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Localization Techniques in Wireless Sensor Networks

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***Abstract*—Recent advances in micro electro mechanical system (MEMS) technology and embedded systems have enabled the proliferation of wireless sensor networks (WSNs). WSNs are used to perform various tasks such as monitoring, target tracking, event detection in different environments. The important function of sensor network is to collect and forward the data to destination. In most of the applications, it is important to know about the location of collected data. This kind of information can be obtained using localization technique in WSNs. Node localization is very crucial to find and determine the location of sensor node with help of localization algorithms. Hence node localization has become one of the fundamental challenges in wireless sensor networks. We make the rigorous reviews on different techniques of node localization in wireless sensor networks. The taxonomy of localization techniques discussed on the basis of certain features such as global positioning system (GPS), anchors, computational model and scalability. In this paper detailed study has been carried out to understand and select the best localization algorithms for WSNs. At the end some issues are discussed for future research in area of localization in WSNs.**

Index terms - wireless sensor networks, localization algorithms, anchor, global positioning system, scalability.

I. INTRODUCTION

Latest developments in micro electro mechanical system (MEMS) and communication technology have made possible to use the large networks of sensors for variety of applications including monitoring, tracking and control [1]. A wireless sensor network (WSN) is comprised of tiny and cheap devices called sensors which are constraints in memory, power and processing capabilities [2]. In many applications, location awareness is useful or even necessary [3]. The collected data is valueless without knowing the position of sensor node. Since most applications rely on the success of localization, it is important to devise efficient localization algorithms. There are various ways for sensor's localization. Node localization can help out in routing [4], [5], [6]. Node localization performed the monitoring of progress of the children in smart kindergarten [7] by keeping the watch on their interaction with toys and also with each other. It is useful in tracking of various entities in different environments. There is one easy way i.e. the manual configuration, but this is impractical in large scale or when sensors are deployed in inaccessible areas or sensors are mobile. A simple wireless sensor is shown in figure 1. Another way is to add global positioning system (GPS) to the sensor. GPS has been affected by dense forests, mountains or buildings because of non line of sight problems. The network lifetime is reduced due to power consumption overhead caused by GPS. In addition, using GPS is not feasible due to it's size and cost. Due to such reasons, alternate solutions of GPS are needed which must be cost effective, easily deployable in diverse environments. Therefore, various localization algorithms have been discussed in this paper. This paper categorizes localization techniques in with certain viewpoints and aims. The rest of the paper is organized as follows. Section 2, describes the formulation of localization problem in sensor networks. Section 3, describes the related works. Section 4, describes the localization process along with the approaches for location discovery. Section 5, presents the classification of localization techniques. Section 6, presents the comparison of various localization techniques. Some open issues are discussed in Section 7 and Section 8 concludes the paper.

Figure 1. Wireless Sensor (source: [41])

II. PROBLEM DEFINITION

Let us deployed a network consists of N sensors at locations S= {S_1, S_2,…..,S_N}. Let S_x^i refer to the x-coordinate of the position of the sensor i and S_y^i and S_z^i refer to the y-coordinate and z-coordinate respectively. We focused on 2 Dimensional problems so constraining S_z^i to be zero. Determining these coordinates formulate the problem of localization. Some nodes aware of their locations are called anchors or beacons. The remaining nodes localize themselves with the help of some localization technique. So, mathematically the localization problem can be formulated as follows: for a multi hop network represented by graph G= (V, E), and a set of anchor nodes A, their positions $\{x_a, y_a\}$ for all a in A, we have to find out the position $\{x_u, y_u\}$ for all unknown nodes u in U.

III. Related Work

Localization is one of the major issues in sensor networks. Node localization is hot research field but few papers have been reported in literature [8], [9], [10], [11]. In these papers, the authors discussed important localization techniques and figure out demerits of these techniques. Some techniques use the combination of localization schemes [10], [11]. These hybrid techniques give new directions in sensor localization due to good accuracy and cost. On the other hand some papers [12], [13], [14], [15], [16] describes the interferometric ranging based localization techniques. This text gives ample survey of localization techniques. At the end it compares the various localization techniques and addresses some issues and future directions in this area.

