

A well-known example of an area-based localization technique is APIT [23]. The key procedure in this approach is the Point in Triangulation (PIT) test, which allows a node to determine these triangles. In this test, once a node has determined the locations of a set of reference nodes, it tests whether it resides within or outside of each triangle formed by each set of three reference nodes.

Once the PIT test completes, a position estimate can be computed as the center of gravity of the intersection of all triangles in which the normal node resides in [24].

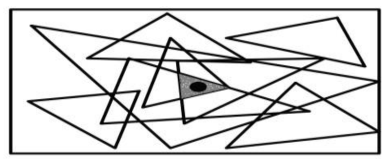

Figure 4. APIT location method.

2) Bounding Box (BB)

The bounding box method is proposed in [25]. The principle of this approach is shown in Figure 5. For each reference node i, a bounding box is defined as a square with its center at the position of this node (xi, yi), with sides of size 2di (where d is the estimated distance). The intersection of all bounding boxes gives the possible positions of the node to be localized. The final position of the unknown node is then computed as the center of gravity of the obtained rectangle.

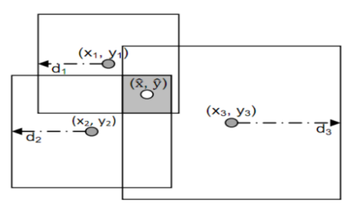

Figure 5. Bounding box location method.

3) Centroid

Centroid algorithm is first proposed in [2]. The basic principle of this algorithm is to consider the centroid point of neighbor anchors as the estimated position of the normal node Nx. More exactly, the anchors periodically broadcast their position; Nx then receives the position of anchors and compute its position. The scenario is shown in Figure 6. In the network, there is a total of m anchors A1, A2 ... Am. All these anchors have the same communication range denoted as R. Their transmission areas have an overlap. Inside this overlap, the normal node Nx is located.

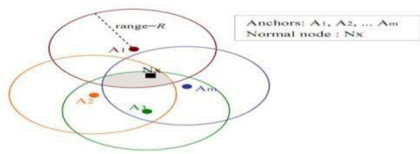

Figure 6. Centroid algorithm.

4) *Convex Position Estimation(CPE)*

The CPE [26] is very simple algorithm, but it requires that the normal nodes have at least three neighboring anchors. The authors of this algorithm first provide an optimization concept, and then the locations of normal nodes in a WSN are found as a result of an optimization problem. To illustrate the principle of this algorithm, consider the case shown in Figure 7, where the three anchors A1, A2, A3 have the same communication range. The normal node Nx locates inside the overlap of anchors radio transmission. The challenge of CPE algorithm is to find the smallest rectangle (in Figure 7) that bounds the overlap, and then to take the center of this rectangle as the estimated position of Nx. Now, the problem is how to find the smallest rectangle. A solution of this problem is detailed in [26].

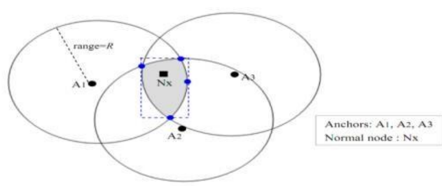

Figure 7. Principe of CPE algorithm.

5) *Simplified CPE*

The original CPE algorithm is not very flexible because it is centralized. So, a simplified and distributed version of CPE algorithm has been proposed in [27]. This algorithm defines an Estimated Rectangle (ER), which limits the overlap zone ranges A1, A2 ... Am. As shown in Figure 8, the centre point of ER denoted as N_{ER} is the estimated position of Nx by this algorithm.

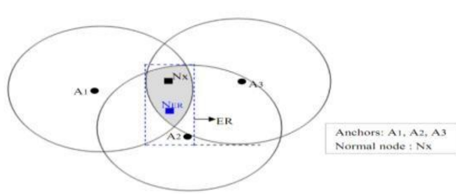

Figure 8. Principe of Simplified CPE algorithm.

6) *AT-Family: family of distributed approximation techniques*

In [28], a family of three distributed approximation techniques (called AT-Family) is presented for the localization problem in static WSN while taking capabilities of sensors into account. These three methods are: AT-Free, AT-Dist and AT Angle. They consider respectively the cases where: sensors have no capability or they can calculate distances with their neighbors or angles [28].

D. Class 4: General Techniques

1) *Probabilistic approach*

The uncertainty in distance estimations has motivated the appearance of probabilistic approaches for computing a node's position. In these approaches, the result of calculation of the position is not a single point, but a set of points with their probability to be the real position of the node to be localized. An example of a probabilistic approach is proposed in [29].

