ISSUES AND CHALLENGES IN LOCALIZATION OF WIRELESS SENSOR NETWORKS

[1]Javed Iqbal Bangash, [2]Abdul Hanan Abdullah, [3]Abdul Waheed Khan
Faculty of Computing, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2]Tel.: +607-553-8761; Fax: +607-553-8822.
E-mail: [1]ibjaved2@live.utm.my, [2]hanan@utm.my, [3]wkabdul2@live.utm.my

ABSTRACT: *The Wireless Sensor Networks (WSNs) can be used for many different applications. However, there are several applications where the sensor data is of no use and can result in an incorrect interpretation of the given data particularly if the coordinate's information is not known. Therefore, localization is of Paramount importance in several operations of WSNs. In this paper, we present a comprehensive study of the issues and challenges being hindered in localization of the sensor nodes in WSNs.*

KEYWORDS: Wireless Sensor Networks (WSNs), Localization, Localization Issues and Challenges

1. INTRODUCTION

With the massive and exponential growth of the computing and communication technology, the computing devices such as laptops, cell phones, PDAs and GPS devices are becoming cheaper, more mobile, distributed and smaller in size. These devices are becoming an integral part of our daily life.

A Wireless Sensor Network (WSN) is a network of independent, low-cost and tiny sensing stations also known as sensor nodes. Each sensor node consists of computing component, communication component, a power source, and some sensor(s) depending upon the application and the environment. Upon deployment these sensor nodes organize themselves and form a network, which is typically consists of several to thousands of such sensor nodes. These sensor nodes are used to monitor the surrounding environment for some activity and send the sensory data to base station also known as sink [1].

The deployment of the sensor nodes can be on large scale or small scale depending upon the application to detect and collect the information from physical environment [2]. They can be used for different applications such as environmental monitoring & forecast [3], national defense & military surveillance [4,5], buildings' health monitoring [6,7], patients' health monitoring[8 – 9], smart homes [10-12], emergency environment for search & recues [13], traffic management [7,14-16] and other commercial areas can also be monitored with the help of WSNs [2,17-19]. However, in many applications, the sensor data in not beneficial and can result in an incorrect interpretation of data, if the coordinate's information is not known [20-23]. As a result, localization in WSNs has gained the attention of the researchers and its significance has increased tremendously quite recently [22,24].

Localization schemes in WSNs aims at determining the coordinate's information of the reporting sensor nodes and these coordinates information can be locally or globally significant [25]. The most common solution used to know the coordinate's information of the sensor nodes in WSNs is to add Global Positioning System (GPS) to each node. But as discussed in [22,24-26], the use of GPS in WSNs for localization purposes is not viable, well-suited and feasible solution, because:

- In indoor environment or in the presence of the some obstacles like dense forests, mountains, or tall buildings, GPS is not accessible
- GPS consumes enormous amount of power, which is a limited resource in WSNs
- Cost and size constraints of GPS delimits the popularity of the sensor nodes

Localization in WSNs aims at developing such schemes, which results into reliable coordinate's information within the constraints being posed by WSNs. [25].

The rest of this paper is organized as follows:

i. Section 2 presents the different techniques and algorithms used for localization in WSNs.
ii. Section 3 discusses the unresolved issues and challenges in the localization process.
iii. Section 4 concludes our paper

2. LOCALIZATION IN WSNS

As discussed that localization in WSNs is an active area of research, [2,22,24-26] present some existing literature review and surveys on this topic. Localization is the process to determine the location of the sensor nodes [22]. Localization techniques and algorithms are used to estimate the location of the sensor nodes, whose coordinates are not known initially [25,26]. It can be done with the help of the absolute position of a few sensors and inter-sensor measurements. The sensors having known coordinates information are called as Beacon Nodes or Anchor Nodes [22,24,25]. The positions of the Anchors or Beacons can be obtained either by GPS or by placing them at points having known coordinate [26].