IV. Localization Process

The problem of localization is to find out the location information of all or subset of sensor nodes. Location information means any form of location indicator such as exact location, the location region or the location distribution. The localization process [17], [18] is shown in figure 2.

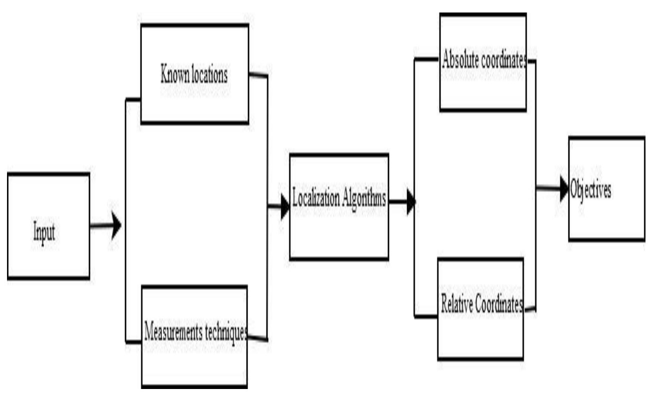

Figure 2. Localization process

Localization process localizes sensor nodes based on input data. If there is any anchor available in the network, the 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. The measurement techniques can be proximity based, distance based or angle based. The proximity based techniques are based on radio or acoustic waves. Location discovery is important in the localization process. A localization process objective varies accordingly.

A. Location discovery approaches

Location discovery approaches comprised of two phases such as: distance (or angle) estimation and distance (or angle) combining.

a. Distance estimation methods

The popular methods for the estimation of distance between two nodes are shown in figure 3.

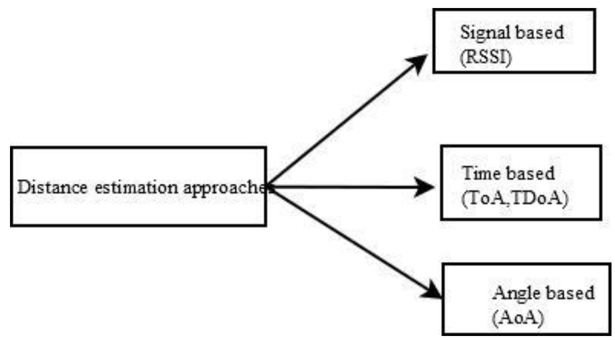

Figure 3. Taxonomy of distance estimation methods

- *Signal based method:* Received signal strength indicator (RSSI) is measured at receiver. Propagation loss can be calculated in accordance with transmitted power. Then an empirical model translates this loss into distance estimates. The performance of this approach is not good due to RF signals [19] multipath propagation.

- *Time based method:* The time of arrival (ToA) or time difference of arrival (TDoA) are time based schemes which convert the propagation time into distance [17], [18]. These methods are applicable to various signals such as: radio, acoustic, ultrasound and infra red. Accuracy of time based methods are depends on line of sight conditions.

- *Angle based method:* Angle of arrivals (AoA) estimates the angle at which signals are received and then compute the node location on the basis of some geometric relationship [8], [30]. This approach is much more costly due to its high hardware cost.

b. Distance combining methods

The most popular methods for distance (or angle) combining are shown in figure 4.

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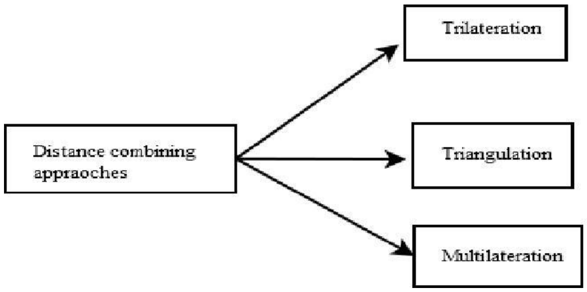

Figure 4. Taxonomy of distance combining methods

- *Trilateration:* Lateration is used when inter node distance is calculated for location estimation [16]. In trilateration, the intersection of three circles is considered, which give a single point i.e. position of unknown node as shown in figure 5(i).