2) *GPS-Less*

GPS-Less [2] is very simple algorithm. It considers several nodes in the network with overlapping regions of coverage serve as reference points, that form a regular mesh and transmit periodic beacon signals (period = t) containing their respective positions. In this approach, it is assumed that neighboring reference points can be synchronized so that their beacon signal transmissions do not overlap in time. Furthermore, in any time interval t, each of the reference points would have transmitted exactly one beacon signal. A node which wants to be localized listens for a fixed time period t and collects all beacon signals that it receives from various reference points. The authors characterize the information per reference points by connectivity metric (CMi). From the beacon signals that it receives, the receiver node infers proximity to a collection of reference points for which the respective connectivity metrics exceed a certain threshold, CM_{thresh} (say 90%). The receiver localizes itself to the region which coincides to the intersection of the connectivity regions of this set of reference points, which is defined by the centroid of these reference points.

3) *GPS-Free*

The GPS-Free algorithm, which is used in mobile Ad Hoc networks without GPS receivers or fixed anchor nodes, was proposed first in [30]. In [31], the authors present a GPS-free localization scheme for node localization in WSN called the Matrix transform-based Self Positioning Algorithm (MSPA), where the task is to use the distance information (using for example TOA) between nodes to determine the coordinates of static nodes. Similar to other relative localization algorithms, the coordinate establishment phase of MSPA is split into two phases: the establishment of local coordinates at a subset of the nodes (called master nodes) and the convergence of the individual coordinate systems to form a global coordinate system [31].

4) *Ad Hoc Positioning System(APS)*

As an example of a hop count based localization technique, the Ad hoc Positioning System [32] provides a distributed connectivity-based localization approach that estimates node locations using a set of at least three reference nodes. APS is a hybrid between two major concepts: distance vector (DV) routing and beacon based positioning (GPS). What makes it similar to DV routing is the fact that information is forwarded in a hop by hop fashion. What makes it similar to GPS is that eventually each node estimates its own position, based on the anchors readings it gets. In APS approach, a reduced number of reference nodes is deployed with the unknown nodes. Then, each node estimates its distance to the beacon nodes in a multi-hop way. Once these distances are estimated, the nodes can compute their positions using multilateration or trilateration. Three methods of hop by hop distance propagation are proposed: DV-Hop, DV-Distance, and Euclidean distance. These propagation methods are described in detail in [32].

IV. SUMMARY OF LOCALIZATION TECHNIQUES

A set of the most used methods dealing with the positioning problem in wireless sensor networks was summarized. It should be noted that this presentation is not exhaustive. The choice of the method of the position estimation influences the final performance of the localization system. Finally, according to some proposed criteria, our contribution is to give a synthesis and classification of the different techniques reviewed in this paper which is done in Table1.

As we saw previously, the localization in sensor networks is essential for many sensing applications and network management activities. This paper provided a survey of different localization techniques in WSN, including geometric techniques, multidimensional techniques, area-based techniques and general techniques. For many of these techniques, it is required that there are sufficient reference nodes and that those nodes are evenly distributed throughout the network. While the accuracy obtained by range-free localization techniques is typically lower than the accuracy of range-based techniques, a main advantage of range-free localization is that typically no additional hardware is needed and localization can therefore be performed at a lower cost. Also, the comparison of a variety of centralized and distributed localization techniques has been presented.

V. CONCLUSION AND FUTUREWORK

Localization of sensor nodes is crucial in Wireless Sensor Network due to its various applications like surveillance, tracking, navigation, etc. Various techniques for localization have been proposed in literature by different researchers. In this paper, we present a survey localization of nodes in wireless sensor network. This survey is useful to have a global view of localization methods and to allow

TABLE I. SUMMARY OF LOCALIZATIONTECHNIQUES.

Class	**Method**		**Range-free**	**Range-based**	**Anchor-free**	**Anchor-based**	**Centralized**	**Distributed**
Geometric	Trilateration			•		•		•
	Multilateration			• (TDOA)		•		•
	Triangulation			• (AOA)		•		•
Multidimensional	MDS(MDS-MAP(c))		•		•		•	
	MDS-MAP(p)		•		•			•
	CCA-MAP		•		•		•	
Area-based	CPE	CPE original	•			•	•	
		simplified CPE	•			•		•
	Centroid		•			•		•
	BoundingBox			•		•		•
	APIT		•			•		•
	AT-Family	AT-Free	•			•		•
		AT-Dist		• (SumDist)		•		•
		AT-Angle		•		•		•
General	Probabilisticapproach			• (RSSI)		•		•
	GPS-Less		•			•		•
	GPS-Free			•	•			•
	APS			•		•		•

knowing which algorithm is better with regard of the utilization context.

In the future, we want to continue our work in the direction of improvement of the precision of positioning. We will be interested in the family of localization Geometric. More exactly, we propose a combination of multilateration and trilateration algorithms by using the technology of measure of distance RSSI.

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