According to [27] the localization process can be divided into three parts, which are Distance/Angle Estimation, Location Calculation and Location Algorithms.

2.1 Distance/Angle Estimation Techniques

The Distance/Angle Estimation is to provide the estimation on distance or angle between two sensor nodes. The most popular techniques used to estimate the distance or angle of a particular sensor node include Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), Roundtrip Time of Arrival (RToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA) [22,24-28] and Lighthouse Approach [26].

2.1.1 Received Signal Strength Indicator

Received Signal Strength (RSSI) – the most common localization technique – estimates the distance between the transmitter (Beacons) and the receiver based on power of the received signal, knowledge of the transmitted power and propagation loss. RSSI is a cost effective solution as all sensor nodes are equipped with a radio but, at the same time, its performance is undermined due to the multipath propagation of radio signals.

2.1.2. Time of Arrival

Time of Arrival (ToA) estimates the distance between the Beacon and a particular sensor node based on the time required to propagate and the speed of the transmitted signal. As ToA is based on the accurate measurement of time at the receiver and transmitter, synchronization is has to be rendered.

2.1.3. Roundtrip Time of Arrival

According to [22], to overcome the synchronization constraint of Time of Arrival (ToA), Roundtrip Time of Arrival (RToA) and Time Difference of Arrival (TDoA) have been introduced. As mentioned in [22,28], RToA estimates the distance based on the difference between the time when a signal is transmitted by a node and the time when the same signal is re-transmitted by another node is received at the original node. In RToA the same clock is used but the drawback of this technique is that it is difficult to estimate the processing time at the receiver.

2.1.4. Time Difference of Arrival

Time Difference of Arrival (TDoA) is further classified into two types, i.e. Multi-Node TDoA, and Multi-Signal TDoA [22,28]. The Multi-Node TDoA uses ToA measurements of signals transmitted from multiples Beacons and this technique is based on measuring the difference in time. The Multi-Signal TDoA uses two different types of signals having different propagation speed to estimate its distance to another node. However, this technique needs additional equipment - a microphone and a speaker. As the distances between a transmitter and different receivers vary, the transmitted signal is delayed accordingly [22]. Figure 1, redrawn from [26], 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.

Another way of estimating TDoA pertains to measuring the time delay between the receivers by computing the cross-correlation of the received signals [22,26]. All the aforementioned TDoA methods demonstrate high accuracy only under line-of-sight conditions [24,28].

2.1.5. Lighthouse Approach

Lighthouse approach is a very interesting method of distance measurement [26], which involves an optical receiver and a parallel rotating optical beam, and the distance is measured by the time for which the receiver was in the light. Figure 2, redrawn from [26], clarify the lighthouse approach of measuring distances.

