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The Wireless Network Localization Techniques

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Abstract - The WSN to the passive localization and tracking of non-cooperative targets has been proposed by exploiting the pervasive and low-cost nature of such technology and the properties of the wireless links which are established in a meshed WSN infrastructure. Wireless sensor network localization is an important area that attracted significant research interest. This interest is expected to grow further with the proliferation of wireless sensor network applications. This paper provides an overview of the measurement techniques in sensor network localization and the one-hop localization algorithms based on these measurements. A detailed investigation on multi-hop connectivity-based and distance-based localization algorithms are presented.

***Keywords** – AOA, RSS, TDOA*

I. INTRODUCTION

A wireless sensor network (WSN) consists of spatiallydistributed autonomous sensors to monitor p hysical or environmental conditions, such s temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity. Wireless sensor networks (WSNs) are a significant technology attracting considerable research interest. Recent advances in wireless communications Cheap, smart sensors, networked through wireless links and deployed in large numbers, provide unprecedented opportunities for monitoring and controlling homes, cities generating new capabilities for reconnaissance and surveillance as well as other tactical applications [1].

Sensor network localization algorithms estimate the locations of sensors with initially unknown location information by using knowledge of the absolute positions of a few sensors and inter-sensor measurements such as distance and bearing measurements. Sensor nodes are, by design, tiny and inexpensive, but due to their need to work in large numbers make full-scale testing a fairly expensive process to be carried out using real hardware. Sensors with known location information are called anchors and their locations can be obtained by using a global positioning system (GPS), or by installing anchors at points with known coordinates. In applications requiring a global coordinate system, these anchors will determine the location of the sensor network in the global coordinate system.

Because of constraints on the cost and size of sensors, energy consumption, implementation environment (e.g., GPS is not accessible in some environments) and the deployment of sensors (e.g., sensor nodes may be randomly scattered in the region), most sensors do not know their locations. In this paper, we provide an overview of techniques that can be used for WSN localization.

Review of wireless network localization techniques can be found in [2–4].

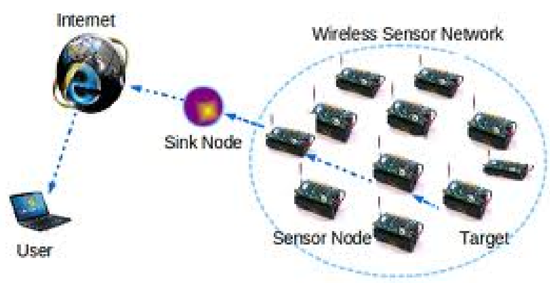

Fig. 1.1

Sensor networks vary significantly from traditional cellular networks and WLAN, in that sensor nodes are assumed to be small, inexpensive, and cooperative and deployed in large quantity. These features of sensor networks present unique challenges and opportunities for WSN localization.

The rest of the paper is organized as follows. Measurement techniques in WSN localization are discussed; these include angle-of-arrival (AOA) measurements, distance related measurements and RSS profiling techniques. (RSS)-based distance measurements. We discuss nonline-of-sight error mitigation techniques in WSN localization and focus on Multi-hop localization techniques, in particular

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connectivity-based and distance-based multi-hop localization techniques.

II. MEASUREMENT TECHNIQUES

With the growing popularity of wireless local area networks (WLANs) has come an increased need for effective measurements of real-world WLANs and their applications. This paper presents three categories:

1. Angle-of-arrival measurements.
2. Distance related measurements.
3. RSS profiling techniques.

III. ANGLE OF MEASUREMENTS

Angle of arrival (AoA) measurement is a method for determining the direction of propagation of a radio-frequency wave incident on an antenna. AoA determines the direction by measuring the Time Difference of Arrival (TDOA) at individual elements of the array -- from these delays the AoA can be calculated. Generally this TDOA measurement is made by measuring the difference in received phase at each element in the antenna array. This can be thought of as beam forming in reverse. In beam forming, the signal from each element is delayed by some weight to "steer" the gain of the antenna array. In AoA, the delay of arrival at each element is measured directly and converted to an AoA measurement. The angle-of-arrival measurement techniques can be further divided into two subclasses: those making use of the receiver antenna's amplitude response and those making use of the receiver antenna' phase response. The measurement unit can be of small size in comparison with the wavelength of the signals. The beam pattern of a typical anisotropic antenna is shown in Fig. 2.