- *Triangulation:* Angulation is used when the angle of nodes is estimated. In triangulation, at least two angles of unknown node from two known nodes are calculated to estimate the node positions [17], [18]. Node positions are calculated by using sine and cosine laws of trigonometry as shown in figure 5(ii).

- *Multilateration:* In multilateration [16], [18], the position is estimated from distances to three or more localized nodes by minimizing the error between estimated position and actual position as shown in figure 5(iii).

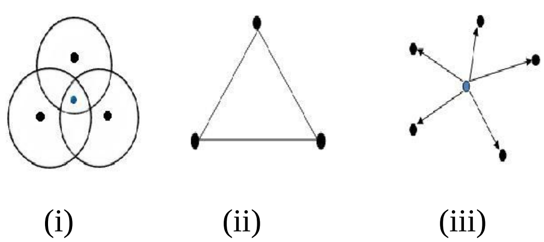

Figure 5. Distance combining methods (i) Trilateration (ii) Triangulation (iii) Multilateration

V. CLASSIFICATION OF LOCALIZATION TECHNIQUES

Here, authors presents the classification of localization techniques [17,18]. On the basis of computational model, sensor localization can be broadly classified into two categories: centralized localization and distributed localization. The taxonomy of localization schemes are shown in figure 6.

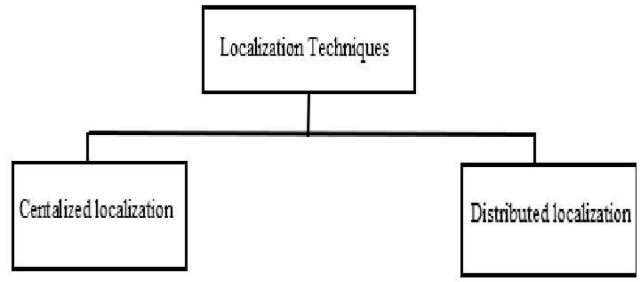

Figure 6. Taxonomy of Localization Techniques

A. Centralized Localizations

In the centralized localization [20], [21], [22], all the measurements are collected at central base station (BS), where the computation takes place. After that the results are forwarded back to the nodes. The data transmission within the network causes latency and more consumption of energy and bandwidth [23]. The benefits of this technique are that they eliminate the problem of computation in every node. The drawback of this scheme is lack of ability to access data in proper way as well as inadequate scaling. It is more accessible for small scale networks. Because of existence of global information, it is more accurate than other algorithm. The popular centralized localizations algorithms are: Multi Dimensional Scaling-Mobile Assisted Programming (MDS-MAP), Semi Definite Programming (SDP), Simulated Annealing based Localization (LBSA).

B. Distributed Localization

In distributed localization, sensor nodes perform the required computation themselves and communicate with each other to get their own location in network. The taxonomy of distributed localization algorithms is shown in figure 7.

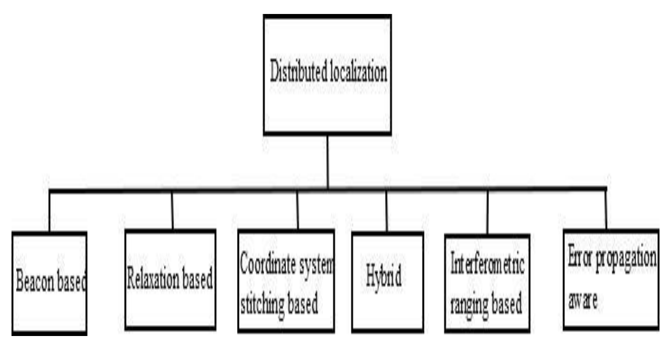

Figure 7. Taxonomy of distributed localization techniques

a. *Beacon based distributed localization algorithms*

Beacon based localization algorithms [24], [25], [26], [27] begin with group of beacons and unknown nodes to obtain measurement to a small number of nodes. After that measurements are used to find out their own locations. These algorithms can be classified into diffusion, bounding box and gradients algorithms. In diffusion, node's most probable location is at the centroid of its nearby recognized nodes. The approximate point in triangle (APIT) [24] is based on range free schemes. The benefit of APIT is its simplicity and easiness of implementation. The bounding box [25], [26] makes a confined reason for every node and then improve their positions. The bounding box is based on collaborative multilateration. Gradient [27] is an algorithm for devising a global coordinate system from local information.