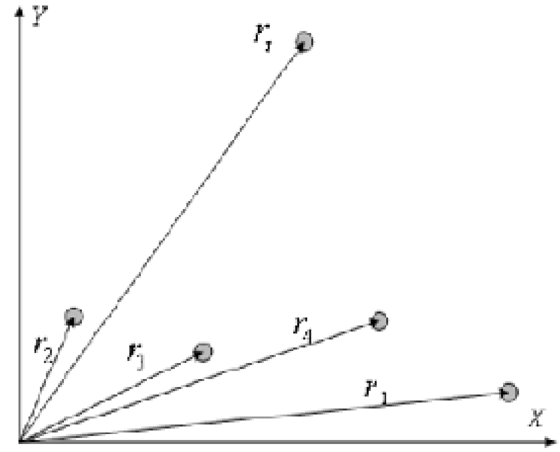

Figure 1: Time Difference of Arrival

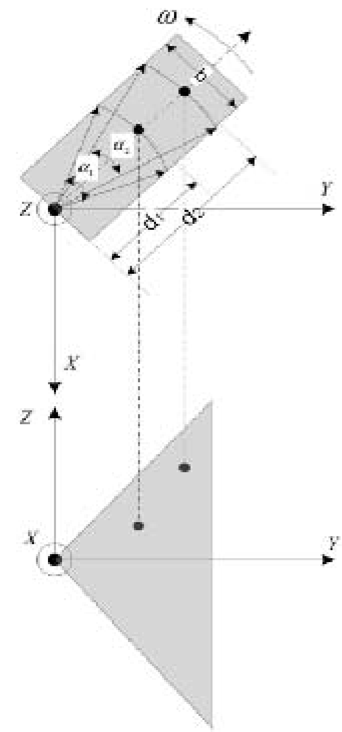

Figure 2: Lighthouse Approach

2.1.6. Angle of Arrivals (A0A)

Like signal's power and time, the angle of the received signal can also be used to estimate the location of the nodes [28]. AoA techniques that mainly depends on multiple or directional antennas estimate the angle at which the signals are received. Subsequently, some geometrical formulas are applied to calculate the node positions. The two sub-classes, in which the AoA can easily be divided, are: those which are used to measure the receiver antenn's amplitude response, and those which are used to measure the receiver antenn's phase response [26].

Different measurement techniques are used for the localization of WSN, and the selection of the technique is based on the specific application [26]. As for their efficacy, AoA methods provide more accuracy as compared to RSSI techniques. However, a high cost is involved therein.

2.2 Location Calculation Techniques

Location Calculation deals with calculating the location of the sensor nodes on the basis of available information. The basic techniques employed for location calculation are: Trilateration, Triangulation, Maximum Likelihood (ML) Mulilateration [22,24,27,28].

2.2.1. Trilateration

This technique estimates the position of node from the intersection of three (3) circles of three (3) Beacons as shown in Figure 3, redrawn from [22,28].

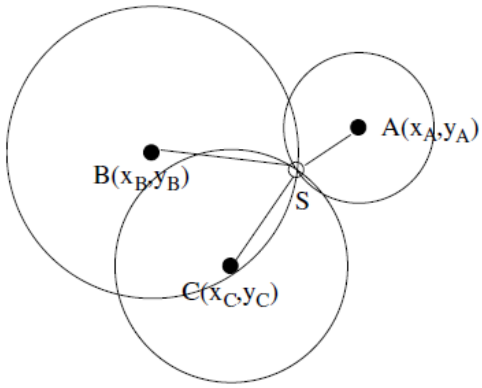

Figure 3: Trilateration Location Calculation Technique

2.2.2. Triangulation

As this technique is concerned, it is used to estimate the angle of the node instead of the distance. The angle information of two Beacons along with some trigonometric functions (sine and cosine) can estimate the position of the node, as shown in Figure 4, redrawn from [22,28].

2.2.3. Maximum Likelihood (ML) Mulilateration

ML Mulilateration technique is employed in place of Trilateration if the distance measurements are noisy, as Trilateration cannot give accurate results in such conditions. This technique estimates the position of a node by minimizing the difference between distance measurements and estimated distance, as shown in Figure 5, redrawn from [22,28].

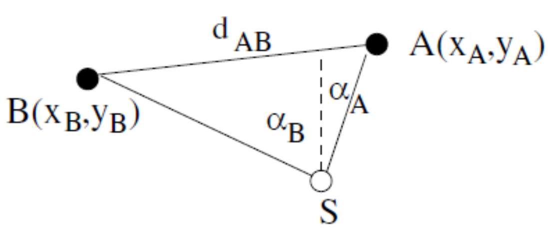

Figure 4: Triangulation Location Calculation Technique

2.3 Localization Algorithms

The localization algorithms in WSNs can be classified into two broad categories [22,24,25]: (a) Centralized Algorithms and (b) Distributed Algorithms, as shown in Figure 6, redrawn from [22,24,25]. A summary of algorithms and schemes of localization in WSNs as discussed in this section is given in Table 1.