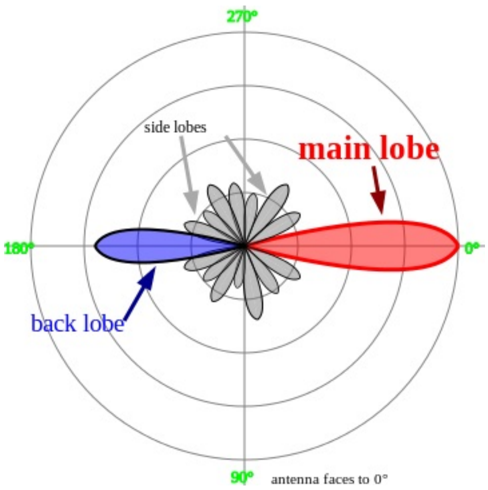

Fig. 3.1 – Horizontal Antenna Pattern

Fig. 3.1. The horizontal antenna pattern of a typical anisotropic antenna.

The second category of measurement techniques, known as phase interferometer [7], derives the AOA measurements from the measurements of the phase differences in the arrival of a wave front. The accuracy of AOA measurements is limited by the directivity of the antenna, by shadowing and by multipath reflections. How to obtain accurate AOA measurements in the presence of multipath and shadowing errors has been a subject of intensive research.

IV. DISTANCE RELATED MEASUREMENTS

Distance related measurements include propagation time based measurements, i.e., one-way propagation time measurements, roundtrip propagation time measurements and time-difference-of-arrival (TDOA) measurements, and RSS measurements. Another interesting technique measuring distance, which does not fall into the above categories, is the lighthouse approach shown in [8].

One-way propagation time and roundtrip propagation time measurements are also generally known as time-of-arrival measurements. Distances between neighboring sensors can be estimated from these propagation time measurements.

One-way propagation time measurements measure the difference between the sending time of a signal at the transmitter and the receiving time of the signal at the receiver. It requires the local time at the transmitter and the local time at the receiver to be accurately synchronized. This requirement may add to the cost of sensors by demanding a highly accurate clock and/or increase the complexity of the sensor network by demanding a sophisticated synchronization mechanism.

Another interesting approach to distance measurements is the lighthouse approach [14] which derives the distance between an optical receiver and a transmitter of a parallel rotating optical beam by measuring the time duration that the receiver dwells in the beam. Fig. 3 illustrates the principle of the lighthouse approach.

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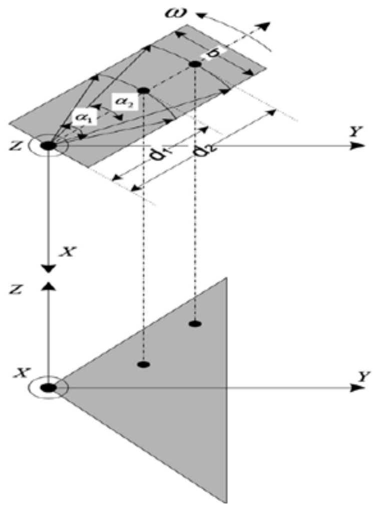

Fig. 4.1 - The lighthouse approach for distance measurement

The optical beam rotates at an unknown angular velocity x around the Z axis. An optical receiver in the XY plane and at a distance d1 from the Z axis detects the beam for a time duration t1. From Fig. 4.1, it can be shown that

$$d1 \approx b / 2 \sin(\alpha 1/2) = b / 2\sin(\acute{\omega} t1/2)$$

The unknown angular velocity x can be derived from the difference between the time instant when the optical receiver first detects the beam and the time instant when the optical receiver detects the beam for the second time. Therefore the distance d1 can be derived from the time duration t1 that the optical receiver dwells in the beam.

V. RSS PROFILING MEASUREMENTS

Another category of localization techniques, the RSS profiling-based localization techniques [12–14], work by constructing a form of map of the signal strength behavior in the coverage area. In this technique, in addition to there being anchor nodes (e.g., access points in WLANs) and non-anchor nodes, a large number of sample points (e.g., sniffing devices) are distributed throughout the coverage area of the sensor network.

At each sample point, a vector of signal strengths is obtained, with the jth entry corresponding to the jth anchor's transmitted signal. a number of measurement techniques are available for WSN localization. Which measurement technique to use for location estimation will depend on the specific application? Typically, localization algorithms based on AOA and propagation time measurements are able to achieve better accuracy than localization algorithms based on RSS measurements [5].

VI. NONLINE-OF-SIGHT ERROR MITIGATION

A common problem in many localization techniques is the nonline-of-sight (NLOS) error mitigation. NLOS errors between two sensors can arise when either the line-of-sight between them is obstructed, perhaps by a building, or the line-of sight measurements are contaminated by reflected and/or diffracted signals. NLOS corrupted measurements are inconsistent with LOS expectations, they can be treated as outliers. A typical approach is to assume that the measurement error has a Gaussian distribution, then the least-squares residuals are examined to determine if NLOS errors are present [16,18] . this approach fails to work when multiple NLOS measurements are present as the multiple outliers in the measurement tend to bias the final estimate decision and reduce the residuals. This behavior motivates the use of deletion diagnostics. In deletion diagnostics, the effects of eliminating various measurements from the total set are computed and ranked [12].