b. Relaxation based distributed localization algorithms

The relaxation based algorithms are used for the estimation of node's location in the network. The opening position of nodes is fine-tuned against their nearby node's estimated positions. After that every node changes its location to obtain the approximate result [8]. The relaxation based algorithms can be classified on basis of two approaches: spring model approach and cooperative ranging approach. Anchor free localization algorithms [28] (AFL) are based on spring model approach. The assumption based coordinate system (ABC) are based on cooperative ranging [29], exploits the soaring network connectivity to convert the global positioning into a number of dispersed local positioning problems. The benefit of this approach is that there is no need of global resource or communication.

c. Coordinate system stitching based localization algorithms

Coordinate system stitching based techniques divides the network into small overlapping sub regions, all of them construct an optimal local map. After that those local maps are merged into a single large map known as global map. The coordinate system stitching based distributed algorithms are generally based on two approaches: cluster based and inter node distance based approach. In the cluster based distributed algorithm [30], the node have distance estimation ability in close proximity. Cluster based distributed localization is basically consists of two phases. First one is cluster localization phase and second one is cluster transformation phase. The benefit of this approach is that it supports lively node inclusion and mobility. The inter node distance approach based distributed localization algorithm [31] construct a spatial map and distance matrix. This approach tries to curtail the differences between them by some transformations. The benefit of this approach is that it is anchor free localization.

d. Hybrid distributed localization algorithms

Hybrid algorithms use diverse approaches such as: multidimensional scaling (MDS) and proximity based distance map (PDM) or MDS and ad-hoc positioning system (APS) to reduce processing cost. MDS and PDM based localization algorithm [10] consist of two phases. In the beginning a few anchors are deployed known as primary anchors. In the first phase, secondary anchors are localized by using MDS. In the subsequent phase, the normal nodes are localized by using PDM. The measurements obtained from the first phase are circulated to the neighboring normal nodes. Finally, the node position is calculated through multilateration. The benefit of this approach is the minimization of computation cost. MDS and APS based localization algorithm [11] known as simple hybrid absolute relative positioning (SHARP) consists of three phases. The random selection of reference nodes is done in first phase. In second phase, the reference nodes are localized by using a relative localization method. The remaining nodes are localized through an absolute localization method in the last phase.

e. Interferometric ranging based localization algorithms

The radio interferometric positioning system (RIPS) [12], [13], [14] exploits interfering RF signal emitted from two locations to obtain the essential ranging information. The synchronization problems cause relative phase offset of the signal. Relative offset is utility of the relative positions of the involved sensor nodes and the carrier frequency.

f. Error propagation aware localization algorithms

Error propagation aware (EPA) algorithm [15] integrates the path loss and measurement error model. Initially, beacon nodes broadcast their information which contains their IDs, global coordinates, and the error variance. After that, node positions are computed by integrating its weight matrix into weighted least square (WLS) algorithm [35]. After obtaining its own position the node becomes beacon and start broadcasting its ID, global coordinates, and ranging variance. This method is repetitive and continues until and unless each node obtains its positions.

VI. COMPARISON

The performance of localization algorithm depend on various factors such as accuracy, computation and communication cost, coverage information, scalability, computation model, network topology, and node density. All techniques have certain merits and limitations, making them appropriate for diverse applications. Some algorithms need beacons [36] and some do not require. Beaconless algorithms create relative coordinate system than can optionally be mapped to a global coordinate system [37]. Some algorithms are centralized while some are decentralized. Centralized algorithms usually compute more accurate positions and can be appropriate to situations where accuracy is important. Distributed algorithms [34],[38] do not rely on large centralized system and potentially have better scalability. Multilateration [32] has low computation and communication cost and performs well in high anchor density. The MDS-MAP has higher communication and computation cost and performs well when there are few anchor nodes [39], [40], [42]. The various localization techniques reviewed in this paper are summarized in table 1.