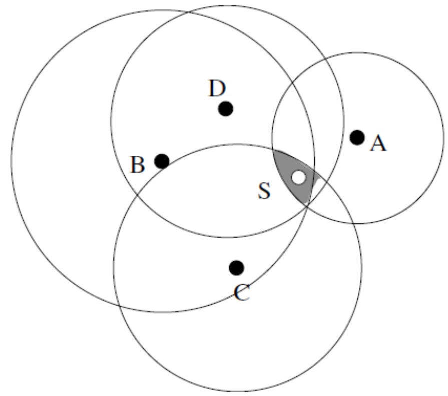

Figure 5: Maximum Likelihood (ML) Mulilateration Location Calculation Technique

2.3.1. Centralized Algorithms

The Centralized Algorithms run on a central computing machine that performs complex mathematical operations at the cost of more computational power. They also eliminate the computation problem at each node. However, the constraint of the Centralized Algorithms is its communication cost, as the computed positions are sent back to respective sensor nodes. As compared to the Centralized Algorithms, the Distributed Algorithms are more efficient [22]. Different Centralized Algorithms use different methods to process the data at the central machine – including Multidimensional Scaling (MDS) [29], Semi-Definite Programming (SDP) [30], and Localize Node-Based on Simulated Annealing [31].

2.3.2. Distributed Algorithms

On the other hand, the Distributed Algorithms perform all the relevant computation at each sensor node, which require more inter-node communication to function like the centralized system to find the positions of the sensor nodes in the network. The Distributed Algorithms can be classified into six (6) different categories [22,24], including:

i. Beacon Based Algorithms: According to [22,24], these are further sub-categorized into: Diffusion [32], Bounding Box [33], Gradient [34], and Approximate Point In Triangle (APIT) [35].
ii. Relaxation Based Algorithms [36,37]
iii. Coordinate System Stitching Based Algorithms [38]
iv. Hybrid Localization Algorithms [39]
v. Interferometric Ranging Based Localization Algorithms [40]
vi. Error Propagation Aware Localization Algorithms [41].

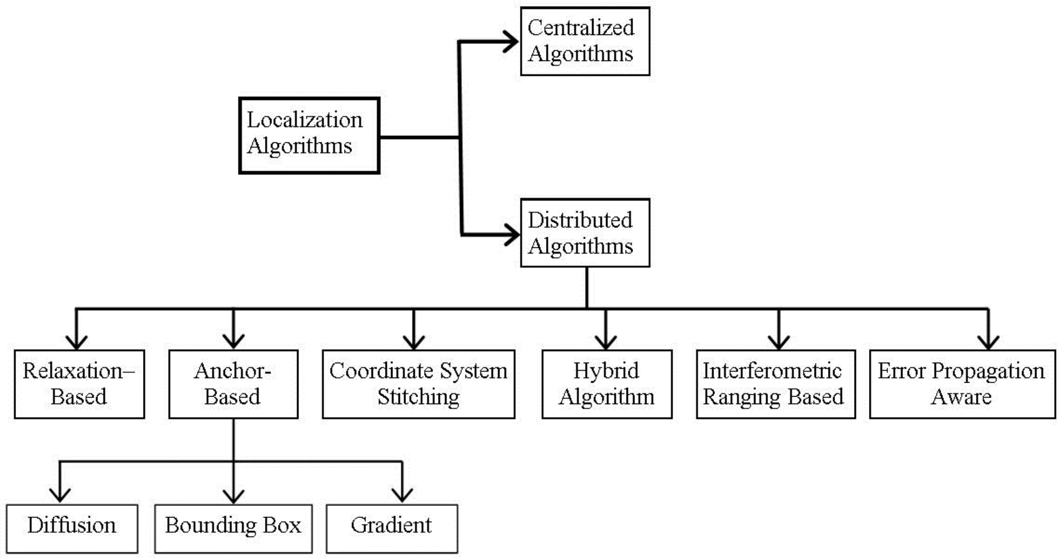

Figure 6: Localization Algorithms Classification

2.3.3. Centralized Vs. Distributed Algorithms

In [26], the authors have made a comparison of Centralized and Distributed localization algorithms on the basis of location estimation, implementation and computation issues, and energy consumption.