VII. CONNECTIVITY BASED MULTI-HOP LOCALIZATION ALGORITHMS

In this section we shall review multi-hop localization techniques in which the non-anchor nodes are not necessarily the one-hop neighbors of the anchors. In particular, we focus on connectivity-based and distance-based multi hop localization algorithms due to their prevalence in multi-hop WSN localization techniques. This category called "range free" localization algorithms, which do not rely on any of the measurement techniques in the earlier sections. Instead they use the connectivity information, ''who is within the communications range of whom'' [10] to estimate the locations of the non anchor nodes.

VIII. DISTANCE-BASED MULTI-HOP LOCALIZATION ALGORITHMS

For large-scale wireless sensor networks (WSNs) with a minority of anchor nodes, multi-hop localization is a popular scheme for determining the geographical positions of the normal nodes. However, in practice existing multi-hop localization methods suffer from various kinds of problems, such as poor adaptability to irregular topology, high computational complexity, low positioning accuracy, etc. To address these issues in this paper, we propose a novel Multi-hop Localization algorithm based on Grid-Scanning (MLGS). First, the factors that influence the multi-hop distance estimation are studied and a more realistic multi-hop localization

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model is constructed. Then, the feasible regions of the normal nodes are determined according to the intersection of bounding square rings. Finally, a verifiably good approximation scheme based on grid-scanning is developed to estimate the coordinates of the normal nodes. Additionally, the positioning accuracy of the normal nodes can be improved through neighbors" collaboration. Extensive simulations are performed in isotropic and anisotropic networks. The comparisons with some typical algorithms of node localization confirm the effectiveness and efficiency of our algorithm.

It's based on the approach of processing the individual inter-sensor distance data, distance-based localization algorithms can be considered in two main classes: centralized algorithms distributed algorithms. Centralized algorithms use a single central and processor to collect all the individual inter-sensor distance data and produce a map of the entire sensor network, while distributed algorithms rely on self-localization of each node in the sensor network using the distances the node measures and the local information it collects from its neighbors.

- Centralized algorithms
- Distributed algorithms.

IX. CENTRALIZED ALGORITHMS

The most straightforward way to achieve mutual exclusion in a distributed system is to simulate how it is done in a one-processor system. One process is selected as the coordinator (e.g., the one running on the machine with the highest network address). Whenever a process wants to enter a critical region, it sends a request message to the coordinator stating which critical region it wants to enter and asking for permission. If no other process is currently in that critical region, the co-ordinate sends back a reply granting permission, as shown in Fig. 4.When the reply arrives; the requesting process enters the critical region**.**

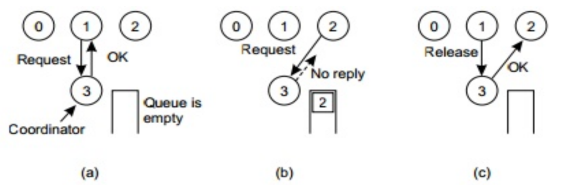

Fig. 9.1

Figure 9.1. (a) Process 1 asks the coordinator for permission to enter a critical region. Permission is granted. (b) Process 2 then asks permission to enter the same critical region. The coordinator does not reply. (c) When process 1 exits the critical region, it tells the coordinator, which then replies to 2.

Now suppose that another process, 2 in Fig. 9.1(b), asks for permission to enter the same critical region. The coordinator knows that a different process is already in the critical region, so it cannot grant permission. The exact method used to deny permission is system dependent. In Fig. 9.1(b), the coordinator just refrains from replying, thus blocking process 2, which is waiting for a reply. Alternatively, it could send a reply saying ''permission denied.'' Either way, it queues the request from 2 for the time being and waits for more messages.

X. DISTRIBUTED ALGORITHMS

Ricart and Agrawala's algorithm requires that there be a total ordering of all events in the system. That is, for any pair of events, such as messages, it must be unambiguous which one actually happened first. According to Lamport's algorithm there is one way to achieve this ordering and can be used to provide time-stamp for distributed mutual exclusion. When a process receives a request message from another process, the action it takes depends on its state with respect to the critical region named in the message. Three cases have to be distinguished:

1. If the receiver is not in the critical region and does not want to enter it, it sends back an OK message to the sender.
2. If the receiver is already in the critical region, it does not reply. Instead, it queues the request.
3. If the receiver wants to enter the critical region but has not yet done so, it compares the timestamp in the incoming message with the one contained in the message that it has sent everyone. The lowest one wins. If the incoming message is lower, the receiver sends back an OK message. If its own message has a lower timestamp, the receiver queues the incoming request and sends nothing. Queues the incoming request and sends nothing.