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Table 1. Summary of localization techniques in WSNs

Schemes	Objective	Computation model	Cost (communication & computation)	Accuracy	Scalability
Y. Shang et al. [20]	Presents MDS-MAP algorithm that uses connectivity information for node localization	Centralized	High	High	No
Anushiya A Kannan et al. [21]	Present a localization method based on simulated annealing which takes error into account	Centralized	High	High	No
Cesare Alippi et al. [22]	Present a multi hop localization technique exploiting acquired RSSI	Centralized	High	High	No
T. He et al. [24]	Present a range free algorithm to make scheme cost effective	Distributed	Low	Low	Yes
A. Savvides et al. [25]	Present a collaborative multilateration approach to enable nodes for accurate estimation of locations via beacon	Distributed	Low	Low	Yes
S. Simic et al. [26]	Present a decentralized approach for node localization in wireless network	Distributed	Low	Low	Yes
J. Bachrach et al. [27]	Present an approach to discover the position of wireless network when the nodes have literally been scattered over terrain	Distributed	Low	Low	Yes
N. Priyantha et al. [28]	Present an anchor free approach for localization where node start from casual initial assignments and converge to consistent solution	Distributed	Low	Low	Yes
C. Savarese et al. [29]	Present a cooperative ranging approach to get rid of burden due to beacons	Distributed	Low	Low	Yes
David Moore et al. [30]	Present a scheme that localize sensor nodes in a region by use of robust quadrilaterals	Distributed	Low	Low	Yes
Lambert Meertens et al. [31]	Present an approach that construct a global coordinate system in network	Distributed	Low	Low	Yes
Jaime Lloret et al. [32]	Present a localization algorithm by using inductive and deductive approach	Distributed	Low	High	Yes
King-Yip Cheng et al. [10]	Presents a distributed algorithms composed of MDS and PDM	Distributed	Low	High	Yes
A .A. Ahmad et al. [11]	Present a localization algorithm composed of MDS and APS	Distributed	Low	High	Yes
M. Maroti et al. [12]	Present a localization algorithm based on interferometric ranging	Distributed	High	High	Yes
N. Patwari et al. [13]	Present a localization algorithm based on interferometric ranging	Distributed	High	High	Yes
Rui. Huang et al. [14]	Present a localization algorithm based on interferometric ranging for larger networks	Distributed	Low	High	Yes
N. A. Alsindi et al. [15]	Present an error aware algorithms for localization in WSNs	Distributed	Low	High	Yes

VII. ISSUES IN LOCALIZATION TECHNIQUES

Sensor network localization is an active research area and has numerous issues so still has a lot of scope for research community. Some of the issues need to be addressed are:

- ***Cost effective algorithms:*** During the design of localization algorithm, designer must keep in mind the cost incurred in hardware and deployment. GPS is not suitable because of its cost and size of hardware.

- ***Accuracy:*** If there is incorrect estimation of node position, then localization accuracy is compromised. Designer must keep in mind that accuracy is very much important factor in sensor localization.

- ***Scalability:*** In large scale deployment, it is generally desirable to enlarge the monitoring area amid nodes. So careful observations are required to check the scalability of localization techniques.

- ***Robust algorithms for mobile sensor networks:*** Mobile sensors are much useful in some environments because of mobility and coverage facility. Hence, development of new algorithms is needed to accommodate these mobile nodes.

- ***Algorithms for 3 Dimensional spaces:*** For many WSN applications, accurate location information is crucial. The more of the proposed algorithms are applicable to 2D space. Some of the applications need 3 D positioning of WSNs.

- ***Security:*** Accuracy of localization algorithms is much important. Some algorithms have high accuracy. But, after implementation they are subject to attacks. Therefore, it is important to consider the security and privacy of node locations.

VI. CONCLUSION

Wireless sensor network localization has gain lot of attention of research community. This concern is likely to grow further with the increase in sensor network applications. This paper had provided a review of various localization techniques and their corresponding localization algorithms for sensor network. In this paper, the taxonomy of localization techniques has been discussed. In this work, we compare the different localization algorithms and represent that comparison in tabular form. This paper reported the classification of distributed localization algorithms. Regardless of significant research development in this area, some unsolved problems are still there. At the end, we focused on the certain issues need to be addressed. This paper is very useful for the research group those are interested in development, modification and optimization of localization algorithms for wireless sensor networks.

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