- Distributed localization algorithm is extremely harder that the centralized one – an algorithm for distributed localization can be applied to centralized problems, but not vice versa.
- In terms of location estimation accuracy, centralized algorithms tend to be more accurate than distributed algorithms with a limitation that the former have a scalability problem and are not able to be implemented for a large scale sensor networks.
- Centralized algorithms have some other advantages over distributed algorithms which require higher computational complexity and lower reliability because of accumulated information inaccuracies/losses caused by multi-hop transmission over a wireless network.
- Distributed algrithms are more difficult to design because there is potentially complicated relationsjip between local behavior and global behavior (for instance, locally optimal algorithms may be not doing well in global terms).
- Optimal distribution of the computation of a centralized algorithm in a distributed implementation in general is a research problem that still remains unresolved.
- Distributed algorithms normally need multiple iterations to arrive at a concrete solution which delays the localization process.
- The Distributed algorithm will be more energy-efficient than a typical centralized algorithm if in a particular sensor network and distributed algorithm, the average number of hops of a central processor exveeds the number of iterations [42].

3. ISSUES AND CHALLENGES IN LOCALIZATIONN OF WSNS

In consequence of the above, much research has been done in WSNs to propose and develop new techniques and algorithms for localization in WSNs to compensate the inaccuracy in the distance measurements and positions of the sensor nodes. But there are some open problems that need further attention and investigation to improve the localization process of the WSNs. These problems are discussed below:

3.1. Efficient Energy Consumption in WSNs Localization

As WSNs are resource constraint in nature, these make energy efficiency as one of the major design goals [43]. Normally, in WSNs the tiny sensing nodes are equipped with limited and irreplaceable energy supplies and these limited energy supplies limit lifetime of the whole system. The senor nodes perform many other tasks besides their main task. These tasks involve collection of information, such as localization related measurements, communication among the neighbors and location estimation, among others. In many applications of WSNs, energy consumption is one of the most important issues [44]. Recently, the researchers have highlighted the efficient energy consumption in localization of WSNs [43-46] but it is still quite challenging to design energy efficient localization algorithms.

3.2. Localization in 3D WSNs

Typically, localization in WSNs means to determine the location of the sensor nodes in a two dimensional (2D) plane but according to [47,48] in many applications such as surveillance of terrains, study of underwater ecosystem, space monitoring and exploration, environment monitoring etc. the deployments of WSNs are in three dimensional (3D) plane. Due to the complexities, the localization problem has not been researched thoroughly in three dimensional (3D) WSNs [47]. According to [49], complete distributed three dimensional (3D) localization algorithms are very computationally intensive. Due to the non-uniform densities and irregular topologies, it is very difficult for the sensor nodes to obtain sufficient ranging measurements, is another issue [49]. As compared with two dimensional (2D) WSNs; there are relatively few localization schemes for three-dimensional (3D) WSNs. Only a few researchers have addressed this problem in [26,47,49,50] and is still under exploration.

3.3. Localization in Mobile Wireless Sensor Networks (MWSNs)

Among other challenges of WSNs, maintaining the connectivity and maximizing the lifetime of the network are of critical consideration. The integration of the mobile devices into WSNs can address these challenges [51]. In addition, mobility can improve the coverage and the tracking phenomena of the moving targets [52]. Localization is a significant challenge in MWSNs among others. In static WSNs, the estimated sensor nodes positions are unlikely to change, while in MWSNs, the mobile sensor nodes must estimate their position periodically [52]. Recently, mobility in WSNs has attracted the attention of the researcher. In [52], the author has identified the following parameters to enrich the location in MWSNs.