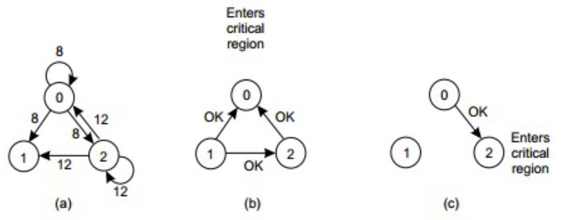

Fig. 9.2

XI. RESEARCH PROBLEMS IN DISTANCE BASED SENSOR NETWORK LOCALIZATION

A fundamental problem in distance-based sensor network localization is whether a given sensor

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network is uniquely localizable or not. A framework that is useful for analyzing and solving the problem is graph theory. In a graph theoretical framework, a sensor network can be represented by a graph G = (V,E) with a vertex set V and an edge set E, where each vertex i 2 V is associated with a sensor node si in the network, and each edge (i, j) 2 E corresponds to a sensor pair si, sj for which the inter-sensor distance dij is known. Use of graph rigidity and global rigidity notions in sensor network localization are well described and their importance is well demonstrated from both the algorithmic and the analytic aspects in the recent literature [16,19,10,11].

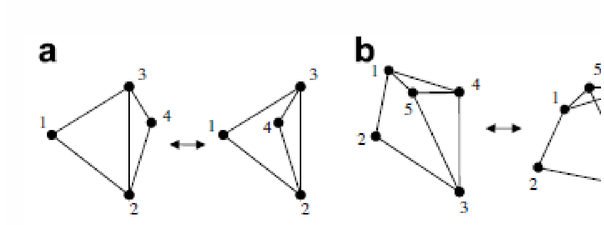

Fig. 11.1

An illustration of discontinuous deformations on nonglobally rigid frameworks: (a) Flip ambiguity: vertex 4 can be reflected across the edge (2, 3) to a new location without violating the distance constraints. (b) Discontinuous flex ambiguity: removing the edge (1, 4), flexing the edge triple (1, 5), (1, 2), (2, 3), and reinserting the edge (1, 4) so that the distance constraints are not violated in the end, we obtain a new framework.

Note that the necessity of global rigidity for unique localization as stated is valid for general situations where other a priori information is not helpful. Rigidity is needed, in any case, to have a finite number of solutions. However, in some cases where ðG; pÞ is rigid but not globally rigid, some additional a priori information may compensate the need for global rigidity. For example, consider a sensor network that can be represented by a unit disk graph, where there is an edge between representative vertices of two sensor nodes if and only if the distance between them is less than a certain threshold R > 0, which is called the transmission range or sensing radius [16]. Then the ambiguities due to the non-globally rigid nature of the representative graph may sometimes be eliminated using the unit disk graph properties , a wireless sensor always has a limited transmission range, which implies that a WSN may have the property of a unit disk graph. Therefore global rigidity is only a sufficient condition for unique localization of a WSN; the necessary condition for unique localization is still an open research problem. Another relevant research problem is understanding and utilizing the error propagation characteristics in a sensor network. This issue emerges especially in estimation of the location of no immediate neighbors of anchor sensors, i.e., k-hop neighbors of anchor nodes with kP 2. Other things being equal, a node further away from anchor nodes is likely to have a larger location estimation error, because its location estimation error is not only affected by the distance measurement errors to its neighbors but also affected by the location estimation errors of its neighbors using which the node's location is estimated.

Finally, we note current interest in characterizing statistical properties of random sensor networks which will ensure, at least with high probability, that the network is localizable, or even possesses trilateration structure, so that localization computations are straightforward and indeed decentralizable [15,18,14].

XII. SUMMARY

Wireless sensor network localization has attracted significant research interest. This interest is expected to grow further with the proliferation of wireless sensor network applications. This paper has provided a review of the measurement techniques in WSN localization and the corresponding localization algorithms. These localization algorithms were divided into one-hop localization algorithms and multi-hop localization algorithms. A detailed investigation on connectivity-based and distance-based localization algorithms were presented because of their popularity in wireless sensor network localization. Despite significant research developments in the area, there are still quite many unsolved problems in wireless sensor network localization. A discussion on some fundamental research problems in distance-based location and possible approaches to these problems was also presented in this paper.

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