- Reducing the location latency while maintaining the positions accuracy
- Development of more distributed localization techniques
- Development of new methods to expand the mobile sensing to the areas where data cannot be obtained safely

3.4. Secure Localization

Secure localization has always been among the key issues of widely deployed WSNs. WSNs may be deployed in hostile environments and the localization procedure is vulnerable to many localization-specific attacks [53]. Recently, the security issue in the localization of WSNs is getting the researcher's attention and some security schemes have been introduced in [53,54]. But still the door is open to enrich the secure localization. In [55,56], the authors have identified the following parameters to more secure the localization process.

- Localization verification in range-free based algorithms
- Hiding the legitimate sensor's location, while enabling the sensors to communicate with each other
- Secure localization algorithms for mobile sensor nodes
- Localization in un-trusted environment

3.5. The Beacon Movement Problem in WSNs Localization

In most beacons-based localization algorithms, beacons are always assumed to be reliable. Based on this assumption, Beacon Movement Detection (BMD) problem has been identified in [57], where a beacon is moved unexpectedly to a location other than its supposed location. To detect and identify such unexpected movements of beacons, four detection schemes namely, Location-Based (LB), Neighbor-Based (NB), Signal-Strength-Binary (SSB), and Signal-Strength-Real (SSR) have been proposed in [57]. All these four schemes do not consider the observations of the moved beacons. It deserves to further investigate the proposed schemes to re-locate the moved beacons, which could be more beneficial to the localization process.

3.6. Minimum Number of Beacons

Much of the existing techniques used for the localization in WSNs are based on the beacon nodes, requiring a set of beacon nodes – nodes with known locations. The locations of the beacon nodes can be obtained either by Global Position System (GPS) or by placing them at points with known coordinates. According to [24], an optimal technique will have the minimum number of beacon nodes. Further investigation is required to find the minimum number of the beacon nodes to localize the whole network while maintaining a certain level of accuracy.

3.7. Error Propagation in Interferometric Ranging Based Localization

A ranging Technique based on Radio Interferometery has been proposed as a possible way for the localization in WSNs in [58]. It has the advantage that the measurement could be highly precise over other commonly used localization techniques, such as Received Signal Strength (RSS), Time of Arrival (ToA) and Angle of Arrival (AoA).But it is difficult because of more measurement readings and limited to smaller networks – only 16 nodes [59]. In [59], the author proposed an iterative algorithm based on Interferometric ranging to localize larger networks. Nevertheless, the simulation indicates that the error propagation could be a significant problem. The future localization algorithms based on Interferometric ranging require finding ways to reduce the error propagation [24,59].

4. CONCLUSION

On the basis of the aforementioned discussion, we can safely conclude that there are multiple applications of WSNs. They can be used for environmental monitoring and forecasts on the one hand and for national defense and military surveillance, on the other. Besides, we can benefit from them in buildings' health monitoring, building smart home and developing emergency environment for search and rescues. Their deployment can ensure efficient traffic management, as well. Even in human bodies for patient's monitoring, WSNs can play a cardinal role. However, at the same time we cannot overlook their constraints and limitations. In several applications, the sensor date is not of much use and may lead to incorrect interpretation of the given information. This is likely to happen if the coordinate's information is inaccessible. The current paper attempts to present a detailed and comprehensive study and an in-depth understanding of the issues and challenges in the localization of the sensor nodes in WSNs. Cooperative localization research will continue to grow as sensor networks are deployed in large numbers of the applications are becoming more and more variegated. This necessitates that localization algorithms must be designed in such a manner as to ensure as low bias and variance as possible. Simultaneously, they need to be scalable to a considerably large network sizes without dramatically increasing energy consumption and computational processes

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Table 1: Summary of Different Algorithms for Localization in WSNs

Proposal	Objective	Brief Description
Shang et al., 2003. [29]	Present Centralized algorithm 'MSD-MAP' to derive the locations of the sensor nodes in the network	MDS-MAP employs an all-pairs shortest-paths algorithm to approximately estimate the distance between each possible pair of nodes. Then MDS is used to locate the sensor node. Finally, the resulting coordinates are normalized taking into account any node with the known position.
Doherty, et al., 2001. [30]	Propose feasible solutions to the position estimation problem in WSNs.	A description of a method for estimating unknown node positions in WSNs on the basis of connectivity-induced constraints is given. In addition, there is another way in which rectangular bounds around the possible positions for all unknown nodes in the network are placed.
Kannan et al., 2006. [31]	Propose a centralized two phase localization method to address the issue of localization in WSNs.	A two-phase Simulated Annealing based localization algorithm (SAL) is proposed. In this method, a preliminary location estimate is worked out in the first phase. Subsequently, in the refinement phase, serious error owing to flip ambiguity is eliminated, using neighborhood information of nodes.
S. Simic, and S. Sastry, 2002. [33]	Present a distributed algorithm for localization of sensor nodes of random ad-hoc network	This algorithm divides the whole area into several square cells. In this arrangement each unknown sensor node will send hello packet to its neighbors, and the beacons will respond to these signals. As a result, the unknown nodes can update their position estimates.
Bachrach et al., 2004. [34]	Present a distributed algorithm for achieving robust and reasonably accurate localization in a randomly placed WSN.	An algorithm is employed that utilizes the attributes of ad hoc WSNs in order to discover position data even when the elements have literally been sprinkled over the terrain. The algorithm makes use of two principles: first, the communication hops between two sensors can apprise us of an easily obtainable and reasonably accurate distance estimate. Second, position error can be fairly mitigated by using imperfect distance estimates from many sources.
He et al., 2003. [35]	Propose Range-Free localization schemes for large scale sensor networks	This research makes three major contributions to the localization problem in WSNs. First, it put forth a novel range-free algorithm, called APIT, with enhanced performance under realistic system configurations. Second, it gives a realistic and detailed quantitative comparison of existing range-free algorithms to determine the system configurations under which each is optimized. Third, it provides an insight into the effect of localization accuracy on application performance degradation and identifies bounds on the estimation error borne by applications.
Savarese et al., 2001. [36]	Present distributed algorithms for positioning nodes in an ad-hoc sensor.	Presents algorithms for positioning nodes in an ad-hoc sensor network. This considerably minimizes positioning error that occur because of inaccurate range measurements by exploiting 7 or more reference points in a 3-dimensional triangulation computation
Priyantha et al., 2003. [37]	Propose an anchor free distributed algorithm.	In this algorithm the nodes are modeled as points, interlinking them with springs. Hence use-force relaxation method is employed that leads to a lesser consumption of energy.

Table 1: Summary of Different Algorithms for Localization in WSNs (Conti…)

Proposal	Objective	Brief Description
Moore et al., 2004. [38]	Propose a distributed algorithm to localize the sensor nodes in a region by the use of robust quadrilaterals.	This algorithm functions in two phases. In the primary phase each node measures the distances of the neighboring nodes and make a cluster in a localized coordinate system. The second phase leads to the computation of coordinate transformation to embed the cluster in GPS (Global coordinate System).
Cheng et al., 2007. [39]	Present a distributed algorithm, which composed of MDS and PDM.	This algorithm also functions in two phases. Firstly, a selection of some sensor nodes as secondary anchors is made and these are localized by means of MDs. Second, localization of the normal sensor nodes is carried out with the help of Proximity Distance Mapping (PDM).
Patwari et al., 2006. [40]	Propose a distributed localization scheme based on Interferometric Ranging.	In this algorithm a genetic approach is used that leads to optimization of the localization problem. This carried out by utilizing interferometric ranging.

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